Maize production systems for improving resource-use efficiency and livelihood security

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PREFACE

Maize (*Zea mays* L) is one of the most versatile and multi utility crops, having wider adaptability in diverse ecologies. Globally, it is known as queen of cereals because of its highest genetic potential. It is the major source of food, feed, fodder and industrial raw material and provides enormous opportunity for crop diversification, value addition and employment generation. Maize is also grown for many other special purposes *viz*. quality protein maize, sweet corn, baby corn, pop corn, waxy corn, high oil and high amylase corn. It is also a solution for various stresses like weed and lowering water table and abiotic stresses like drought, terminal heat, cold, *etc.* besides providing opportunity for farm mechanization and conservation agriculture and consequently increasing the resource-use efficiency and farm profitability. Presently, maize production is 21.8 million tons and projected demand of maize to be 45 million tonnes by 2030. This demand of maize will be met either by technological intervention or by bringing more area under maize cultivation. The technological interventions for meeting this demand will be adoption of high yielding single cross hybrids seeds, biotechnological intervention and improved package of practices in different agro-ecological regions of the country. It is now well established the adoption of appropriate management practices may prove favourable for sustaining crop productivity and reducing ecological hazards. There is a scope of manipulating production technologies in respect of crop diversification, resource conservation, insect-pest control for improving crop yields on sustainable basis. To make farming sustainable and economically viable, there is a need for rethinking, planning and management in order to face the emerging challenges. Research on maize production systems has therefore provided exciting opportunities for improving input use efficiency, productivity and sustainability. Innovative practices are being attempted to improve productivity, resource-use efficiency and livelihood security.

Model training was organized at Directorate of Maize Research, New Delhi to educate the extension workers, agricultural officers, technical personnel *etc*. of different states in India with regards to all aspects of maize cultivation. This training was attended by 34 personnel from 14 states and eminent experts were invited to deliver lectures. A feedback was also obtained from the participant and they demanded to provide the covered topics which were important from farmer's point of view in the form a book and with publication of this book the gap has been filled.

We express sincere thanks to Dr. O.P. Yadav, Project Director, DMR for providing guidance and other support required for organization of this short training and bringing out this publication We are also grateful to Directorate of Extension, Government of India for generous financial support for organization of this short training and publication of this book. We are also thankful to administrative staff and supporting staff of DMR for their timely help at every point of time. We wish to express a deep sense of gratitude to the scientists who delivered lectures and contributed article for this publication.

In this book we included 26 important chapters on various aspect of maize including production technology, input management, conservation agriculture, crop diversification and intensification, crop improvement, plant protection, fodder preservation, specialty corn, diversified uses maize and extension approaches for technology dissemination. We are sure that extension workers will further disperse this information to the benefit of the farmers. In addition to this, it will also helpful as updated knowledge bank to researchers, students and policy makers in maize research, teaching and extension.

Editors

Contents

1. Maize and its diversified uses

Sain Dass

Maize is the third most important cereal in India after rice and wheat which contributes nearly 9 % in national food basket. In addition to staple food for human being and quality feed for poultry and animals, it serves as a basic raw material for the industry for production of starch for textile, pharmaceutical, cosmetic industries, high quality corn oil, protein, alcoholic beverages, food sweeteners etc. It is used as an ingredient in more than 3000 products. The maize has shown a satisfactory growth rate (4.5%) which is highest among the food grains. Since 1970, the area, production and productivity of maize has increased by 36, 148 and 80%, respectively and during 2007-08 the area, production and productivity is 7.89 m ha, 18.54 mt and 2350 kg/ha, respectively. Maize is also grown for other purposes such as QPM for human nutrition, alleviation of malnutrition and quality feed for poultry and animals, baby corn for vegetable and other table purposes including value added products like pickle, soup, corn *pakora*, *kheer*, *etc.*, sweet corn for soup, and other recipes.

Current utilization pattern of maize in India and global

The current maize utilization pattern in India shows that for food only 24%, for poultry, livestock, fish, pig, mithun, goats *etc*. 63%, for starch and brewery 12%, and for seed 1% are utilized (Fig 1). Feed requirement of maize by the various sectors in the world is at par with India but, higher percentage (22%) of its industrial use in the world is due to bio-fuel extraction in USA. It is also grown as several other types *viz.*, quality protein maize (QPM), sweet corn, baby corn, pop corn, waxy corn, high oil corn etc.

Industrial importance of maize

Apart from food and feed maize has great demand in the development of various products in different industries *viz*. pharma, textile, paper, film, tyre, processing, packaging and biofuel, *etc*. More than 1000 products are being developed from maize in India and >3500 products in USA and other countries.

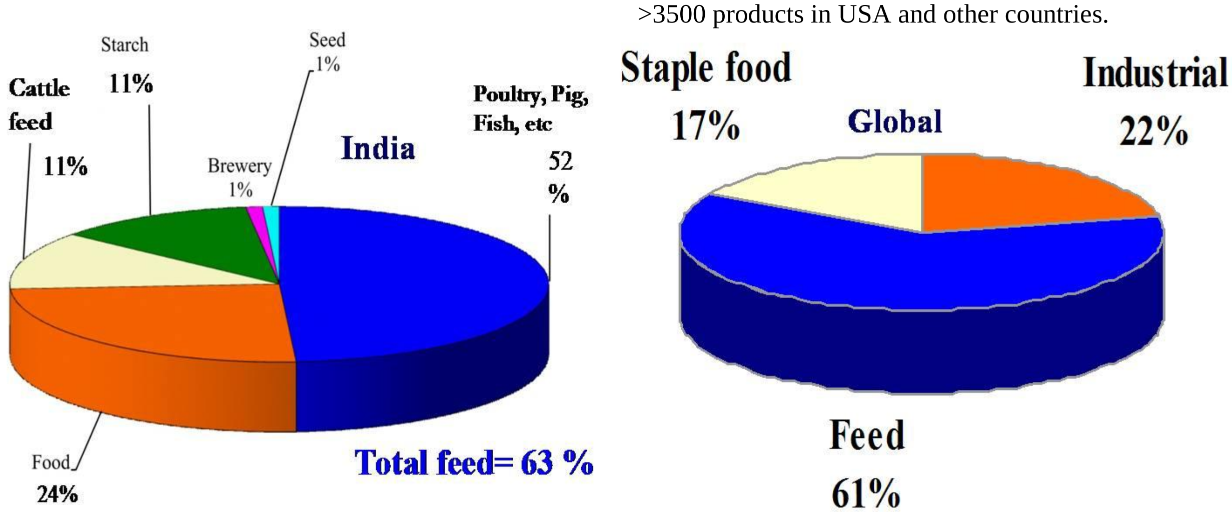

Figure 1. Current utilization pattern of maize for different purposes in India and in Global

Maize and their diversified uses

In India, maize is emerging as third most important crop after rice and wheat. Maize has its significance as a source of a large number of industrial products besides its uses as human food and animal feed. Maize spread to the rest of the world because of its ability to grow in diverse climates.

Types of Maize

There are a number of different types of maize like Normal corn, Sweet corn, Baby corn, Pop Corn, QPM maize, oil corn, waxy corn, Ae corn, fodder maize and pop corn, *etc.*

Diversified uses of maize as a food, feed, fodder, fuel, starch industry and potential for exports has added to the demand of maize in India and all over world.

Normal corn

It is mainly used (more than 60%) to feed the poultry and livestock in the world including India. Whereas, 17-20% of maize produce in many countries is used as a direct food, 16-20% used in starch and bio fuel industry. In USA more than 30% of corn production is utilized for Bio-fuel production. World over more than 3000 products are developed from the field corn, which are the largest numbers of products developed from any cereal crops.

Sweet corn

It has a genetic variation that accumulates more sugar and less starch. The dry kernels of sweet corn are wrinkled and mainly used in the form of green cob. The green cobs are harvested when there is 70% moisture in the grain. Generally, the harvesting is done in the evening or during the time when the day temperature is low and harvested cobs are kept at cold place. After harvesting of green cob farmers get sufficient green fodder for their livestock.

Baby Corn

Baby corn is unfertilized finger look immature cob. Generally, it is 7-10 cm long with 1-1.5 cm diameter having regular row arrangement and yellow to creamy in colour is a preferred size baby corn for canning and export quality. Thailand is the largest producer and exporter of baby corn in the world. India has also started baby corn cultivation and export to UK and other neighbouring country but still there is great scope in India to meets its own demand and export. The green fodder from baby corn is very nutritious and supports the livestock industry. By grazing baby corn fodder to milch cattle 10-15 % milk increased has been reported by the farmer ₹ Baby corn cultivation can be done round the year in India except Jan-Dec in North India and hill states of the country. By products of Baby corn are produced by the cultivation of baby corn such as tassels, silks, husks and green plant material after harvest. All these by- products are highly nutritive and can be fed to the cattle which increase milk yield.

Popcorn

Pop corn is a small hard endosperm flint kernel with low-test weight there are two types of popcorn varieties reported *viz.* butterfly and mushroom. The popcorn varieties are different from the normal corn in their popping behaviour some time field corn also popped but did not the way pop corns expand. Generally, it is popped at 180^0C temperature, when heated; pressure builds inside the kernel until an explosive “pop” results. The better quality of pop corn variety is the one, which has maximum volume and minimum percentage of left out un-popped kernel.

Quality Protein Maize (QPM)

This is a significant contribution of Dr. S.K. Vasal, Ex- Distinguish Scietist, CYMMIT, Mexico to develop QPM maize. The quality protein maize has double or even more than double lysine and tryptophan in the protein than the traditional maize or normal/field corn. The protein quality of QPM is at par with the milk protein. Non-Zein portion is increased which is responsible for increasing the quality of the protein, high digestibility and high biological value. The QPM promotion will address both food and nutrition security issue in the under developed and developing country of the world. Large number of products have been developed using QPM maize in India.

Waxy Corn

An Indian corn with grains that have a waxy appearance when cut, that contain only branched-chain starch, and that are used especially for desserts and adhesives and as a replacement for tapioca. Waxy corn was established in China but it is not used as much around the world. It may not be use as much but, it still has its benefits such as, the chemical starch that it contains: amylopectin- “which makes it more digestible than regular dent corn. The difference between waxy corn and other corn is the inside of the kernel. The kernel within the waxy corn has a greater amount of amylopectin than from the inside of other types of corn.

Fodder maize

The fodder maize crop growing for the fodder purpose, which is very nutritious for livestock. *Uses of Corn-based products*

More than 3 thousand products have been developed in USA. In India, also large numbers of maize based industry have been established. India is big exporter of Maize starch to south East Asia.

Raw materials Corn meal, starch, syrup, oil, Ethanol, *etc***.**

Beverage Vinegar distilled, beer and whiskey, malt, malt syrup, malt extract, etc.

- *Dishes* corn meal, corn flakes, candies, baby formula, ice cream, custer, jelly, chocolates,
- *Corn Syrup* Glucose syrup, high-fructose corn syrup, high maltose corn syrup, etc.
- *Soft drinks* Non - food bio fuel, corn stalk fiddle, paper, textile, tyre, film, toothpaste, pharmaceuticals, paint and varnish, paper products, cosmetics, etc.

Environmentally friendly uses

Maize biofuel

It is a fuel that is derived from a living or recently living organism, as opposed to fossil fuels, Biofuels can be used to power vehicles, heat or cool homes, and many other uses. There is increasing interest in biofuels because they are a renewable resource than fossil fuels, and better for the environment. In USA 30% of the maize produced is utilize for biofuel production and in India the biofuel production is started in Andhra Pradesh and Maharashtra.

Biodegradable plastic polymers

It is created from maize (specifically from the lactic acid that is generated during the fermentation process) are biodegradable and safer for the environment than synthetic polymers, which are long-lasting, non-biodegradable, and can be toxic.

Corn starch

Corn starch is made from the endosperm of the corn, the part of the seed that exists to nourish the potential new plant. After the hull and germ are removed, the endosperm is ground up and the gluten is separated from the starch, leaving nothing but carbohydrate. Cornstarch is used as a thickening agent for liquid food and an alternative to talc in body building powder. It is mixed with sugar to make confectioners’ sugar and was once used to make clothing keep a nicely pressed look. Corn starch is also the main ingredient in biodegradable plastic.

Corn silk

Tea brewed from corn silk is used as a remedy for urinary tract infections, as it has diuretic properties. The tea has been marketed to help everything from bedwetting to diabetes to cancer, but the medical community says there is insufficient evidence for such claims. Corn silk is not harmful to most people, but there are some warnings for those with some health conditions or who are taking certain medications.

Corn cobs

Corn cobs might seem like the throw away part of corn, but have their uses and more uses are discovered or developed all the time. Grinded are used for livestock feed. Traditional farm uses include animal bedding, toilet paper substitute, landfill, fuel and to make corn cob jelly. Modern industrial products made from corncobs include absorbents for oil and hazardous waste, insecticides, fertilizer, and grit for tumbling and blasting. Cobs, as well as corn stalks, are starting to be used to produce ethanol. In addition, you can still make a pipe out of a corn cob.

Corn oil

Oil is produced by squeezing the germ of the corn. It is used as a food ingredient and for frying food in (most appropriately for popping popcorn). Margarine is often made from corn oil, although other oils are used as well. Corn oil is also used in many cosmetics, soaps, medicines, and other products.

Cake mixes

Use a pregelatinized corn starch that will form a paste in cold or warm water. In baked goods that use yeast for rising, dextrose is used as a yeast nutrient.

Candies

Corn syrup is used in hard candies to provide a body giving them chewiness and a desirable mouth feels without excessive sweetness. Candies that are coated use a pyrodextrin cornstarch for a coating.

Caramel is cooked sugar, often used for flavoring or coloring dark breads or soft drinks, especially colas. You can make caramel from cane or beet sugar, but commercial food producers often use corn syrup.

Carbonated beverages

High fructose corn syrup (HFCS) blended with sucrose in a 50/50 blend is sweeter than the same concentration of sucrose. The use of HFCS in carbonated beverages is common throughout Canada and the U.S.

Citric acid

Most commonly used to provide tartness in some candies and drinks. It can be made from corn, although it isn't necessarily.

Confectioner's sugar

Ordinary table sugar, reduced to a fine powder. To keep the powder from caking, manufacturers commonly add corn starch to it. A recognised food cooking contributor gave 4% as a typical fraction, but another correspondent claims it can run as high as 30%. Monitor Sugars Big Chief brand powdered sugar is made with 3% wheat starch instead.

Cookies

Corn starch, corn flour or dextrose may be found in cookies.

Corn flakes

The flaking grits are cooked to a rubbery consistency with syrup, malt, salt and flavouring added. After tempering, the cooked grits are flattened between large steel rolls, followed by toasting in travelling ovens to a golden brown color.

Corn meal

It is a popular dry corn product because of its long shelf life. It is used to produce an assortment of chemically leavened bread and fried products like corn bread and muffins.

Corn starch

Derived from the wet milling process and is an important manufactured product. Some uses depend on the properties in the dry state, but most applications related to its properties as a cooked, hydrated paste.

Cosmetics

Corncobs, when finely ground, are relatively dust free and absorbent. This absorbency makes corncobs useful carriers for pesticides, fertilizes, vitamins, hand soaps, cosmetics, and animal litters.

Instant coffee & tea Malto

Dextrins are derived from the wet milling process. They are a dextrose equivalent product of complete solubility but little or no sweetness. Maltodextrins are sprayed on instant tea and coffee to keep the granules fee flowing. This solution is also used instant soup mixes or other packages where the contents must be kept free flowing.

2. Crop diversification through maize based cropping systems

Ashok Kumar, S.L. Jat, C.M. Parihar, A.K. Singh and Vipin Kumar

India has become self-sufficient in food grain production and the cereal based cropping systems imparted great role in it. Further there is need to increase the production not only of the cereals but also of other commodities like fodder, feed, fiber, fuel *etc.* to meet the demand of burgeoning population. This is possible either through increase in area or productivity or both. But scope for horizontal expansion is negligible, only vertical expansion in crop production is the option left to fulfill the demand of various commodities. In this way, crop diversification with intensified sequential and inter cropping plays a key role. Crop diversification refers to a shifting or bringing a desirable change in the existing cropping systems towards more balanced cropping systems to meet ever rising demand of food, fiber, fuel, fodder etc. and aim to improve soil health and profit (Banu *et al.*, 2005). At present among cereal based cropping systems, rice-wheat, rice-rice, pearl millet-wheat, maize-wheat and sorghum–wheat are the major cropping systems and occupy 85 % area. The continuous cultivation of these cropping systems results in various problems viz. reduced soil fertility in root zone with specific reference to micronutrients, declining water table, infestation of similar kinds of pests and predominance of specific weeds, which is resulting in reduced efficacy and sustainability of the cropping systems (Katyal, 2003). Crop diversification is one of the major components for sustainable production under these changing situations. It also helps in overcoming the problems like excessive mining of soil nutrients and ground water, mitigating ill effects of abnormal weather, conservation of natural resources, minimizing pollution and multiplication of pests and diseases and less dependence on farm inputs.

Maize is one of the major cereal crops with wide adaptability under diverse agro-climatic conditions that serves as an important driving crop for diversification under all ecologies. Maize being a potential crop in India occupies an important place as human food (24%), animal feed (11%), poultry feed (52%) and as a source of large number of industrial products (12%). In north western plains, maize is generally grown is maize-wheat cropping system resulting in stagnant/reduced productivity and profitability. But diversified maize based cropping systems produced more yield with higher profitability and efficient utilization of inputs (Gill and Sharma, 2005).

Sequential cropping

Maize provides sufficient opportunities for intensified sequential cropping due to wider adaptability under diverse soil and climatic conditions. Due to availability of different maturity groups of genotypes and various kinds of corn, it can be fitted well in any cropping sequence. The important maize based intensified cropping sequences including cereals, pulses, oil seed crops, vegetables *etc.* adopted in irrigated and rainfed conditions of different agro-climatic zones have cropping intensity of 200 and 400% (Table 1).

In field studies at different locations the improvements in productivity and resource use efficiency were reported due to adoption of maize based cropping systems. At Modipurum the cropping system of maize-peas-wheat recorded more rice equivalents and water use efficiency to the tune of 8.7 and 7.8 % over rice-wheat cropping sequence, respectively. Inclusion of vegetables in maize based cropping system also resulted in 101.5 % more system productivity with double irrigation water productivity with maize-potato-onion in comparison to rice-wheat cropping system (Gill and Sharma, 2005). For *peri*-urban areas, inclusion of high value vegetables like peas, onion, radish *etc.* in maize based sequences proved more remunerative than rice-wheat system and maize (cobs)-radish-onion is the most productive (20.51 t/ha, wheat equivqlents) and profitable (₹ 75,909/ ha) cropping system (Table 2) (Singh, 2006). At DMR, under conservation agriculture, maize-mustard-mungbean closely followed by maize-wheat-mungbean gave the highest maize equivalents with all tillage practices (Figure 1). Similarly, under different nutrient management practices, maize-baby corn-mungbean was the best cropping sequence in terms of net return and benefit: cost ratio (Table 3). Bed planting also showed the superiority over flat planting in respect of water and nutrient use efficiencies in maize based cropping systems (Table 4).

Intercropping systems

Maize has compatibility with several crops of different growth habit that led to development of various intercropping systems. In *peri*-urban interface, maize based high value intercropping systems are also gaining importance due to market driven farming. The compatible crops with maize during *kharif* and *rabi* seasons are mentioned in Table 5 and 6.

Table 1. Maize based sequential cropping systems in different ago-climatic zones of India

Agro-climatic region	**Cropping system**	
	Irrigated	**Rainfed**
Western Himalayan Region	Maize-wheat Maize-potato-wheat Maize-wheat-green gram Maize-mustard Maize-sugarcane	Maize-mustard Maize-legumes
Eastern Himalayan Region	Summer rice-maize-mustard Maize-maize Maize-maize-legumes	Sesame-Rice+maize
Lower Gangetic Plain region	Autumn rice-maize Jute-rice-maize	Rice-maize
Middle Gangetic Plain region	Maize-early potato-wheat-mungbean Maize-wheat Maize-wheat-mungbean Maize-wheat-urdbean Maize-sugarcane-mungbean	Maize-wheat
Upper Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-sunflower Maize-potato-onion Maize-potato-sugarcane-ratoon Rice-potato-maize	Maize-wheat Maize-barley Maize-safflower
Trans Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-sunflower Maize-potato-onion Mungbean-maize-toria-wheat Maize-early potato-late potato-mungbean	-
Eastern plateau & hills region	Maize-groundnut-vegetables Maize-wheat-vegetables	Rice-potato-maize Jute-maize-cowpea
Central plateau & hills region	Maize-wheat	Maize-groundnut
Western plateau & hills region	Sugarcane + Maize	
Southern plateau & hills region	Maize-rice Rice-maize	Sorghum-maize Maize-sorghum-Pulses Maize-potato-groundnut
East coast plain and hills region	Rice-maize-pearlmillet Maize-rice Rice-maize Rice-rice-maize	Maize-maize-pearlmillet Rice-maize + cowpea
West coast plain and hills region	Maize-pulses Rice-maize	Rice-maize Groundnut-maize
Gujarat plains and hills region	Maize-wheat	Rice-maize
Western dry region	Maize-mustard Maize-chickpea	Maize+legumes
Island region	Rice-maize	Maize-rice Rice-maize + cowpea Rice-maize-urdbean Rice-rice-maize

Specialty corn for diversification

For diversification and value addition of maize as well as the growth of the food processing industry, cultivation of specialty corns like baby corn, sweet corn, pop corn *etc*. in *peri*-urban pockets of the country becomes popular at it provides regular employment to rural masses. The farmers are earning 50-60 thousand rupees per annum per acre with the cultivation of 2-3 crops of baby corn and sweet corn and 100 quintal nutritious fodder/crop/acre (Dass *et al.,* 2009). Specialty corn helps the livestock industry in meeting the scarcity/regular supply of green fodder for the growing dairy industries to increase the milk production of the country. By feeding this fodder, there is increase of about 15-20 % milk and farmer does not require additional land for fodder. Therefore, speciality corn cultivation helps the livestock industry in meeting the regular supply of green fodder for the growing dairy industries to increase the milk production of the country.

Off season cultivation of maize

The adoption of maize in low rainfall areas and under lowering water table situations coming up at very fast rate due to availability of good quality hybrids in the country, where maize is more remunerative than rice. The maize is a solution crop for the lowering water table in the *rabi* rice growing areas of Andhra Pradesh, Karnataka and Tamil Nadu and also for the low rainfall areas of upland rice in the states of West Bengal and Odisha. Similarly, maize is solution for the heat stress in wheat causing significant yield reduction in the Northern India. The favourable temperature in the *rabi* season of the states like West Bengal, Odisha, Rajasthan, Gujarat and Madhya Pradesh offers a great potential for maize hybrid seed production and areas under seed production is coming up very fast in these areas in recent yea₹The remunerative seed production in these states will cater the needs of the states as well as have potential for export to neighbouring states and countries. The cultivation of spring maize after harvest of potato is now became reality in North Indian states like Punjab, Haryana and western Uttar Pradesh and giving more productivity.

Table 2. Diversification options in *peri*-urban interface through inclusion of maize and vegetables in cropping systems

Cropping systems	Wheat equivalent yield (t/ ha)	Net returns (₹/ ha)
Rice-wheat	8.15	24,427
Rice-pea (veg)- maize (cob)	11.93	30,649
Maize (cob)-radish-onion	20.51	75,909

Table 3. Economics of different maize based cropping systems under different nutrient management options

Treatment	(₹/ha)			B: C Ratio		
	M-W-M	M-Bc-M	M-P-M	M-W-M	M-Bc-M	M-P-M
Control	40,196	43,353	43,664	0.78	0.81	0.60
150:60:40	97,574	1,10,374	90,981	1.69	1.84	1.14
150:60:40 + FYM 5t/ha	1,41,170	1,55,075	1,31,028	2.30	2.45	1.58
75:30:20 + FYM 5t/ha	88,098	99,364	85,355	1.51	1.65	1.07

M-W-M- Maize-wheat-mungbean; M-Bc-M- Maize-baby corn-mungbean;
M-P-M-Maize-Potato-mungbean

Table 4. Maize equivalents of different cropping systems under different planting methods and nutrient levels

Treatment	Maize-baby corn-mungbean	Maize-wheat-mungbean	Maize-potato-mungbean
Planting method			
Flat planting	14.94	12.32	15.46
Bed planting	17.99	13.41	18.80
L.S.D. (5%)	2.24	NS	2.30

Table 5. Maize based intercropping systems

All maize growing areas	*Peri*-urban interface
Maize+ Pigeon pea	Maize + high value vegetables
Maize+ cowpea	Maize + flowers
Maize + Mungbean	Baby corn + vegetables
Maize + urdbean	
Maize + Sugarcane	
Rice + maize	
Maize + soybean	

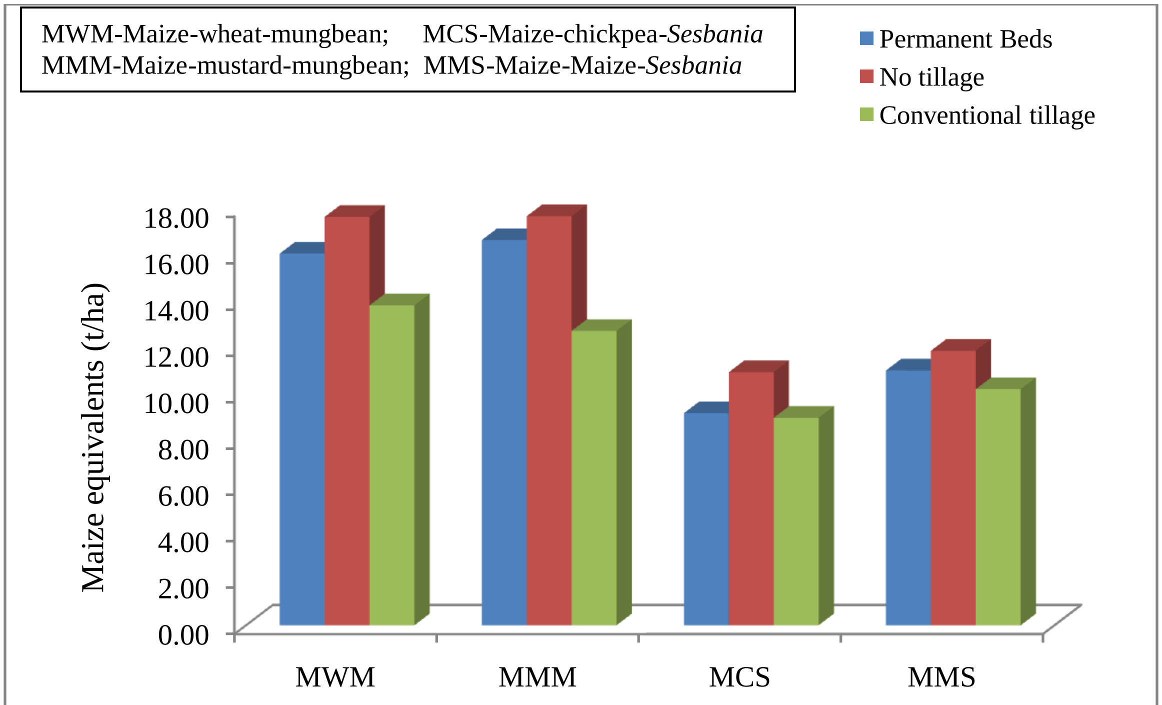

Figure 1. Maize equivalents of different cropping sequences under various tillage

Table 6. Suitable crops for intercropping with *rabi* maize

State	Recommended crops
North-western Region (Punjab, Haryana, Delhi and western Uttar Pradesh)	Pea, French bean (rajmah), lentil
North eastern region (Bihar, eastern Uttar Pradesh, Orissa, West Bengal and NE Region	Pea, rajmah, potato, lentil, bakla and onion
Southern region (Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu)	Fenugreek (methi), coriander, safflower and cluster bean
Central region (Rajasthan, Madhya Pradesh and Guajrat)	Pea, lentil, onion, garlic and methi

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3. Production technologies for winter maize (*Zea mays* L.)

Vijay Pooniya, Anil K. Choudhary, M.M. Puniya, Ashok Kumar and R.S. Bana

Winter maize is a recent technological intervention for cultivation of improved maize germplasm well suited to winter months. Under *rabi* maize, only those cultivars are being recommended that have more tolerance to low geo-thermal regimes of winter season. Winter maize has many advantages over wheat and *rabi* crops under changing climate as it can absorb the soil moisture from deeper soil profile because of its well-developed deep root system. This crop remains dormant under peak winter months because of which it need less external inputs. The moment the temperature shoots up in first week of March it grows well at faster rate and results into higher productivity with higher input use efficiencies in term of nutrient use efficiency, water use efficiency, factor productivity, land use efficiency, energetic and employment generation. In *rabi* season, maize tends to be more efficient in terms of productivity due to lower photo respiration losses and larger leaf surface for effective photosynthetic activities (DMR, 2012).Similarly, the price of crop produce as green cobs in April-May in the urban market is quite lucrative for winter maize produce. The grain yield in the winter maize is also high over *kharif* maize, thus, resulting in higher profitability to practicing farmers. Overall, the farmers are in win-win situation while adopting winter maize. In this paper, an attempt has been made to discuss agricultural practices for winter maize which can play a vital role in sustainable maize production in India.

Cultivation practices of winter maize

Cultivar and hybrid selection to a particular agro-ecology is a key factor for getting higher productivity. Farmers are suggested to select high yielding hybrids/composites suitable for particular region (Table 1). The hybrids realize higher productivity than local cultivars, with an average yield level of 6 tonnes/ha or more (DMR, 2012). Well drained, aerated deep-loams and silt loams with good organic matter content, having higher water holding capacity with neutral pH soils are fit for higher productivity.

Table 1. List of winter season maize cultivars/hybrids.

States	**Cultivars**
Delhi	H: PMH 3, Buland, NK 61, Pro 311, Bio 9681, Seed Tech
Punjab	H: PMH 3, PMH-1 , Buland, Sheetal , Pro 311, Bio 9681, NK
Haryana	H: PMH 3, Buland, ,HM 5, NK 61, Pro 311, Bio 9681, Seed
Uttar Pradesh	H: PMH 3, Buland, Pro Agro 4212, Pro 311, Bio 9681, NK
Rajasthan	H: Pro 311, Bio 9681, Seed Tech 2324, HM8
Andhra Pradesh	H: The late maturing hybrids of Kharif e.g. Kargil 900 M, Seed Tech 2324, Pro 311, Bio 9681, Pioneer 30 v 92, Prabal, 30 V 92, 900 M
Tamil Nadu	H: COHM 5, Prabal , Pro 311, Bio 9681, Seed Tech 2324, 30 V
Maharashtra	H: Prabal, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M
Karnataka	H:Nithya Shree, DMH 1, DMH 2, 900 M, Bio 9681, Prabal, Pro 311, Bio 9681, Seed Tech 2324 C: NAC 6004, 30 V 92
Bihar	H: Rajendra Hybrid 2, Rajendra Hybrid 1, Pro 311, Bio 9681, Seed Tech 2324, 30 V 92, 900 M C: Hemant, Suwan& Lakshmi
Jharkhand	H: Pro 311, Bio 9681, Seed Tech 2324C: Suwan
Chhattisgarh	H: PEHM 1, Pioneer 30 V 92 & 30 R 26, Bio 9681, Pro 4640 & 4643, 900M
NEH Region	H: Pro 311, Bio 9681, Seed Tech 2324 C: NLD white

H: Hybrids, C: Composite cultivars.(Source: Prasad, 2012)

Sowing

Time of sowing is the most important non-monetary input having significant effect on crop growth, phonological development, insect-pest dynamics and crop productivity. The environment conditions *viz.* temperature, photo-period and moisture availability *etc.* significantly changes with time of sowing. The optimum sowing time of winter maize is mid-October to end of October (Table 2). Delay in sowing results in poor germination and low yield due to low temperature in December and January (North-Western India), shortening of growing season (Eastern and Southern India).

Table 2. State-wise sowing time for winter maize.

States	Time of sowing
Andhra Pradesh	25 October- 20 November
Bihar	20 October- 15 November
Maharashtra	20 October- 15 November
Uttar Pradesh	20 October- 15 November
Tamil Nadu	20 October- 15 November
Karnataka	15 October- 15 November
Orissa	20 October- 10 November
Punjab and Haryana	25 October- 15 November
West Bengal & N E region	20 October- 10 November

The crop remains dormant up to end of January and very fast development in growth as soon as the season warm up. In late sown crop, there is a chance of higher incidence of insect and diseases, which is not observed in timely sown crop. During winters, crop should be sown on the southern side of ridge so that the plant can absorb optimum sunshine for its growth and development.

Plant population and seed requirement

Optimum plant population is very essential for obtaining higher yield, nutrient and water-use-efficiencies and it does not change with planting date or row width. About 85,000-90,000 plants/ha are optimum for achieving higher yield during *rabi* season with a crop geometry of 60 cm × 20 cm. Optimum seed requirement for higher yield of winter maize is about 20-25 kg/ha the seed should be sown 4-5 cm deep. For protecting the crop from various biotic stresses, it is necessary to treat the seed with Bavistin/Captan @ 2 g/kg and Imidaclorpid@ 2g/kg seed before sowing that would help in obtaining better plant stand.

Establishment methods

Raised-bed method

Raised-bed is a land configuration where irrigation is given in furrows and the technology increases water use-efficiencies and gives better crop yields. Due to high fertilizer use-efficiency, reduced weed infestation and improvement in root proliferation. The irrigation water saving depends on size of bed-furrow system where larger bed saves more irrigation water. Using this technology, 20-30% irrigation water can be saved without any negative impact on productivity. For achieving higher yield under raised-bed technology, permanent beds are advisable wherein sowing can be done without any preparatory tillage and raised bed provide better soil conditions for root proliferation and nutrient uptake (Bakht *et al*., 2011).

Zero-tillage method

Zero-tillage, synonymous to no-tillage or conservation agriculture is worldwide accepted term and this addresses many global challenges of climate change, soil degradation and food security. No-till farming is a way of growing maize without disturbing soil through tillage. It increases the amount of water and organic matter (nutrients) in the soil and decreases erosion. Zero-till seeding technology ensured timeliness of operations, input use efficiency and immediate economic returns in terms of savings in land preparation, seeding cost and less irrigation time leading to saving of fuel. Winter maize can be successfully grown without any preparatory tillage under no-till situation with higher profitability and resource use-efficiency. Under this situation, seed and fertilizers should be band-placement using zero-till seed-cum fertilizer drill. If the field is infested with annual and perennial weeds, spraying of non-selective herbicides i.e. paraquat and glyphosate should be done before sowing. Now, farmers are practicing zero-till technology in rice-wheat belt of Indo-Gangetic plains.

Nutrient management

Maize is an exhaustive crop and needs balanced supply of macro and micro-nutrients. Nitrogen is the key nutrients and adequate supply of nitrogen is necessary for achieving potential yield. The response of winter maize is observed up to 180 to 200 kg N/ha. Nitrogen utilization is better during, because of better irrigation water management, lower leaching losses and weed infestation. The recommended dose of fertilizers to be applied depends on soil fertility status and the preceding field management. For better productivity, application of nutrients is scheduled in such a way so as to match the nutrient supplying capacity of soil and plant demand. Chemical fertilizers should be applied on soil-test based recommendations (Suri and Choudhary, 2012). In general, application of 10-15 tonne FYM/ha or green maturing, 15-20 days before sowing along with 150-180 kg N, 70-80 kgP_2O_5, 70-80 kg K_2O and 25 kg $ZnSO_4$per hectare is recommended. Thus, application of organics in maize is of paramount importance to harness higher yields (Yadav *et al*., 2013). Nitrogen is mobile nutrient so that it should be applied in different splits i.e. basal (20%), four leaf stage (25%), eight leaf stage (30%) and grain filling stage (5%) (DMR, 2012).

Weed management

The dominant weed species in r*abi* season are *Phalaris minor*, *Avenaludo viciana*, *Poa annum*, *Melilotusalba*, *Convolvulus arvensis* and *Anagalis arvensis* etc. The weeds compete with crop plants for nutrient, water, space and light and cause yield reduction up to 40%. One to two weeding at initial stage is necessary for better weed control. Timely weed control is must for achieving higher yield. Application of Atrazine @ 1.0 kg a.i. /ha as pre-emergence can be controlled most of weeds. Atrazine can also be sprayed as 20 cm wide band over the crop rows up to 10 DAS followed by one hand weeding. Under zero-till conditions, pre-plant application of non-selective herbicides *viz*. Glyphosate @ 1.0 kg a.i. or Paraquat @ 0.5 kg a.i./ha is also recommended.

Water management

Winter maize requires frequent and mild irrigations during December-January to protect crop from low temperature and frost damage. The water management depends on season as about 75-80% of maize is grown under rain fed conditions. However, in areas with assured irrigation facilities depending upon the rains and moisture holding capacity of the soil, irrigation should be applied as and when required by the crop and first irrigation should be applied 3-4 weeks after sowing and subsequent irrigations at 4-5 weeks intervals depending on rainfall and air temperature. In raised bed planting system, the crop can be irrigated in alternate furrow to save more irrigation water. In light soils, it is desirable to schedule the irrigation 70% soil moisture availability throughout the period of crop growth and development. The crop grown during winter should not be subjected to moisture stress at critical growth stages i.e. flowering and grain development stages.

Maturity, harvesting and productivity

Maize is harvested at physiological maturity when the husk dried and turned pale brown. Harvesting should be done at optimum moisture content (15-20%) to avoid post-harvest losses. Maize productivity is highly affected by the degree of crop production management practices. For harnessing potential yield of HYVs under suitable crop production management systems effective precision nutrient, water and weed management strategy holds the key to success. By adopting production technologies as indicated above, winter maize hybrids can yield about 8 - 10 tonnes of grain/ha under irrigated conditions, thus, bringing higher remunerations and profitability to farmers.

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4. Specialty corns for livelihood security in *peri*-urban agriculture

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Maize (*Zea mays* L.) is largely being grown as food and feed crop across the globe and every part of maize plant *viz.*, the grain, leaves, stalk, tassel, and cob has economic value and all the parts are being used to produce a large variety of either food or non-food products. Maize has its versatility with respect to its ability to produce economic product in different stages of its life cycle, which probably no other cereal crop plants can match. Maize in its vegetative stage can be used as nutritious green fodder; during its silking stage, its immature cobs can be used as baby corn, a nutritious vegetable; in its grain filling stage, it can be harvested prematurely as green cob, which is being used either a nutritious vegetable/snack and finally once it completes its life cycle/fully matures then it can be used as grain which has diverse uses like food, feed, biofuel production etc. In the past, commercial cultivation of maize was practiced mainly for grain purposes but after realizing its diverse economical products farmers started growing for different purposes. The genetics of maize is also very complex and diverse which has evolved into different types of maize like sweet corn, popcorn, quality protein maize, high oil corn, waxy corn, etc. and each type of maize has its own economic importance. Among all few types of maize like quality protein maize, sweet corn, popcorn have high consumer acceptability thus leading to investment in research and development and their commercial cultivation. Therefore, cultivation of different kinds of maize *viz.*, quality protein maize, sweet corn, popcorn or cultivation of different kinds of maize for special purpose but other than grain are known as 'Specialty Corn'. The investment in specialty corn research and development in being taking place and quite good number of quality products in the form of high yielding specialty corn single cross hybrids are available in the market elsewhere in USA. In the past India has not invested much in research and development of specialty corn but until recently India was importing specialty corn like sweet corn, popcorn and baby corn from other countries to meet the domestic demand mainly to meet growing demands of specialty corn in urban areas. However, now a day's specialty corns are becoming more and more popular even in small towns and cities. By realizing the importance of increasing popularity of specialty corn, India has started a research on specialty corn in the recent past which has led to development of some good hybrids of specialty corn like HM 4 of baby corn and HSC 1 of sweet corn in the year 2005 and 2011 respectively. In addition some multi-national seed companies are also selling their seed of specialty corn hybrids in the Indian market. Since specialty corns are becoming more and more popular in urban and semi-urban areas and also specialty corn hybrids suitable for different agro-climatic conditions of the country are also available both from public and private research organizations, the Indian farmers especially farmers living in and around urban areas (*peri*-urban) can increase their farm profitability by growing some specialty corns especially baby corn, sweet corn and popcorn. The success of commercial cultivation of specialty corn in *peri*-urban areas depends on finding a suitable market to sell the produce. In this regard, a long-term contract/agreement/tie-up between producers/suppliers i.e. farmers and purchasers is very crucial for continuous supply of quality specialty corn, maintaining the price stability in long-run, and also ensure assured return/profitability to the farmer. The international demand for specialty corn is also increasing and recently India has started exporting baby corn and sweet corn to other countries. However, apart from assured market there is also need to understand economics and production technology of specialty corn before venturing into large-scale commercial cultivation of specialty corn for enhanced, sustained and assured farm profitability. The objective of present article is to give the brief understanding on the production technology for specialty corn and its farm profitability especially in *peri*-urban agriculture.

Specialty corn and its production technology

The term specialty corn comprises quality protein maize, sweet corn, popcorn, baby corn, high oil corn, waxy corn etc. In general sweet corn and baby corn are recommended for *peri*-urban agriculture because of their short shelf life and perish ability; in these cases the proper storage facilities in the form of cold storage or quick transport to nearby processing plant are immediately required after harvest of sweet corn and baby corn. The genetics of specialty corn is very typical in the sense that special traits of maize like sweetness, QPM and waxy are governed by recessive genes (express their phenotype in recessive homozygous condition) where as popping and high oil are altered due to *xenia* (alteration in trait expression during seed development due to fertilization with foreign pollen) effect. Finally, in case of baby corn care should be taken that the silk should not be pollinated either with its own plant pollen or pollen of any other neighbouring plants of the same variety or other. Therefore, all the specialty corn should be grown in isolation to avoid pollen contamination from the neighbouring maize/field corn. The brief description about each type of specialty corn is given below but, in India only sweet corn and baby corn are more popular which can enhance the farm profitability in *peri*-urban agriculture.

Popcorn

The traditional maize often called field corn and popcorn belong to same plant species (*Zea mays*), but only popcorn pops, it was found that the pericarp (hull) of popcorn and starch packaging are important for popping. Popcorn are harvested for their grain and sold for human consumption. Popcorn is a special type of flint corn/kernel with small hard endosperm and low-test weight and it can be sold un-popped for microwave or conventional use; or it can be packaged as a plain or flavour-added popped product. The kernels of pop corn are very small and oval/round in shape. Popcorn is being used as one of the common snack items in many parts of the world, particularly in cities and is liked because of its light, porous and crunchy texture. The popcorn flour can also be used for preparing many traditional dishes. It is consumed fresh, as it has to be protected against moisture absorption from the air. The commercial cultivation popcorn will succeed if it is grown under contract with a processor who should specifies both the hybrids to be planted and the number of acres because he is the one who knows how much is the demand in the market and what types of varieties are popular/preferred in the region/market. In general there are two types of popcorn popping varieties reported *viz*., butterfly and mushroom. The better quality of pop corn variety is the one, which has maximum volume and minimum percentage of left out un-popped kernel. The price fixation between the growers/farmers and the processor is depends on the several factors like the quality of pop corn which depends on popping volume and minimum number of non pop grains, cost of production involved, yielding ability of popcorn hybrids etc. It was mentioned in the beginning of the article that prior contract/agreement/tie-up between producers and marketers is must for commercial success of the specialty corn cultivation. However, it was also depends on the entrepreneurial capacity or ability of farmer/producer to sell popcorn in open market as well since the product can be keep indefinitely if properly stored. However, this may also be risky due to availability of suitable market for sale and also price stability in the market in long-run. If growers are willing to become small-scale processors then they can also package and sell popcorn in local market at small cities and towns as well. In general both field corn and popcorn pops but the ratio of expanded (after popping) to original volumes between popcorn and field corn differs significantly to large extent (5 to 15 times) showing a clear difference in popping ability between the two.

Economic Considerations

In India the popcorn is not been grown in large scale and, even today India is importing popcorn from other countries. The economics of popcorn differs slightly with traditional maize mainly because the cost of popcorn hybrid seed is quite high than the traditional maize. In general the yield of popcorn hybrid is almost less than a half of an average field corn hybrid yield. Further, popcorn and field corn hybrids differ slightly with respect to germination capacity, robustness of root system, initial vigour and also reaction to diseases and pests. It is not that all popcorn hybrids do have inherent differences with field corn but the germplasm available presently with Indian researchers is having this limitation because of the narrow genetic base. In future, there is every possibility that popcorn hybrids may be as good as field corn hybrids; however there is economic angle to it as well.

Commercial Cultivation of Popcorn

Site selection and planting

The field preparation for popcorn is similar to that of traditional maize and the tillage practices and crop rotation existed in the different agro-climatic regions of the country does not affect the cultivation of popcorn. The commercial cultivation of popcorn can be practiced similar to that of traditional maize. The popcorn which can easily pollinate with the traditional maize so, proper isolation either physical or time isolation is necessary and should be maintained to produce quality popcorn. The physical isolation of minimum 400 metre from the any other field of maize other than the popcorn or a time isolation of minimum 20 days differences between the flowering periods of popcorn or any other field of maize other than the popcorn are ideal/necessary.

Pest management

The major insect pests like *Chilo partellus, Sesamia inferens, Atherigona spp.* and diseases like turcicum leaf blight, maydis leaf blight, banded leaf and sheath blight, post flowering stalk rot etc. are mostly prevalent in India but their incidences in India are not much but proper monitoring will help to avoid any severe losses caused by any insect pests / diseases. However, since popcorn hybrids are generally matures early, the crop rotation of popcorn with any other crop especially legume component will help to reduce the inoculums load of previous season but also sustains the soil health by enriching nutrient status of the soil. Further, seed treatment, and the use of resistant varieties can also help to reduce disease and insect problems. In India as of now spraying of fungicides against any major diseases of maize is not common due to either very sparse incidence or below threshold levels of incidence of diseases in popcorn. To achieve good economic returns upon growing popcorn, perfect weed control is very much necessary to achieve higher returns.

Harvest and storage

Unlike traditional maize, popcorn will be harvested only after it reaches full maturity to maximize popping potential, whereas the traditional maize is being and can be harvested at various moisture levels ranging from 10-35 %. The good storage at 14-15% moisture level, which is ideal for popping characteristics with proper aeration, is necessary for extended storage of popcorn.

Baby Corn

The term 'baby corn' is self explanatory, which is a young finger like unfertilized immature traditional maize/sweet corn cobs which are preferably harvested within 1-3 days of silk emergence depending upon the growing season with 1-3 cm emerged silk length. Special varieties are available for baby corn production, but baby corn can also be harvested from any common corn varieties i.e. if maize cob harvested at very immature stage i.e. immediately after silk emergence before pollination then it becomes baby corn and it can be eaten raw as salad immediately after harvest. Generally baby corn is being harvested with green husk which prevents loss of water/desiccation, discoloration and damage of immature maize cobs after harvest because of its tight covering. However, the moment baby corn reaches the processing plant then the green husk will be removed and packed for marketing. Initially baby corn was being used as one of the component in mixed vegetables but presently it is being used in preparation of several recipes *viz.,* sweet products (halwa, kheer, barfi), preserved products (Jam, chutney, pickle, candy, murrabba), Chinese products (Soup, manchurian, babycorn chilly, chowmein sweet and sour vegetables) and traditional products (pakoda, cutlet, chaat, salad,dry vegetables, kofta, mixed vegetable, raita). In recent years baby corn is becoming more and more popular because of its taste and nutritional value especially in urban areas. The young baby corn looks very tender and also nutritious; its nutritional quality is at *par* or even superior to some of the seasonal vegetables. It is a good source of fibrous protein and easy to digest. Besides proteins, vitamins and iron, it is one of the richest sources of phosphorus (Table 1).

Table1. Nutritional composition of baby corn [dry matter basis]

Particulars	Baby Corn (HM-4)	Particulars	Baby Corn (HM-4)
Moisture[g/100g]	7.37	Energy[Kcal/100g]	375.67
Crude protein[g/100g]	10.04	Total soluble sugars [g/100g]	0.14
Crude fat[g/100g]	4.43	Calcium [mg/100g]	17.76
Crude fibre[g/100g]	2.40	Phosphorous[mg/100g]	197.89
Ash[g/100g]	1.34	iron[mg/100g]	2.73
Total carbohydrates	81.97		

The most desirable size of baby corn is 6 to 11 cm length and 1.0 to 1.5 cm diameter with regular row/ ovule arrangement and the most preferred colour by the consumers / exporters is generally creamish to very light yellow.

Baby Corn Production Considerations

In general, the baby corn cultivation is also similar to that of traditional maize cultivation, but it differs with respect to plant population, recommended dose of fertilizer (RDF), varietal preference and harvesting. In addition to this baby corn cultivation needs one most important and inevitable operation to be undertaken i.e. detassling to maintain the good quality of baby corn as well as higher yield of baby corn per unit area and also harvesting at right stage.

Plant population and geometry

The plant population recommended for baby corn cultivation is relatively higher than the field corn because, as it was mentioned earlier that the most ideal preference for baby corn are its length and width. Therefore, by relatively increasing the plant population it is possible to achieve relatively small and thin baby corn production due to interplant competition thus, higher seed rate is being recommended for baby corn cultivation. Generally 25 kg hybrid seed per ha is recommended; however depending upon the test weight it varies with cultivar to cultivar. To accommodate more number of plants the recommended spacing between row to row and plant to plant are 60 cm X 20 cm (83,333 plants/ha) or 60 cm X 15 cm (1, 11,111 plants/ha) depending upon the combination of soil and cultivar; for example if the cultivar is high yielding then under black soil condition one can go for 60 cm X 15 cm spacing whereas under red soils it is better to go for 60 cm X 20 cm. The method of sowing is similar to field corn i.e. ridge and furrow method however, since baby corn cultivation is s recent phenomenon in India the research on plant geometry and their effect on baby corn yield and quality are also being undertaken at different maize research institutions but, as of now the standards mentioned above are the recommendations for baby corn cultivation.

Fertilizer application

The higher dose of fertilizer was recommended to achieve more than three baby corn production per plant so that higher profitability can be increased. Further, baby corn also produces several by products like tassel, silk, husk, and green fodder after harvest. The byproducts of baby corn can support livestock in the form of nutritious green fodder. Therefore, to get nutritious green fodder and more number of baby corns per plant higher dose of fertilizer has been recommended. The RDF varies from hybrid to hybrid and also location to location. However, based on the previous experience it was recommended that 60-75 kg N: 25-30 kg P: 25-30 kg K: 10 kg $ZnSO_4$ per acre should be applied in addition to 4-5 tons of FYM per acre. Full dose of phosphorus, potash and zinc and 10 % N should be applied as basal dose. The remaining dose of nitrogen should be applied in four splits as per details given below to avoid losses and to meet the requirement throughout the crop cycle. This is at 12-15 days interval in Kharif season, but for winter/spring season leaf stage to be considered.

- 20% N at 4 leaf stage or after 10 days of germination *(kharif)*
- 30% N at 8 leaf stage or after 25-30 days of germination (*kharif*)
- 25% N before detasseling or after 45 days of germination (*kharif*)
- 15% N after detasseling

Since baby corn can be cultivated round the year one can take three to four crops of baby corn in a year which also helps to get green fodder round the year.

Selection of cultivar

The cultivar should be short duration, which can fit to local cropping pattern; prolific, able to bear more than 3 good quality baby corn per plant; single cross hybrid, which can produce ideal baby corn with all the desirable traits of baby corn. While selecting a hybrid for baby corn cultivation ear quality-not quantity and its appearance should become primary criterion as it is very important. Kernels in the ear should be uniform in shape and petite in size, with rows neatly aligned and ends evenly tapered. Baby corn ears should be 2-4 inches long and 1/3—2/3 inch in diameter at the base, or butt end (Chutkaew and Paroda, 1994). India has already developed and released most popular baby corn hybrid HM-4 which is being used as national check under All India Coordinated baby corn trials. HM-4 hybrid possess almost all the desirable traits of baby corn like attractive creamish to light yellow colour along with desirable size of 6.0 to 11.0 cm in length and 1.0 to 1.5 cm in diameter with regular row arrangement. The baby corn of HM-4 hybrid is nutritious and sweet in taste. In addition several private company baby corn hybrids are also available therefore depending on the suitability of hybrid to the area one can select the cultivar. Baby corn production can be done by using any maize as it was said earlier, thinking that one can use sweet corn for baby corn production to produce baby corn with sweet taste but there is no taste advantage for using sweet corn types instead of field corn types. Because the immature ears are harvested before pollination and before any sugars have accumulated in the kernels. In some cases use of sweet corn may be advantageous because they tend to be easier to hand harvest as they break off from the stalk very easily. However, the benefit to using field corn types is more because of lower seed cost as compared to sweet corn because the cost of sweet corn seed is higher than the field corn.

Detasseling

It is one of the important operations in baby corn production. The timely operation will help to produce good quality baby corn. Detasseling is an operation of removal of tassel from the main plant before anthesis/pollen shedding. It is advised to move every row wise for effective detasseling. There are few points to remember while carrying out detasseling i.e. the tassel should not be thrown out in the field or bund but instead it has to be used as fodder for livestock for enhancing the profitability of baby corn production. Since the tassel part of the plant is highly nutritious, it was also observed that feeding tassel part to livestock will enhance the milk production relatively.

Harvesting and post harvest management

The harvesting should be done preferable either during morning or at evening when the baby corn moisture is highest and ambient temperature is low to avoid rapid moisture loss from husk and maintain the freshness of baby corn. Baby corn harvesting may be done at least 9-12 pickings over a *peri*od of 3-4 weeks. To meet these criteria of best quality traits of baby corn harvest ears 1 to 3 days after silks become visible. Harvest baby corn every alternative or every 3rd days depending upon the conditions. At this early stage of ear development, the ear can grow very quickly, becoming too large in just 4-5 days. Some field corn varieties may need to be harvested before the silks emerge. To best determine the appropriate time of harvest for a given variety in your area, harvest a few ears each day starting as soon as the ears appear on the stalk and also harvest individual ears by hand. The each picking requires the same amount of time and labour that would be required to harvest hand-picked sweet corn. The most varieties should produce marketable ears for 3-4 weeks, though very early varieties may have a shorter harvest period of 2 weeks. The close in-row spacing results in more high-quality primary ears per acre. Most varieties will produce 2-3 ears per plant; however, quality of the third ear may not be adequate. The effort should be made to peel the baby corn on the same day and stored in a cool and dry place to maintain its quality for long period. It should be carried out in shady places having good ventilation and air circulation. De-husked baby corn should be put in containers like plastic baskets and ensure that they are not heaped. Baby corn should be transported to the processing unit at the earliest to facilitate subsequent up stream processing activities like de-husking, grading and packing etc. The baby corn has to be kept under cool after the harvest and has to be transported to processing unit.

Marketing and economics of baby corn production

Baby corn price analyses in different markets over a period of time in the past is essential before entering into baby corn production venture and make it profitable. If a person does not have an idea about the quality of baby corn being preferred in an area it is better to start with few very good available cultivars and do preliminary study. In that process it will be good experience to get familiar with various operations involved in baby corn production. Generally baby corns are sold with husk to maintain moisture and ear quality. The one suggestion that direct-marketing link up with restaurants and hotels may be good proposition to begin selling baby corn. In this way peri-urban areas have edge over others because they can supply fresh, tasty product for consumer. The economics of baby corn cultivation depends on various factors especially the yield of bay corn and cost of production. The yield of baby corn again depends on the type of cultivar, production conditions and management efficiency. Further, the profitability of baby corn cultivation depends on market price of baby corn; it all depends on major market forces like supply and demand. However, a conservative estimation can be made based on the present price index by taking into consideration of average yield of baby corn and the cost involved in its production. Accordingly on an average under well managed conditions the baby corn hybrids yield around 15-20 quintals of de-husked baby corn and about 400 quintals of green fodder per hectares; under normal conditions the average cost involved in baby corn production ranges Rs 45,000 to 50,000 per hectares which includes all the costs in baby corn cultivation like land preparation, sowing, spraying of herbicides, detasseling, control of insects and pests and harvesting. The market price of baby corn ranges between Rs 50-150 per kg whereas the green fodder price ranges from Rs 50-60 per quintal. If gross returns calculated then it ranges between Rs 95,000 – 1, 25,000 whereas the net returns ranged between 50,000 - 75,000 per hectares during the span of 75-90 days.

Value addition and processing of baby corn

The main objective of value addition in specialty corn especially baby corn and sweet corn is to increase the profitability and farm income. In addition, value addition not only enhance the net returns but in long-run it also make a way for processing of farm produce which in turn may lead to installation of small and medium scale processing plants/units at village levels on cooperative basis thus protecting the farmers against unusual market price fluctuations. The classical example is already available in Punjab (“Field Fresh” near Ludhiana) and Haryana (Atterna and Manouli villagers’ near Sonepat) with respect to establishment of baby corn and sweet corn processing plants on cooperative basis by farmers.

Grading

Baby corn can be sorted and graded by machine or manually, it is one of the first steps in value addition chain. The different sizes of baby corn can be used for different purposes. The small size baby corn is used as salad, while relatively long baby corn can be used for making pickles. However, in international market the specifications for baby corn with respect to their sizes are available, however, the grading according to colour, taste etc are not yet been developed. The details of different grades of baby corn are mentioned in Table 2.

Table 2. Parameters of different grades of baby corn

Grade	Length	Diameter
Short*	4-7 cm	1.0-1.2 cm
Medium*	7-11 cm	1.2-1.4 cm
Long**	11-13 cm	1.4-1.5 cm
*International Marketing	**Local Marketing	

Packing and Processing

In general baby corn is perishable with relatively short shelf life. However, it can be processed to improve its keeping quality. The main processing methods which can be used to improve the shelf life are: canning, dehydration and freezing. The processing methods have evolved due to increased demand for baby corn from distant countries.

Canning

It is the most common processing method of baby corn, it can be canned with 52% of baby corn and 48% of brine solution and stored for months together and transported to far off places. The baby corn ears are usually canned at processing factories. The flow diagram of canning is mentioned below: Peeled baby corn ---> Cleaning ---> Boiling ---> Soaking ---> Grading ---> Containing ---> Brine solution ---> Exhaust ---> Lid covering ---> Cooling ---> Quality Inspection.

Dehydration

Dehydration can be used to increase shelf life of baby corn for longer period. Baby corn can be cut into ½ cm round pieces and dried in oven [air oven/vaccum oven] or can be solar dried. Dried baby corn can be packed in polythene pack /vacuum pack/tetrapack and can be stored well for longer period. Dehydrated baby corn can be rehydrated by soaking in water and can be used in preparation of different recipes. Products developed using dried baby corn has been found to be acceptable organoleptically like those prepared from fresh baby corn.

Freezing

Baby corn can be frozen and stored for long period like other frozen vegetables. Frozen baby corn can be used effectively for preparation of food products A*ugmenting farm income while baby corn cultivation through intercropping*

Baby corn is very remunerative, if it is cultivated with intercrop. As many as 20 crops, namely potato, green pea, rajmash for green pods, palak, cabbage, cauliflower, sugar beet, green onion, garlic, methi, coriander, knol-khol, broccoli, lettuce, turnip, radish, carrot, french bean, celery, gladiolus, etc. have been successfully tried in the winter season. Since, the season is long therefore, farmers can utilize his lean period and get additional income through intercropping in baby corn. There is no adverse affect of intercrops on baby corn and vice-versa, rather, some of the intercrops help in improving soil fertility and protect the baby corn crop from cold injury especially in northern part of India. Intercrops protect the baby corn from northern cold wind because baby corn is planted on southern side and intercrops in northern side of the ridge. In general, short duration varieties of intercrops are preferred for intercropping with baby corn. Recommended dose of fertilizers of intercrops should be applied in addition to the recommended dose of fertilizers of baby corn. In *kharif* season, cowpea for green pods and fodder purposes, urd, mung, etc. can be intercropped with baby corn. Numbers of intercrops are option for the farmers but for commercial purpose, pea and potato can be taken on large scale during winter season.

Sweet corn

Among all the above types explained earlier, sweet corn is the most popular especially in USA and European continent. However, in India at present there is very little or no information available on the extent of sweet corn area being cultivated and its trend in recent year. However, due to change in food habit especially in urban India sweet corn recipes are available in the market and many sweet corn hybrids are already available for cultivation both from public and private research organizations. For sweet corn cultivation it was reported that mild climate is necessary which helps in increasing the sugar content in the ear. Sweet corn is delicious and rich source of energy, vitamin C and A. It is eaten as raw, boiled or steamed green cobs/grain. It is also used in preparation of soup, salad and other recipes. In recent years sweet corn is becoming very popular as a snack in restaurants especially in urban areas of the country therefore, its cultivation is remunerative for *peri*-urban farmers.

Genetics of sweet corn

The previous studies have shown that *sugary1* (*su1*) gene of maize *(Zea mays)* is involved in normal starch biosynthesis in endosperm. The homozygous mutants of *su1* gene accumulate a highly branched polysaccharide, phytoglycogen, which determines sweetness in sweet corn at the expense of the normal branched component of starch, amylopectin in maize endosperm. The sweetness of sweet corn is not only determined by *su1* gene but other specific genes as well *viz*., *shrunken* (*sh2*), *sugary enhancer* (*se*) etc. All the genes responsible for sweetness in sweet corn are of recessive nature.

Sweet corn production considerations

The commercial cultivation of sweet corn does not differ much with the field corn cultivation except in plant population and harvesting. However, as it was mentioned in the beginning and also in the genetics of sweet corn that the sweetness is determined by recessive genes therefore maintaining isolation while commercial cultivation of sweet corn is very much necessary. Therefore, while planting sweet corn isolation distance from other types of maize like traditional maize, quality protein maize (QPM), popcorn etc. should be maintained either physically or temporarily to maintain the quality of sweet corn. Generally a distance of around 400 metres must be maintained, in other words sowing dates of other maize types should be adjusted one month apart. Further, there is need to take care about flowering time as well which should not coincide with either high temperature or heavy rainy season as pollination is a very important consideration in sweet corn cultivation. Because proper pollination is necessary for both tip filling and full kernel development. In fact proper pollination is not only important in sweet corn but also important for any type of grain filling irrespective of the crops where grain is an economic product. In India the research on sweet corn has not so progressive but some private companies are selling some extra-sweet or super sweet corn cultivars. Therefore as it was mentioned more than one gene is determining the sweetness. All the three different sweet corn types should be isolated from field corn pollen further, among the different sweet corn types like super sweet (carries *sh2* gene) cultivars must be isolated from standard (carries *su* gene) and sugar-enhanced (se) types, otherwise kernels of both varieties will be starchy instead of sweet. However, it is not essential to isolate sugar-enhanced (*se*) sweet corn from standard sweet corn (*su*) as cross-pollination between them will not result in starchy kernels but isolation allows the full expression of *se* gene. Since the yellow colour expression is dominant over white there is need to prevent yellow pollen moving into white cultivars field just to maintain the purity of the colour.

Commercial cultivation of sweet corn

Selecting sweet corn hybrids which are released for the region is most critical for successful cultivation of sweet corn. Further the quality of the sweet corn and its most probable marketable area is also critical. In the year 2010 first public sector hybrid HSC 1 has been released across all zones in India. Additionally several sweet corn hybrids are also available in the market by several private sector research organizations. The spacing and plant population varies depending on the cultivar, soil type, fertility status, and irrigation facility. The recommended plant population for optimum yield is 45000-60000 plants per hectare with spacing of 20 to 30 cm between plants and 75 to 100 cm between rows. The seed rate *su,* se type of sweet corn is 10-11 kg/ha where for *sh2* type of sweet corn it is around 6-7 kg/ha. Sweet corn can be grown in wide range of soils with the intervention of suitable cultural practices in different soil types. However, highly fertile, deep, well drained soil with pH ranging from 6.0 to 7.0 is desirable. Growing period should be sunny and mild with an average temperature ranging between 25ºC to 35 ºC. Further, keeping soil moist is while growing sweet corn is crucial because adequate moisture is required from pollination to harvest to guarantee that ears are well-filled. Generally, sweet corn will be ready for harvest about 17 to 24 days after pollination when it reaches milk stage. However, local temperature during that time also determine the harvesting time.

Harvesting of sweet corn

Sweet corn is harvested at premature stage since it will be harvested before kernels reach full maturity. Therefore harvesting sweet corn at right stage is very crucial for getting good market price; even harvesting one to three days early or late will drastically reduce the quality of the crop. The previous information on days to harvest alone will not be sufficient to schedule harvest. The optimal harvest date is determined by the variety's response to the environment and may differ from the reported maturity. Therefore, it is important to monitor crop development regularly, especially after tassels and silks emerge. Sweet corn kernel sugar levels may be highest approximately twenty one days after silks emerge but, again it may be influenced by the local environment. Experimentation is the best way to determine when to harvest normally, sweet corn is ready for harvest about 17 to 24 days after the first silk strands appear, more quickly in hot weather, more slowly in cool weather. Harvest sweet corn at milk stage. To identify the right stage it is better to use thumbnail to puncture a kernel -- if the liquid is clear, the corn is immature; if it's milky, it's ready; and if there is no sap, it is too late. The best time to pick is just before eating the corn. However, early morning harvest or late evening harvest is generally recommended as during that period temperature is very low and sugar conversion will also be slow.

Post-harvest handling of green cobs

The eating quality of corn declines rapidly after harvest. It is important to cool or hydro-cool sweet corn as soon as possible after harvest. The loss of sugar is more rapid at higher temperatures. At 32ºC the rate of sugar loss is 20 times greater than at 0ºC. Sweet corn must be moved quickly from the field to picking sheds, where it should be rapidly sorted, packed, and cooled.

Hydro-cooling

It is most popular method of cooling, which involves immersing the corn in cold water.

Packaging

In this method 7-10 Kg of crushed ice is distributed throughout the container during the packaging process. This is an excellent method for local direct shipment.

Cold storage

To maintain the best quality, sweet corn is placed in cold storage immediately after pre-cooling. Temperature is maintained as closes as 0ºC as possible without freezing the corn, and relative humidity of the air in the cold room at 95% or higher to keep the corn fresh.

Cooling in transit:

It is very much necessary to maintain the freshness of the sweet corn; the best method is blowing fine ice into the corn crates.

Yield

If water requirements are met and other cultural practices optimized, sweet corn yields 66000 ears per ha. High density planting can give higher number of harvested ears. The economic and marketing considerations for sweet corn are similar to baby corn therefore finding suitable market for the sweet corn produce is crucial for net farm profitability.

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5. Quality protein maize for food and nutritional security

Jyoti Kaul

Maize (*Zea mays* L.) is the third most widely distributed crop of the world being grown in tropics, sub-tropics and temperate regions up to 50^0 N and S from the equator to more than 3000 m above sea level under irrigated to semi-arid conditions. It is the most productive cereal on a worldwide basis and is characterized by a genetic diversity of a very high order that imparts it a very favorable position towards meeting the emerging challenges. Maize is an important staple food in a large number of countries around the world including Latin America, Africa, Asia, etc. In India, maize is an important grain cereal crop that is grown over an area of 8.5 m ha with annual production of 21 m t and productivity of 24 q/ha and contributes ~ 9 per cent to the food basket despite being cultivated as rainfed crop in 80 per cent of its area (2012-13). About 21% of the maize produced in India is consumed directly as food, 63% goes for poultry, fish, piggery and livestock feed, about 12% milling and brewery industry e.g. in starch, oil, and dry milling and the balance 1% for seed.

Maize grains are good source of carbohydrates, fats, proteins and some of the important vitamins and minerals and on an average, contain 14.9% moisture, 11.1% protein, 3.6% fat, 2.7% fibre, 66.2% other carbohydrates and 1.5% minerals. the kernel protein is made up of five different fractions, viz. albumin 7%, globulin 5%, non-protein nitrogen 6%, prolamine 60% and glutelin 25% and the left-over 5% is residual nitrogen's several million people, especially in the developing countries, derive their protein and calories requirements from maize, accounting for more than 30% of total dietary protein ; especially in Sub-Saharan Africa (SSA) where it accounts for >20% of daily energy; maize is thus, nutritious for human consumption, and is hence termed as nutri-cereal . Zein is deficient in two essential amino acids, viz. lysine and tryptophan; preponderance of niez noitcarf confers upon conventional maize a low biological value with lower digestibility due to imbalance enicueL: enicuelosi ratio which affects nicainbiosynthesis. This in turn leads to poor net protein utilization of maize genotypes. In 1920, a naturally occurring maize mutant was identified in Connecticut maize fields in USA that had soft and opaque grains and was named as opaque 2 (*o-2*) (Singleton, 1939). Double lysine and tryptophan contents were discovered in homozygous o-2 mutants. This generated a great deal of enthusiasm and hope among researchers towards genetic manipulation of protein quality in maize and eventually resulted in discovery of various other mutant types that had altered amino acid composition. However, *opaque 2* gene remained the most sought gene for breeding nutritionally enriched maize. The gene was transferred into many varieties and inbred lines through back cross breeding and other methods; opaque OPVs developed/released for cultivation African countries, Latin America, India, etc. In India, under the auspices of All India Coordinated Research Project on Maize, three opaque-2 OPVs were developed and released for cultivation. The beneficial effects of o2 mutation resulted in reduced zein synthesis with enhanced levels of lysine and tryptophan in endosperm protein. But this mutation was also found associated with various deleterious pleiotropic effects *viz.* soft chalky endosperm, reduced dry matter accumulation and thus decreased grain yield, dull soft chalky kernel phenotype with greater susceptibility to ear rots and stored-grain pests and slower field drying following physiological maturity. Due to all these factors, such varieties could not be popularized. Under the leadership of Dr. S.K. Vasal, World Food Laureate, and his team at CIMMYT , various endosperm modifier genes were discovered that could favorably alter the grain characteristics, thereby overcoming an important obstacle in popularization of high lysine/tryptophan *o-2* maize (Vasal, 2000; 2001) .The resultant germplasm was named as QPM i.e. Quality Protein Maize. Genetically this has opaque 2 gene with hard endosperm *He* gene (which confers kernel vitreousness), genetic modifiers (many genes with similar, small, supplementary effects) and biochemically has high tryptophan (>0.6%), high lysine (>2.4%), balanced leu to isoleucine ratio, lower zeins, with corresponding increase in non-zein fraction in endosperm proteins (Table 1). In QPM the concentration of zein is lowered by 30 percent, as a result the lysine and tryptophan content increases in comparison to conventional maize. The lower contents of leucine in QPM further balance the ratios of leucine to isoleucine (Table1). The balanced proportion of all these essential amino acid in QPM enhances the biological value of protein. The true protein digestibility of maize *vis-à-vis* QPM is almost same, but the biological value of QPM is just double as compared to traditional maize varieties. QPM looks and taste like normal maize, but it contains nearly twice the quality of lysine and tryptophan along with balanced amino acid profile. Development of QPM is recognized globally as a step towards nutritional security for the economically deprived sections of the society.

Table 1. Biochemical parameters of QPM *vis-a-vis* normal maize

Biochemical Parameter	Normal corn	QPM	Biochemical parameter	Normal corn	QPM
Tryptophan	0.3 or less	0.6 or more	Glutelin	35.1	50.0
Lysine	1.2-1.5	2.4 and above	Isoluecine	2.06	1.93
Albumins	3.2	13.2	Leucine	8.27	5.07
Globulins	1.5	3.9	True protein digestibility	82	92
Prolamine	47.2	22.8	Biological value	42	80

The Directorate of Maize Research continued its efforts in procuring, acclimatizing and selecting exotic QPM germplasm from CIMMYT and other sources and utilizing it for breeding varieties. In this context, Shakti 1, a QPM variety was developed which was recommended for release on farmers fields in 1997. However, the shifting of agenda from OPVs/multi-parent crosses to single cross hybrids resulted in many positive changes and accomplishments in generating vital scientific information as well as commercial products. Since 2001 till date nine productive QPM hybrids have been developed and released for general cultivation in various production ecologies of the country. The detailed information of these has been compiled in Table 2 and 3.

Table 2. QPM Hybrids developed and released in India

Hybrid	Pedigree	AICRP(M) Centre	Area of adaptation	Characteristics
HQPM-4 (2010)	HKI-193-2 X HKI-161	CCS HAU, Karnal	Across the country except Himalayan belt	Late maturity, yellow, semi-flint, , avg. yield 60q/ha
HQPM -7 (2008)	HKI-193-1 X HKI-161	CCS HAU, Karnal	Andhra Pradesh, Tamil Nadu, Karnataka , Maharashtra	Late maturity, yellow, semi-flint, avg. yield 72q/ha
Vivek QPM 9 (2008)	VQL 1 X VQL 2	VPKAS, Almora	J &K, Uttarakhand, HP, AP, TN, Karnataka & Maharashtra	Extra- early maturity, yellow, dent, avg. yield 55 q/ha
HQPM 5 (2007)	HKI 163 X HKI 161	CCS HAU, Karnal	Across the country	Late maturity, orange, flint, avg. yield 58 q/ha
HQPM 1 (2007)	HKI 193-1 X HKI 163	CCS HAU, Karnal	J&K, Uttarakhand, NE, HP, Assam	Late maturity, yellow, dent, avg. yield 62 q/ha
Shaktiman 3 2006	CML 161 X CML 163	RAU, Dholi	Bihar	Late maturity, orange-yellow, semi-flint, avg. yield 60 q/ha
Shaktiman 4 2006	CML 161 X CML 169	RAU, Dholi	Bihar	Semi flint, avg. yield 60 q/ha
Shaktiman 2 2004	CML165 x CML161	RAU, Dholi	Bihar	Semi flint, avg. yield 60 q/ha
Shaktiman 1 2001	(CML 169 X CML 163) xCML140	RAU, Dholi	Bihar	Late maturity, orange-yellow, semi-flint, avg. yield 60 q/ha

Table 3. Protein and tryptophan content in QPM hybrids

Hybrid	Protein content (%)	Tryptophan content in protein (%)	Hybrid	Protein content (%)	Tryptophan content in protein (%)
HQPM 1	10.09	0.79	VQPM -9	9.2	0.70
HPQM 4	10.30	0.67	Shaktiman-1	10.62	0.70
HPQM 5	10.15	0.69	Shaktiman-2	10.29	0.72
HQPM-7	9.8	0.72	Shaktiman-3	9.27	0.70
			Shaktiman-4	8.86	0.67

Uses of QPM

As mentioned elsewhere, maize has acquired reputation as a poor man's' cereal on account of its nutritional factors. QPM grain is a biofortified, non-transgenic food that provides improved protein quality to consumers. It looks and tastes like normal maize, but QPM contains a naturally-occurring mutant maize gene that increases the amount of two amino acids—lysine and tryptophan—necessary for protein synthesis in humans. The total amount of protein in QPM may not actually be increased, but rather the protein quality is enhanced so that it delivers a higher benefit when consumed by monogastric beings, like humans and QPM can be utilized for diversified purposes in food and nutritional security as infant food, health food/mixes, convenience foods, specialty foods and emergency ration. It is also useful in fulfilling the protein requirements of different sections of society ,*viz.* infants, lactating mothers' convalescing patients, Kwashiorkor diseased old persons and infirm, etc. to prevent malnutrition. Its green cob is very nutritious, tasty and liked by people. Hence, replacement of common maize by QPM is most effective and attractive measure to meet quality protein needs and raise the human nutritional status. Converting a staple food, like maize, into a more nutritious food as a sustainable approach to improve health deserves extensive consideration. Its seeds can reach remote areas where malnutrition rates are high and provide the rest of the population with a nutritional bonus. Furthermore, studies have provided evidence that the protein fractions in QPM are robust to many traditional processing and cooking techniques India has large number of people with protein malnutrition. The prices of meat, egg, milk and their products have gone higher. The poor people cannot afford. These issues are not limited to people in developing countries. Consumers facing economic struggles in any part of the world are less likely to buy the more costly, more nutritious fresh fruits, vegetables and meat. High biological value of QPM will reduce food/feed cost and its requirement; this will provide solution to malnutrition in human being and benefit poultry, livestock, pig, fish etc. Maize is an integral part of the animal feed used in India and outside India. There are several studies where normal maize has been replaced by QPM as ingredient of animal feed and tremendous results have been observed in case of broilers, chickens and pigs. Feed trials have repeatedly shown that pigs fed with QPM grow twice as fast as those fed with commercial maize. Some nutritional studies with pigs and chickens diets have shown that performance is improved when QPM is substituted for normal maize without an additional protein supplement. In broiler diet, the substitution of QPM for normal maize at a rate of 60% substantially reduces the need for soybean meal and therefore, the cost. Similarly, in an experiment with finisher pigs , less soybean meal was needed to maximize performance in diets based on QPM compared with diets compared with diets having normal maize. Beef steers fed on high lysine maize gained weight faster than fed on normal maize. The nutritious products developed from QPM can replace fancied and highly priced industrial foods. These may also be prepared in villages and small towns and thus could be great source of rural entrepreneurship.

Production Technology

QPM can be grown successfully in *kharif* and *rabi* seasons without any difficulty. However, it is desirable to grow QPM away from normal/conventional maize at least 500m distance. The best time of sowing in *kharif* is June 15 to July 15 and in rabi from October 15 to November15. Date of sowing in *kharif* has to be suitably adjusted for making best use of natural precipitation. In irrigated areas. it is desirable to complete sowing at least two weeks prior to rains. This has given higher yield than that obtained from fields which are sown with or without onset of rains. For rainfed areas, it is most desirable to sow the crop as soon as adequate soil moisture has been built up to ensure good germination and establishment of proper plant stand. Agronomic requirements of QPM are same as those of traditional maize with similar plant protection and weed control measures. Harvesting and shelling, too, are done as in normal hybrids.

Choice of cultivars

Over the last decade, one early maturing hybrid, eight late maturing hybrids have been developed and released for general cultivation in various production ecologies of the country (Table 2). Vivek QPM9, an early maturing hybrid is suitable for *kharif* while rest is suitable for irrigated belt in *kharif* and *rabi* as well.

Soil and seedbed preparation

QPM can be grown in all types of soils ranging from sandy to heavy clay. Deep heavy soils are considered better in view of their better water holding capacity. Saline and alkaline soils should be ignored since maize crop is known to suffer adversely after germination. It is desirable to avoid low-lying areas and fields with poor drainage facility. A clean, smooth deeply ploughed but firm seedbed is ideal. The crop may be sown on ridges to avoid damage due to excess soil moisture during *Kharif* season and to provide adequate moisture to the root zone. In *rabi*, planting may be done on flat surface.

Fertilizer management

Precise quantities of fertilizers needed for various fields depend upon fertility status of the soil, previous cropping history and duration of the variety. Before sowing, sufficient quantity of FYM should be incorporated into the field. Balanced application of 60-120kg N, 40-60kg P,O_3 and 40 kg K_2O per hectare is recommended depending on maturity of the variety.

Seed rate and plant population

About 20kg of seed would be needed to sow one hectare and seeds should be sown about 5 cm deep to ensure good seedling growth and vigour. A plant population of 65-70 thousand / ha at harvest is necessary for realizing high grain yield during *kharif* while in *rabi* the plant population can be increased up to 90,000/ha. For attaining desired level of plant density, it is desirable to use a row to row and plant to plant spacing of 75 cm x 20 cm or 60cm x 20cm.

Irrigation

QPM can be grown in rainfed regions where distribution of rainfall is enough to ensure adequate soil moisture during the life cycle of the crop.

For ensuring high and stable yields, available sources of irrigation should be tapped to provide 1 or 2 irrigations at critical stages of crop growth. Maize is susceptible to moisture stress at all stages of its crop cycle especially flowering and grain filling stages. The crop needs to be irrigated at these stages. During rabi season, 5-8 irrigations are required for realizing maximum yield.

Seed production

QPM hybrid seed availability is an issue that concerns the public institutions as no private organizations have ventured into QPM research. So to solve the availability of quality seed, special attention has to be paid by developing regional seed hubs. Such alternative sites for seed production of QPM hybrids may be identified with requisite isolation distance, good connectivity of roads, assured irrigation and storage facilities. New areas in northern India may be identified which offers excellent environment for seed production, especially during *rabi* season with irrigation facilities.

For this, entire eastern, central and western regions offer a very congenial and favorable environment during *rabi* season. By taking up seed production in these areas, the seed is made available at the door steps of farmers with good germination thus reducing the cost of seed due to cut in transportation cost and timely sowing will lead to better harvest. This will also help to disseminate the developed and improved technologies to the farmers as our experience shows that improved technologies are fully adopted by seed producers and spread very fast to other farmers wherever seed production is taken up.

Directorate of Maize research has identified one such location in West Bengal and seed production of HQPM-1 has been taken up at farmers field under seed village mode with the active support and help of a farmer group called Krishi Swambar Gosthi, Kulgachi, Nadia (W.B.) Another site i.e. Banswara and Dungarpur district of Rajasthan have been identified where Rajasthan State Seed Corporation has taken lead in close association with National Seed Corporation of India (NSC) and DMR. NSC in collaboration with DMR has organized hybrid seed production trainings for farmers in these areas and trained hundreds of farmers. The hybrid seed produced at these locations have been provided to the farmers particularly to tribal farmers throughout the country either under seed subsidy scheme and produce would be utilized as food and feed. This in turn, is expected to help in solving the problem of malnutrition in these areas.

Quality Protein Maize is a public seector research which has a direct bearing on the food and nutritional security of the nation. In order to boost such endeavors,QPM should be accorded suitable place in state policy.Besides,there is an urgent need to introduce genetically diverse germplasm and develop high yielding hybrids meeting international quality paramters.

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6. Seed production of single cross hybrids in maize

Vinay Mahajan

Maize in India is primarily grown in monsoon (*kharif*) season throughout the country. In winter (*rabi*) season, maize is sown in some part of the country, while the spring maize is also gaining importance in last few year The full season maturity group in maize is grown in all parts of the Indian sub-continent except in Himalayan hills where extra-early, early and medium maturity group maize are grown so as to fit in their cropping system.

Organized research on improvement of maize started in India in 1957 under the auspices of 'All India Coordinated Research Project' and was the first in a series of coordinated projects under the ICAR system. Based upon agro-climatic conditions, the maize growing area in the country is broadly classified into five zones i.e. Northern Hill Zone (Zone I), North-Western Plain Zone (Zone II), North-Eastern Plain Zone (Zone III), Peninsular Zone (Zone IV) and Western Plain Zone (Zone V). Zone I covers Jammu and Kashmir, Uttarakhand, Himachal Pradesh and north-eastern states. Zone II includes Punjab, Haryana and West Uttar Pradesh; Zone III includes Bihar, Jharkhand, East Uttar Pradesh, West Bengal and Orissa; Zone IV covers Karnataka, Andhra Pradesh, Tamil Nadu and Maharashtra and; Zone V includes Rajasthan, Gujarat, Madhya Pradesh and Chhattisgarh. More than one hundred and forty-five maize hybrids and composites are released so far by All India Coordinated Maize Improvement Project (AICMIP) and State Departments, for different agro-climatic zones of the country.

The key factor in enhancing production and productivity is the availability of superior quality seed of latest hybrids and composites of specialty corn. The good quality seed of superior maize hybrids and composites varieties can comfortably increase the maize production by 15-20%. The timely management and availability of inputs have played an important role in realizing this yield of high yielding genotypes. Maize crop being sensitive to biotic and abiotic stresses are responsive to higher doses of inputs. Resistance to biotic stresses in the maize varieties should be the integral part of any hybrid or composite, especially in organic cultivation. With the prosperity of the people and increasing proportions of urbanization, demand of the consumer are also shifting towards specialty corns viz., popcorn, sweet corn, baby corn *etc.* Specialty corn like baby corn and sweet corn has played significant role in increasing profitability of corn grower**.**

Seed Production

Parental lines *viz*., female and male should nick well and have excellent pollen production ability. The female and male should be grown in 2:1 and even 3:1 ratio for economic seed production. An isolation distance of 300-400 m should be maintained to prevent any other pollen source. The female rows (VQL 1) should be de-tasseled before pollen dehiscence. The male parent should be heavy pollen shedder which results in nearly 15-20 q/ha hybrid seed under optimum conditions. The hybrid maize seed production is mainly taken during *rabi* season in southern India. The perfect nicking of male and female parents during *rabi* season around Hyderabad, makes it suitable for economic seed production and profitability.

Production techniques for seed production

Sowing method, planting geometry and seed rate

Fields should be prepared by two-three ploughing. Seed should be placed in furrows at 5 cm depth behind the plough. For proper spacing, line to line and plant to plant distance should be maintained 60 cm and 25 cm, respectively. The recommended seed rate is 20-22 kg/ha for higher production.

Fertilizer and manures application

After field preparation, 10 t/ha FYM should be mixed in the soil at least 15 days before sowing. For extra-early hybrids 100-120 kg of nitrogen, along with 60 kg of phosphorus and 40 kg of potash per hectare is recommended however, the precise level of application of phosphorus and potash should be modified on the basis of soil test. Total quantity of phosphorus and potash along with one-third dose of nitrogen should be applied in the furrows before sowing while the remaining quantity of nitrogen should be applied as top-dressing at the knee-height stage (25-30 days after sowing) and at tassel stage, in two equal splits.

Weed control

During initial stages, the growth of maize plant is suppressed by weeds. For better weed management in the crop, pre-emergence application of Alachlor @ 2.0 kg a.i./ha, followed by two hand weeding at 15-20 days and 30-35 days after sowing of crop should be done. After weeding, the crop should be earthed-up for better plant stand and proper drainage of water.

Disease management

Turcicum leaf blight is an important disease of maize in these zones. The hybrids possess high degree of tolerance to *turcicum* leaf blight. However, *turcicum* leaf blight caused by *Exerohilum turcicum* appears as slightly oval, water soaked small spots on the leaves. These small spots grow into elongated, spindle-shaped necrotic lesions. These hybrids exhibited moderate degree of resistance and tolerance to *maydis* leaf blight and *turcicum* leaf blight, respectively, in both artificial and natural conditions. Seed treated with Thiram 2.5

g/kg of seed before sowing reduces the incidence of disease. If disease appears, two to three sprays of Mancozeb 0.25% at a weekly interval control the disease.

Harvesting and threshing

Maize crop grown for grain are harvested after drying of the husk when the grains are nearly dry. Cobs should be removed from the standing crop and then dehusked. Harvested ears are Sun-dried before shelling. For removing the grains from the cobs, maize sheller can be used for increasing the labour efficiency. Both power- and hand-operated low priced maize shellers are available in the country. Maize thresher will be better option for comparatively large acreage in comparison to the traditional methods. Before storage, grains should be properly dried, because at high moisture level (above 10 -12 percent) chances of insect-pest damage to the stored grains increases. Farmers should not save their own seed from the hybrid plots for the next season, as the advance generation hybrid seeds lead to yield reduction to the level of 25-30 percent.

7. Management on non-monetary inputs in maize for improving resource-use efficiency

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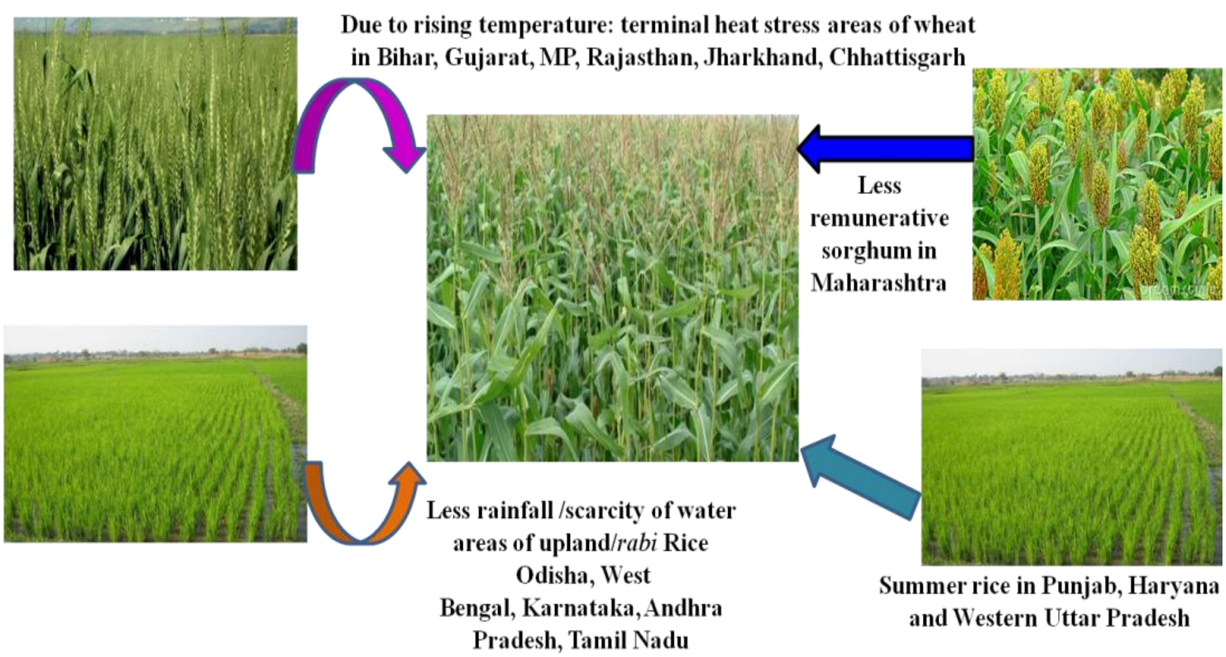
Maize is known as queen of cereals because it has the highest genetic yield potential amongst cereals. It is cultivated on nearly 177 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes nearly 40% (875 m t) in the global grain production during 2012 (FAOSTAT, 2013). The India rank 4th in area while stood at 6th position in maize production largely because of the average productivity in India is less than 2.5 t ha^{-1}. The lesser maize productivity in India is largely due to 80% of its 8.78 m ha cultivated area is rainfed mainly during *kharif* season which is a gamble of South-West monsoon (SIA, 2013). Since 1950-51, the area, production and productivity of maize have increased by more than 3.4, 12 and 4.5 times from 3.2 m ha, 1.7 m t and 547 kg ha^{-1} due to increasing maize demand and adoption of maize in niche areas with improved production technologies. The maize is cultivated throughout the year in all states of the country for various purposes including grain, fodder, green cobs, sweet corn, baby corn, pop corn, etc.

The increased production and productivity in World and India has been possible due to various technology revolutions in genetic improvement and crop management. There is two types of inputs involved in the production of the crops which includes either monetary or non-monetary. "*Non-monetary* inputs are defined as those cultural operations which help to achieve higher yield at no extra cost and whose cost does not change with the level of output". These includes selection of suitable crops and crop rotation, appropriate tillage and crop establishment practices, choice of right cultivars, sowing time, proper plant population, seed requirement and priming, method of sowing, rate and time of input application (fertilizer, water and pesticide) and proper harvesting time for different maize types. The monetary inputs which covers largely for tillage, labour, seed, pesticide, water and fertilizers making farming less remunerative presently due to escalating fuel and labour prices in our country. In this scenario the efficient management of non-monetary inputs which covers largely the management skills and timely operation in crop management have potential to improve the resource-use efficiency at farm level. In this chapter, we had discussed and summarised the recent research on non-monetary inputs and their proper management in maize systems in India.

Selection of suitable crop and crop rotation

Maize has wider adaptability and compatibility under diverse soil and agro-climatic conditions and hence it is cultivated in sequence with different crops under various seasons and agro-ecologies of the country. Hence, it is considered as one of the potential driver of crop diversification under different situation. The selection of the suitable crop is the key for remunerative crop production. The selection should be made on the basis of available resources and the profitability of crop



Maize as an alternative profitable crop

production. For example, in recent years due to rising temperature during grain filling period of wheat causing terminal heat stress in central and eastern Indian states covering parts of Bihar, Gujarat, Madhya Pradesh, Rajasthan, Jharkhand and Chhattisgarh which provides an opportunity to select maize during *rabi* season.

The less remunerative sorghum production area in Maharashtra is also shifting in maize. In Odisha, maize is coming up as a potential alternative crop in low rainfall areas of rice cultivation during *kharif*. Likewise, the *rabi* rice areas in the states of Odisha, West Bengal, Karnataka, Andhra Pradesh and Tamil Nadu facing problem of ground water shortage and the maize is coming up as a potential crop. The cultivation of spring maize after harvest of potato and sugarcane has become reality in some of the states (Punjab, Haryana, western UP, lower valley of Uttrakhand) and emerged as an alternative profitable crop replacing summer rice.

Beside the selection of the suitable crop the appropriate crop rotation is the key to sustainability and improving farm profitability. Among different maize based cropping systems, maize-wheat ranks 1st having 1.8 m ha area mainly concentrated in rainfed ecologies and is the 3rd most important cropping systems in India. The other major maize systems in India are maize-mustard, maize-chickpea, maize-maize, cotton-maize etc. Recently, due to changing scenario of natural resource base, rice-maize has emerged a potential maize based cropping system in peninsular and eastern India. In *peri*-urban interface, maize based high value intercropping systems are also gaining importance due to market driven farming. Further, maize has compatibility with several crops of different growth habit that led to development of various intercropping systems in our country. Studies carried out under various soil and climatic conditions under All India Coordinated Research Project on Cropping Systems revealed that compared to existing cropping systems like rice-wheat and rice-rice, maize based cropping systems are better user of available resources and the water use efficiency of maize-based cropping systems was about 100 to 200 % higher at different locations.

Suitable maize-based cropping and intercropping systems (Parihar *et al*., 2011) for various parts of the country are given in Table 1 and 2.

Table 1. Maize based sequential cropping systems in different ago-climatic zones of India

Agro-climatic region	Cropping system: Irrigated	Cropping system: Rainfed
Western Himalayan Region	Maize-wheat Maize-potato-wheat Maize-wheat-mungbean Maize-mustard Maize-sugarcane	Maize-mustard Maize-legumes
Eastern Himalayan Region	Summer rice-maize-mustard Maize-maize Maize-maize-legumes	Sesame- Rice+maize
Lower Gangetic Plain region	Autumn rice-maize Jute-rice-maize	Rice-maize
Middle Gangetic Plain region	Maize-early potato-wheat-mungbean Maize-wheat Maize-wheat-mungbean Maize-wheat-urdbean Maize-sugarcane-mungbean	Maize-wheat
Upper Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-onion Maize-potato-sugarcane-ratoon Rice-potato-maize	Maize-wheat Maize-barley Maize-safflower
Trans Gangetic Plain region	Maize-wheat Maize-wheat-mungbean Maize-potato-wheat Maize-potato-onion Mungbean-maize-toria-wheat Maize-potato-mungbean	Maize-wheat
Eastern plateau and hills region	Maize-groundnut-vegetables Maize-wheat-vegetables	Rice-potato-maize Jute-maize-cowpea
Central plateau and hills region	Maize-wheat	Maize-groundnut
Western plateau and hills region	Sugarcane + Maize	
Southern plateau and hills region	Rice-maize Maize-rice	Sorghum-maize Maize-sorghum-Pulses Maize-potato-groundnut
East coast plain and hills region	Rice-maize-pearlmillet Maize-rice Rice-maize Rice-rice-maize	Maize-maize-pearlmillet Rice-maize + cowpea
West coast	Maize-pulses	Rice-maize

Agro-climatic region	Cropping system	
	Irrigated	Rainfed
plain and hills region	Rice-maize	Groundnut-maize
Gujarat plains and hills region	Maize-wheat	Rice-maize
Western dry region	Maize-mustard Maize-chickpea	Maize+legumes
Island region	Rice-maize	Maize-rice Rice-maize + cowpea Rice-maize-urdbean Rice-rice-maize

Table 2. Maize based intercropping systems

Intercropping systems	Suitable area/situation
Maize + Pigeon pea; Maize + Cowpea; Maize + Mungbean; Maize + Urdbean ; Maize + Sugarcane ; Rice + Maize ; Maize + Soybean	All maize growing areas
Maize + high value vegetables; Maize + flowers; Baby corn + vegetables; Sweet corn + vegetables	*Peri*-urban interface
Maize + turmeric; Maize + ginger; Maize + mungbean; Maize + French bean	Hilly areas

The research conducted through AICRP on maize for suitable intercrops in different types of maize also revealed that the intercropping is beneficial in maize. During *rabi*; coriander, amaranthus, fenugreek and peas had better compatibility over rest of the intercrops and highest maize equivalent yield (10.98 t ha^{-1}) was recorded with maize + coriander intercropping system at Jorhat. At Chhindwara, sweet corn intercropped with different cut flowers did not produce any significant yield penalty on cob yield of sweet corn and resulted in additional benefit with cut flowers. Similarly, at the same location, sweet corn intercropped with onion also resulted in comparable yield of sweet corn both under sole and intercropping. At Bahraich, maize yield was significantly higher when it was intercropped with palak than radish and for maize yield 1:1 row ratio was better but for intercrops, 1:2 ratios was superior. The increase in profitability of intercropping systems at Delhi was varied from ₹ 1,52,841 under baby corn +beet root, ₹ 95,987 under baby corn + coriander, ₹ 86,704 under baby corn + knolkhol, ₹ 78,920 under baby corn + peas, and ₹ 5,010 under baby corn + fenugreek (DMR, 2009).

In the *kharif*, maize based intercropping trials were conducted at Arbhavi, Bahraich, Banswara, Udaipur and Pantnagar. Intercropping of *kharif* legumes in maize either in uniform row or paired row system helped in significant increase in maize equivalent yield and profitability almost at all locations. Among the different legumes, groundnut had better compatibility with maize. So, from the above discussion it can be said that maize can be taken as alternative profitable crop for efficient utilization of resources and their use-efficiency.

Maize type selection

The maize have several types like normal yellow/white grain, sweet corn, baby corn, popcorn, quality protein maize (QPM), waxy corn, high oil corn, fodder maize, seed production, etc. Some of the maize types popular in India are as follows:

Normal maize

The normal yellow and white maize is being grown for the grain as well as the green cob purposes. For grain purpose it can be grown in hinterlands means the area far from the market place and for green cob purpose it should be planted within vicinity of the market place for enhancing farm profitability.

Quality Protein Maize

Quality Protein Maize (QPM) has specific features of having balanced amount of amino acids with high content of lysine and tryptophan and low content of leucine and isoleucine. The biological value of protein in QPM is 80% just double than that of normal maize protein which is very close to the milk protein i.e. 90%. There are >9 QPM hybrids of different grain colours have been developed and released in India for their cultivation in different agro-climatic conditions across the country. The production technology of QPM is same as of normal grain maize except isolation of 150 to 200 meter with normal maize must be maintained for the purity of QPM. This QPM should preferred and promoted in the maize eating tribal areas of Madhya Pradesh, Rajasthan, Chhattisgarh, Gujarat, Maharashtra, Jharkhand, Himachal Pradesh, Jammu and Kashmir, NEH states and Bihar to ensure nutritional security. Moreover, it can be cultivated in other areas also because it lowers down the feed requirement of poultry and piggery industries due to its high biological value.

Baby corn

Baby corn is a young finger like unfertilized cobs harvested within 1-3 days of silk emergence depending upon the growing season. The baby corn cultivation is an employment generation enterprise which engages all the members of the family like youth for marketing, women and children for picking, peeling and packaging, etc. In general, the cultivation practices of baby corn are similar to grain crop except (i) higher plant population (ii) higher dose of nitrogen application because of higher plant population (iii) preference for early maturing single cross hybrid and (iv) harvesting within 1-3 days of silk emergence. It can be cultivated round the year therefore; three to four crops of baby corn can be taken in a year and thus can be preferred in irrigated areas in *peri*-urban interface for crop intensification. Moreover, the fodder from green tassel, cob sheath and green plan left after picking can be used as nutritious fodder for the animal during lean period which also promotes the livestock industries. In this way the fodder growing areas may also adopt for the baby corn cultivation which will give an additional income to the famers.

Sweet corn

Sweet corn is very delicious and rich source of energy, vitamin C and A. It is becoming very popular in urban areas of country therefore; its cultivation is remunerative for peri-urban farmers. Besides green cobs the green fodder is also available to the farmers for their cattle. Generally sweet corn is early in maturity and is harvested in 70-75 days during *kharif* season. Green cobs are harvested after 18-20 days of pollination during *kharif* but the duration may vary season to season.

Pop corn

It is hard endosperm flint maize and one of the common snack items in many parts of the world. It should be grown in isolation of 150 to 200 meter with normal maize. It is to be preferred in the hilly tracts as pop corn village concept in the far away areas from the cities.

Fodder maize

The most important factor for preference of maize fodder is that it can be used at any crop growth stage which is not the case with other crops having anti-quality factors at some early crop stages. Its quality is adversely affected after anthesis due to immobilization of the nutrients. The tall, leafy and longer duration cultivars are most preferred for maize fodder cultivation. The cultivation of maize for fodder can be done round the year in any part of the country except the sowing in North India should be avoided in the month of December and January due to very low temperature conditions.

Seed production

Seed village concept is necessary for maintaining the genetic purity and addressing the isolation issues. To address the issue of isolation non-traditional areas as well as seasons are more suitable for the seed production. The seed production of public bred hybrid in West Bengal and Rajasthan is an excellent example for *in-situ* seed production and its availability at affordable prices. So, the seed production of hybrids can be taken up in these areas for enhancing income of farmers and ensuring availability of quality hybrid seed at affordable prices in the market due to reduced transportation and handling cost.

Appropriate tillage and crop establishment practices

Traditionally, maize, wheat and other crops in maize based crop sequence were grown either in row geometry or by random broadcasting, mostly after thoroughly tilling the field till proper tilth is obtained for good crop emergence. Tillage is one of the soil management practices that usually used to conserve soil profile water content by increasing the percolation rate, checking the water runoff and later conserves through the soil mulching and also help to regulate hydrothermal status of soil in root zone. Since time memorial, repeated ploughing and planking was practiced to create fine tilth, considered desirable for better crop establishment.

Contrary to the common notion, it is now believed that tillage can be dispensed without affecting crop yield. Intensive tillage systems results to a decrease in soil organic matter and biodiversity (Biamah *et al*., 2000) and the tillage practices contribute greatly to the labour and fuel cost in any crop production system resulting to lower economic returns (Jat *et al*., 2005). In certain situation, tillage operations caused delay in sowing and add to the cost of production. Conservation tillage management systems (zero/minimum tillage) are effective means in reducing water loss from the soil and improving soil moisture regime. The beneficial effect of conservation tillage practices compared to conventional tillage on water-use efficiency through soil water retention properties were reported by many researchers. Soil pore geometry (pore size, shape and distribution), infiltration and soil structure are affected by tillage management and influence soil water storage and transmission. Hence, conservation tillage practices such as zero, minimum tillage and permanent beds may offset the production cost and other constraints associated with land preparation.

The trials on different tillage, crop establishment, residue management and tillage x genotype interactions in different maize systems were conducted at Pantnagar, Udaipur, Banswara, Dholi and Delhi centers. The performance of different tillage techniques varied across locations but, the yield at most of the locations was on par in bed planting and conventional tillage practices. However, the performance of zero-tillage across the locations was non-consistent as it recorded higher or equal yields at Dholi, Udaipur and Delhi but lower at Pantnagar compared to conventional tillage (DMR, 2009).

The trails on different tillage, crop establishment, residue management, tillage x weed control practices and tillage x genotype interactions in different maize systems were conducted at Pantnagar, Udaipur, Banswara, Dholi and Delhi centres. The performance of different tillage and crop establishment techniques varied across locations but, the maize yield at most of the locations was on par in bed planting and conventional tillage practices in *kharif* 2009. However, the performance of zero-tillage across the locations was non-consistent as it recorded higher or equal yields at Dholi and Delhi but lower at Pantnagar compared to conventional tillage.

Interactions between maize genotypes and tillage and crop establishment techniques were recorded at Dholi and interactions between tillage and weed control practices at Udaipur. Under rice-maize system the rice yield with conventional tillage was on par compared to zero till at Dholi and Banswara while at Hyderabad yield was significantly higher with conventional tillage over to zero tillage. In *rabi* 2008-09, the maize yield in rice-maize system under conventional tillage was significantly higher compared to zero tillage and on par with permanent bed at Banswara (DMR, 2010).

A long-term experiment was initiated at DMR, New Delhi during monsoon season of 2008 consisting three tillage and crop establishment methods *viz*. (i) Permanent bed, (ii) No-tillage, (iii) Conventional tillage with four maize based cropping systems i.e. (i) Maize-wheat-mungbean, (ii) Maize-mustard-mungbean, (iii) Maize-chickpea-*Sesbania*, (iv) Maize-maize-*Sesbania*. After five years of cropping we found that zero-tillage followed by permanent raised bed planting is better option in maize production systems for enhancing resource-use efficiency and farm profitability.

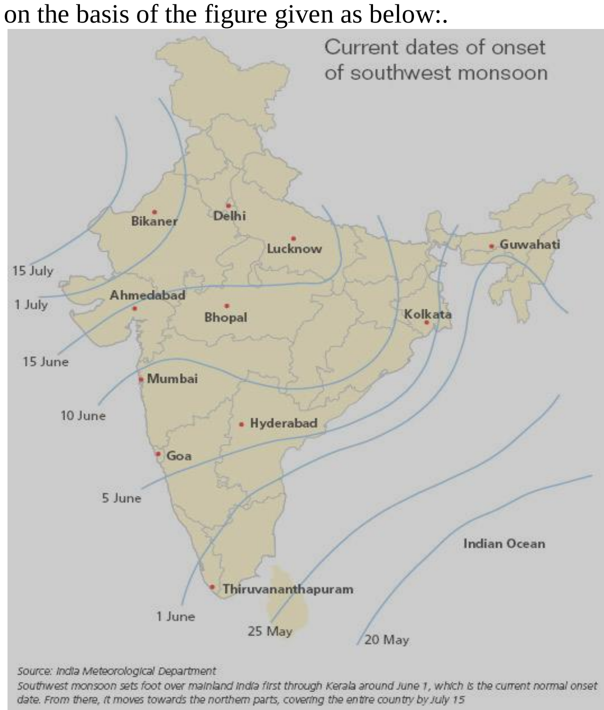
The cultivation of maize under zero-till coinditions after rice made a big success in Andhra Pradesh (Jat *et al*., 2011). But it requires some special operations along with the normal maize cultivation practices. Some important tips for obtaining maximum yields of zero-till maize are as follows:

- No preparatory tillage is required for raising the maize crop.
- Dibble the maize seed after harvesting of previous crop at 2-3 cm depth, in optimum moisture, or else, give light irrigation before dibbling depending on the soil type.
- Practice line sowing by adopting a spacing of 60 cm x 25 cm.
- Spray Parquet 24%sh@/2.5 litre/ha (5 ml /l) to prevent the re-growth of rice or other crop stubbles and control of initial flush of weeds before maize planting.
- Spray Atrazine 50wp@/1.5 – 2.0 kg/ha (4 g/l) immediately after sowing or next day to prevent broad leaved weeds. Ensure proper moisture at the time of spraying herbicide.
- Inter-cultivation and earthing up to be practiced at 25-30 days after sowing.
- The fertilizers should be applied through placement method for better utilization of nutrients.
- Adopt need based plant protection measures like normal Maize.

Choice of right cultivars

The choice of the right cultivars depends on the season and cropping systems in particular agro-ecologies. For contingency crop planning short duration hybrids are preferred. In *kharif* and spring season, short and medium duration hybrids are generally preferred but during *rabi* season medium and long duration hybrids must be cultivated for higher resource-use efficiency. In *kharif* also if the rainy period is longer and irrigation facility are available than the long and medium duration hybrid will give higher returns.

Sowing time: The optimum temperature for maize growth and development is 18 to 32 °C, with temperatures of 35 °C and above considered inhibitory. The optimum soil temperatures requirement for germination and early seedling growth is 12 °C or greater, and at tasseling stage 21 to 30 °C is ideal. Cultivation not possible when day temperatures are less than 19^0C and night temperatures during the first three months falls below 21^0C. At maturity noon temperature above 35^0C destroys pollen by tassel blasting results in poor seed setting and yields are drastically reduced. However, in rainfed areas, the sowing time should be coincided with onset of monsoon and it can be predicted on the basis of the figure given as below:.



The experiment on performance of maize hybrids to adopt rainfall changes and climatic aberrations was initiated during 2011 for standardization of sowing time in different maturity genotypes under changing rainfall pattern. At Bajaura and Udhampur, sowing at normal time sowing is recorded the highest yield. While, sowing before and after normal dates, there was considerable reduction in the yields. While, at Kangra 10 days early sowing was found beneficial and at Almora and Kashmir early normal sowing yielded similar, but further delay in sowing had negative effect on maize yield. While at Udhampur late maturity genotypes performed better than early and medium maturing genotypes (DMR, 2013).

Delay in sowing by 20 days after normal sowing drastically reduced the grain yield in Karnal, Ludhiana and Pantnagar. Advance sowing could not enhance the yields over normal sowing at Ranchi and Ambikapur. However, at Ranchi delay in sowing by 10 days found beneficial over normal sowing. In Gosaingaon, 10 days advance sowing gave the highest yield but sowing with other dates considerable reduced the yields.

However, advance sowing by 10 days at Arbhavi found beneficial and at Hyderabad normal sowing and early sowing could not show significant variation. At Kolhapur sowing earlier and later than normal date reduced the productivity. At Udaipur, 10 days earlier sowing, being at par with normal date of sowing gave the highest productivity. Further delay in sowing showed the reduction in yield.

Maize can be grown in all seasons *viz*; *kharif* (monsoon), post monsoon, *Rabi* (winter) and spring. During *Rabi* and spring seasons to achieve higher yield at farmer's field assured irrigation facilities are required. During *kharif* season it is desirable to complete the sowing operation 12-15 days before the onset of monsoon. The optimum time of sowing are given below.

Season	Optimum time of sowing
Kharif	Last week of June to first fortnight July
Rabi	Last week of October for inter cropping and up to 15th of November for sole crop
Spring	First week of February

Proper plant population

Proper plant stand is the key to higher maize productivity and it varies from seasons well as agro-ecologies point of view. During rabi season more plant population compared to kharif is desirable. Likewise increased plant population is desirable for inbred seed production, baby corn and fodder while lower plant population is required in green cob and sweet corn production. In hilly areas more plants are required compared to plains for giving higher economic returns.

Several experiments were conducted for the plant geometry standardization for various type of maize in the country in various agro-ecologies through AICRP on Maize. Row and plant geometry had significant effect on yield performance of inbred lines during winter wherein closer plant spacing (70 x 15 cm) resulted in significantly higher grain yield at Karnal (DMR, 2008). Trials on plant geometry and nutrient interaction were conducted at Udaipur, Kashmir, Almora, Bajaura, Kangra, Udhampur, Karnal, Ludhiana, Pantnagar, Ranchi, Arbhavi, Kolhapur, Ambikapur, Banswara, and Chhindwara during *Kharif* 2011. At Bajaura, Kangra, Kashmir, Ranchi, Arbhavi, Kolhapur and Udaipur row arrangement of either equal row at 67/60 cm or paired row at 84:50/80:40 cm does not have significant influence on yield performance of maize genotypes.

Row ratio plays important role in seed production of hybrid maize. At Ludhiana and Udaipur 3:1 (male: female) ratio and at Pantnagar, Hyderabad, Arbhavi, Chhindwara 2:1 (male: female) ratio while at Ranchi, Vagarai and Ambikapur 4:1 (male: female) ratio was found optimum (DMR, 2011).

The trial on development of agro-techniques for seed production of inbred parents was conducted at 7 locations of five zones. Planting geometry of 67 x 20 cm was found significantly superior at Almora, Ludhiana and Udaipur over the planting geometry 67 x 25 cm, while at Srinagar, Vagarai and Ranchi planting geometry of 67 x 25 cm was found significantly superior over planting geometry of 67 x 20 cm. To achieve higher productivity and resource-use efficiencies optimum plant stand is the key factor. The seed rate varies depending on purpose, seed size, plant type, season, sowing methods *etc.* The crop geometry and seed rate has been mentioned in table given below:

Seed requirement and seed treatment

Seed requirement is a function of plant population, seed weight, physical purity (%) and germination (%). The maize having variable seed weight as well as grown under different population regime. So, in this scenario the plant population will vary accordingly and hence care should be taken for seed rate determination in different types of maize production.

Seed soaking in normal water for overnight fastens the germination and hence helps in early vigour of the crop. To protect the maize crop from seed and major soil

Purpose	Seed rate (kg ha^{-1})	Plant geometry (plant x row, cm)	Plant population
Normal grain maize	20	60 x 20	83333
		75 x 20	66666
Quality protein maize (QPM)	20	60 x 20	83333
		75 x 20	66666
Sweet corn	8	75 x 25	53333
		75 x 30	44444
Pop corn	12	60 x 20	83333
Green cob (normal maize)	20	75 x 20	66666
		60 x 20	83333
Fodder	50	30 x 10	333333
Inbred production	20-25	60 x 15	111111
		60 x 20	83333
		70 x 15	95238
Hybrid seed production	15(Female) + 10 (Male)	60 x 15	111111
		60 x 20	83333
		70 x 15	95238

borne diseases and insect-pests, seed treatment with fungicides and insecticides before sowing is advisable/ recommended as per the details given below.

Disease/insect-pest	Fungicide/Pesticide	Application rate (kg^{-1} seed)
Seed borne diseases	Bavistin/Captan	2.0 g
Downy mildew	Matalaxyl	2.5 g
Termite and shoot fly	Imidachlorpid	6.0 ml

Method of sowing

Soil texture and crop rotation are the dominant factors that determine the need for tillage to successfully produce maize in particular conditions. Appropriate use of tillage can increase spring soil dry-down rates by loosening soil. This improves drainage and/or reduces residue cover, which increases rates of soil water evaporation. Tillage and crop establishment is the key for achieving the optimum plant stand that is the main driver of the crop yield. Though the crop establishment is a series of events (seeding, germination, emergence and final establishment) that depends on interactions of seed, seedling depth, soil moisture, method of sowing, machinery etc but, the method of planting plays a vital role for better establishment of crop under a set of growing situation.

Maize is mainly sown directly through seed by using different methods of tillage and establishment but during winters where fields are not remain vacant in time (till November), transplanting can be done successfully by raising the nursery. However, the sowing method (establishment) mainly depends on several factors *viz* the complex interaction over time of seeding, soil, climate, biotic, machinery and management season, cropping system, etc. Recently, resource conservation technologies (RCTs) that include several practices viz. zero tillage, minimum tillage, surface seeding etc. had came in practice in various maize based cropping system and these are cost effective and environment friendly. Therefore it is very important that different situations require different sowing methods for achieving higher yield as described below:

Raised- bed (ridge) planting

Generally the raised bed planting is considered as best planting method for maize during monsoon and winter seasons both under excess moisture as well as limited water availability/rainfed conditions. Sowing/planting should be done on the southern side of the east-west ridges/beds, which helps in good germination. Planting should be done at proper spacing. Preferably, the raised bed planter having inclined plate, cupping or roller type seed metering systems should be used for planting that facilitates in placement of seed and fertilizers at proper place in one operation that helps in getting good crop stand, higher productivity and resource-use efficiency. Using raised bed planting technology, 20-30 % irrigation water can be saved with higher productivity. Moreover, under temporary excess soil moisture/water logging due to heavy rains, the furrows will act as drainage channels and crop can be saved from excess soil moisture stress. For realizing the full potential of the bed planting technology, permanent beds are advisable wherein sowing can be done in a single pass without any preparatory tillage. Permanent beds are more beneficial under excess soil moisture situations as the infiltration rate is much higher and crop can be saved from the temporary water logging injury.

Zero-till planting

Maize can be successfully grown without any primary tillage under no-till situation with less cost of cultivation, higher farm profitability and better resource use efficiency. Under such condition one should ensure good soil moisture at sowing and seed and fertilizers should be placed in band using zero-till seed-cum-fertilizer planter with furrow opener as per the soil texture and field conditions. The technology is in place with large number of farmers particularly under rice-maize and maize-wheat systems in peninsular and eastern India. However, use of appropriate planter having suitable furrow opener and seed metering system is the key of success of the no-till technology.

Conventional-till flat planting

Under heavy weed infestation where chemical/herbicidal weed management is uneconomical in no-till and also for rainfed areas where survival of crop depends on conserved soil moisture, in such situations flat planting can be done using seed-cum-fertilizer planters.

Furrow planting

To prevent evaporative losses of water during spring season from the soil under flat as well as raised-bed planting is higher and hence crop suffers due to moisture stress. Under such situation/condition, it is always advisable to grow maize in furrows for proper growth, seed setting and higher productivity.

Transplanting

Under intensive cropping systems where it is not possible to vacate the field on time for planting of winter maize, the chances of delayed planting exists. Due to delay planting, crop establishment is a problem due to low temperature so under such conditions transplanting is an alternative for winter maize. Therefore, for the situation where fields are vacated during December-January, it is advisable to grow nursery and transplant the seedlings in furrows and apply irrigation for optimum crop establishment. Use of this technique helps in maintenance of temporal isolation in corn seed production areas for production of pure and good quality seed as well as quality protein maize grain. For planting of one hectare, 700 m^2 nursery area is required and the nursery should be raised during second fortnight of November. The age of seedlings for transplanting should be 30-40 days old (depending on the growth) and transplant in the month of December-January in furrows to obtain higher productivity.

Input application (fertilizer, water and pesticide)

The fertilizer and the pesticides are becoming costlier day by day and their efficient management can only enhance the resource-use efficiency and farm profitability. The key input and their rate and time of application are as follows.

Herbicide application

Weeds are the serious problem in maize, particularly during *kharif* season they compete with maize for nutrient and causes yield loss up to 35 %. Therefore, timely weed management is needed for achieving higher yield. Atrazine being a selective and broad-spectrum herbicide in maize checks the emergence of wide spectrum of weeds. While spraying, precautions should be taken care by the person and he should move backward so that the Atrazine film on the soil surface may not be disturbed. Preferably three boom flat fan nozzle should be used for proper ground coverage and saving time. One to two hoeing are recommended for aeration and uprooting of the remaining weeds, if any. While doing hoeing, the person should move backward to avoid compaction and better aeration.

Studies on weed management trials for diverse weed flora in maize based cropping systems were conducted in different agro-ecologies at various AICRP centres. The result of different weed management practices varied significantly from location to location. The use of cover crops in maize was also found beneficial at Banswara. However, at Karnal, Ranchi and Udaipur centres, pre-emergence application of Atrazine @ 1.0 kg a.i./ha followed by one hoeing at 25-30 days stage was the best weed management practices (DMR, 2011).

Fertilizer application

Among all the cereals, maize in general and hybrids in particular are responsive to nutrients applied either through organic or inorganic sources.

Application of Fertilizers

Apply NPK fertilizers as per soil test recommendation as far as possible. If soil test recommendation is not available adopt a blanket recommendation.

- The 20% N in irrigated and 34% N in rainfed conditions; full dose of P_2O_5 and K_2O as basal before sowing.
- In the case of ridge planted crop, open a 6 cm deep furrow on the side of the ridge, at two thirds the distance from the top of the ridge. Apply the fertilizer mixture along the furrows evenly and cover to a depth of 4 cm with soil.
- If bed system of planting is followed, open furrows 6 cm deep at a distance of 60/70 cm apart. Place the fertilizer mixture along the furrows evenly and cover to a depth of 4 cm with soil.
- When *Azospirillum* is used as seed and soil application, 25% reduction in the total N is recommended.
- *Seed Treatment* Seeds treated with fungicides may be treated with three packets (600 g/ha) of *Azospirillum* before sowing.
- Apply rest 80% N in four splits as top dressing in following proportions in irrigation areas:

S. No.	Crop Stage	Nitrogen rate (%)
1	V_4 (four leaf stage)	25
2	V_8 (eight leaf stage)	30
3	V_T (tasseling stage)	20
4	GF (grain filling stage)	5

The top dressing may be done in two equal splits for rest 66% N under rainfed conditions at around knee high and tasseling stage of the crop according to the moisture availability in the field.

Water application

The irrigation water management depends on season as about 80 % of maize is cultivated during monsoon season particularly under rainfed conditions. However, in areas with assured irrigation facilities are available, depending upon the rains and moisture holding capacity of the soil, irrigation should be applied as and when required by the crop and first irrigation should be applied very carefully wherein water should not overflow on the ridges/beds. In general, the irrigation should be applied in furrows up to 2/3rd height of the ridges/beds. Young seedlings, knee high stage (V_8), flowering (V_T) and grain filling (GF) are the most sensitive stages for water stress and hence irrigation should ensured at these stages. In raised-bed planting system and limited irrigation water availability conditions, the irrigation water can also be applied in alternate furrow to save more irrigation water. In rainfed areas, tied-ridges are helpful in conserving the rainwater for its availability in the root zone for longer period. For winter maize, it is advisable to keep soil wet (frequent and mild irrigation) during 15 December to 15 February to protect the crop from frost injury. Maize is sensitive to both moisture stress and excessive moisture; hence regulate irrigation according to the requirement with proper drainage facilities in the field. Ensure optimum moisture availability during the most critical phase (45 to 65 days after sowing); otherwise yield will be reduced by a considerable extent.

Provide irrigation according to the following growth phase of the crop:

Germination and establishment phase	1 to 14 days
Vegetative phase	15 to 39 days
Flowering phase	40 to 65 days
Maturity phase	66 to 95 days

In the irrigated areas, the irrigation may be given as per the soil type and crop stages mentioned as below:

Stage	Irrigation	Days after sowing
Heavy soils		
Germination and establishment	3	After sowing, 4^{th} ,12^{th} day
Vegetative	2	25^{th}, 36^{th} day
Flowering	2	48^{th} , 60^{th} day
Maturity phase	2	72^{nd} , 85^{th} day
Light soils		
Germination and establishment	3	After sowing, 4^{th} ,12^{th} day
Vegetative Phase	3	22^{nd} ,32^{nd} and 40^{th} day
Flowering phase	3	50^{th} ,60^{th} and 72^{nd} day
Maturity phase	2	85^{th} , 95^{th} day

Drip Irrigation in Maize

The crop must be planted in paired rows (60/90 × 30 cm) for drip irrigation to reduce cost of drippers and laterals. Irrigation is provided once in 2 days based on climatological approach for higher water-use efficiency which is described as follows:

Irrigation volume = Pe x Kp x Kc x A x Wp – Re

- Pe – Pan evaporation rate (mm/day)
- Kp – Pan co-efficient (0.75 to 0.80)
- Kc – Crop co-efficient (0.4 – Vegetative stage; 0.75 – Flowering stage; 1.05 – Grain formation stage)
- A – Area in above pained row
- Wp – Wetted percentage (80% for maize)
- Re – Effective rainfall (mm)

The duration of the irrigation can be calculated from the following formula:

$$\text{Irrigation duration} = \frac{\text{Water requirement per plant once in 2 days}}{\text{Dripper / plant x Discharge rate (lph)}}$$

The higher advantage of the drip irrigation realized more when the fertilizers are applied along with the irrigation water. Ventury assembly (3/4”) with injector pump (0.5 HP) required for the drip based fertigation system. (Source:http://agritech.tnau.ac.in/agriculture/agri irrigationmgt_maize.html).

Proper harvesting time for different maize types

Normal, QPM and pop corn should be harvested when black layer starts forming on the tip of the grain, the crops acquires physiological maturity. The crop must be harvested at less than 22 to 25 per cent moisture in grain with husk colour turns pale brown which comes normally at 25 to 30 days after tasseling. The harvesting of the cob and plant can be done separately or stalk cut method of whole plant harvesting may be followed in manual harvesting. The harvesting may also be done by using combine at appropriate stage when hybrid is being cultivated. After harvesting the grain of maize must be dried up to 12% moisture levels for safe storage.

Average yield of the maize hybrid by following the recommended package and practices are as follows under Indian conditions:

Season	Yield (tonnes/ha)		
	Early	Medium	Late
Kharif	4.0 – 5.0	5.0 – 5.5	6.0 – 7.0
Rabi	-	6.0 – 6.5	7.0 – 8.0
Summer/spring	4.0 – 4.5	4.5 – 5.0	-

Baby corn

The emerged silk should preferably harvest within 1-3 days of emergence depending upon the growing season. Suitable time for harvesting of ears may be determined by sampling for size. Harvesting is usually done in the morning when the moisture is high and the temperatures are low. The picking of baby corn is to be done once in three days and generally 7-8 pickings are required depending on genotypes used. Picking should be done daily in *kharif* and on alternate days in winter season within 1-3 days of silk emergence from the leaf sheath depending upon the variety. Harvesting should be done when baby corn silk comes out 2.0-3.0 cm from the top of ears, preferably in the morning or evening, when the baby corn moisture is highest and ambient temperature is low. In single cross hybrid plant, 3-4 pickings may be obtained from single plant.

In a good crop on an average 15-19 q/ha baby corn can be harvested. Additional income may also be obtained through sale of green fodder, which may yield up to 250-400 q/ha. The husk is to be carefully removed so as not to break or damage the ear. Ears intended for processing must be carefully hand husked and de-silked. Subsequent to the removal of the ear husks, the shanks are cleared of the silks. Then the shanks are graded based on their size and colour and packed in polythene begs before marketing. In many cases baby corn for vegetable use is marketed without dehusking of the cobs. This reduces labour involved in processing but fetches lesser market prices. Optimum size for market and cannery industries is 4.5-10 cm long and 7-17 mm diameter of dehusked cobs. Yellow coloured cobs with regular row arrangement fetch better market price. Harvested baby corn may be stored for 3-4 days at 10^0C without much effect on its quality. For long-term storage and distant transport, baby corn is canned in brine solution (3%), sugar (2%) and citric acid (0.3%) solution and stored under refrigerated conditions. Baby corn may also be stored in vinegar. Baby corn pickle is also gaining popularity in Indian market and it already has an established international market, particularly in Europe.

Sweet corn

At the harvest time the moisture is generally 70 % in the grain and sugar content varies from 11 to more than 20 %. Sweet corn is generally dull yellow and white but dull yellow color is preferred. Its picking should be done in the morning or evening time. Green cobs should be immediately transported to the cold storage in refrigerated trucks to avoid the conversion of sugar to starch. It loses new if kept in high temperature after picking. Sweet corn with high sugar content should not be planted when temperature is below 16^{o}C.

Hybrid seed

Following points must be kept in mind for harvesting of hybrid seed production plots:

First, harvest male parent and keep it separately or male can be harvested for green cob purposes. The harvested cobs should be spread evenly instead of making heap kept on Tarpauline to avoid infestation from pest and diseases. Moisture in grain at harvesting should be around 20% in female seed.

Special operations

Beside all the above non-monetary input discussed, there is some operations that contributes towards higher productivity and profitability are as follows:

Baby corn

For production of quality baby corn detasseling must be done before full emergence of the tassel. It should be green and may be used to feed the cattle.

Hybrid seed production

Synchronization in male and female is a key success for the higher production of hybrid seed. It may be ensured by differential depth seeding, differential date of sowing, selection of suitable parent and seed coating of the male parent. Detasseling of female at right stage must be done before pollen shedding and it should be green. Detasseling in female should be practiced row-wise and person should follow to monitor each row to check no part of tassel is left inside and detasseling must continue for 8-10 days. While detasseling, leaf should not be removed and removal of 1 to 3 leaves along with tassel reduces 5-15 % yield. The removed tassel should not be thrown in the field but fed to the cattle as it is nutritive fodder.

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8. Integrated weed management techniques for enhancing maize productivity

Rajvir Sharma and Ajay Kumar

The cultivation of high yielding poor competitive crop varieties responsive to fertilizer and irrigation. The new intensive cropping systems have brought to the forefront problems of weeds which cause tremendous losses to crops and their produce. However, the reduction in yield depends upon the density, type of weeds (broad leaved or grassy weeds), season as well as cultivation practices. Hence, weeds became the major biotic constraints for realizing the potential yield of crops. Amongst the various seasons, weeds interference in *kharif* season's crop causes greater yield loss as availability of adequate moisture due to frequent rains provides congenial conditions or weeds to compete well with crops for moisture, nutrients and light. In case the situation is unattended for weed control, there would be the infestation of *Trianthema portulacastrum* L. (*Aizoaceae*), popularly known as horse purslane or carpet weed representing 85% of weed population and hardly any space will be left for growing the main crop. Sometimes the crop completely fails due to weeds.

Maize is an important cereal crop of India grown in both *kharif* and *rabi* season. This crop has a very high yield potential, particularly the hybrids which may produce as high as 6 t/ha during *kharif* and more than 10t/ha during *rabi* season but the average yield (2.5 t/ha) is consiered to be very low due to various constraints. Wide row spacing in maize coupled with favourable environment allows luxuriant weed growth which may reduce the yield by 30-90%. In addition, maize is generally raised under marginal conditions with meager inputs which make it poor competitor. Timely weed control in maize has become the essential for realizing its potential yield.

Major weed flora

Knowledge of the type and nature of weed species commonly occuring in maize crop is the pre-requisite for their effective and economic management as single method for weed control may not be able to work for the control of all weed species. Generaly, three types of weeds species are found in maize crop.

Kharif season

Grassy weeds: *Echinochloa colonum, Echinochloa crusgalli, Acrachne racemosa, Digitaria sanguinalis Dactyloctenium aegyptium. Paspalum dialatum* and *Cynodon dactylon.*

Broad leaves weeds: *Trianthema portulacastrum, Trianthema monogyna, Digera arvensis, Commelina benghalensis, Phyllanthus niruti, Xanthium strumarium, Boerhaavia diffua, Oxalis corniculata and Parthenium hysterophorus.*

Sedges: *Cyperus rotundus, Cyperus esculentus* and *Cyperus iria.*

Rabi season

Grassy weed: *Phalaris minor, Avena fatua and Cynodon dactylon*

Broad-leaves weeds: *Chenopodium album, Melilotus indica, Anagallis arvensis, Cirsium arvense, Convolvulus arrevensis and Rummex spp.Fumaria perviflora, and Spergula arvensis*

Suitable time for weed control

Occurrence of weeds in cropped field is always harmful as they are competing with crop for all the natural resources. But their presence/unchecked growth during certain period of crop growth is causing the highest losses in crop yield. That period of crop growth is called critical period for crop-weed competition which is different for different crops. It is well established that first 30 days after sowing is critical period of weed competition in maize. Therefore, maize crop should be kept weed free for at least first 30 – 45 days after sowing to obtain full potential of cultivars grown in *kharif* season. However, the maize crop sown during *rabi* season should be kept weed free for at least first 15 – 60 days.

Weed control methods

Weeds can be controlled through the use of several methods *viz.* mechanical method, cultural method, biological method and herbicidal (chemical) method. But no single method is generally proved effective and economical. Manual removal of weeds is effective and most common practice. But several flushes of weeds due to incessant heavy rains, non-availability high wages of labour make it difficult, tedious, back breaking, unpractical and finally uneconomical. Weed control through use of herbicides (chemical) assumed a greater significance/importance due to their accessibility, selective and quick action after the discovery of 2,4- D in 1935 for broad leaved weeds. But over reliance on herbicide use sometimes may cause residual toxicity to succeeding crops and ground water contamination. Massive pollution pressures on the environment from different sources including herbicide use necessitate sustained efforts of exploring non-chemical weed control. In order to minimize their ill effects, several crop husbandry techniques like stale seed bed technique (a practice of allowing to germinate the weed seeds and killing them subsequently before sowing crop), tillage practices (conservational/conventional), soil solarization (mulching) planting techniques (raised furrows) could be combined in an integrated way to make weed control strategy effective and economical.

Pre-sowing practices

Prior to sowing of maize, spreading of polyethylene sheet of 25 um thickness during the hottest moth of May for 30-35 days results in raising the soil temperature, particularly in top soil. The raised

temperature becomes lethal for most of the dormant and viable weed seed and finally results the direct killing of weed seeds by heat. Generally the maximum temperature is solorized plots at 5 cm soil depth is 10-12 ^{0}C higher than maximum air temperature. Results of some experiments conducted at IARI shown that minimum tillage practices (one ploughing) for maize sowing are proved better in reducing weed population as compared to conservation tillage (no tillage). (Table 1).
Intercropping Practice of growing maize with cowpea (1:1) as intercrop also helps in reducing the weed growth. Cowpea is known as cover crop which does not leave the space in between two rows of maize for weeds emergence.

Table 1. Effect of tillage practices and herbicide use on weeds and productivity of maize

Treatments	Yield of green cobs (q/ha)	Weeds count/m2 at 60 DAS
Methods of Planting		
Zero tillage (No tilled)	68.0	105.5
Minimum tillage (one)	71.1	91.4
Repeated tillage (three)	72.5	90.0
LSD (P = 0.05)	0.71	3.66
Weed control measures		
Control	32.0	249.9
Weed free	99.7	16.9
Altrazine 1000 g/ha	81.0	70.8
Metribuzin 200 g/ha	54.8	87.6
Atrazine+Pendimethalin 500+750 g/ha	86.7	53.1

Mechanical methods

Removal of weeds by *khurpi, hand hoe, wheel hoe* is very effective method. But sometime, it is not possible due to shortage of labour and continuous rain. Moreover, it is costly and time consuming. In maize crop several flushes of weeds appear due to adequate moisture which becomes the major constraint for its productivity. Therefore, weeds should be removed through intercultural operation at 20 and 40 days after sowing in order to obtain the potential yield of *kharif* maize (60 q/ha). However the maize crop sown during *rabi* season needs weed removal atleast thrice (at 20, 40 and 60 DAS) owing to long duration of the crop.

Chemical method of weed control

Application of chemical for the control of weeds is quick and cheaper than mechanical method of weed control. Choice of herbicides, their dose and time of application is very important for obtaining higher weed control efficiency which is similar for both season. Several

Table 2. Herbicides for weed control is Maize.

Name	Dose (ga.i./ ha)	Time of application	Remarks
Atrazine	1000	Apply with 500 litre/ha of water before emergence of crop as well as weeds	Control all weeds except *Dactyloctenium aegyptium* and *Cyperus rotundus*
Atrazine	1000-1500	Can be safely applied upto 15 days after sowing of maize crop	-do-
Pendimet-halin	750-1000	Apply with 500 litre/ha of water before the emergence of crop as well as weeds	Control all weeds except *Commelina benghalensis* and *C.rotundus*
Metribuzin	200-300	It can be safely applied both pre-emergence and post emergence (upto 15 days after sowing)	It is effective against both broad leaved and grassy weeds.

herbicides along with their dose and time of application recommended for controlling weeds in maize are given in Table 2. Results of the field experiments conducted at Research Farm of I.A.R.I. for evaluating the efficacy of various herbcides alone and tank mix application revealed that tank mix application of atrazine + pendimethalin (0.50 + 0.75 kg/ha) before the emergence of both weeds and crops recorded the highest increase in productivity of maize over unweeded situation (Table 3). However, alone application of atrazine (1.0 kg/ha pre-em.) and pendimethalin (1.0 kg/ha pre-em) were found equally effective in controlling weeds but inferior to their tank mix application.

In other field experiments, it has also been proved that atrazine (1.0 kg/ha) can also be applied as post emergence (15 DAS) without any toxic effect on maize plant, if it could not have been done as per-emergence (Table 4).

Integrated weed management

Practice of combining two or more methods for controlling weeds in a particular crop is called integrated weed management. Over reliance of any one method is not always economical. Pre-sowing crop establishement practices like stale seed bed technique, soil solarization and timely sowing on ridges could be very important

Table 3. Effect of pre-emergence herbicides on weed growth and maize yield

Treatments	Dose (g a.i./ha)	Weed (No/m^2)	Weed dry Wt. (g/m^2)	Grain yield (q/ha)
Weedy check	-	124.3	84.5	28.1
Hand weeding	-	16.6	5.8	42.7
Atrazine+	1000	42.6	32.2	39.1
Pendimethalin	1000	53.3	45.2	37.6
Atrazine+Pen dimethalin	500+750	19.6	8.7	42.9
FOE(5043)	150	86.0	62.7	31.6
FOE(5043)	300	75.3	54.9	31.7
FOE(5043)+ Metribuzin	150+200	47.3	39.7	40.1

FOE-Flufenacet

components of integrated weed management in maize. Brown manuring with growing *dhaincha* subsequently smoothered by application of 2,4-D (0.25 kg/ha) at 25 days after sowing was also reported effective integrated weed management practice in maize sown in *Kharif* season. Application of chemical before the emergence of weeds and maize crop followed by one hand weeding at 40 days after sowing has been proved effective and economial for weed management in maize crop.

Table 4. Effect of post emergence herbicides on maize yield

Treatments	Dose (g a.i./ha)	Grain yield (q/ha)
Weedy check	-	22.3
Atrazine 15 DAS	1000	33.5
Atrazine 30 DAS	1000	30.9
Atrazine 15 DAS	1500	35.1
Atrazine 30 DAS	1500	34.9
Metribuzin 15 DAS	100	29.7
Metribuzin 30 DAS	100	28.1
Metribuzin 15 DAS	200	35.3
Metribuzin 30 DAS	200	31.5

9. Management of insect and pests of maize

Pradyumn Kumar, J.C. Sekhar and S.B. Suby

Maize, (Zea *mays* L.) has tropical origin and traditionally grown in monsoon season in India. In respect to production and area, it ranked third next to rice and wheat in cereals. The crop can be grown in diverse geographical and climate conditions. Maize is grown in '*kharif', 'rabi'* and spring seasons. Of late, the area under winter maize has increased because of higher productivity. In India, maize is grown in 8.0 m/ha and its production has reached about 21 mt in year 2012-13. The average productivity of 2.47t/ha is very low in comparison to its potential. Often the yield realized by the farmers is much less than the in-built yield potential of the variety. There are umpteen numbers of operations that need to be taken to optimize the yield. They can be broadly grouped in to crop production factors like fertilizers, irrigation, plant population density, weed management, etc. and crop protection factors such as host plant resistance, cultural control, chemical control, biological control, etc. In spite of taking due care of the production components, the insects take a heavy toll of the crop thus bringing crop yield abysmally low.

Integrated pest management strategy is a rational approach exploiting variety of pest management components in harmony with ecology. As contrary to schedule application of chemical pesticides the control measures must be need based. How to determine the time of application is a big question? Economic threshold has been worked out for some of the pests. In case of *Chilo partellus*, date of sowing, intercrop, crop rotation, etc. have profound influence on insect fauna in the crop.

Major pests

One of the major causes of low productivity is the damage done at various stages of the crop by variety of insect pests. The insect pest complex changes in time and space. The insect pests have increased due to the large scale cultivation of maize as sole crop and widespread use of pesticides for pest control (Mathur, 1983).

The literature of previous years recorded 160 insects and mite species which attack maize crop (Fletcher, 1914, 1917; Ayyar, 1963; Bhutani, 1961; Pant and Kalode, 1964) but afterward Mathur (1983) observed over 250 species of pests associated with maize in field and storage conditions.

Dick and Guthrie (1988) identified 87 species that directly or indirectly exert severe stress on corn culture in tropical and temperate regions throughout the world. Excluding stored grain insects, Luckman (1978) lists 34 pests or pest groups for which chemical controls are recommended on corn in the United States. More than 130 insect pests have been reported to cause damage to maize in India but only about a dozen cause economic loss (Sarup *et al*., 1987). The pyralid *Chilo partellus*, the noctuid *Sesamia inferens* and muscids *Atherigona soccata* and *A. naqvi* are of major importance. Insect pests are a major production constraint for maize (Table 1).

Chilo partellus Swinhoe

Chilo partellus as widely distributed pest in maize and sorghum agro ecosystem. It is however, the control measures for egg stage have been precisely determined to be 10-15 days old plants. For monitoring of flying insects Kumar *et al*. (2001) developed aerial insect-trap) which can be used both for pests as well as bio-control agents. Since the gap between the productivity and the potential is very wide, there is tremendous scope for the management of crop production/protection practices. The protection management is inextricably linked to the production management as the components of it such as seed, seed rate, fertilizers, irrigation time distributed in south Asia, south east Asia, Afghanistan, Pakistan and part of Africa. The pest is prevalent during *'kharif'*. It infests the plant in all stages. The major loss is caused in the early stage of the plant. The larvae of *C. partellus* after hatching, feed on leaves where they form small irregular holes and later bore into stem to form tunnel. The caterpillar cut the growing point of the maize plant resulting in the drying up of the central shoot and subsequently formation of dead-heart. The infestation in early stage eventually led to the death of plant. When the grown up plants are infested, they damage all plant parts and its vigour gets reduced. The pest is active from March to October and has 6-7 overlapping generations. During winter, it undergoes hibernation in larval stage in the stubbles or stalk. In peninsular India, the winter is not severe; therefore, the pest remains active round the year. The moth lay eggs in cluster on the under surface of the leaves. The eggs are naked, flat and cream in colour. Each cluster has 10-50 eggs arranged in 2-3 rows. There is no overlapping of eggs. The average fecundity is 250-300. The longevity varies from 2-10 days. The incubation period at 27^{o}C is 4-5 days at low temperature; it is increased up to eight days. The larval period varies from 14-28 days. After passing through six instars, the full-grown larva makes exit hole in the stem and pupate inside it. The moth emerges from the stem through the exit hole.

Table 1. Insect-pests of maize, their common name and zoological description.

Name of pest	Common name
Chilo partellus Swinhoe	Maize stalk borer
Euproctis subnotata Walker	Hairy caterpillar
E. virguncula Walker	Hairy caterpillar
Psalis pennatul Fabricius	Rice yellow hairy caterpillar
Spodoptera litura Fabricius	Rice warming caterpillar
S. mauritia Boisduval	Rice warming caterpillar
S. exigua Hubner	Cutworm
Argots ipsilon Hufnagal	Cutworm
(*A. yipsilon* Rott.)	
A. spinifera Hubner	Cutworm
Mythimna separata Walker	Armyworm
Sesamia inferens Walker	Pink borer
Rhyacia herculea Corti & Draudt	Climbing cutworm
Helicoverpa armigera Hb.	Gram pod borer
Marasmia trapezalis Guenee	Leaf Roller
Cryptoblabes angustipennella Hampson	Cob caterpillar
Atherigona naqvii Steyskal	Shootfly
A. soccata Rond	Shootfly
A. orientalis Shiner	Shootfly
Amsacta moorei Butler	Red hairy caterpillar
A. lactinea Cramer	Red hairy caterpillar
Hieroglyphus nigrorepletus Bol.	Phadka Grasshopper
Atractomorpha crenulata crenulata Fab.	Grasshopper
Chrotogonus sp.	Grasshopper
Oxya ebneri Willemse	Grasshopper
O. velox Fb.	Grasshopper
Colemania sphenariodes Bol.	Deccan wingless Grasshopper
Holotrichia consanguinea Blanch.	White grub
H. serrata Fabricius	White grub
H. insularis Brenske	White grub
Myllocerus discolor F.	Ash weevil
Mylabris macilenta Marshll	Blister beetles
M. phalerata Pallas	Blister beetles
M. pustulata Thunber	Blister beetles
M. tifpensis Billb.	Blister beetles
Zyginidia manaliensis Singh	Cereal Jassid
Rhopalosiphum maidis Fitch.	Aphid
Hysteroneura setariae Thomas	Rusty plum aphid
Pyrilla perpusilla Walker	Sugarcane leaf hopper
Peregrinus maidis Ashm.	Corn lanternfly

Sesamia inferens Walker

It is widely distributed pest, prevalent in south Asia, South East Asia, Pakistan and China. It infests maize, wheat, sorghum, paddy, sugarcane, barley and few grasses. Pink borer infestation is serious in peninsular region. In northern part of India it is common in 'rabi'. Almost all parts, leaves, stem, the larvae attack tassel and ear. The larvae have migrating tendency and may attack a number of plants. The larvae feed under the leaf sheath and remain there in the early stage of growth. Later, they make inroad into the central shoot causing the death of central leaf much the same way as in *C. partellus*. Due to larval feeding the grown up plants show many slit like oval elongated holes on the leaf blades. They also form tunnel inside the stem and exit holes at the surface. The tunnels are generally filled with excreta. The decaying shoots in grown up plant cause cob to rot, causing complete loss of grain. Larvae also feed on immature cobs and tassels. The moths lay bead eggs in 2-3 longitudinal rows on the sheath of bottom leaves of young maize plant. Eggs are cream colour when laid which turn steal gray before hatching. The incubation period is about a week. The full grown larvae are 25-30 mm long and purple from dorsal side. The larval period is 3-4 weeks. The pupae are robust dark brown having a powdery appearance. The pupation occurs in the stem or in between the stem and leaf sheath. The pest has 4-5 generation a year.

Odontotermites obesus Rambur *Microtermes obesi Holmgr*

The pest is prevalent in Bihar, Madhya Pradesh, Punjab and Utter Pradesh (Agarwal and Sharma, 1954; Bindra, 1960;Butani, 1961). It is considered as minor pest, but in heavily infested areas the crop is seriously damaged. Termites remain quite active in sandy and sandy loam soils during dry season. Termites attack maize after germination and also at all other stages of the crop growth. The early infestation is evident by the presence of dead plants. Such plants are easily pulled out along with the chewed roots. The grown up plants infested with termites show complete wilting; root loose strength and usually the plants fall over the ground. Earthen galleries appear on the outer surface of the infested stem and the inner hollow space of the stem is also filled with the soil. The incidence of termites is sporadic.

Atherigona spp.

A complex of shoot fly species cause severe losses in spring-sown maize in northern plains of India. Six species of *Atherigona* are reported from India. Among these *A. soccata* and *A. naqvii* are serious pests in northern India. *A. soccata* and other four species, *A. bidens, A. falcate, A. orientalis*, and *A. punctata* occur occasionally in the southern region. *A. orientalis* is predominant in the ‘tarai’ region (Panwar and Sarup, 1985). *A. soccata* lays eggs on lower side of the lower leaves and stalk while *A. naqvii* lays in the cracks and crevices in the soil around the seedlings. The maggots damage the plants during early growth period, starting from 3-leaf stage up to 25 days after sowing. The newly emerged maggots crawl along the leaf surface, then enter the leaf whorl, feed on the plant tissues and moves down. Browning of the central axis, which gradually dries up to form ‘dead heart’, manifests the infestation? These symptoms usually appear after 5-7 days of egg laying. The infestation cause development of tillers and the plant shows stunted growth. Older plants do not show dead hearts but the damaged leaves get interwoven with the central leaf and show scorching and distorted symptoms. The plants usually show poor growth and bear small size ear with limited number of grains. The shoot fly infestation vary from 69 to 97 per cent in spring crop (Chaudhary and Sharma,1975).

Rhyacia herculea Corti and Draudt

Singh and Sinha (1965) first reported climbing cutworm from wheat and gram from Bihar. With the introduction of the winter maize in Bihar, the insect has become a serious pest in this area (Singh *et al*.,1979). The caterpillars attack on 20-30 days old plants during winter season in Bihar. They feed voraciously on the apical portion and margin of leaves, consuming all except the mid-rib. Feeding takes place during night and the larvae remain hidden inside the whorl during day. The faecal pallets in the whorls mark the characteristics of larval presence. The losses caused by the pest vary from 12 to 34 percent (Verma *et al*., 1979; Verma and Sinha, 1980).

Mythimna separate Walker

The caterpillars of *Mythimna* spp., cause heavy losses to maize at two stages of its growth: (1) immediately after germination up to development of nodes and internodes and (2) one month after sowing when spacious whorls are formed. Early infestation gives the appearance of a grazed crop while late infestation results in complete defoliation due to larval feeding from leaf edge towards the mid-rib. Later instars are usually gregarious. The larvae excrete fecal matter in the form of pallets, which are seen in the plant whorls.

Pyrilla perpusilla Walker

The pest is prevalent in Uttar Pradesh, Punjab and Delhi . The eggs are laid in clusters of 60-90. Both nymphs and the adults sit on the lower surface of the leaves. In severe outbreaks, these may be seen spread over all parts of the plants. The insects suck the leaf sap and the infested leaves turn yellow, brown and wilted. The secrete honeydew they invites fungus, which reduces the photosynthetic activity of the plant. They cause general debilitation in the plants thus reducing the yield potential.

Helicoverpa armigera Hb.

The eggs are laid singly on the silk, husk or over the tassel. The neonate larvae feed on tassel and silk. The grown up larvae enter the cob from the top and feed on the apical grains first then it continue feeding and reduce the yield. Usually, one larva damage one cob.

The varieties with tight husk, offer resistance to the larvae making road in to the cob. Often the damage to the grain is not much yet the infestation marks reduce the market value of the green cobs.

Heiroglyphus nigrorepletus Bol.

This is a serious pest of ‘*kharif*’ maize in arid region. The grasshoppers lay the eggs in the loose soil on the bunds. The nymphs feed on the grass. As the hoppers grow, they invade the maize crop and more amount of biomass is consumed per hopper. In the later stage of their growth they voraciously feed the leaves and produce lots of fecal matter in the whorl thus rendering the crop unfit even for fodder. The crop gives withered look. Based on the leaf area consumed by the hopper during its development, Pradhan and Peshwani (1961) estimated 18 percent crop loss caused by this pest.

Chiloloba acuta Wiedemann

This is flower eating scarabid causing damage to maize (Bhatnagar, 1970). Sekhar *et al*. (2000) reported *C. acuta*, and few other coleopteran infesting maize tassels during *kharif* 1996-98 at Hyderabad. Only heavy infestation of this beetle cause economic loss.

Yield losses

The yield losses in maize reported by earlier workers (Rahman, 1942; Trehan and Bhutani, 1949; Reddy, 1968) were estimated empirically rather than by experimentation. This crude estimate of loss due to *C. zonellus* was 70-80 per cent. Similarly, Srivastava (1959) was of the opinion that at the very conservative estimate, 10-15 per cent of the maize produce is lost annually in Rajasthan on account of the insect alone. Reddy (1968) also put forth estimated gross loss caused by insect pest and diseases in India to be at 10 percent. These guesswork estimates are generally covered under the accepted loss of 10- 12 percent. Chatterji *et al.* (1969) showed that the percentage of avoidable loss primarily due to *C. zonellus* varied from 24.3 to 36.3 in different agro climatic regions of India.

The loss due to *C. partellus*, the most important pest of maize over wider geographical area of maize cultivation varied from 26.7 to 80.4 per cent in different agro climatic region in India (Chatterji *et al*., 1969). *C. partellus* alone causes an estimated crop loss of 20-87 percent under varying climatic conditions (Rahman, 1944; Singh *et al*., 1962; Chatterji *et al*., 1969; Mathur, 1983). *S. inferens* causes loss in winter season in peninsular India, which vary from 25-80 per cent (Rao, 1983). Pradhan and Peshwani (1961) have estimated the crop loss caused by *H. nigrorepletus* to be about 18 per cent using the indirect method of considering the amount of maize. Shoot flies causes severe crop loss in spring maize and also to some extent in winter maize. Different varieties suffer shoot fly infestation varying from 69-97 per cent (Chaudhary and Sharma, 1975) but the overall grain loss is reported to be 20 per cent (Pathak *et al*., 1971).

The cutworm cause serious damage to the crop in hill region. During epidemic, the insect cause 45-54 percent crop loss. The economic losses by thrip, *Anaphothrips sudanensis* accounted for 19 percent to the young plants. Termites generally cause minor crop loss in maize but at sandy places, it sporadically occur and heavily damage the crop. With the introduction of winter maize, the climbing cutworm has become a serious pest of maize in north Bihar. The insect cause 12-34 percent crop loss during active season (Verma *et al*., 1979; Verma and Sinha, 1980).

Insect management component

Host plant resistance

Painter (1951) attributed the resistance to insects to three major categories: non-preference, antibiosis and tolerance. The non-preference is the insects negative response to plant lacking the characteristics of a good host for oviposition and shelter. Kogan and Ortman (1978) have proposed the use of antixenosis (avoiding a bad host) to replace the term 'non preference'. The antibiosis includes the negative effect on the growth and development of the insect. Tolerance is the ability of the plant to compensate by producing more for the loss caused by the insect. Horber or hober (1980) pointed out that all the three categories of resistance put forth by Painter are Independent of each other it is only the antibiosis which mean true resistance to the insect. The occurrence of DIMBOA and its decomposition product 6-MBOA besides some other allelochimicals like falvone glycoside maysin and its related luteiolin c-glucoside in the silk of resistant varieties are the cause of antibiosis. The plant morphological features such as leaf-fibre content, increased silica content, vascular bundle density, increased, husk tightness, reduced leaf trichome density act as physical resistant mechanism.

The relationship between crop and its pest is very specific. Most of the pests are oligophagous. This is proved by the fact that in spite of myriads of insects, no crop suffers from more than 4-5 major pests. An insect assumes pest status only when its nutritional requirements are completely met by the plant. A compatibility between insect and plant lead to rapid increase in the insect population. In the event of lack of compatibility, the growth of the insect would retard; the life cycle would get prolonged. The female would lay less eggs and eventually the population of the insect would get decimated. On the other hand the impact of plant can be measured directly in term of plant injury caused, it may range from slight damage to total loss of plant, interference in the normal growth and development of the plant, reduction in the quality of the economic produce and indirectly in predisposing the plant to the attack of fungi, bacteria and viruses.

Use of insect resistance varieties is the most acceptable component of IPM as it offers built-in mechanism to ward off pests by antixenosis or antibiosis. Further, the host plant resistance very well gets along with other components of IPM including chemical control. The population of any insect in the crop is the function of the initial population (Xo) of the pest and the rate of increase of pest 'r'. While Xo depends upon the population of hibernating pupae of the previous crop, the rate of increase depends upon many factors such as environmental factors and plant susceptibility. The insect develop faster on a susceptible plant and complete more number of generations during the crop season. Any control measure that would help reduce 'r' is likely to avoid the occurrence of any major outbreak of pest while the level of 'Xo' will determine the level of infestation. Screening of germplasm from different parts of the world to identify the sources of resistance and utilizing them for the development of varieties have so far remained main stay in the management of maize pests. From American and European belt, germplasm was collected. These germplasm were tested against european corn borer and were having varying level of resistance. In previous experiments, it was studied that the germplasm resistance against *Ostrinia nubilalis* does not have resistance against *C. partellus*. It is, therefore, necessary to screen the same material against *C. partellus* to select the resistant lines for the development of resistant varieties. The countries from where materials collected in 1973-74 were Austria, France, Canada, USA, Hungary, Polland, Rumania, Spain, USSR, Yugoslavia, West Germany, Holland and Czechoslovakia.

Antigua Group 1&2, CML-139 and CM-67 were found to be resistant against *C. partellus*. The Indian lines were also screened along with foreign materials. The susceptibility of the single cross hybrids were compared with the susceptibility of their parents. Parents were always found more susceptible than the hybrids.

The screening of germplasm for resistance against insect pests have become possible with the development of suitable techniques for mass rearing of the insects in the laboratory on semi synthetic diet; artificial inoculation techniques and a reliable leaf injury rating following the artificial inoculation.

Mass rearing of C. partellus

Screening of germplasm for resistance on uniformly infested plants give acceptable results. Mass rearing of host insect is, therefore, prerequisite for screening a large number of germplasm for resistance. Besides, mass rearing of host insect is also important for other studies such as diverse entomological problems, physiological, toxicological, biological, host plant relationship, production of insect parasitoids and pathogen and also attractants and hormones.

Artificial diet

Mass rearing of host insect involves development of suitable low cost artificial diet and efficient mass rearing technology. Rearing of host insect on natural food is time consuming due to frequent change of food which involve lot of wastage of plant material and mortality of the insect due to disturbing the insects number of times during their development. Taking clue from the artificial diet developed for *O. nubilalis*, several artificial diets were developed for *C. partellus*. The most accepted artificial diet based on pulse were developed by Siddiqui and Chatterji (1972); Siddiqui *et al*. (1977); Sharma and Sarup (1978), Singh and Sarup (1987) and Chandish *et al*. (1995). The ingredients of diet developed by Siddiqui *et al*. (1977) are green grain powder (75 g), wheat powder (20 g), yeast (5 g), ascorbic acid (1.7 g) methyl para hydroxy benzoate (0.8 g), sorbic acid (0.4 g), Vitamin E (0.2 g), agar powder (6 g), 40% formaldehyde (1 ml) and water (390 ml). The required quantities of all the ingredients are accurately weighed. Barring agar all the ingredients are added in the blender with half the quantity of water. The contents are mixed thoroughly. Mean while the agar is heated with the remaining half quantity of water for 5-6 minutes. The host agar solution is then added to the blender and thoroughly homogenized. The diet mixture is later poured into glass jars (15cm x 10 cm) up to a height of 2 cm. The jars are covered with sterilized paper and kept at room temperature for a day or two for setting of diet and evaporation of moisture condensed inside on the wall of the jar.

Rearing procedure

The cut pieces of butter paper containing eggs of *C. partellus* are stick on to the diet surface in the jar . Care is taken to keep the egg side up. The jars are covered with sterilized thick cotton cloth. Each jar is further covered by sterilized black paper from all the sides as well as top. This is done to facilitate the confinement of larvae on the diet. After 3rd day the butter paper bits bearing hatched egg shells are removed from the surface of the diet. The jars are kept in racks. The room is maintained with 27±2^{0}C and 70-90 percent relative humidity. The development period from egg to pupa takes about 20 days. The moths emerged after 10 days. Development period of males is about 2 days shorter than females. This feature causes limitation in the mass rearing of the insect. The pupae of male, therefore, are kept at 10^{0}C in the BOD. This operation helps synchronizing the physiological state of both males and females. For obtaining eggs, the pupae are kept in the oviposition jars. The oviposition jar is done up by providing 2-3 cm moist sterilized sand. The sand surface is covered by a circular butter paper. The inner wall including the ceiling of the jar is also lined by the butter paper. The moist sand helps maintaining high humidity. These jars are kept in BOD at 21±1^{0}C. The adults on emergence; lay the eggs on the butter paper. The eggs are collected by cutting the portion of butter paper bearing egg mass.

Cultural control

The type of machinery and the timing (fall or spring) depth and frequency of tillage can influence the survival of certain insects (Steffey *et al*., 1992). Tillage can affect soil temperature, soil moisture, aeration, organic matter content and bulk density of the soil. Each of these factor may have direct or indirect effects on the survival of some insects. The insects most influenced by changes in tillage include the soil insect complex. Foliage feeding insects are not much affected by tillage. In most situations, the diversity of insects is greater within a reduced tillage system. This increased diversity does not cause an increase in crop injury because both pests and beneficial insects may respond to tillage. Predatory ground dwelling spiders and ants are associated more with plant refuge than with bare soil.

Manipulation of sowing

Effect of date of sowing of maize on the incidence of *Atherigona* sp. and loss in yield due to its attack studied by sowing hybrid Ganga-3. It was observed that 'dead hearts' were formed in 18.84%, 36.25% and 40.50% of the plants in the 1st , 2nd and 3rd sowings (7th February, 14th February and 22nd February, respectively) due to attack of shoot fly. On the basis of dissection of 10% of the plants (25 days after sowing), the highest infestation, 62.5% was recorded in the 3rd week of sowing as compared to 37.5%, 59.37% and 50% in the 1st, 2nd and 4th sowing respectively. On the basis of egg count on the plants, the highest number was recorded again in the 3rd sowing (81.25%) as compared to 43.75%, 75.0% and 65.62% in the 1st, 2nd and 4th week sowing respectively (Mikoshiba, 1971). In the irrigated area, sowing during mid June is most appropriate time for harnessing the optimum potential in Haryana, Punjab and Western Uttar Pradesh. (Sarup *et al*., 1978). The yield was observed 29.1 per cent higher in unprotected crop as compared to unprotected normal sown crop. This yield could be increased up to 50.1 per cent when the crop was protected by chemical spray. The proposition is pragmatic for the farmers with small holdings.

Intercropping and pest reduction

The egg laying by *C. partellus* was observed on non hosts such as cowpea and cassava when these crops were inter-cropped with maize or sorghum. The eggs did hatch on cowpea but the number of neonate larvae reaching the host plants diminished with distance (Ampong Nyark *et al.*, 1994).

Table 2. Losses due to major pests.

Station	Season	Variety	Avoidable loss	Percentage of avoidable loss
a. Percentage of avoidable loss primarily due to *Chilo zonellus* Swinhoe				
IARI, New Delhi	*Kharif*	Jullunder Local	946.3	84.7
		Ganga 101	1730.6	32.2
PAU, Ludhiana (Kandaghat)	*Kharif*	Solan Local Him 123	546.9	30.3
			535.2	26.2
APAU, Hyderabad, (Amberpet)	*Kharif*	Hyderabad Local	1415.2	25.6
		Deccan Hybrid	1482.6	24.3
b. Percentage of avoidable loss primarily due to *Sesamia inferens* Wlk.				
APAU, Hyderabad (Amberpet)		Hyderabad Local	1394.8	30.6
	Rabi	Deccan Hybrid	2346.5	36.3

Average of two years (1965 & 1966)

The incidence of damage to rice and maize by stem boring lepidopteran was investigated under monocrop condition and under inter-cropping with soybean in the wet season of 1982. Intercropping gave almost a 13% reduction in *C. partellus* and *S. inferens* on maize and a 9.2% increase in grain weight per plant. Yield per unit area of land increased by 24%.

The agronomic practices such as tillage, crop intensity, crop rotation, intercropping, irrigation, fertilizers etc. have far reaching effect on the pest status. While developing pest management strategy for any crop it is imperative to study the impact of these activities on the important pest population. For the control of *C. partellus* it has been recommended to plough the field soon after the harvest and destroy the stubbles so that the hibernating pupae of the pests get destroyed (Rahman, 1942; Trehan and Butani, 1949; Ayyar, 1963).

Management of crop residue

Crop residues are important for carrying over stem borer larval populations from one growing season to the next. Population of *C. partellus* were observed in stalks after harvest (Warui and Kuria, 1983). An effective control option would be to reduce the first generation of adult population by destroying the larvae in old stalk (Kfir *et al*., 1987 and Kfir, 1990). Slashing maize and sorghum stubble destroyed 70% of *C. partellus* and *Busseola fusca* population and additional ploughing and disking destroyed a further 24% of the pest population in sorghum and 19% in maize (Kfir, 1990). Tillage may reduce the borer population through mechanical damage either by burying then deeply into the soil or by breaking the stems and exposing the larvae to adverse weather conditions (Harris, 1962) as well as birds, rodents, ants, spiders, and other natural enemies (Kfir, 1990; *Kfir et al.*, 1989) Farmers normally stack dry stalks in the field where they are kept until commencement of rain thus creating a reservoir for infestation in the following season. To solve this problem early cutting of stalks and horizontal placement on the soil surface has been recommended. This was observed to cause the mortality to 97% of stem borers in maize and 100% in sorghum in Ethiopia (Gerbre Amlak, 1988). The high level of mortalities of *C. partellus*, *Corichal cociliellus* and *S. Calamistis* in horizontally placed stalks was ascribed to the effects of sun and heat (Pats, 1996). In Tanzania, almost complete eradication of *C. partellus* on maize and sorghum was achieved by burning the crop residue immediately after harvest (Duerden, 1953). The burning causes loss of organic content which otherwise would have gone to the soil fertility. The burning of leaves and protecting stem from burning cause enough heat to kill 95% of the stalk borer and preventing the organic content. The heat also cures the stem which makes them termite resistant (Adesiyun and Ajayi, 1980).

Chemical control

Soil application and foliar sprays of major hydro chlorinated compounds were in use for the control of pest in the earlier days. Furrow application of granules of carbofuran are still used for shoot fly, thrips and aphids. Since the thrips remain hidden in the folds of leave whorl, the contact insecticides generally fail to reach the site. It is therefore desirable to use systemic pesticides either as spray or granular application at the time of sowing to suffers the population of thrips. Rajgopal and Channa-basavania (1977) conducted experiment using nine chemical pesticides of which carbofuran 10 per cent (1 kg. a.i. per acre) gave good control for most of the pest except *Helicoverpa armigera*. Seed treatment of Chlorpyriphos, imidachlopid, cruiser 70 WS are effective for the control of termite. Spray of 0.1 percent solution of Endosulfan 35 EC is used for the control of stalk borers.

Sex pheromone

In lepidopterous insects the females release pheromone to attract males for mating. Sex pheromones are use in the management of insect pests in three ways:

a. Monitoring of the adult population; based on which its egg laying period can be predicted for appropriate interventions

b. Mating disruption by charging the agro-ecosystem with the pheromone of pest we need to manage. The females get confused and normal mating behavior of searching the females and mating gets disrupted.

c. Mass trapping of males

The structure of the female sex pheromone of *S. inferens* from the Philippines was shown to be Z-11-hexadecenyl acetate (Nesbitt *et al*., 1976). Sex pheromone for *Chilo partellus* has also been identified and is available commercially (Van den Berg., *et al* J, 1998).

Biological control

Natural enemies decimating the pest population to a great deal. Often their utility is realized when their number is dwindled because of the severe jolt received by them due to various agricultural operations.

The role of chemical pesticides is most detrimental to the natural enemy guild. Biological control agents are density-dependent. The agro-ecosystem as such is very unstable, however, maize provide a very congenial niche for the variety of natural enemies. As regards the applied biological control, *Trichogramma* spp. holds promise for the management of stalk borers. Narayanan (1953) suggested mass rearing and release of the native parasite *T. minutum* Riley in field to control the borer population. Katiyar (1960) made an attempt to control the borer by periodic colonization of this parasite in the field but the success of this pest remains elusive. The efficacy of *T. minutum* on *C. partellus* eggs was assessed on the basis of large scale field trials (Atma Ram *et al*., 1971). Later efficacy of *T. chilonis* proved beyond doubt in several lepidopterous pests in rice, sugarcane and cotton. Of late, *T. chilonis* was used in large area IPM trials in Punjab in maize with success. Kumar and Sharma (2004) managed the *C. partellus* with two releases of 1,50,000 parasitized eggs/ha. in Hoshiarpur district of Punjab. It is necessary to synchronize the release of parasitoid with the egg laying of the pest. There are a host of natural enemies in the field which need to be conserved. Habitat management is an ecologically based approach aimed at favouring natural enemies and enhancing biological control in agricultural system.

The goal of habitat management is to create suitable ecological infrastructure within the agricultural landscape to provide resources such as food for adult natural enemies, alternative prey or hosts and shelter for adverse conditions. The copious production of pollen grains in maize provides food for several predators and the spacious whorl provides a most suitable niche for host of natural enemies to find shelter during the midday heat. The parasitoid *Stenobracon deesae, Microbracon chinensis, M. hebetor* and *Apanteles* sp. affect a wide range of lepidopterous pests including maize borers. Subba Rao *et al*. (1969) recorded 42.83 percent parasitism of field collected non diapausing *C. partellus* larvae by *A. favipes*. Varma and Bindra (1973) described the technique of mass rearing of larvae parasitoid on the larvae of *Corcyra cephalonica*. Sharma (1975) established that the larvae parasitoid, *Bracon bravicornis* and *B. hebetor* could be effectively reared on *C. partellus*. This suggests that the combined use of both, egg and larval parasitoid could effectively manage the population of *C. partellus*.

During study in Ludhiana in 1975-76 on the population dynamics of *C. partellus* (Singh *et al*., 1977) found the carabid *Chlaenius hamifer* Chaud. and the coccinellids *Brumoides suturalis* F. (Brumus suturalis), *Coccinella septumpunctata* L. and Memochilus sexmaculatus (F.) were observed preying on larvae and pupae of the pest in the whorl of maize and sorghum.

Reported forty-two natural enemies including one egg, thirty-seven larval and three pupal parasitoids in the fodder maize in different seasons in Karnataka. The important among them are *T. chilonis, Myosoma chinensis, Xanthopimpla stemmator* and *Tetrastichus howardi*. The potential predators are anthocorid bug, *Orius tantillus*, two species of reduviid and seventeen species of spiders.

Weed management

Plant diversity adjacent to main crop provide refuse for predators thus acting as colonization sources (Altieri and Whitcomb, 1980). Populations of insect pests and associated predaceous arthropods were sampled by direct observation and other relative methods in simple and diversified maize habitats at two sites in North Florida during 1978 and 1979. Through various cultural manipulations, characteristic weed communities were established selectively in alternate rows within maize plots. Fall armyworm (*Spodoptera frugiperda*) incidence was consistently higher in weed free habitats than in the maize habitats containing natural weed complexes or selected weed associations. Corn earworm (*Heliothis zea*) damage was similar in all weed-free and weedy treatments, suggesting that this insect was not affected greatly by weed diversity. Only diversification of maize with a strip of soybean significantly reduced corn earworm damage. There were greater population densities and diversities of common foliage insect predators in the weed manipulated maize systems than in the weed free plots. Tropic relationships in the weedy habitats were more complex than food webs in monocultures. Predator diversities (measured as mean number of species per unit area) and predator density was higher in maize plots surrounded by mature, complex vegetation than in those surrounded by annual crops. Poor weed control associated with some tillage systems may favour an increase in the density of some insects (black cutworm, stalk borers). The response of different insect species to the many types of tillage systems is likely to vary according to their life cycle and physiological requirements.

IPM case studies

IPM Case Study in US

A decision framework is used to examine the economic implications of alternative pest control technologies in Massachusetls sweet corn farmers. The pest control alternatives examined can be grouped into three categories: 1. No control, 2. Scheduled spraying and 3. Prescribed spraying or integrated pest management. The performance measures used to compare the alternative pest control technologies are generated using a computer programme that integrate biological performance indicators with input and output prices to generate economic indicators (i.e. not returns). The result showed that the scheduled spraying pest management strategies allowed for more field spraying (with pesticides) than the integrated pest strategies. The integrated pest management strategies yielded higher average net returns than the scheduled spraying strategies. Three conclusions can be drawn: 1. the inclusion of biological information into the pest management models was valuable to the decision maker; 2. risk attitudes play an important role in the adoption of pest management technologies; and 3. changes in parameter values effected the biological and economical performance measures (Nyada, 1992).

Case study of IPM in Punjab state of India

An experiment was conducted in farmers' fields in Hoshiarpur district of Punjab to promote maize cultivation with special emphasis on Integrated Pest Management (Kumar and Sharma, 2004).

IPM trials of maize were initiated in 20 acres of farmers' fields in four blocks of Hoshiarpur district. Before undertaking the experiment a benchmark survey was conducted to know the major constraints in maize production, which revealed that maize stem borer, *Chilo partellus* was posing a major threat to the crop with some minor incidence of stalk rot and Maydis leaf blight. The importance of IPM was explained to the participating farmers and IPM strategy was developed suitable for Hoshirarpur. The variety Bio-9681, recommended for Punjab was used for this experiment. The sowing was completed in ten days i.e. June 22-July 3, 2003. For fifteen acres, the seeds were treated with *Bacillus lantimorphus* strains obtained from National Botanical Research Institute, Lucknow.

The IPM strategy was developed by taking inputs from maize scientists of different disciplines at Directorate of Maize Research, New Delhi (Table 3).

C. partellus is most important pest of maize during kharif. The eggs are laid in the underside of the leaves. The crop remains susceptible only in the first month after which it acquires resistance. The larvae bore into the whorl and kill the central leaf which becomes noticeable by the presence of dry central leaf popularly called as 'dead heart'. Some infested plants recover the damage. As the plants grow the dead plants do not get noticed hence the incidence is seeming low. *Trichogramma chilonis*, an egg parasitoid of *Chilo* is, therefore, released to decimate its population in the egg stage. Three cards (60,000 wasps) per acre per release give satisfactory results. During our experiment two releases were sufficient to arrest the *Chilo* population. The fields were observed every week for insect and disease incidences. *C. partellus* population remained below 4 percent where the parasitoids, *T. chilonis* were released while in control the infested plant population increased up to 12 percent in August.

Table 3. IPM strategy adopted for maize in Hoshiarpur district of Punjab

Practices	Details
Seed treatment	Variety: Bio-9681 Seed rate: 8 kg/acre Seed were treated with *Bacillus lentimorphus* culture provided by NBRI, Lucknow.
Time of sowing	10-15 days before onset of monsoon However sowing can be done any time after 15th June depending on the rain forecast or irrigation facility available with farmers.
Sowing method	Sowing to be done on flat ground and later the ridges may be made during weeding operation when the crop attains knee height.
Weed Management	Atrazine @ 800g/acre at pre-emergence stage i.e immediately after sowing
Fertilizer Application	Apply recommended doses of the fertilizers.

Practices	Details
	One third of total quantity of nitrogen and entire quantity of phosphorus, potash and zinc should be applied at the time of sowing. The rest of the nitrogen should be applied in two equal doses; first at knee height stage of the crop and second the emergence of tassel. The MOP and DAP can be mixed with the first dose of urea but zinc sulphate should not be mixed with DAP; it has to be applied separately.
Irrigation	As per crop requirement
Monitoring for insect pests	Crop was monitored at weekly interval for pests as well as their natural enemies status in the field.
Plant Protection measures	Release *Trichogramma chilonis* @ 8 cards/ ha on 8,13 and 18 days after germination (DAG) (each card having 20,000 parasites eggs with *T. chilonis* wasp) Dead- hearts will be removed If symptoms of banded leaf and sheath blight (BLSB) disease is noticed, then remove two base leaf sheaths only from the infected plants to prevent spreading of BLSB. (need based) For Maydis and Turcicum leaf blight, spray Dithane Z-78 @ 250g/100 L of water. Repeat the application after 15 days (need based) For aphids, only need based application of oxydemeton methyl 25EC or dimethoate 30EC @ 250 ml/acre when 10% plant are infested. (need based) For bacterial rot, bleaching powder to be used

Minor incidence of grasshopper, hairy caterpillar and *Myllocerus* was also observed. Natural enemies such as spiders, *Coccinellids*, *Paederus* sp. and *Cotesia* sp. were observed in the maize ecosystem which contributed in controlling the pest population. Minor incidence of Maydis leaf blight, Bacterial stalk rot and Banded Leaf and Sheath blight (BLSB) was observed near the maturity of the crop at few locations which required no chemical control measures.

Table 4. Economics of maize Cultivation per acre in *kharif* 2003 at Hoshiarpur

Crop Stage/Item	Quantity Required	Rate unit)	Farmer Practice	IPM
Tillage & Sowing	Tractor & Labour		350	350
Seed		50 per Kg	400	400
Fertilizer Application			-	
Urea	85 Kg.	240/50 Kg.	75 Kg. 360	408
DAP	50 Kg.	480/50 Kg.	25 Kg. 240	480
MOP	20 Kg.	222/50 Kg.	-	88.80
Zinc Sulphate	8 Kg.	103/10 Kg.	-	82.40
FYM	2 Trolly	200 per Trolly	1 Trolly 200	400
Weeding			-	
Herbicide Atrazine	800 gm.	220 Kg.	176	176
Manual Weeding			375	375
Trichocard	8 cards for 3 releases	30/card	-	240
Irrigation	1 Irrigation	20/ hrs. 12hrs. in 1 acre	240	240
Harvesting		350/trolly	2 Trolly 700	3 Trolly 1050
Shelling	20th share of yield	27.5/q	330	495
Total cost			3,371	4785.2
Yield			12q	18q
Gross Income			6,600	9,900
Net Profit/ acre			**3,229**	**5,115**
Net Profit/hectare			**8,073**	**12,787**

The yield in treated seed fields ranged from 66.56 to 36.80 q/ha; average being 49.09 q/ha. The yield from untreated seed plots was 8.76 per cent less than treated seed plots. In other non IPM farmers field the yield varied from 18-27 q/ha. On comparing the maximum yield of 27 q/ha of this range with our experiment the yield recorded 81.83 and 66.15 per cent higher for treated-seed and untreated-seed fields of IPM respectively. The higher yield is attributed to the crop management adopted; beginning with the selection of seed, balanced use of fertilizers, weedicides and other IPM inputs. Here it is pertinent to mention, that no chemical pesticide was used in the experiment.

The cost of cultivation was calculated based on the local cost. The cost incurred in non-experimental cultivation is mean of two farmers and was compared with experimental fields. The net profit was Rs. 4,714 per hectare more, when the farmers adopted the technology (Table 4). The gains of adopting technology were:

- Maize growers in Hoshiarpur district can substantially increase their profit by adopting proper crop management.
- Maize can be cultivated profitably without using chemical pesticides

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10. Maize disease scenario in India and their management through integrated management approach

Meena Shekhar and Sangit Kumar

Maize (*Zea mays* L.) occupies an important place in world agriculture due to its high yield potential and greater demand. It is a third largest planted crop after wheat and rice in India. Maize can be successfully grown in rainy (*kharif*), winter (*rabi*) and summer/spring (*zaid*) crop seasons. It can also be grown in all types of soils ranging from sandy to heavy clay. Deep heavy soils are considered more suitable in view of their better water holding capacity. Saline and alkaline soils should be avoided since these affect crop growth and development adversely. Diversified uses of maize for starch industry, corn oil production, baby corns, popcorns, etc., and potential for exports has added to the demand of maize all over world. Rising income in much of developing world and the consequent growth in meat and poultry consumption has resulted in rapid increase in demand of maize for livestock and poultry feed.

Among the factors adversely affecting productivity, ubiquitous incidence of diseases is prominent. Maize diseases have been a major constraint in increasing productivity. Besides reduced production, we incur heavy economic losses every year due to various diseases. In India, it is prone to a number of biotic stresses like foliar diseases, ear rot, and stalk rots caused by fungi, bacteria and virus. These diseases are difficult to control because their populations are variable in time, space and genotype. Disease may be minimized by the reduction of the pathogen's inoculum, inhibition of its virulence mechanisms, and promotion of genetic diversity in the crop. Conventional plant breeding for resistance has an important role to play now which can be facilitated by marker-assisted selection.

Based on research efforts for the last five decades, under the aegis of Directorate of Maize Research, 16 out of 62 diseases adversely affecting this crop have been identified as a major constraint (Table 1). *Turcicum* leaf blight, *Maydis* leaf blight, Banded Leaf and Sheath Blight, Post Flowering Stalk Rots, Common rust, Polysora rust, downy mildews, *Pythium* stalk rot and Bacterial stalk rot are the major threat to the potential yield of maize. Corporality, losses due to maize diseases have been estimated to the tune of 9.4 % annually, for the countries of Asia it is 12 %, while for the African countries it is as high as 14 % (Cramer, 1967; James 1981). Even for the developed countries like USA, 12 % of the produce is lost annually due to diseases. In India the total loss in economic products of the crop due to diseases has been estimated to the tune of Rs 17, 83, 320 (Table 1) and in terms of percent losses is 13.2 % (Payak and Sharma, 1985). Some economically important diseases of this crop along with their pathogen, symptoms, and their distribution and management practices are being described to achieve better crop management in this chapter.

Table 1. Major disease affecting the maize crop in India

Disease	Affected part	Pathogen	Losses
Seed and Seedling Blights	Seedilngs	Species of *Fusarium, Rhizoctonia, Pythium Penicillium Aspergillus, Acremonium, Cephalosporium* etc.	By reducing plant stand
Turcicum Leaf Blight	Foliar part at knee high stage	*Exserohilum turcicum* (Pass) Leon. & Sugs	Severe infection causes 70% yield reductions
Maydis Leaf Blight	Foliar part at knee high stage	*Drechslera maydis* Niskado Syn. *H. maydis*	Severe infection causes a premature death and 83 % yield reductions
Common Rust	Foliar part	*Puccinia sorghi* Schw	Yield losses as high as 50% have been recorded
Polysora Rust	Foliar part	*Puccinia polysora* Underw.	In excess Yield losses of 45% have been recorded
Brown Stripe Downy Mildew	Foliar part	*Sclerophthora rayssiae* var. *zeae* Payak and Renfro	Losses ranging from 20-100% depending on the species and cultivars in maize
Sorghum Downy Mildew	Foliar part & in severe case tassels.	*Peronosclerospora sorghi* (Weston & Uppal) Shaw	Severe outbreaks have occurred in all over world including India. The yield loss as high as 90 % has been reported.
Rajasthan Downy Mildew	Foliar part	*Peronosclerospora hetropogoni* Siradhana *et. al.*	Very serious in Rajasthan and in excess 70% Yield losses in excess of 70 % have been recorded.
Brown Spot	Leaf & mid rib	*Physoderma maydis* Miyake	It is not so carious in India, however, in favorable condition the disease can develop up to greater incidence and cause alarm

			situations.
Banded Leaf and Sheath Blight	Started from lower leaf & whole plant	*Rhizoctonia solani* f. sp. *Sasakii* Exner	yield losses close to 40 % have been reported
Pythium Stalk Rot	Stalk at pre flowering stage	*Pythium aphanidermatum* (Eds) Fitz	The yield reduction in susceptible genotypes has been reported to the tune of 100 %
Bacterial stalk rot	Stalk at pre flowering stage	*Erwinia chrysanthemi* p. v. *zeae* (Sabet) Victoria, Arboleda & Munoz	Early infection led to complete death of plant at flowering stage resulted in 92.2 % yield loss and late infection in 57.0 to 36.3 % yield losses
Post Flowering Stalk Rots	Stalk at post flowering stages	*Fusarium moniliforme* Sheld *Macrophomina phaseolina* (Goid) Tassi *Cephalosporium maydis* Samara, Sabeti & Hingorani	Yield losses influenced by various factors like climatic conditions, crop density, fertilization rates and cultural practices. So, estimating precise yield loss due to maize stalk rot is often complicated by number of factors involved.
Charcoal Rots	Stalk at post flowering stages	*Macrophomin aphaseolina* (Goid) Tassi	The disease incidence was recorded in Karnataka ranged from 10 to 42.9% (Desai *et al*., 1991; Meena Shekhar et.al 2012).
Fusarium Stalk Rots	Stalk at post flowering stages	*Fusarium moniliforme* Sheld	Estimated loss from 36.2 3-38.93 % (Meena Shekhar *et.al* 2012).
Late Wilt	Stalk at post flowering stages	*Cephalosporium maydis* Samara, Sabeti & Hingorani	In India where it occurs endemically, with incidence as high as 70% and economic losses up to 51% (Johal *and Briggs*, 1992).

For disease management, it is important to understand the potential of a pathogen to infect a crop and spread within the crop in a specific region. The three main parameters of disease progress are as follows:

- Initial (primary) amount of pathogen's inoculum
- Rate of disease increase
- Duration of crop development

These parameters interact to produce a rapid increase in pathogen populations, which manifests as exponential disease development in many production systems. The rate of disease increase over time is dependent upon the interactions of the pathogen, host plant, and the environment. For disease management purposes, the biggest concern for growers is the interaction of the pathogen and host and the ideal environmental conditions, which plays a critical role in determining the nature of plant disease epidemics. This set of interactions is known as the disease triangle (Figure - 1), which determines the fate of a disease on a crop.

Figure 1. Disease triangle

Under favorable environmental conditions, these pathogens are capable of causing severe losses and deteriorate the quality of the produce. Though, Chemical control measures for some of the diseases are effective in reducing losses yet their use is limited by the high cost involved and residual toxicity they leave in the food chain. However, for minimizing the losses due to diseases, it is necessary to introgress an adequate level of genetic resistance against maize diseases of economic importance.

The extent the damages due to diseases depends on following factors;

- Susceptibility of maize genotypes to specific disease.
- Level of pathogen's inoculum present.
- Environmental condition during cropping season.

The aim of integrated disease management programme is to disrupt the combination of factors necessary for disease development including a favorable environment, susceptible plants, sufficient quantities of a virulent pathogen, and adequate time for disease development. Integrated disease management, which combines biological, cultural, physical and chemical control strategies in a holistic way rather than using a single component strategy proved to be more effective and sustainable. It is based on an understanding of host and pathogen's biology and the factors involved in infection and disease development. Short-term control may be achieved by a single practice. However, long-term reduction of disease losses requires the implementation of an integrated control programme, including the use of disease-resistant hybrids, crop rotation, tillage, and balanced fertility, insect and weed control, and, if necessary, the timely application of disease-control chemicals/pesticides.

The main components of an integrated disease management programme are as follows:

Prevention

By restricting entry of pathogens into fields through reducing the primary inoculum by obtaining certain cultural practices like;

- Sanitation practices aimed at excluding, reducing, or eliminating pathogen populations.
- Crop rotation is a very important practice, especially for soil borne disease control. For many soilborne diseases, at least a three-year rotation using a non-host crop greatly reduces pathogen populations.
- Avoid soil movement from one site to another to reduce the risk of moving pathogens. For example, sclerotia of *Macrophomina phaseolina*, *Fusarium moniliforme* and *Rhizoctonia solani etc.* are transported primarily in contaminated soil.
- Deep plowing and disking is helpful in reducing pathogens carryover in old crop refuse. Fallowing this for long period, the pathogen populations will be reduced.
- Preparation of raised beds generally allows for better drainage. Prior to planting, soil should be tested for nutrient levels and nematode populations

Monitoring

Regular field scouting is necessary to identify diseased plant and simultaneously important information related to disease development stages in respect to the environment can be collected to develop disease management strategy.

Monitoring for accurate Disease diagnosis

Direct disease monitoring should be based on symptoms or signs of the pathogen to identify the correct disease. When visible symptoms are evident, disease levels may be so low and we should manage the control strategy like judicious use of fungicide to reduce further spread of secondary infection**.**

Optimal selection of management tools

High soil moisture enhances the development of soilborne pathogens, including *Phytophthora* spp. and *Pythium* spp. Excess water damages roots by depriving them of oxygen and creating conditions that favour infection by bacterial stalk rot (pre flowering stalk rot). If post flowering stalk rot is a problem, scouting will provide information on the severity of stalk rot and we can manage to irrigate the field as per requirement and make our harvest and storage strategy accordingly to minimize the further losses.

Future strategies

Recording information on incidence and severity of diseases in cropping field will provide the information, that information can be used to make future strategies on hybrid selection, crop rotation, judicious use of fungicide and other cultural practices to prevent the losses due to various diseases in future.

A successful integrated disease control programme depends on a good crop production system; we must start with the selection of good hybrid, good irrigation system and timely application of fertilizer leads healthy and optimal plant growth. To minimize the losses due to diseases in maize, it is important to identify the disease correctly so that the appropriate management steps can be taken. Integrated management programme for various diseases in maize is given below along with their symptoms.

Seed and seedling blights

The disease is prevalent in sub temperate areas where the soil temperatures are low (below 13^0 C) during planting time. These diseases pose a serious problem in temperate areas by reducing plant stand. This group of diseases does not pose a serious threat in the major tropical environments of India because of rapid emergence of seedlings. A variety of pathogens are associated with seed rots and seedling blights including *Pythium* sp. *Fusarium* sp. *Acremonium* sp *Penicillum* sp. *Sclerotium* sp.

Management

- Plant good quality healthy and injury free seed for high germination.
- Proper seed bed preparation, planting seed in warm, fairly moist soil (above 15.8^0C).
- Correct placement of fertilizer, herbicide and other pesticides.
- Fungicides seed treatment with Thiram/Captan @ 2 g/kg seed.

Foliar diseases

Turcicum leaf blight (TLB) Teleomorph: *Setosphaeria turcica*, Anamorph: *Exserohilum turcicum* (Pass) Leon. & Sugs: Syn. *Helminthosporium turcicum.*

Distribution

Jammu & Kashmir, Himachal Pradesh, Sikkim, West Bengal, Meghalaya, Tripura, Assam, Rajasthan, Uttar Pradesh, Bihar, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu The disease is prevalent in areas where cooler condition prevails and maize is planted in high lands, winter planting in the plains as the cool/moderate humid conditions (18-27^0C) favors disease developments. When infection occurs prior to and at silking stage and conditions are optimum, it may cause significant economic damage.

Symptoms

The first infection occurs at knee high stage and recognized as slightly oval water-soaked, small spots produced on leaves and grow into elongate, long, elliptical, spindle shaped grayish green or tan lesions ranging from 2.5 to 15 cm. in length (Figure - 2). In damp weather, large number of grayish black spores is produced on the lesions. Severe infection causes a prematurely death of plant.

Maydis leaf blight (MLB) Teleomorph: *Cochliobolus heterostrophus*, Anamorph: *Bipolaris maydis* Syn. *Helminthosporium maydis.* The disease is prevalent in hot, (20-30^0C) humid, maize-growing areas. The fungus required slightly higher temperature than *Exserohilum turcicum*.

Distribution

Jammu & Kashmir, Himachal Pradesh, Sikkim, Meghalaya, Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Bihar, Madhya Pradesh, Gujrat, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu.

Maydis leaf blight (or southern maize leaf blight) is prevalent in hot, humid, maize-growing areas where the temperature ranges from 20-30^{0}C during cropping period. The fungus required slightly higher temperature for infection than *Setospharia turcica*.

Figure 2. TLB

Figure 3. MLB

Symptoms

Lesions on the leaves are elongated between the veins, tan, 2-6 x 3-22 mm long (Figure - 3), with limited parallel margins and buff to brown borders. Lesion size may vary in inbreds and hybrids due to different genetic backgrounds. Lesion produced by race `T' is tans, 0.6-12 x 0.6-2.7 cm. elliptical with yellow green. A major difference is that the race `T' affects husk and leaf sheath, while the `O' race normally does not.

Management strategy for TLB and MLB

- Residue management through crop rotation, tillage and sanitation.
- Ploughing down of crop debris may reduce early infection.
- Foliar Spray of mancozeb (Dithane M 45, Indofil M 45) or zineb (Dithane M 45) at first appearance of disease@ 2 -2.5g/litre of water followed by 2 to 4 applications at 10 days interval if needed.
- Two to three fungicidal applications are recommended at 15 days interval when weather conditions are favorable for disease development to reduce secondary infection.
- Two to four applications are recommended when disease is severe.
- *Use of resistant varieties for TLB* - PEMH– 5, Vivek 21, Vivek 23, Vivek 25, Pratap Kanchan 2, Nithyashree for Karnataka & Andhra regions
- *Use resistant varieties for MLB* -HM 10, PAU 352, Malviya Hybrid Makka 2, PEMH 1, HQPM 7, HQPM 5, HQPM 1, PEMH 5, HQPM 4, and HSC1.

Common rust Puccinia sorghi

The disease is common in subtropical, temperate and highland environment moderate temperature (16-25^{0}C) and high relative humidity.

Distribution

Jammu & Kashmir, Himachal Pradesh,

Sikkim, Meghalaya, West Bengal, Punjab (*Rabi*), Haryana (*Rabi*), Rajasthan, Uttar Pradesh, Bihar (*Rabi*), Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu.

Symptoms

The disease is common at knee high and tasseling stage. Circular to elongate, golden brown to cinnamon brown pustules are sparsely scattered over both leaf surfaces and become brownish black as the plant matures (Figure - 4). The alternate host (*Oxalis* spp.) is frequently infected with light orange coloured pustules.

Polysora rust Puccinia polysora –Underw**.**

The disease is favoured by high temperature (27º C) and high relative humidity.

Distribution

Peninsular India - Andhra Pradesh, Karnataka, Tamil Nadu

Symptoms

The disease resembles common rust. The pustules appear on leaf are light cinnamon golden brown, circular to oval 0.2-2.0 mm long densely scattered on the upper surface of leaf. The uredinospore are yellowish to golden. Development of pustules on lower surface is more as compared to upper surface. The telia are circular to elongate, covered by epidermis and longer then the as in common rust. (Figure - 5).

Figure 4. Common rust

Figure 5. Polysora rust

Management strategy for C. rust and P. rust

- Residue management through sanitation, tillage and crop rotation.
- Ploughing down of crop debris may reduce early infection.
- Spray of fungicide Dithane M-45 applications @ 2.5-4 g/L of water at first appearance of pustules.
- If disease is severe three sprays at 15 days interval are recommended.

- Use resistant varieties –
- *For C. rust* - pusa prakash, HHM 1, HHM 2 and HQPM 1, Nithyashree
- *For P. rust* - The sources of resistance are; NAI 112, SKV 18, SKV 21, NAH 2049 resistant hybrid for Karnataka.

Downy Mildews

This group of the pathogens constitutes one of the most important factors limiting maize production in India. They are very significant maize diseases in tropical/subtropical regions of India, where prolonged periods of leaf wetness and cultivation of alternate hosts are prevalent during the growing season. Cool, wet and humid conditions are optimal for disease development. In favorable conditions, disease cycles are rapid, leading to severe infection and spread of disease. The important species causing downy mildew in maize in India are the Sorghum downy mildew, Brown stripe downy mildew, Rajasthan downy mildew. The crop is most vulnerable to downy mildew infection during the seedling stage 15 to 20 days after planting.

Brown stripe downy mildew (BSDM) Sclerophthora rayssiae var. *Zeae* Payak & Renfro.

Distribution

Himachal Pradesh, Sikkim, West Bengal, Meghalaya, Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Bihar, Madhya Pradesh, Gujrat

The disease is most prevalent in warm, humid regions and common in the Himalayan areas of northern India. The disease is limited to location below 1500 masl.

Figure 6. BSDM

Symptoms

Initially, lesions develop on the leaves as narrow, chlorotic or yellowish stripes, 3-7 mm wide with well-defined margins and delimited by the veins (Figure - 6). The stripes later become reddish to purple. Downy or wooly cottony whitish growth occurs early morning hours on both surfaces of the lesion

Sorghum downy mildew (SDM) - *Peronosclerospora sorghi* (Weston & Uppal) Shaw. It is common in peninsular India.

Distribution

Gujrat, Maharashtra, Andhra Pradesh, Karnataka, Tamil Nadu

Symptoms

Infected plants are chlorotic, leaves of infected plants tend to be narrower and more erect than these healthy plants (Figure 7).

Figure 7. Field view of healthy and SDM affected plant

A white downy cottony growth may appear on both surfaces of infected leaves (Figure - 8).

Figure 8. Cottony growth on leaf of SDM affected plant

In severe cases the tassels of diseased plants may exhibit phyllody (Figure - 9), abnormal seed set. In tolerant varieties, the plant show symptoms of infection but have normal seed setting.

Figure 9. Phyolldy

Rajasthan downy mildew Peronosclerospora hetropogoni Siradhana *et.al*

Distribution

The disease is distributed in Rajasthan and surrounding areas.

Figure 10. Rajasthan Downy Mildew from *H. melenocarpus*

Symptoms

In susceptible seedling a complete chlorosis or chlorotic strips is appeared. Secondary symptoms appear at two to three leaf stages. The symptoms are similar to *P. sorghi* (Figure - 10) the only difference is that the *P. heteropogoni* infects *Heteropogon contortus* (Figure - 11) and *P. sorghi* does not. Tassels may be malformed producing less pollen while ears may be aborted resulting partial or complete sterility. In early symptoms plants are stunted and may die.

Figure 11. Advance infections on *H. melonocarpus* showing chlorosis up to the tip of leaves

Management option for Downy mildews

- Residue
- management through sanitation, tillage and ploughing down of crop debris.
- Planting before rainy season begins, can minimize the occurrence of disease.
- Destruction of infected crop debris, weed control, reduced crop density, crop rotation with non-host crops and low seed moisture (<10 %) at planting time.
- Seed treatment with metalaxyl (Ridomil 25 WP, Apron 35 SD) @ 2.5g/kg seed.
- Foliar spray of systemic fungicide such as metalaxyl (Apron 35FN) @ 2-2.5g/L at first appearance of diseases.

For Brown stripe downy mildew

- In addition to above practices use resistant varieties –PAU 352, Pratap Makka 3, Gujarat Makka 4, Shalimar KG 1, Shalimar KG 2, PEMH 5, Bio 9636, NECH- X 1280

Sorghum downy mildew

- In addition to above practices avoid sowing of maize Avoid maize-sorghum crop rotation in field where disease has occurred and avoid adjacent to a field of maize or sorghum to avoid the spread of sec. infection.
  - Use resistant varieties –DMH 1, NAC6002, COH (M) 4, COH (M) 5, Nithyashree.
  - *For Rajasthan Downy mildew*
  - In addition to above practices destroy alternate host *Heteropogon melonocarpus*

For Brown spot

Physoderma maydis Miyake

Distribution

Jammu & Kashmir, Himachal Pradesh, Sikkim, West Bengal, Punjab, Rajasthan, Madhya Pradesh, Karnataka

This disease mainly occurs in subtropical areas with abundant rainfall with high temperature. It attacks leaves, leave sheaths, stalk and sometimes outer husk.

Symptoms

Small chlorotic spots appeared on leaf blade arranged as alternate bands of diseased and healthy tissue (Figure 12).

Figure 12. Brown Spot

Spots on the mid ribs are circular and dark chocolate brown, white lesions on the lamina continue as chlorotic spots. Nodes and internodes are also show brown lesions. In severe infection, these may coalesce and induce stalk rotting and lodging.

Banded leaf and sheath blight Anamorph: *Rhizoctonia solani* f.sp. *sasakii* Exner, Teleomorph: *Corticium sasakii* Syn. Thanatephorus cucumeris

Distribution

Jammu & Kashmir, Himachal Pradesh, Sikkim, Punjab, Haryana, Rajasthan, Madhya Pradesh, Delhi, Uttar Pradesh, Bihar

The disease is prevalent in hot humid foothill region in Himalayas and in plains.

Symptoms

Symptoms produced on lower leaves and sheath, (Figure 13) is characteristic concentric spots that present on large areas of infected leaves and husks. The developing ear is completely damaged and dried up prematurely with cracking of the husk leaves.

Figure 13. BLSB

Management for options Brown spot

- Residue management through sanitation, tillage and ploughing down of crop debris.
- Follow crop rotation with non-host crops.
  Spraying with copper fungicides at the rate of 3g/L in the whorls of maize plant twice a week for four weeks before silking.
- Seed treatment with fungicide viz. Benlate, Bavistin and Plantavax were found to control the disease symptoms.
- Use resistant varieties and hybrids JH 10655 , FH-3113, DMR-1, DMR-5

Management options for BLSB

- Residue management through sanitation, tillage and ploughing down of crop debris.
- Follow crop rotation with non-host crops.
- Stripping of lower 2-3 leaves along with their sheath considerably lowers incidence and also does not affect grain yield.
- Foliar spray of Rhizolex 50 WP @ 10 g/10 L of water or foliar spray of Sheethmar (Validamycin) 2.7 ml/L water at first appearance of disease.
- Seed treatment of peat based formulation @ 16 g/kg of *Pseudomonas fluorescence* or as soil application @ 7 g/L of water.
- Hybrids such as EH-1389, JH-10704 were found to have moderate level of resistance to BLSB

Stalk Rots

Pre-flowering stalk rot

Pythium stalk rot *Pythium apharidermatum* (Eds) Fitz

Pythium stalk rot causes extensive damage to the crop in the lowlands of northern India. Maximum disease development occurs within temperature range of 30-35^{0}C with relative humidity of 80-100 %.

Distribution

Sikkim, Himachal Pradesh, West Bengal, Punjab, Haryana, Rajasthan, Delhi, Bihar Uttar Pradesh

Symptoms

Pythium stalk rot occur prior to flowering, confined to a single internode just above the soil. The diseased area is brown, water-soaked, soft and causing lodging. The affected plants topple but do not die up to two weeks after attack. The stalks may also be twisted and distorted (Figure - 14). Infected plants remain green and turgid up to several weeks because the vascular bundles remain intact.

Figure 14. Pythium Stalk Rot

Figure 15. (Erwinia Stalk Rot)

Erwinia stalk rot (ESR) *Erwinia chrysanthemi* p.v. *zeae* (Sabet) Victoria, Arboleda & Munoz. The disease is prevalent in the *Tarai* area of northern India. The high incidence of this disease is favoured by high temperature (32-35^{0}C) and high relative humidity in water logged condition.

Distribution

Himachal Pradesh, Sikkim, West Bengal, Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Bihar, Madhya Pradesh, Andhra Pradesh

Symptoms

Primary symptoms appear in mid season when plant suddenly falls over. Tan to dark brown, water soaked slimy lesions appear on the stalk (Figure – 15). One to several internodes above oil level may be affected. The infected tissues are macerated and emit foul odour. Affected plant may remain green for several days.

Management options for pythium stalk rot

- Regulate planting time between 10 and 20th July in North India.
- Plant population not to exceed 50,000/ha in endemic areas.
  - Good field drainage to avoid water logging that helps in zoospore dispersal.
  - Removal of previous crop debris.
- Application of 75% captan @ 12 g/100 litre of water as soil drench at the base of the plants when crop is 5 to 7 week old.
- Enrich the soil with biocontrol agents impregnated composts for good development of antagonists against the soil borne pathogens.
- Solarization, fumigation and soil drenches with bioagents and fungicides to mitigate the soil inoculum.
- Use resistant varieties such as – Pusa early hybrid, X 1280.

Management options for ESR

- Avoidance of water logging.
- Planting of the crop on ridges rather than flat soil.
- Avoid use of sewage water for irrigation
- Bleaching powder containing 33 % of chlorine @ 10 kg/ha as soil drench at pre-flowering stage.
  - Use resistant verities - PAU 352, PEMH 5, DKI 9202, DKI 9304.

Post-flowering stalk rot

Post-flowering stalk rots are of the most serious destructive and widespread group of diseases in maize. The disease caused internal decay and discolouration of stalk tissue, directly reduced yield by blocking translocation of water and nutrients, and can result in death and lodging of the plants prematurely (**Figure** 16) during the cropping season. Following three pathogens are involve in this disease.

Figure 16. FSR Advance infections on *H. melonocarpus* showing chlorosis up to the tip of leaves

Fusaium stalk rot (FSR) Fusarium moniliforme Sheld.

The infected plants typically wilt, leaves turn dull grayish-green and symptoms become conspicuous when the crop enters senescence phase. The leaves of infected plant turn to dull green instead of dark green color and the lower stalk becomes yellowed/ straw-colored and whole plant is wilted (Figure - 17).

The symptoms become conspicuous when the crop enters senescence phase. Pink-purple discolouration (Figure - 18) is observed when split open, the stalk.

Distribution

Rajasthan, Uttar Pradesh, Bihar, Andhra Pradesh. The disease is more common and important in warm and dry areas.

Figure 17. FSR

Symptoms

The disease is caused by *Fusarium moniliforme* Sheld. The symptoms become conspicuous when the crop enters senescence phase in dry and warm areas. There are no signs of the fungus that make it easily recognizable. The pathogen commonly affects the roots crown regions and lower internodes. When split open, the stalk show pink-purple discolouration. The disease causes a permanent wilting, leaves become flabby and basal stalk tissues obtain a pinkish to purple tinge colouration. Pre-mature drying of green plants is a conspicuous symptom in the field.

Charcoal rot **–** *Macrophomina phaseolina* (Goid) Tassi

Distribution

Jammu & Kashmir, West Bengal, Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu Charcoal rot is a common stalk rot disease in warm and dry areas. It occurs in areas where drought conditions generally prevail. The disease is favoured by soil temperature ranging from 30^0C to 42^0C and low soil moistures. The pathogen overwinters as sclerotia and may penetrate roots and lower stems during growing season. Water stress at flowering predisposes the plants to infection.

Symptoms

This disease is prevalent in comparatively drier maize growing areas and apparent as the plant approach maturity. Affected plant dry prematurely, the affected internodes becomes disintegrated and the presence of small pin-head like black sclerotia on the rind of the stalks (Figure 19) is a distinguishing character water stress or after flowering has been found to predispose the plant infection

Figure 18. Symptoms of Charcoal rot

Figure 19. Symptoms of Late wilt

Late wilt Cephalosporium maydis Samara, Sabeti & Hingorani

Distribution Andhra Pradesh, Rajasthan and Uttar Pradesh Sick soils in endemic areas favour the disease development in susceptible cultivars.

Symptoms

The first symptoms observed as moderately rapid wilting of the leaves beginning at tasseling time. The leaves turn dull green and then dry. Vascular bundles in the stalk are discoloured (Figure - 20). Later, lower portion of the stalk become dry, shrunken and hollow with or without wrinkling turn purple to dark brown which is more prominent on lower 1-3 internodes. Presence of wet rot with some typical sweetish smell in the lower internodes in infected area.

Management option for PFSR

- Residue management through sanitation, tillage and ploughing down of crop debris Avoiding water stress at flowering time reduces disease incidence
- Balanced soil fertility; avoid high level of N and low level of K
- Manage the attack of borers in maize as their injury predisposes to stalk rot
- In stalk rot affected field, balance soil fertility specially increases the potash level up to 80 kg/ha help in minimising the disease.
- Use Trichoderma Formulation in furrows after mixing with FYM @ 10g/kg FYM (1kg/100 kg FYM/acre) at least 10 days before its use in the field in moist condition
- Use resistant verities - JH 6805, Bio 9636, Pusa early hybrid X 1280JKMH – 1701, JH 6805, Bio 9639, Bio 9636, X 1280.

Ear and cob rot

Number of field fungi that invade the ear and kernels before harvest while the corn is in the field which affects the quality and appearance of kernels. The common fungi responsible for the ear rot in India are *A. flavus, Fusarium moniliformae, Gibberella, Trichoderma, penicillium* etc. Among them *A. flavus, F. moniliformae* are important.

Aspergillus ear rot

Aspergillus may invade corn in field as well as in the storage causing ear and kernel rot. *A. flavus* form yellow green masses of spores (Figure - 21) while *A. niger* produces black powdery masses of spore on the that cover both cob and kernel.The disease is favoured by high temperature and dry weather. Spores are spread by wind or insects to corn silks where they initiate infection. Insects damage and other stresses tend to increase the Aspergillus infection. These infected kernel are responsible for aflatoxin, production, a fungal metabolites that harmful for animal and human health. Corn planted and harvested late and grown under nitrogen stress more commonly contains aflatoxins prior to harvest than corn grown under good management practices and supplied with adequate nitrogen.

Figure 20. Ear rot caused by *A. flavus*

Figure 21. Ear rot caused by *Fusarium* sp.

Fusarium ear rot

Fusarium ear rot caused by *F. moniliforme and* occurs when harvest is delayed. The symptom of this disease is pink to reddish brown discoloration on the kernels and later on it spread on whole ear (Figure 22). As the disease progress, infected kernel becomes covered with a powdery/cottony pink mild growth. Kernels infected late in the season develop whitish streaks on the grains. Kernels become infected in several ways. The most common pathway is infection via silk channel. Air born spores present on residues can land on corn silks when it turns dark brown. Green silks are relatively resistant. Infection follows some form of injury, bird damage, feeding of corn borers. Disease development and spread one favoured by dry warm weather. Under certain conditions that are stressful for maize plant as the fungus becomes pathogenic and causes disease. Stalk rot, ear rot, kernel rot can occur in infected tissue although many times infected tissue have no symptoms. Infection follows some form of injury, bird damage, feeding of corn borers. Disease development and spread one favoured by dry warm weather after pollination. As molds grow and become established their metabolic activities and create microenvironments with elevated temperature and moisture content. As the moisture content increases, conditions become suitable for other, less xerophilic moulds in a process known as fungal succession Aspergillus sp. and Penicillium sp. are the common molds in some tropical countries like India which can grow in low water active value and cause deterious change in maize grains in addition to the formation of mycotoxins. Such contaminated seed/grain again spoiled at the time of poor storage conditions due to colonization of Aspergillus sp. and other microflora and consequently mycotoxin formation takes place on such contaminated grains that cause serious feeding problems in a wide range of animals, when used as animal feed.

Management

- Use recommended plant population and crop production practices.
- Use a balanced fertility programme.
- Plant early.
- Practices of tillage and crop rotation should be followed.
- Timely irrigation to reduce drought stress.
- Adopt practices to minimize the insect damage.
- Hybrid selection (Use high yielding hybrid, resistant for diseases)
- Harvest crop in time.
- Minimize mechanical damage.
- Dry and store the grains properly at 13% or less moisture.
- Segregate, blend or destroy contaminated grains.
- Keep storage facilities clean.

Conclusion

The aim of integrated disease management (IDM) is to disrupt the combination of factors necessary for disease development, including a favorable environment, susceptible plants, sufficient quantities of a virulent pathogen, and adequate time for disease development. IDM is currently defined as: “a sustainable approach to managing diseases by combining biological, cultural, physical and chemical tools in a way that minimizes economic, health and environmental risks”. The success and sustainability of IDM strategy, especially with resource poor farmers greatly depends on their involvement in helping generate locally specific techniques and solutions suitable for their particular farming systems and integrating control components that are ecologically sound and readily available to them. Training and awareness of farmers, disease survey teams, agricultural development officers, extension agents and policy makers remains to be an important factor for the successful implementation of IDM strategies. All direct stakeholders including farmers, extension workers, and local crop protection technicians should have a practical understanding of the ecology, etiology and epidemiology of the major diseases of the crop. Integrated disease management (IDM) is a disease control approach that uses all available management strategies to maintain disease pressures below an economic injury threshold. It does not advocate a routine chemical application program to prevent disease, but promotes the integration of cultural, physical, biological and chemical control strategies. The routine application of fungicides for insurance purposes is not appropriate, as it does not focus the proper attention on the real problem and can lead to resistance and potential environmental issues. It can be achieved by

- reduce the possibility of introducing diseases into the crop
- avoid creating conditions suitable for disease establishment and spread

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11. Site specific nutrient management in maize based cropping systems

Aditya Kumar Singh

Many countries in Asia have started replacing existing blanket fertilizer recommendations for vast areas with rice, maize, or wheat with more site-specific guidelines adapted to local needs. Site-specific nutrient management is a set of nutrient management principles combined with good crop management practices that help farmers attain high yield and achieve high profitability both in short-and medium-term.

Nutrient management in maize-wheat-green gram cropping systems under different tillage practices In this trial following treatment combinations were taken in CA practices as fertilizer management in conservation agriculture is a big challenge and under present scenario of reducing fertilizer subsidy, we have to develop practices by which maximization of target yield may be possible. In first year of experimentation, hence only fertilizer dose in the form of nutrient expert resulted significantly higher yield over absolute control and 50% RDF dose, however, nutrient expert was found at par with recommended dose of fertilizer dose amongst different tillage practices no significant difference was found as this the first year of trial, however, maximum grain yield of maize was obtained with Zero tillage (Figure 1.)

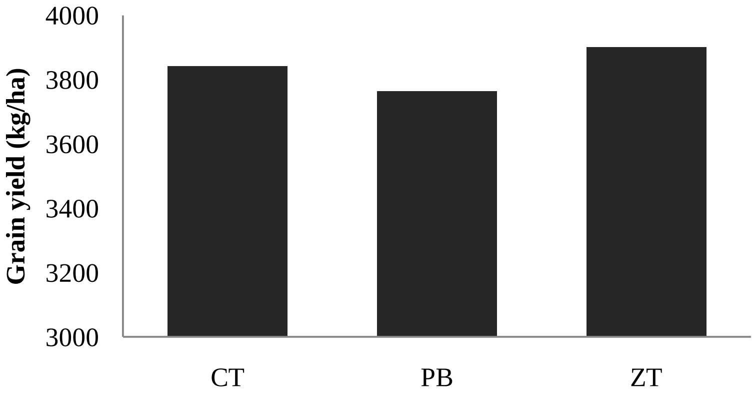

Figure 1. Grain yield of kharif maize under various tillage pratices

Table 1. Effect of site specific nutrient management practices on net returns and Benefit : cost ratio of maize hybrids.

	Target yield (kg/ha)	Absolute control	100% RDF	50% RDF	SSNM
		Net return (Rs/ha)			
PMH 1	8000	15015	34086	33423	37768
PMH 3	9000	23995	35501	33127	55334
HQPM 1	7000	13470	23225	23221	30022
Bio 9637	7000	10922	21756	23665	30225
DHM 117	8000	14826	33723	22870	41976
		Benefit: cost ratio			
PMH 1	8000	1.12	1.66	1.83	1.82
PMH 3	9000	1.78	1.72	1.82	2.51
HQPM 1	7000	1.00	1.13	1.27	1.47
Bio 9637	7000	0.81	1.06	1.30	1.48
DHM 117	8000	1.10	1.64	1.25	2.03

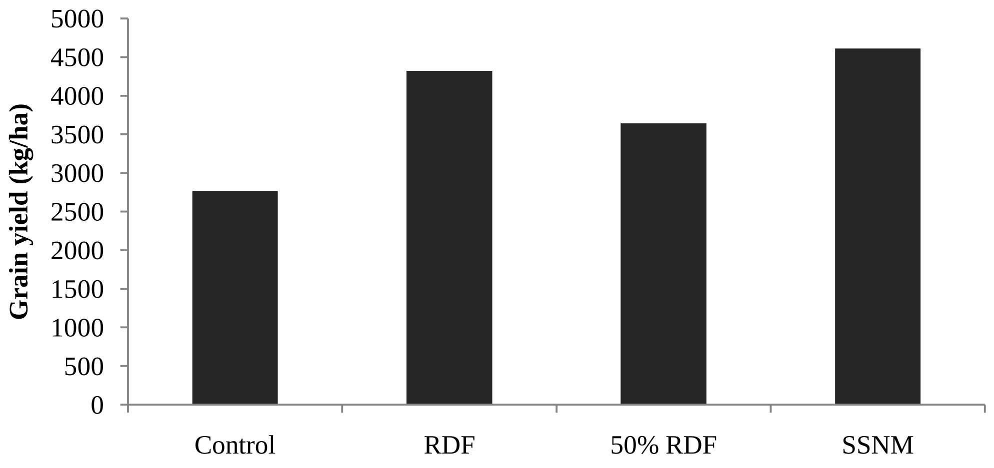

Figure 2. Effect of nutrient management practices on *kharif* maize grain yield

Nutrient management of maize genotypes under different cropping systems by Nutrient Expert – Decision Support System has been planned to test SSNM with five genotypes viz. PMH-1, PMH-3, DHM-117, HQPM-1 and Bio-9637.

In SSNM x genotype experiment, nutrient expert gave significantly higher yield over 100% RDF, 50% RDF and absolute control by 19.2%, 371.7% and 105.8%, respectively. Similarly amongst genotypes, PMH-3 gave significantly higher yield over PMH-1, DHM-117, HQPM-1 and Bio-9637 by 15.0%, 19.3%, 36.7% and 39.6%, respectively (Figure 2).

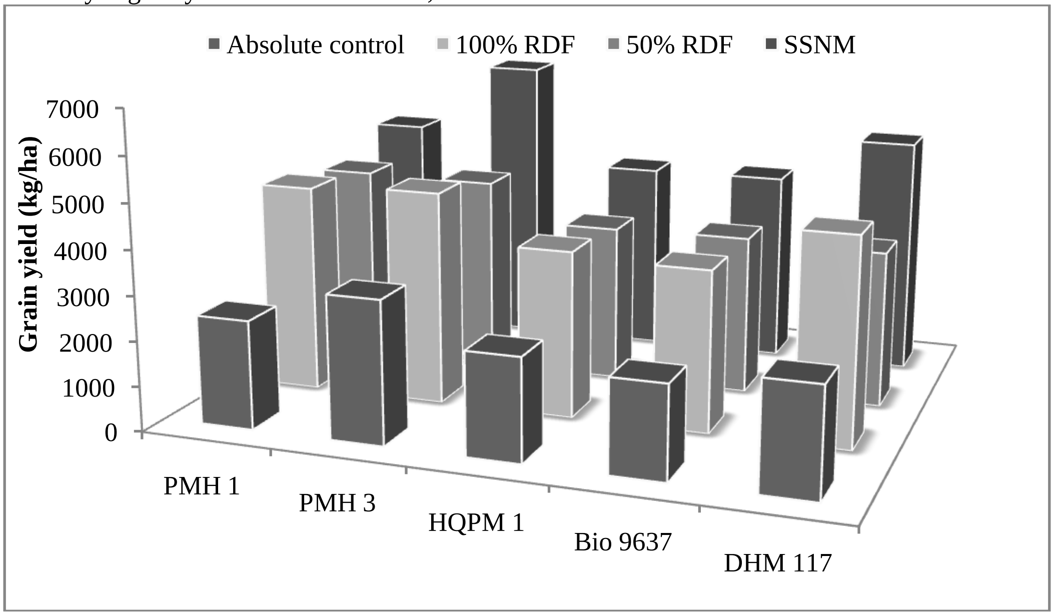

Figure 3. Interaction effect of site-specific nutrient management practices on grain yield of *kharif* maize

A significant interaction was found between genotypes and nutrient management practices and it is clear from data that PMH-3 with nutrient expert (180: 60: 90 kg/ha N: P_2O_5: K_2O) resulted significantly higher yield over all over treatment combinations. Next best treatment was obtained from DHM-117 with nutrient expert (170: 47: 56 kg N: P_2O_5: K_2O), however, it was found at par with PMH-1 with nutrient expert (170: 47: 56 kg N: P_2O_5: K_2O) treatment (Figure 3). In economic terms, highest net returns (Rs 55334) and B: C ratio (Rs 2.51) was also obtained by PMH-3 followed by DHM-117 which resulted net returns of Rs 41976 and B: C ratio of Rs 2.03.

12. Abiotic stresses and their management in maize

Ishwar Singh and Ashok Kumar

In India, maize (*Zea mays* L.) is the third most important food crop after rice and wheat. It is grown in a wide range of environments, extending from extreme semi-arid to sub-humid and humid regions. The crop is also very popular in the low- and mid-hill areas of the western and northeastern regions. However, the productivity of maize in India is quite low (< 2.5 t/ha) as compared to other major maize growing countries like U.S.A. and China. Besides other factors, biotic and abiotic stresses are the major threats for low maize productivity in India. Among the abiotic stresses drought, water logging and extreme of temperatures (low and high) are the most prevalent one. Besides these, soil salinization is one of the major factors of soil degradation under irrigated conditions

Major abiotic stresses on maize

1. Moisture stress
   a. Drought
   b. Water logging
2. Temperature stress
   a. High temperature stress
   b. Low temperature stress
3. Salt stress

Moisture Stress

Drought

Drought stress is one of the major limiting factor for maize production and productivity in India. Of the total 8.78 ha area under maize cultivation (2011-12), about 50 % area is prone to drought as 80% of maize grown in *kharif* (monsoon) season is rain-fed.

Drought stress negatively affects all stages of maize growth and production, however, the reproductive stage, particularly between tassel emergence flowering and early grain-filling, is the most sensitive to drought stress. Drought stress during this period result in a significant reduction in grain yield, associated with a reduction in kernel size. The susceptibility of maize to drought stress is generally attributed to its separation of male and female flowers. While silking is delayed under drought stress, there is little effect on the timing of pollen shed. Comparisons of the responses of male and female reproductive tissues under drought stress confirmed female tissues to be the most sensitive one.

Drought affected states in India

Rajasthan, Maharashtra, Madya Pradesh, Chhattisgarh, Uttar Pradesh, Gujarat, Andhra Pradesh, Karnataka and Odisha.

Consequences of drought stress

- When drought ensues after initial rains, seed germinate but the soil dries out, so that subsequent establishment and plant stand are badly affected.
- Drought leads to reduction of leaf, silk, root and grain expansion.
- Incomplete ground cover results from reduced leaf area expansion.
- Leaf senescence is accelerated (from the bottom of the plant first, but in conditions of high potential evapo-transpiration it can also occur at the top of the plant as well), which further reduces radiation interception.
- Retarded silk growth gives rise to delay in silking and an increased anthesis–silking interval (ASI).
- Stomatal closure occurs which leads to declination of photosynthesis and respiration from photo-oxidation and enzyme damage.
- Assimilate fluxes to growing organs is reduced.
- Low biomass production
- Crop becomes more susceptible to pest and disease attack.
- Ear abortion and kernel abortion increase and plants may become barren. Barrenness can lead to a complete loss of grain yield.
- Female reproductive structures are more seriously damaged than tassel, though tassel blasting can occur if drought coincides with high temperature.
- Remobilization of stem reserves can occur, when stress coincides with the phase of linear grain growth. In extreme cases this can result in premature lodging.

The maize crop is particularly sensitive to drought in the period of one week before and two week after flowering. Drought during this period results in an increase in the anthesis-silking interval (ASI) and grain abortion.

Traits associated with drought tolerance in maize

- Deeper root system
- Short ASI/ Longer pollen shedding
- Erect leaves
- Earliness
- Protogyny
- Dark green leaf /stay green/ high chlorophyll stability
- Low canopy temperature
- Non barreness
- Osmotic adjustment
- Pubescence, waxy leaves
- More proline, ABA and Glycine-Betaine accumulation in specific tissue of plants

Management of drought in maize

Single cross hybrids Single cross hybrids have better tolerance due to its inherent genetic capacity to cope better in moisture deficit than OPV and composites

Table 1. Maize crop growth stages sensitive stages to drought stress

Crop stage	Consequences
Seedling (primordial stage)	Initial establishment, root growth, plant vigour, cob length, kernel/row etc.
Knee high	Plant height, Photosynthetic rate, LAI, total biomass
Flowering*	Reduce pollen production, duration of pollen shedding, pollen viability, induce tassel blasting, prolong ASI up to 80-90% reduction in yield
Grain filling**	Reduced seed size/ test weight, 20-50% reduction in yield

*Most sensitive **Second most sensitive stage

Method of sowing

Furrow sowing may conserve moisture and provide microclimate for better plant growth and better root development in furrows which prolong the availability of moisture to sustain plant life during water deficit condition.

Water logging

Water logging caused by a high water table and poor drainage is one of the major constraints to maize production and productivity. In India, about 8.5 m ha of arable soil is prone to this problem. Approximately, 2.4 m ha, area planted under maize, is subjected to water logging, causing considerable loss of maize production almost every year.

Water logging stress can be defined as the stress inhibiting plant growth and development when the water table of the soil is above field capacity. The diffusion rate of gases in the flooded soil could be 100 times lower than that in the air, leading to reduced gas exchange between root tissues and the atmosphere. As a result of the gradual decline in oxygen concentration within the rhizosphere, the plant roots suffer hypoxia low oxygen, and during extended water logging, (more than 3 days) anoxia (no oxygen). Carbon dioxide, ethylene and toxic gases (hydrogen sulphide, ammonium and methane) also accumulate within the rhizosphere during periods of water logging. A secondary effect of water logging is a deficit of essential macronutrients (nitrogen, phosphorous and potassium) and an accumulation of toxic nutrients (iron and magnesium) resulting from decreased plant root uptake and changes in redox potential.

The extent of damage due to water logging stress varies significantly with the developmental stage of the crop. Previous studies have shown that maize is comparatively more susceptible to water logging from the early seedling stage to the tasselling stage. The first symptoms of water logging are leaf rolling and wilting and reduced stomatal conductance followed by root growth inhibition, leaf senescence and brace root development by above ground nodes.

Major water logging affected states in India

- Eastern UP
- Bihar
- Jharkhand
- West Bengal
- Odisha

Consequence of water logging on soil

- Decreased soil porosity
- Less diffusion of oxygen in root zone
- More CO_2 accumulation in root zone
- Root injury

Consequence of water logging on nutrients availability

- Loss of N through denitrification and leaching.
- Reduced activity of ammonifers and nitrifers leads to lesser availability of N to plants.
- Anaerobic condition causes the deficiency of zinc and molybdenum but releases the toxic elements like Fe, Al, and Mn.
- ESM condition restricts the root development leading to logging of the plants.
- Decreased total root volume affects less transport of water and nutrients from root to shoot.

Most critical crop growth stages, duration and temperature for water logging

In general, the presence of excess water in the rhizosphere negatively affects maize at every growth stages. But the extent of susceptibility varied remarkably at different growth stages.

Traits associated with water logging

The most prominent morphological, anatomical and metabolic changes widely observed in maize genotypes under low oxygen partial pressure in rhizosphere are-

- Development of brace root system at above ground nodes
- Root growth towards ground surface
- Development of arenchyma cells
- More root porosity
- Regulatory induction of alcohol dehydrogenase(ADH)
- Low ethanol accumulation
- High level of Super oxidise dismutase

Table 2. Most important crop stages duration and temperature for water logging in maize

Stages	Seedling, knee high, flowering, grain filling stage
Duration	➢ Within 48 hours the oxygen supply in a flooded soil is depleted. ➢ Respiration process impaired leads to mortality.
Temperature	➢ More than 25^0C during flooding even for 24 hours causes mortality.

Management of water logging

Genetic Approaches

- Selection for brace root plant type
- Cultural management
- Sowing of the seeds at the top of the bed
- Avoid heavy clay soils
- Provide proper drainage

Temperature stress

Low temperature stress

Maize is highly sensitive to frost and moderately sensitive to chilling. The extreme cool temperature affects the maize growth in a number of ways right from emergence till flowering and seed setting. Temperature below threshold level (10/4^{0}C, day/night) causes various type of irreversible physiological damage during late vegetative/early flowering stage. The severity of damage depends on temperature and its duration, developmental stage and the genotype. Early flowering with long grain filling duration and extended stay green character provided the basis for hybrid with high yield potential under low temperature stress. Low temperature stress injuries can be categorized under two heads.

- Chilling injury- Between the temperature range of 0-15^{0}C
- Freezing injury- occurs only when external temperature drops below the 0^{0}C

Major cold affected states in India

- Punjab, Haryana and West U.P are the major affected states

Consequences of low temperature stress

- Reduced germination
- Reduction in plant height
- Induces wilting
- Yellowing, discoloration of leaves (at early growth stages) and the leaves become dark brown and brittle (at later growth stages).
- Leaf tip firing due to death of leaf tissues
- Delayed anthesis and anther gets detached from tassel branches.
- Reduced tassel size/ branches
- Reduced pollen viability
- Reduced silk size and proliferation due to non fertilization.
- Crop becomes more sensitive to soil pathogen
- Cob with no or less grains

Management of low temperature stress

Cultural management

- Plant the seeds on southern side of the ridge where it gets maximum sunlight during day time. Planting of tall barrier crops in northern side of the field protects the crop from cold winds.
- Potassium application helps to protect roots from cold stress.
- Frequent irrigation is needed because it equalizes the root temperature with surrounding microclimate temperature.

Genetic approaches

- In general, full season and medium maturity single cross hybrids are more tolerant than open pollinated varieties (OPV's)/ composites.
- Selection of traits such as dark green, purple colour and erect leaves plants.
- Selection of genotypes with high density lateral roots.
- ABA induced somaclonal variants showed high accumulation of proline resulted in increased cold tolerance.

High temperature

High temperature stress is the second major abiotic stress after drought that reduces grain yield more than 15 percent. Spring season is most suitable time for the cultivation of maize in India but transitory or constantly high temperatures cause an array of morpho-anatomical, physiological and biochemical changes, which affect plant growth and development more at reproductive stage through pollen abortion, silk desiccation and reduced grain set, ultimately leading to a drastic reduction in economic yield.

A comparison of the response of male and female reproductive tissues to heat stress demonstrated that female tissues have greater tolerance. Pollen production and/or viability have been highlighted as major factors responsible for reduced fertilization under high temperatures. Pollen produced under high temperature has reduced viability. Additionally, high temperatures are responsible for reduced pollen water potential, quantity of the pollen shed and pollen tube germination.

Maize growth is affected adversely when temperature increases beyond 32^{0}C. Net photosynthesis is inhibited at leaf temperature above 38^{0}C due to thermal inactivation of enzymes. The activation state of Rubisco decreases at temperature exceeding 32.5^{0}C with nearly complete inactivation at 45^{0}C. High temperature stress and low humidity can desiccate exposed silk and pollen grain due to their thin outer membrane when these are released from anthers. The degree of damage depends on the intensity and duration of high temperature spell.

Table 3. Maize crop growth stages sensitive to high temperature stress

Crop stage	Consequences
Seedling (primordial stage)	Poor seed germination, root growth and plant vigour.
Knee high	Stunted plant height, leaf rolling, leaf firing, reduced net photosynthetic rate, LAI, total biomass and increased transpiration rate.
Flowering	Reduce pollen production, duration of pollen shedding, pollen viability, induce tassel blasting and pollen abortion, and delay silking and poor receptivity of silk.
Grain filling	Poor seed set and reduced seed size/

Crop stage	Consequences
	test weight, 25-50% reduction in yield

Consequences of high temperature stress

- Plant shows stunted growth
- Leaf rolling
- Leaf firing
- Reduced net photosynthetic rate
- Increased transpiration rate
- Tassel blasting
- Unviable pollen grains
- Silking delay and desiccation
- Poor receptivity of silk
- Pollen abortion and poor seed set

Management of high temperature stress

- Selection of early maturing single cross hybrids.
- Planting the seed in furrows.
- Creation of congenial microclimatic condition by application of water, if possible sprinkler irrigation system helps to reduce the temperature effect on plants.
- Avoid sowing at improper time, which might result in coincidence of high temperature with flowering time.
- Selection of hybrids which have shorter ASI.
- Use of organic waste, mulching helps in conserving soil moisture.
- In case of large area sowing, go for staggered sowing, this prolongs the pollen availability throughout the period.

Salinity stress

Soil salinity affects plant production in many parts of the world, particularly on irrigated land. Maize is considered as a moderately salt-sensitive plant. Salt resistant of plants is a complex phenomenon that involves biochemical and physiological process as well as morphological and developmental changes. In addition to general osmotic stress, Na^+ is toxic to maize. While, salt tolerance is a multi-genic trait that allows plant to grow under salt stress by maintaining salt balance through osmotic adjustment without reduction in yield.

Consequences of salinity stress

- Poor germination
- Yellowing of leaves
- Burning of leaf tips
- Rottening of leaves
- Plant mortality

Management of salinity stress

Sowing of the seeds on the side of the ridges, as salinity has the tendency to move in the upward direction.

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13. Enhancing eco-efficiency in the maize based cropping systems under Indo-Gangetic plains of India

Seema Sepat, S.L. Jat, Anil K. Choudhary and Ashok Kumar

Maize is known as "queen of cereals" due to its high yield potential among all the cereals. In India, production of maize is 19.33 million tons from 8.78 m ha area with an average productivity of 2414 kg/ha. The area, production and productivity of maize have increased by 3.4, 12 and 4.5 times, since 1950-51, but still the average productivity of maize in India (2.5 t/ha) is low as compared to USA (≥9.6 t/ha). Maize is the only cereal, which can be grown throughout the year. So, it fits very well in any cropping sequence. Among the major cropping systems in India, maize-wheat is the 5th most important cropping systems after rice-wheat, rice-rice, millet–wheat and rice-pulses, covering 1.80 m ha with 2.25 % contribution in Indian food basket (Table 1).

Table 1. Major cereal cropping systems in India

Cropping system	Area (m ha)	Share in cropping area (%)	Contribution in food basket (%)
Rice–Wheat	9.20	11.81	25.00
Rice–Rice	4.70	6.03	5.00
Millet–Wheat	2.44	3.13	1.72
Rice–Pulses	3.50	4.49	0.80
Maize–Wheat	1.80	-	2.25
Rice–Vegetable	1.40	1.80	-
Cotton–Wheat	1.39	1.78	2.36
Rice–Rice–Rice	0.04	0.05	-
Rice–Maize	0.53	0.68	-

(Source: Jat *et al*., 2011).

Recently, in peninsular and eastern part of India, rice-rabi maize has emerged as a potential cropping system due to less water requirement and high yield potential of rabi maize (Timsina *et al.*, 2011). In *peri*-urban interface, sweet corn/baby corn based high value horticulture based intercropping systems are also gaining importance mainly due to market driven escalating prices. Maize based cropping systems are nutrient exhaustive one. It is reported that maize-wheat cropping system depletes 122.3, 29.7 and 111.9 NPK kg/ha, respectively from the soil. Similarly, babycorn-potato-wheat depletes around 250, 67.4 and 190 NPK kg/ha, respectively. Furthermore, continuous maize cropping system without considering organics and legumes can deteriorates soil health. Many researchers found that conventional method of practices in maize based cropping system can decline soil organic carbon, resulting into low productivity in due course of time (Kumar and Shivadhar, 2010). Further, escalating input cost with low input use efficiency under conventional method of farming practices raised a question mark on sustainability of maize based cropping system. In such circumstances, eco-efficient farming can be an option, where package of practices from intensive agriculture are substituted with sustainable technologies.

Eco-efficient agriculture: concept and component

Eco-efficiency is concerned with the efficient and sustainable use of resources for crop production, and it can be enhanced by altering the crop management. Conceptually, the eco-efficiency seems to be similar with ecological intensification (Cassman, 1999; Dobermann *et al*., 2008) and conservation agriculture (CA) (Hobbs *et al*., 2008), as it encompasses ecological and economic dimensions of sustainable agriculture. But here, social, market and policy-related matters determine the extent of development of eco-efficient agriculture (Keating *et al*., 2010). At farm scale, eco-efficiency might be represented in terms such as diverse as food output per unit labor, the biodiversity benefits provided by retention of natural habitat per unit food production, or the aggregate food output per unit water or fertilizer applied (Keating *et al*., 2010). The main aim is that future production increases must come from stabilizing yields in areas, where yields are already high and increases in production in areas where yields are currently low, while promoting ecological sustainability. Practices that have been shown to increase the productivity and eco-efficiency of agriculture at the farm level includes resource-conserving technologies (RCTs) such as laser land leveling, integrated crop management (ICM) (Nguyen, 2002), and integrated crop and resource management (Ladha *et al*., 2009). These and other components of eco-efficient agriculture are discussed in more detail below.

Key components of eco-efficient agriculture in the IGP

Laser leveling and land preparation

Integrating laser leveling with other best management practices has been shown to increase productivity of maize-wheat systems by 7–19% and reduce water consumption for irrigation by 8-10% (Sharma *et al*., 2009).

Zero tillage

Zero-tillage (ZT) wheat has been the most successful technology for enhancing sustainability in rice-wheat cropping system (Erenstein and Laxmi, 2008). The prevailing ZT technology uses a tractor-drawn zero-till seed drill to sow wheat directly into unplowed fields with a single pass of tractor. This technology is also find promising in maize based cropping system also. Combining precision land leveling with ZT enhances system productivity and profitability (Erenstein, 2003). It is estimated that 20-25% of the wheat area in north-west IGP is now under zero tillage with or without crop residues. Zero tillage has the potential to provide several benefits to farmers over conventional practices of land preparation (Gupta and Seth, 2007).

Integrated plant nutrient management

Soil and soil organic matter

Soil organic matter (SOM) is a key component of soil health and acts as a repository of nutrients. Further, more than 50% of crop N is obtained from SOM. Maintenance of SOM is critical for increasing eco-efficiency in farming, especially in tropical soils. SOM levels can also be increased by applying organic materials, including crop residues, green manure, and animal manure, and biowaste, such as byproducts from food processing and city/ municipal biowastes (Singh et al., 2005).

Nitrogen sources and nitrogen use efficiency in eco-efficient farming

Efficient N use is central to eco-efficiency in agriculture (Keating *et al*., 2010). The term nitrogen use efficiency (NUE) relates only to applied fertilizer N, although crops absorb N from other sources also. Four agronomic indices are commonly used to measure NUE in crops and cropping systems: (a) partial factor productivity (PFPN), expressed as the total grain yield per unit of N applied; (b) agronomic efficiency (AEN), expressed as the increase in grain yield over control per unit of N applied; (c) apparent recovery efficiency (REN), defined as the percentage of applied N absorbed by the crop in aboveground biomass; and (d) internal or physiological efficiency (PEN), defined as the increase in grain yield over control per unit of N acquired by the crop (Novoa and Loomis, 1981). Spatial and temporal synchronization of applied N with crop demand is the key factors that can influence crop yields and REN in maize based cropping systems (Balasubramanian, 2010). Norse (2003) has shown that application of NPK kg/ha increases maize yield by 15-10% over control. Maize hybrids in general are responsive to nutrient applied either through organics or inorganic sources. The rate of nutrient application depends mainly on soil nutrient status and cropping system. Application of 10-15 t/ha FYM supplemented with inorganic fertilizer; 120-130:60:60 NPK kg/ha with 25 kg/ha ZnSO4 is generally recommended. Further, deficiency of S and micro-nutrients viz. Zn and B reduces yield f maize considerably. Therefore, 5 kg Zn or 25 kg/ha $ZnSO_4$ with 40 kg S along with 1.5 kg/ha B is recommended for deficient regions. The ideal approach for eco-efficient agriculture is INM, or optimum use of all available nutrients sources viz. BNF, crop residue, manures and mineral fertilizers. Adoption of site-specific nutrient management, and integrated plant nutrient can save 5-30% of nitrogen fertilizer and increases grain yield by 10-15% (Jat *et al*., 2013).

Water management

Growing maize on raised bed furrow system can increase 10-15% crop yield along with 25% saving of water. Similarly, other water conservation techniques, such as crop-need-based water application also increases water use efficiency.

Crop diversification

Growing short-season pulses, such as mungbean (green gram), black gram; green manure crops, such as *Sesbania*, vegetables, or other high-value crops would diversify the maize based cropping systems, improve soil quality, and increase farmers' income.

Conclusion

Through adoption of such practices, eco-efficient farming can play an important role in addressing existing and emerging problems of intensive maize based production systems in the IGP.

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14. Scope and potential of maize (*Zea mays* L.) in north-western Himalayas

Anil K. Choudhary, Vijay Pooniya, Ashok Kumar, Seema Sepat, R.S. Bana and S.L. Jat

Agricultural production is the mainstay of South-Asian agricultural economy as majority of the population depends on agriculture for employment and livelihoods. Rapidly increasing population, shrinking arable land and declining soil fertility and environmental degradation spell out an urgent need for enhancing and sustaining productivity of land through cereal food production systems. Since, agriculture is backbone of developing world economy besides their industrial development, thus, indicating a dire attention of developing countries on enhancing food production. Keeping in view above aspects, maize (*Zea mays* L.) appears to be a potential cereal crop because of its highest genetic yield potential over other cereals and its suitability to diverse climates and management practices; that's why it is known as queen of cereals. Globally, maize cultivation is done in over 170 million ha area in about 160 countries having wider diversity of soil, climate, biodiversity and management practice; and contributes to about 40% (844 million tonnes) in global food grains production.

Among leading maize growing countries *viz*. USA, China, Brazil, Mexico, Argentina, India, Canada and Indonesia; USA ranks first in production contributing nearly 35 % of the total production in the world, with highest productivity of more than 9.6 t ha^{-1} with almost double magnitude over global average (4.92 t ha^{-1}). In India, maize is the third most important food crops after rice and wheat mainly grown during *kharif* season. At global level, India ranks fourth in area and 7th in maize production (DMR, 2012). The acreage, production and productivity of maize in India are 8.7 m ha, 20.5 m t and 2.43 t ha^{-1}, respectively in 2010-11. Strategic and focused research on single cross hybrid across the country has further helped in enhancing maize production and productivity in India. Maize in India contributes nearly 9% in national food basket and more than ₹ 100 billion to agricultural GDP apart from generating employment to over 100 million man-days in agricultural and allied sectors besides industrial sector. Maize is staple food for human being and quality feed for animals in India. In Indian industry, maize serves as a raw material/ingredient to thousands of industrial products including starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc.

Maize is one of the most versatile emerging crops with wider adaptability and grown under varied agro-climatic conditions including north-western and north-eastern Himalayan regions. In India, maize is used as human food (23%), poultry feed (51%), animal feed (12 %), industrial (starch) products (12%), beverages and seed (1% each). In India, maize is cultivated throughout the year in all states of the country for various purposes including grain and fodder, green cobs, sweet corn, baby corn, pop corn in *peri-urban* areas. Predominant maize growing states collectively contributing to more than 80% of total national maize production are Andhra Pradesh (20.9%), Karnataka (16.5%), Rajasthan (9.9%), Maharashtra (9.1%), Bihar (8.9%), Uttar Pradesh (6.1%), Madhya Pradesh (5.7%) and Himachal Pradesh (4.4%).

Scope and potential

Apart from major maize growing states, maize is also grown in North-Western and North-Eastern Himalayan states. Himachal Pradesh alone account for about 4.4% of total maize production of the country. In North-Western (NW) Himalayan foothills and wet temperate region, productivity of *Kharif* maize is quite higher with the adoption of improved technology over other parts of the country. Thus, maize is an important cereal crop in Indian NW Himalayas which include Himachal Pradesh, Uttrakhand and Jammu & Kashmir . Exploration and germplasm collection programmes undertaken in past in the hilly regions comprising NW Himalayas and foothills of Himachal Pradesh have also revealed the occurrence of a rich landrace maize diversity (Chandel and Bhat, 1989). Thus, maize crop diversity and favourable agro-climatic conditions for *Kharif* maize cultivation in NW Himalayas emphasize that there is a lot of scope for its cultivation in these hilly areas.

Favourable agro-climatic conditions for maize cultivation in North West Himalayas

Productivity of maize in Indian sub-continent is affected by the distribution of crop seasonal rainfall received from sowing to harvest, and soil fertility, apart from applied fertilizer nutrients. Research studies have shown that among different variables, the quantity of rainfall received during crop growing period significantly influence the response of a crop to fertilizer application under rainfed conditions (Choudhary, 2011). In sub-humid foothill region of NW Himalayas, most of the water used to grow maize crop is derived from ample rainfall received during monsoon. In this region, higher rain water use efficiency along with high production efficiency in maize crop lead to its higher productivity. Low atmospheric temperature during maize reproductive stage in these areas prolong maturity period which enhances photosynthetic harvest potential of maize besides reducing respiration losses to some extent. That's why the maize productivity is quite high in these hilly areas.

Area and production

In North-Western Himalayas, highest acreage and production of maize is found in Shivalik Himalayas and NW Himalayan foothills (Tables 1, 2 & 3). In Himachal Pradesh, highest area and production of maize is found in Mandi district followed by Kangra, Hamirpur, Chamba and Bilaspur, respectively (Table 1). Among, three NW Himalayan states, Himachal Pradesh account for about 4.4% of total maize production of the country Himachal

Pradesh has made a remarkable progress in the maize production during last 6 decades, sowing to favourable agro-climatic conditions, sufficient rainfall during *Kharif* season, adoption of improved technology besides great production potential of maize in the state especially in Himalayan foothills to wet temperate region of the state.

Table 1. District wise maize acreage, production and their contribution to state maize acreage and production trend during 2008–09 in Himachal Pradesh.

District name	Area (ha)	Production (Tonnes)	% of state Area	% of state Production
Bilaspur	26315	50879	8.84	7.52
Chamba	28389	73987	9.54	10.93
Hamirpur	31704	58220	10.65	8.60
Kangra	58455	107230	19.63	15.85
Kinnaur	247	561	0.08	0.08
Kulu	16683	44965	5.60	6.65
Mandi	48346	134051	16.24	19.81
Shimla	11468	24821	3.85	3.67
Sirmaur	22188	60676	7.45	8.97
Solan	22733	54760	7.64	8.09
Una	31168	66444	10.47	9.82
Lahaul & Spiti	22	50	0.01	0.01
Total	297718	676644	-	-

(Source: http://www.dacnet.nic.in)

Thus, there is a tremendous scope and potential of Maize in Himachal Pradesh. In Himachal Pradesh, Shivalik and Himalayan foothill region constitute main conventional maize production areas covering Mandi, Kangra, Hamirpur, Chamba, Bilaspur, Kullu, Solan and Sirmour districts . However, recent studies have revealed that wet temperate region of the state also have ample scope for maize area expansion which would harness higher maize yields.

In Jammu & Kashmir, highest maize area and production is registered in Rajouri district followed by Udhampur, Doda, Kupwara and Poonch, respectively (Table 2).

Table 2. District wise maize acreage, production and their contribution to state maize acreage and production during 2007–08 in Jammu & Kashmir.

District	Area (ha)	Production (Tonnes)	% of state maize area covered	% production contribution
Anantnagh	12566	18940	5.42	5.03
Pulwanna	5509	5050	2.38	1.34
Srinagar	116	130	0.05	0.03
Budgam	12012	10590	5.18	2.81
Baramulla	22199	21020	9.57	5.59
Kupwara	24730	23064	10.67	6.13
Kargil	4	10	0.00	0.00
Udhampur	36188	65540	15.61	17.42
Jammu	11275	17560	4.86	4.67
Kathua	21305	44170	9.19	11.74
Doda	25281	28850	10.90	7.67
Poonch	23712	42520	10.23	11.30
Rajouri	36967	98860	15.94	26.27
Sub-Total	**231864**	**376304**		

(Source: http://www.dacnet.nic.in)

In Uttaranchal, maize acreage is meager with highest area and production in Dehradun district only which adjoins Himachal Pradesh (Table 3). Again, current discussion encompass upon a lot of scope for raising the productivity of maize in Jammu & Kashmir. Contrary to that, sincere efforts of state extension functionaries are also needed in Uttaranchal for maize area expansion in the state. Thus, there are ample opportunities for raising maize production in NW Himalayas which can play vital role in national maize statistics.

Table 3. District wise maize acreage, production and their contribution to state maize acreage and production during 2009–10 in Uttaranchal.

District name	Area (ha)	Production (Tonnes)	% of state maize area covered	% production contribution
Almora	1924	1924	7.35	5.32
Bageshwar	376	512	1.44	1.41
Chamoli	205	132	0.78	0.36
Champawat	505	485	1.93	1.34
Dehardun	10325	16427	39.46	45.39
Haridwar	1034	2079	3.95	5.74
Nainital	4487	7249	17.15	20.03
Pauri Garhwal	2093	1781	8.00	4.92
Pithoragarh	2635	2767	10.07	7.65
Rudraprayag	200	240	0.76	0.66
Tehri Garwal	1851	1897	7.07	5.24
US Nagar	102	161	0.39	0.44
Uttarkashi	429	537	1.64	1.48
Sub-Total	**26166**	**36191**		

(Source: http://www.dacnet.nic.in)

Maize area, production and yield trends in North West Himalayas

During last one decade, maize area in Jammu & Kashmir and Uttaranchal has shown some decline. However, maize area in Himachal Pradesh has shown static trend. On the other hand, maize production in Himachal Pradesh and Jammu & Kashmir has exhibited variation owing to monsoon variability. While in Uttaranchal, there is constant production trend . Overall, Himachal Pradesh is the leading state in terms of production and maize productivity in NW Himalayas followed by Jammu & Kashmir during last one decade , in spite of the fact that Jammu & Kashmir has highest maize acreage in the region.

Production gaps in maize cultivation in NW Himalayas

A study conducted by Yadav *et al*. (2012) have revealed that there are highest production gaps in NW Himalayas in crop management practices such as sowing methods, improved varieties, seed treatment, method of basal dose application, chemical weed control and pest management. This study also indicated partial gap in seed rate and dose of fertilizer application. Overall, 50–55 % yield gap was observed in maize due to non-adoption of recommended technologies. The reason for non adoption of recommended technologies might be due to lack of awareness and less exposure to information sources (Choudhary, 2013). Timely non-availability of critical inputs might be other possible reason for non-adoption of recommended farm technologies (Choudhary *et. al*., 2009). Overall, poor access to HYVs'/hybrids in remote hilly terrains coupled with poor knowledge about production practices are the main reasons for high extension gaps (Table 4); and low productivity of maize in the region. Therefore, extension agencies in this NW Himalayan region should make focus on skill development of farmers and input supply system strengthening.

Scope for yield enhancement in maize crop using improved farm technology in NW Himalayas

Maize is one of the most important cereal crops in NW Himalayan agricultural economy both as food for man and feed for animals. Although, maize productivity in NW Himalayas is quite good; but still there is a scope to increase its yield to desired level, which may be achieved by the adoption of recommended farm technologies (Choudhary, 2011). Maize productivity per unit area could be increased by adopting recommended farm practices using HYVs'. For adoption of improved farm technology, frontline demonstrations (FLD's) are one of the most powerful extension tools in communication of new methods and techniques in agricultural development as it helps to motivate the farmers faster than any other method through the process of observing, hearing, learning by doing and experiencing things (Choudhary *et al*., 2013; Choudhary, 2013). These demonstrations play significant role in improving farmers' skill to perform an activity by their involvement particularly in remote hilly areas where majority of farmers are resource poor, ignorant and less educated. The main objective of conducting FLDs' is to convince the farmers and grass root extension personnel about potentialities of demonstrated technologies for further adoption and diffusion at large scale among farming community (Choudhary, 2013). Directorate of Maize Research (ICAR), New Delhi has made a remarkable progress in this direction in collaboration with ICAR network, SAUs' and KVK network in the whole country though extensive maize FLD programme. A case study of frontline demonstrations on maize in Mandi district of Himachal Pradesh in NW Himalayas has revealed that by the use of improved technology, maize productivity can be raised by 18.6 to 33.5% over farmers practices using hybrids/HYVs'; improved farm technology and recommended farm inputs. Economic analysis also revealed that use of improved production technology can enhance maize profitability and economic viability substantially over farmers' practice (Table 4).

Table 4. Case study of frontline demonstrations on maize in Mandi district of Himachal Pradesh (Source: Annual Report, 2010-11, KVK-Sundernagar).

Variety/ Hybrid	Area (ha)	Farmers	Yield (kg/ha)		% YIOFP*	Extension gap (kg/ha)	Net returns (Rs/ha)		Additional returns (Rs./ha)	IBCR*
			DP*	FP*			DP	FP		
Proagro - 4642	2.1	19	3545	2800	26.61	745	13795	5200	8595	1.58
Double Dekalb	4.2	35	3739	2800	33.54	939	15929	5200	10729	1.79
Proagro - 4640	2.1	15	3321	2800	18.61	521	11331	5200	6131	1.16

DP – Demonstration plot; FP – Farmers' plot; YIOFP – Yield increase over farmers' practice; IBCR – Incremental benefit cost ratio.

Another study at KVK Sundernagar (HP) have observed an average maize yield of 36.2 q ha^{-1} in FLDs' conducted during 2006-2011, which is quite higher over district (28.2 q ha^{-1}) and state averages (25.5 q ha^{-1}). With the transfer of technology under FLD's on maize, grain yield in FLD plots was considerably higher than the farmers' plot yields; which may be attributed to adoption of recommended technologies in FLD's (Choudhary, 2013). From this study, it is concluded that there is a wide gap between the demonstration yields and farmers' plot yields in maize production technology. From these results, it can be summarized that adoption of demonstrated farm technology coupled with better crop management practices in maize can enhance maize productivity and profitability even under rainfed farming situations. Thus, hill farmers must be motivated for adoption of improved agro-technologies to enhance maize production in the region in coming years. Overall, there is a dire need to aware and educate the farmers through trainings and demonstrations for adoption of improved technology besides timely access to critical inputs to abridge the yield gaps and tap the production potential of maize cultivars in the favourable agro-climatic conditions of this NW Himalayan region of the country

Conclusions

Indian agriculture has benefited from innovative frontline research in maize during past five decades especially with development of HYVs'/hybrids. Expansion in irrigation infrastructure, access to productive technologies, extension efforts and market access has further fueled maize production. But, projected maize demand will be further met either by technological interventions or by bringing more area under maize cultivation. In order to explore the opportunities for maize area expansion, NW Himalayan region encompasses great scope and production potential. Maize is an important cereal crop in Indian NW Himalayas especially Himachal Pradesh, and Jammu and Kashmir. Himachal Pradesh alone account for about 4.4% of total maize production of the country. In NW Himalayan foothills and wet temperate region, productivity of *kharif* maize is quite higher with adoption of improved technology. Favourable agro-climatic conditions for *kharif* maize cultivation in NW Himalayas emphasize a great scope and potential in these hilly areas. Thus, we have to focus on frontier technology development, its transfer and adoption in these newly emerging areas for poverty and hunger reduction and regional food security by boosting maize productivity and incomes for resource poor in NW Himalayas and to feed teeming millions in our country.

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15. Fodder preservation for dairying

D. P. Chaudhary, Sapna and Ramesh Kumar

Livestock production is backbone of Indian agriculture, contributing 4% to national GDP and source of employment and ultimate livelihood for 70% population in rural areas. Contribution of livestock to agriculture sector GDP has been steadily increasing. The demand for livestock products has shown an increasing trend, which is driven by sustained economic growth, rising incomes and urbanization. Urbanization has brought a marked shift in the lifestyle of people in feeding habits towards milk products, meat and eggs with resultant increase in the demand for livestock products. To meet out the needs of the ever increasing livestock population, production as well productivity of fodder is to be increased. However, increasing cultivation of cereal and cash crops has, in fact, contributed towards a decline in the area under fodder crops. Therefore, there is a tremendous pressure of livestock on the available total feed and fodder, as land available for fodder production has been decreasing. At present, the country faces a net deficit of 35.6% green fodder, 10.95% dry crop residues and 44% concentrate feed ingredients. At the current level of growth in forage resources, there will be 18.4% deficit in green fodder and 13.2% deficit in dry fodder in the year 2050. To meet out the deficit, green forage supply has to grow at 1.69% annually. Therefore, to meet the current level of livestock production and its annual growth in population, the deficit in all components of fodder, dry crop residues and feed has to be met from either increasing productivity, utilizing untapped feed resources, increasing land area (not possible due to human pressure for food crops) or through imports. Adopting the alternative approaches is therefore seems to be the best fit approach to meet the fodder requirements.

Dry roughage is vastly used as fodder throughout the country. Almost all the wheat straw produced in Punjab and Haryana is utilized as animal fodder in the drier regions of the country such as Rajasthan, Madhya Pradesh, some pockets of Haryana and Chhattisgarh etc. A significant segment of paddy straw is also utilized as animal fodder particularly in the middle as well in the southern states of India. However, the nutritional quality of roughages is very poor. Although wheat straw provides cellulosic carbohydrates and could be utilized as quality fodder in combination with green forages as well as concentrates, but practice of using rice straw as fodder is totally unrealistic as nothing nutritious comes out of it. Moreover, it may contain deleterious amounts of selenium which usually causes life threatening toxicity to animals. This is the main hindrance behind poor productivity of Indian cattle (1000 kg) as compared to the average milk yield of cattle in the world and Europe which is about 2040 kg and 4250 kg per lactation, respectively. Although the genetic potential contributes significantly towards higher milk production but it can be realized only if the animals are fed well with quality fodder.

Green forages are rich and cheapest source of carbohydrates, protein, vitamins and minerals for dairy animals. The importance of forages in our country is well recognized since feeding forages alone accounts for over 60% of the cost of milk production. Hence by providing sufficient quantities of fodder instead of costly concentrates and feeds to the milch animals, the cost of milk production can considerably be reduced. Forages are rich source of protein, vitamins, minerals, carbohydrates, etc. These nutrients are essential for growth, maintenance, reproduction and milk production of the animals. Moreover, the nutrients from the fodders are easily digestible as compared to concentrates. For optimum milk production, an adult animal required at least 40-50 kg nutritious green fodder per day throughout the year.

Maize as fodder

Maize crop has an important place in the food grain basket of our country and is the third most important food grain crop due to its importance in food, feed and fodder. The last few years have seen dramatic improvements in the production and productivity of maize. The adoption of single cross maize hybrids has revolutionized the maize production. Consequently, maize has registered highest growth rate of 6.4 per cent (2007-2010), the highest among all other food crops, surpassing the 4 per cent growth rate for agriculture in general and 4.7 per cent for maize in particular as the target set by Planning Commission. Considering changing climatic scenario and impact of single cross maize hybrid, it is estimated that production and productivity of maize is going to rise further. With the growing demand of poultry feed, the demand for maize is also going up in the country. Some estimates indicate that India may have to produce 55 million tons of maize to meet its requirement for human consumption, poultry, piggery, pharma industry feed and fodder by 2030.

Maize is an excellent crop in terms of biomass production. Since the production as well as productivity of maize is increasing in our country, the availability of biomass from maize is also increasing by the same magnitude. Maize straw is used as animal fodder since ancient times. However, the fodder quality of green maize is far excellent. Amongst the non-legume cultivated fodders e.g. pearl millet and sorghum, maize provides best nutritional quality along with good quantity of biomass. Both sorghum as well as pearl millet possesses anti-quality components which are deleterious to animal health. Crude protein and in-vitro dry matter digestibility (IVDMD) are two important nutritional quality parameters governing fodder quality. Both crude protein as well IVDMD are highest in maize compared to its competitive fodder**.** The biomass production of maize is also equivalent to sorghum and pearl millet. Pearl millet is a hardy crop and cultivated in the dryer regions of the country, whereas, sorghum, though cultivated throughout the country, contains the most toxic anti-quality component called prussic acid (HCN). The toxicity of HCN is so severe that the animal dies within minutes after consuming young sorghum crop. The maize on the other hand is almost free from any anti-quality components. Moreover, baby corn stalks are highly nutritious and its nutritional quality is at par to fodder maize variety (J-1006).

Preservation processes

For economical and successful dairy farming round the year fodder supply is a primary requirement. An acute shortage of green fodder is routinely observed twice a year particularly during the months of Nov-Dec and May-June, called the lean periods. During this period animals are fed with straw or stover along with the costly concentrates to fulfill their daily dietary requirements. The straws or stover are usually deficient in some vital nutrients and hence reduce the milk production potential of the cattle, whereas feeding concentrates alone is economically not viable. Therefore, it is important to conserve forages to be used during lean periods. It is needed to maintain milk production during dry months as well as to put the cattle into good condition so that it will conceive within required time frame.

Silage

Silage is the product from a series of processes by which green forage of high moisture content is fermented to produce a stable feed which resists further breakdown in anaerobic storage. The objective is to retain or augment the nutrients present in the original forage and deliver silage accepted by livestock; this is usually attained through an anaerobic fermentation dominated by lactic acid bacteria. Maize is the most suitable crop for silage making as it possesses the required quantities of soluble carbohydrates required for proper ensiling.

The method of silage making is very simple:

- A pit is to be dug up in the farm at some elevated place.
- Size of the pit depends upon the availability of fodder. One cubic meter pit can accommodate about 5-6 quintals of green fodder.
- The walls of the pit should be slanting with narrow base and broad opening.
- Plaster the walls of the pit with cow dung. The farmers may also prepare a *pucca* silo pit. Cover the plastered pit with polythene. The base of the pit should be covered by straw so that the excess moisture or juice, if present could be absorbed efficiently.
- Now chaff the crop into 5-8 cm pieces and start filling the pit.
- Spread the chaffed fodder up to a height of 1 foot and then press it manually or by using a tractor. The process should be repeated till the pit is filled completely. The major precaution during filling the pit is to exclude as much air as possible by pressing the chaffed fodder.
- By doing so, keep on adding the material till the heap is around one meter above the ground level.
- Finally add some material in the central portion of the heap and then press it.
- Now cover the heap with a polythene sheet. Seal the edges of the sheet by cow dung. Spread about 10-15 cm layer of straw on the sheet followed by 5-7 cm layer of earth. It should then be plastered with a layer of clay or cow dung.
- Any cracks in the cover, which develops subsequently, should immediately be plugged as to avoid entry of air or water into the pit.
- Prepared in this way, the silage is ready for feeding after 35-40 days of sealing the pit.
- Properly prepared silage is recognized from its colour and smell:
- The color of the well-fermented silage is bright light green or dull yellow.
- Properly fermented silage smells like vinegar whereas foul smell is characteristic of poorly fermented silage.

The poorly fermented silage should not be fed to the animals and should be discarded. Properly prepared silage can be preserved for a long period. The properly covered silage could be stored for as long as 10-12 years or so. Once opened, it should be used regularly, and should be consumed within 2-3 months.

To feed the silage opens the pit from one side after removing the earth and straw. Each time, a uniform layer of silage is removed vertically (from top to bottom) as per the requirement. Do not open the whole pit at once. After removing the silage cover the opened side immediately. The top portion may have some mouldy silage which should be discarded. The animals may take some time (3-4 days) to adapt to the silage feeding, therefore start feeding 5-7 kg of silage along with some other fodder for the initial period.

Advantages of silage

Silage acts as a fodder bank which ones made could be used round the year. There are numerous advantages of silage making. Some of these are listed below:

- Silage is used during the scarcity of green forages called lean periods.

- Provides round the year supply of nutritious fodder.
- Silage is as nutritious as green fodders as it preserves the nutrients in their original form, therefore, the animal receives the nutritious fodder throughout the year.
- Could help in reducing green fodder deficit of the country.
- The labor cost in dairy farming is significantly reduced by using only silage as animal food as 4-5 persons can easily manage a flock of 40-50 cattle heads. It is pertinent that maximum labour is consumed in harvesting the green forages.
- The entire crop is harvested in a single step for making silage as is the case with baby corn and sweet corn. Baby corn as well as sweet corn stalks is the best fit fodder for silage making as the entire field is harvested in one go. One time harvesting is beneficial in many ways since we can harvest the crop at the appropriate time and at the same time the field became available for the timely sowing of the next crop.
- Palatability increases as hard stems when fermented into silage become soft and better utilized by the dairy animals.
- Green forages may possess some anti-nutritional components e.g. HCN in sorghum, oxalate in pearl millet and sometimes nitrate in maize. The anti-quality components are either destroyed or lowered during silage fermentation, for example nitrates, if present, were reported to be lowered in silage as compared to the green forages. HCN is almost destroyed whereas; oxalates were also reported to be reduced to half of its original value by fermentation. During silage fermentation the stem of the crop became soft, which helps in easy digestion by animals.
- Lastly the seeds of the most common weeds are destroyed during silage fermentation thereby reducing the problem of dispersal of these seeds with cow dung as farm yard manure.

Therefore, silage could play a significant role in reducing the green fodder shortage of the country and at the same time could help in expanding the dairy sector particularly in the peri-urban regions of the country.

Maize stover

Maize stover consists of the residue: stalk; the leaf, husk, and cob remaining in the field following the harvest of cereal grain. It makes up about half of the yield of a crop. Maize stover is a very common agricultural product in areas having large acreage under maize cultivation. The stover can also contain other weeds and grasses, the non-grain part of harvested corn and has low water content and is very bulky. Stover is widely used as the major source of animal feed in our country particularly in the regions having plenty of maize production. As a result of increasing production, the maize stover is available in plenty. Maize stover amounts would range from 3 to 4 tons per acre. The ratio of corn stover to grain is typically assumed to be 1:1; thus, there is 40 quintals of maize stover produced for every 40 quintals of grain harvested. Thus, stover production estimates are typically based on grain harvest figures (this assumes 12-15 per cent moisture). In our country the current technology of maize harvest is suitable for the 100% availability of stover. Unlike in wheat, where combine harvest is unsuitable for the harvest of straw and most of the straw is burnt in the fields, maize is harvested manually and the stover is collected for animal feeding which is used during scarcity of green fodder. During scarcity period wheat straw as well maize stover is the principle sources of fodder. Due to scarcity of fodder stover is often sold at exorbitant rates ranging from ₹1-5 per kg. It is often transported from maize growing areas to dryer regions of the country and there exists a good business as stover market is flourishing every year. Maize stover can successfully be incorporated in ruminant rations and such rations have relatively high digestibility. However, the nutritional quality of maize stover is poor. It is made up of cellulose, hemicelluloses, lignin etc. Cellulose is almost completely digestible by ruminants as they contain the enzyme cellulase responsible for cellulose breakdown. Hemicellulose is considered partially digestible, whereas lignin which constitute around 15–25% of total feedstock dry matter, cannot be digested by ruminants and, therefore, is termed as indigestible fodder component. More the amount of lignin present in the stover more will be the fodder considered unfit for utilization as animal fodder. Ash (3–10% of total feedstock dry matter) is the residue remaining after ignition of herbaceous biomass. It is composed of minerals such as silicon, aluminum, calcium, magnesium, potassium, and sodium. Other compounds present in lignocelluloses feed stocks are known as extractives. These include resins, fats and fatty acids, phenolics, phytosterols, salts, minerals, and other compounds. In general corn stover is about 38% cellulose, 26% hemicelluloses, and 19% lignin. Maize stover, therefore, contains low levels of crude protein and high levels of indigestible carbohydrates such as lignin. Compared to wheat straw, maize stover contain more protein, but higher lignin content. This is perhaps the reason why wheat straw is considered more popular as animal fodder compared to maize stover. Therefore, it is apparent that the nutritional quality of maize stover is poor and to maintain the health and to increase the milk production potential of milch animals, maize Stover should be fed along with the concentrate. The concentrates will provide the required concentration of protein as well as other nutrients. However, the concentrates are costlier and economically not viable for poor and marginal farmer**.** In this scenario the urea treatment of stover is a simpler and effective technique to enrich the nutritionally quality of easily available maize stover.

Urea treatment of maize stover

Urea treatment of maize stover is an easy and effective method used since long for enrichment of nutritional quality of dry roughages (Table 1). The method is simple and easy to conduct. The chronological events are listed as:

- The stover is chopped to small pieces measuring 5-7 cm in size
- The chaffed fodder is collected in a heap
- Dissolve 3.5 kg urea in a 50-60 kg of water. It may carried out a big size *tub* easily available in dairy farms
- Spray the urea solution uniformly over one quintal of chaffed stover. Simply, the solution may be pored over the fodder and then the fodder to be mixed thoroughly
- Store the mixed stover in a closed room or the form of a *kup*
- Exactly 10 days after storage the treated stover is ready for feeding to the cattle

Before feeding, the stover is spread on ground for some time to allow the gas to escape. The stover is now ready to be used as fodder. Urea treatment is a well-demonstrated method of improving the nutritive value of low quality stover, by the effect of ammonia ion on the cell wall. The ammonia ion swells and hydrolyses the cell wall carbohydrates and phenolic monomer. The final effect is an increase of the digestibilities of dry matter (DM) and cell wall, of the nitrogen content and of dry matter intake. The effect of the urea treatment on the nutritive value of roughage is the result of two processes which occur within the treated forage: (i) ureolysis which turns urea into ammonia through enzymatic reaction that requires the presence of the urease enzyme; and (ii) the effect of ammonia on the cell walls on the forage. Several factor such as urea doses, moisture, temperature, affect the effectiveness of urea treatment.

Nutrient content of urea treated maize stover

The nutritional quality of urea treated maize stover is drastically enhanced compared to normal stover (Yirga *et al*., 2011). A significant increase was observed in crude protein content. The increased microbial biomass in the treated stover may contribute significantly towards higher crude protein concentration. The neutral detergent fiber (NDF) showed a significant reduction in the urea treated maize stover. NDF is an important parameter which is directly related to dry matter intake by the animals. A fall in NDF therefore showed that animal intake of the treated stover is higher compared to normal stover.

Table 1. Comparative chemical composition of urea treated maize stover

Variables	Untreated maize stover	Urea treated maize stover
Dry matter (%)	91.5	95.6
Crude protein (%)	5.83	7.67
Neutral detergent fiber (%)	86.8	73.9

(Source: Yirga *et al*., 2011)

Thus it could be concluded that maize is an excellent crop which could effectively be utilized as a feed and fodder crop. Specialty corn is going to play an important role in the socio economic perspective of the rural folk. Baby corn and sweet corn cultivation will substantially add up to the income of the farmers as specialty corn is sold at reasonably good price in the market, where the green fodder will boost the dairy industry. The silage making is breakthrough technology which could provide a quantum boost to the dairy sector. And lastly the urea treatment of maize stover is a simple technique much suitable for small and marginal farmers, whereby then can easily enhance the milk production potential of their cattle.

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16. Conservation agriculture for higher resource-use efficiency in maize based production systems

C.M. Parihar, S.L. Jat, A.K. Singh, Bhupender Kumar, Chikkappa G. Karjagi, Ashok Kumar, Somya Sharma and Bahadur Singh

Indian agriculture is turning in a new phase through various technological advancements and developments. The scientific and technological innovations have been the basis for promoting agricultural research and development. The historical research focus on improved agricultural technologies has been incontestably successful. While during 'Green revolution' period, the major research and developmental efforts was focused on enhancing the production and productivity of selected food grains. This conventional mode of agriculture through intensive agricultural practices leads to increasing scarcity of resources (labour, water, and energy) and cost of production along with climate variability. These are major challenges for the present agricultural sustainability of the country. The traditional practices of intensive agriculture were successful in achieving the goals of crop production, simultaneously, leads to decline in natural resources bases for future generation. However, the recently developed new technologies focused on efficient resource-use and resource conservation which should receive high priority to ensure the past gains that can be sustained and further enhanced to meet the emerging needs. The upcoming issues of resource conservation have assumed importance in view of widespread degradation of future generation natural resources.

The growing concerns of sustainable agricultural production have been seen as a positive response to balance between low-input traditional agriculture and intensive modern agricultural practices. It will also help in maintaining the ecological equilibrium and encourage natural regenerative processes such as soil regeneration, nitrogen fixation, nutrient cycling and to provide safeguard for natural enemies of harmful pests and diseases as well as the targeted use of inputs. Modern crop production systems and technologies should rely on such approaches which may not only able to support high productivity requirement for burgeoning population, but also preserve biodiversity and protect the environment. Because of these emerging constraints there is an urgent need to reduce production costs, increase profitability, and make agriculture more competitive and sustainable.

Predominant maize-based production systems in India

The current production system is posing a threat to food security and livelihood of farmers, especially to poor and under-privileged farmers; not only in India or region but globally. Maize due to its versatile nature grown in sequence or as companion crop with various crops under different production systems in wide range of ecologies, seasons and regions of the country. Though, its horizontal spread in diverse maize systems primarily depends on land topography, soil type, availability of moisture and markets. However, presently maize-wheat is predominant maize based system with coverage of 1.80 m ha area, contributes ~3.0 % in national food basket. In India, the other foremost maize systems are maize-fallow, maize-mustard, maize-chickpea, maize-maize, maize-potato, etc (Jat et al, 2013).

In recent years, the upcoming challenges of water shortages, temperature stresses in rice primarily in rice systems and to some extent in wheat systems, opportunities of higher productivity of maize under these limited environmental conditions as well as market opportunities for maize have led to introduction of several maize systems in non-traditional maize ecologies.

Rice-maize (~0.5 m ha), has emerged as a potential maize system replacing winter rice in double rice (rice-rice) system of peninsular India and wheat in terminal heat prone shorter wheat season ecologies of India, respectively. Under such situation, the conservation agriculture based resource conserving technologies (RCTs) are serving as potential drivers with high yielding maize hybrids for realizing the potential benefits of intensive rice systems. The conservation agriculture based RCTs has also emerged a major way forward to achieve the goals of sustained agricultural production in new paradigm. But, these strategies had limited impacts on the intended beneficiaries, as the complexity of their livelihood and farming systems has not been taken into consideration.

Conservation agriculture based practices in maize production systems

In recent years, maize had emerged as a potential alternative crop in non-traditional ecologies and seasons which is grown under different cropping systems and practices of crop management. A large information gap on appropriate tillage management practices for maize in different cropping systems exists. The traditional production practices of these crops has several limitations such as inadequate input management, improper plant geometry and plant population due to broadcasting, resulting in inefficient utilization of resources leading to low productivity and input-use efficiency. Under such production scenarios of sole maize and its systems, the better crop management practices are still not well developed to realize the sustainable/higher benefit of these alternative maize based cropping systems. Contrary to the common thought and notion, now a day it is believed that tillage can be dispensed without affecting crop yield. Intensive time-honoured tillage practices results to a decrease in soil organic matter and biodiversity. Tillage management practices contribute significantly in production cost particularly in labour and energy which resulting to lower monetary returns. In certain condition/ situation of particular agro-ecologies, the time-honoured tillage operations may cause delay in sowing and increase the cost of cultivation/production. Conservation agriculture based tillage management systems (zero/minimum tillage, permanent bed planting, etc.) are very effective means in reducing the losses of water from the soil and improving soil moisture regime. Many researchers reported the advantages of conservation tillage based management practices over conventional tillage on water productivity and use efficiency due to soil water retention properties. Soil pore size, shape, distribution, infiltration and soil structure are affected by tillage practices which influences soil water storage and transmission. Conservation agriculture based tillage management systems are getting more emphasis in recent years due to the rising concern of natural resources degradation. Traditional, exhaustive tillage management systems resulted in increased soil compaction and decreased soil organic matter and biodiversity. The repeated tillage practices caused sub-soil compaction which reduces water and nutrient use. Therefore, conservation agriculture in its version of RCTs viz., zero/ minimum tillage, permanent beds, etc. may offset the cost of production and other land preparation related constraints.

Resource conserving technologies (RCTs) in maize systems

The terms 'Resource conserving techniques' and 'Conservation agriculture' are used simultaneously and as if their meaning are similar. In general, the RCTs refer to those practices which will sustain or enhance the natural resources as well as input-use efficiency. The zero tillage and permanent bed practices that save fuel, water and improve water productivity at field level and are considered as RCTs. There are so many other practices in intensive farming systems which save water, nutrients, herbicides, energy, etc.

After more than 35 years of green revolution the Indian agriculture is entering in a new era to overcome the shortfalls of green revolution. The shortfalls of green revolution era mainly occurred because during this period the major research and developmental efforts were focused on enhancing the production and productivity of selected food grains and other crops, the new technologies demand the issues of efficient resource use and resource conservation which receive high priority to ensure that past gains can be sustained and further enhanced to meet the emerging needs. The resource conservation related issues have assumed importance in view of the widespread resource degradation and the need to reduce the agricultural production costs, increase farm profitability, and make agriculture more competitive and beneficial.

Summary of conservation agriculture research findings

Adopting conservation agriculture techniques is a holistic approach for management of soil and water resources, and improving efficiency and productivity per unit of land area. The compilation of different CA based RCTs studies in IGP shows that these practices help in introduction of new cultivars in system and are more efficient in inputs, improve production and profitability, and address the emerging problems (Saharawat *et al*., 2009). Ghosh *et al*., (2010) reported that due to higher microbial biomass carbon, dehydrogenase activity and earthworm population in CA practices (residue retention and double no-till) there was good growth of crops like rice, wheat, mustard and linseed, and yield increased by 44% to 63% over conventional tillage. Mishra and Singh (2012) reported that the continuous ZT resulted in significantly higher yield of rice-wheat system compared to continuous conventional tillage. Mishra and Singh (2012) observed that the intensive tilled conventional RW systems require maximum energy (38,187 MJ ha^{-1}), due to intensive field preparations. While, CA based ZT systems requires least energy have higher energy output: input ratio as well as higher system productivity. Several studies were conducted across the India and have projected weeds as the major constraints in adoption of CA technologies. Studies have suggested a small difference in weed populations between conventional and ZT fields, and in some cases, fewer weeds have been observed in ZT conditions (Hobbs and Gupta, 2003). Duxbury *et al*., (2000) estimated that agriculture contributes 25% of the historical human-made emissions of CO_2 during the past two centuries. However, a significant portion of this C can be stored or sequestered by soils managed with no-tillage and other low-soil disturbance techniques. Improved tillage management techniques have shown that scientific agriculture can also be a solution to environmental issues in general, and specifically to mitigating the greenhouse effect (Lal *et al*., 2007). In the long-term adoption of CA practices, enhanced C sequestration and build-up in SOM, constitute a practical strategy to mitigate GHG emissions and imparting greater resilience to production systems to climate change related aberrations. Saharawat *et al.,* (2012) showed that different CA based resource conserving practices in rice-wheat system has pronounced effects on the global warming potential by reducing the GHG emission and sequestering carbon.

Success story of conservation agriculture in India

Maize hybrids are more input responsive, vigorous and can establish well under conservation agriculture based resource conserving technologies. These RCTs are advancing the sowing time, saving water, fuel, reducing cost of cultivation, improves farm profitability and environment friendly. Also provides options to enhance the soil organic matter, improved soil health, and reduce soil erosion, etc. Conservation agriculture based zero-till technology in rice follow hybrid maize becomes a success story in the country. In Andhra Pradesh zero-till corn production technology is covering more than two lakh hectare area and is increasing with very faster rate. Zero-tillage along with SCH maize brought a revolution in Andhra Pradesh and its area is gradually spreading in other southern states of the country i.e. Tamil Nadu, Karnataka and other states. Under current scenario the maize productivity in zero till SCH cultivation belt is close to 9 tonnes/ha (Jat et al 2009).

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17. Qualitative dynamics of maize for enhanced livelihood security

Sapna, D.P. Chaudhary and Pallavi Srivastava

Maize, an important crop among cereals, is cultivated in more than 160 countries under different agro-climatic conditions and has wider adaptability and acceptability. In India, it ranks third after wheat and rice. Earlier, as a food crop, it is mainly used as feed and as industrial raw material. It is the crop with largest number of products across the world and due to its varied types it is being used in different purposes in the food chain. Maize has many advantages over other cereals, due to its worldwide distribution and relatively lower price. In India, Maize occupies a prominent position and each part of its plant is put to one or the other use and nothing goes as waste and therefore known as "Queen of cereals". Even after harvest of the grain, the remaining dried leaves and upper plant parts including the flowers are used as forage for ruminants. As variation in production and productivity exist in utilization pattern between developed and developing countries. It gives highest average grain yield as compared to major cereals such as wheat and rice. Maize enjoys the status of the highest yield among world's major crops of its own nature *viz.* efficient utilization of radiant energy and fixations of carbon dioxide from the atmosphere being a C_4 plant. Even when compared with other crops the economics of maize cultivation remains the lowest.

Table 1. Weight distribution of main parts of the kernel

Structure	Percent weight distribution
Pericarp	5-6
Aleurone	2-3
Endosperm	80-85
Germ	10-12

(Source: Maize in Human Nutrition, FAO, Rome, 1992)

Maize (*Zea mays*) belongs to the grass family (*Gramineae*) with a long, tall annual plant, extensive fibrous root system and cross pollinating species, with the female (ear) and male (tassel) flowers in separate places on the same plant i.e. monocious. The kernels are mainly white or yellow in colour but black, red, blue and mixed colours are also there. There is a huge variability in number of grain types, distinguished by differences in the chemical compounds deposited or stored in the kernel. The maize kernel is known as a caryopsis botanically; means a single grain contains the seed coat and the seed. The four major physical structures of the kernel are pericarp, hull or bran, germ or embryo, endosperm and tip cap. The endosperm has the largest portion, providing about 83 % of the kernel weight followed by the germ and pericarp with 11 and 5%, respectively (Table 1). Next is the tip cap a conical structure that together with the pedicel attaches the kernel to the ear of maize. Maize kernels develop by accumulation of the products of photosynthesis, metabolism and root absorption of plant on the female inflorescence called the ear. During harvest the ears of maize are removed from the plant either by hand or mechanically. The husks covering the ear are first stripped off, and then the kernels are separated by hand or by machine. There are variations in the chemical composition of the main parts of the maize kernel. The seed-coat or pericarp is characterized by a high crude fibre content of about 87 %, which is constituted mainly of hemicelluloses (67%), cellulose (23%) and lignin (0.1%) (Burge and Duensing, 1989). On the other hand, the endosperm contains a high level of starch (87.6%) and protein to the levels of about 8%. Crude fat content in the endosperm is relatively low. The germ is characterized by a high crude fat content, averaging about 33%. It also contains a relatively high level of protein (18.4%) and minerals (table 2). The endosperm contributes the largest amount, followed by the germ, with only small amounts from the seed-coat.

Table 2. Proximate chemical composition of main parts of maize kernels (%)

Chemical component	Pericarp	Endosperm	Germ
Protein	3.7	8.0	18.4
Ether extract	1.0	0.8	33.2
Crude fibre	86.7	2.7	8.8
Ash	0.8	0.3	10.5
Starch	7.3	87.6	8.3
Sugar	0.34	0.62	10.8

(Source: Watson, 1987)

Nutritionally, maize contains about 60 to 68% starch and 7 to 15% protein. QPM (Quality Protein Maize) have more nutritional value and contain a high percentage of essential amino acids. Yellow maize is the richest source of Vitamin-A. Maize has more riboflavin than wheat and rice, and is also rich in phosphorous. Normally, maize contains 1.2 to 5.7 % oil but varieties developed particularly for high oil may contain up to 20% oil. It is widely used as a cooking medium and for manufacturing of hydrogenated oil and it has the quality of reducing cholesterol in the human blood like sunflower oil. The fat content of the oil is approximately 80%.

Chemical composition of maize Starch

Approximately 70 % of the maize kernel weight is starch which is polymeric carbohydrate consisting of glucose units joined together through α (1- 4) D-glucosidic linkages. Other carbohydrates are simple sugars like glucose, sucrose and fructose also present in small amounts varying from 1 to 3 % of the kernel. The starch in maize is made up of two glucose polymers:

amylose and amylopectin, where amylose is an essentially linear molecule, amylopectin is a branched form. The composition of maize starch is genetically controlled. In normal maize, amylose and amylopectin constitutes 25-30 and 70-75% of starch, respectively. Waxy maize contains a starch that is 100 % amylopectin. An endosperm mutant called amylose-extender (ae) has an increase in the amylose proportion of the starch to 50 % and even higher.

Protein

Protein is the next largest chemical component of the maize kernel after starch. In common varieties it varies from about 8 - 11 % of the kernel weight. It is found in the endosperm followed by germ to a smaller extent. However, since the endosperm represents the major part of the kernel weight, therefore, it follows that, in considering the whole kernel, the essential amino acid content is a reflection of the amino acid content in the protein of the endosperm in spite of the fact that the amino acid pattern of the germ protein is higher and better balanced. Relative amount of proteins contributed by the endosperm and germ vary and are dependent on the phenotype and genotype of corn. Normal maize protein is deficient of two essential amino acids, tryptophan and lysine but with the advance molecular biology techniques and improved breeding practices, quality protein maize (QPM) has been developed with higher nutritional quality including lysine and tryptophan as compared to normal maize as well as other cereals.

Oil

Germ is the major contributor of the oil content of the maize kernel. It has low levels of saturated fatty acid i.e. approximately 2 % stearic acid, 11 % palmitic acid and high levels of PUFA, mainly linoleic acid with an average value of about 24%. Maize has relatively stable oil in terms of high levels of natural antioxidants and it has become the most valuable product of maize grain due to these qualities. Maize oil is highly regarded because of its fatty acid distribution, mainly oleic and linoleic acids. In this respect, populations that consume de-germed maize benefit less in terms of oil and fatty acids than populations that consume whole-kernel products. Therefore, breeding for higher and better oil corn is an important aspect of maize development program.

Carotenoids

Carotenoids are the widespread group of naturally occurring fat-soluble pigments, responsible for the yellow, orange, and red colors of fruits, roots, flowers etc. These are associated with numerous activities of our life including Pro-Vitamin A activity. Approximately 700 carotenoids are known till date. Out of these, 50 are having Pro-Vitamin A activity, highest in β-carotene. Vitamin A is an essential component for normal functioning of our body because its deficiency is a major cause of concern for people in the developing world as it causes night-blindness. Xerophthalmia and complete blindness can also occur since Vitamin A has a major role in photo-transduction. Approximately 250,000 to 500,000 malnourished children in the developing world go blind every year due to the lack of vitamin A and approximately half of which die within a year of becoming blind. Although effects have been made to control this deficiency through supplementation of vitamin A in the diet but some permanent solutions are needed to be developed especially to eradicate this disease. The public health importance of the deficiencies lies upon their magnitude and their health consequences are seen especially in pregnant women and young children, as they affect fetal and child growth, cognitive development and resistance to infection. Since maize is a staple food for the poor world, it may be easily controlled by increasing the content of β-carotene in maize grains. It is converted to vitamin A in the human body, and as discussed above that the world's poorest populations eat a disproportionate amount of staple cereals as compared to fruits and vegetables, therefore, making the staple grains, such as maize, healthier would be a cheap and efficient way to address this problem.

Sugars

At maturity, maize kernel contains carbohydrates other than starch in small amounts. Sugars consist of glucose, fructose and sucrose. In maize total sugars were present in amounts ranging from 1 to 3 % of the kernel weight and sucrose is the major component, found mostly in the germ. Higher levels of monosaccharides, disaccharides and trisaccharides are present in maturing kernel. As the kernel matures, the sugar concentration declines and starch increases. High levels of reducing sugar and sucrose in the immature common maize or sweet corn are the reason for taste priority of the people.

Normal maize needs nutritional enhancement. Several people, particularly from developing countries, derive their protein and calorie requirements from maize. Owing to growing middle to upper class population in India with increasing awareness towards consumption of healthy foods there is a requirement to increase biological value of normal maize. This can be achieved by improving the nutritional profile of maize endosperm, which can ensure more bioavailability of protein to human and animals. Because of the great importance of maize as a basic staple food for large population groups, particularly in developing countries, many efforts have been made to improve the biological utilization of the nutrients it contains. There exists wide variability in the chemical composition of maize. Although environment and cultural practices may be partly responsible, the variability of various chemical compounds is of genetic origin, thus composition can be changed through appropriate manipulation. Efforts in this direction have concentrated on carbohydrate composition and on quantity and quality of oil and protein. Some efforts have also been made to manipulate other chemical compounds such as nicotinic acid and carotenoids. Malnutrition is a major constraint to socio-economic development contributing to a vicious circle of underdevelopment. It has effects on health, learning ability and productivity and has high social and public costs leading to reduced work capacity due to high rates of illness and disability. Overcoming malnutrition is therefore a precondition for ensuring rapid and appropriate national development. Specialty corns have several health benefits along with a delicious taste of their own. Specialty corn types (QPM, Sweet corn, Popcorn, Baby corn) are rich in essential nutrients. Further, nutritional improvement using traditional and modern approaches can be the best option for ensuring nutritional security virtually at no additional cost. Bio fortification for traits like protein quality and vitamin A, and some other essential micronutrient that is insufficient to meet daily requirements such as Fe and Zn will increase its nutritive value. Bio-fortification has numerous advantages over fortification where one aspect is gained at the cost of other. Bio-fortification capitalizes on the regular daily intake of a consistent and large amount of food staples by all family member. The high carotene content of yellow maize is considered to be very useful in importing yellow colour to egg yok and yellow tinge to the milk. No other concentrate is yet to known to substitute maize in this respect.

Maize specialty corn *viz* quality protein maize, baby corn, sweet corn, waxy corn, high amylose corn, high oil corn *etc*. has wider industrial applications as they possess unique market demand for utilization by corn food, feed and processing industries. Alteration of starch, amino acids and oil content of corn can better meet the needs of poultry, livestock, food industry and other industrial users in a better way. A modification of ordinary corn to specialty corn using scientific approaches is improving yield potential and quality parameter**.** Industrial advancement may lead to income generation and livelihood improvement as a whole. Measures such as contract farming, setting up processing units, ensured market, public-private partnership and incentive based value chain will increase production. Low cost of production in India may further promote export of specialty corn and their value added products.

Diverse uses of maize

Forage and Feed

The major field where maize finds extensive use is as livestock feeds viz, cattle poultry and piggery both in the form of seeds and fodder. The crop has to be harvested when the grains are in milky stage. The digestibility of maize fodder is higher than that of sorghum, bajra and other non-leguminous forage crops. Maize plant does not have any problem of hydrocyanic acid or prussic acid production, hence of necessary crop can be harvested and fed to cattle at any stage of its growth, of course ideal stage of harvest for green fodder mid dough stage, when the dry matter content and digestibility are more desirable. Now-a-days, maize fodder is also used for making silage and its importance is growing every day. It can be used in the lean period when there is deficiency of green fodder.

Food

In most of the developing countries maize is consumed directly as food. Most commonly used forms are as chapattis and porridges of various forms like boiled or roasted green ears, breakfast foods like corn flakes and pop corn.

Industrial Uses

The industrial uses are based on the type of corn and physical properties of the cob. Maize used as a primary source in the manufacture of starch, syrup, dextrose, oil, gelatin, and lactic acid etc. Corn flour is used as a thickening agent in the preparation of many edibles like soups, sauces and custard powder while corn syrup is used as confectionary unit's agent. Corn sugar (dextrose) is used in pharmaceutical formulations as a sweetening agent in soft drinks etc. Corn gel is used as a bonding agent for ice-cream cones, and as a dry Dustin agent for baking products, on account of its moisture retention character. Maize ground to powder and used as fillers for explosives in the manufacture of plastics, glues, adhesives, reyon, resin, vinegar and artificial leather. It is also used as diluents and carrier in the formulation of insecticides and pesticides. Based on the chemical properties the processed cobs find their use in the manufacture of furfural, fermentable sugars, solvents, liquid fuels, charcoal gas and other chemicals by destructive distillation. It also has application in the manufacturing of pulp, paper and hard boards. The water in which the maize grains are soaked for the manufacture of glucose is used for growing pencillin moulds. The economics of cultivation of maize, jawar and wheat are almost the same, but the cost benefit ratio in case of maize is highest because of its high productivity. For processing of maize and its products, mini factories should be setup around maize growing-areas of our country. This will enhance the demand for maize and its products and the growers can send their produce directly to the factories.

Agricultural Uses

The central part of the maize cob to which the grains are attached remains as an agricultural waste after threshing; it finds many important agricultural and industrial uses. It forms approximately 15 to 18% of the total ear weight and contains 35% cellulose, 40% pentose and 15% lignin. Their uses in agriculture includes as a litter for poultry and as a soil conditioner.

Future Prospects

India has great potential to export maize in the form of grain, feed, seed and specialty corn (baby corn, sweet corn) due to low cost of production and less freight charges. Maize has great potential and prospects as food, feed, specialty corn, starch, etc. for both domestic consumption as well as export. Further, maize has the potential to capture some areas from coarse cereals, *Rabi* rice in peninsular India as well as upland rice and from wheat in eastern India on account of its better crop returns.

Future strategies for enriching maize quality

The development of QPM hybrids with higher levels of Lysine and tryptophan should be continued for better food and feed requirement and to ensure nutritional security in the country. The emphasis should also be laid on the bio fortification of the maize with the micronutrients like iron and zinc for further enhancement of its biological values. There is also need for development of low phytate maize for considering its absorbing property. The superior quality hybrids of baby corn, sweet corn and pop corn is also need of the nation for nutritious snacks industries development and overall health improvement of the people. With the increase of urbanization, change in food habit and the improved economic status, specialty corn has gained significant importance in *peri*-urban areas of the country. The demand of baby corn, sweet corn and popcorn is increasing every year. The development of suitable hybrids and their production technology for specialty corn should be further strengthened. The popularization of processing products of specialty corn maize for ensuring the livelihood security of rural masses and promotion of small scale entrepreneurship will receive greater attention.

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18. Bio-fortification for quality improvement in maize

Avinash Singode, Ashok Kumar and S.L. Jat

Biofortification is the process by which the nutritional quality of staple crops is enhanced. International Food Policy Research Institute explains bio fortification as a scientific method for improving the nutritional value of foods already consumed by those suffering from hidden hunger. The improvement in nutritional value refers to improvement of protein and oil quality, and enrichment with vitamins and micronutrients essential for normal growth and development.

The nutritional quality improvement in maize has a long history, even before the rediscovery of Mendel's laws of inheritance selection for high and low oil and protein started in University of Illinois. The quality improvement in staple food crops to enhance the nutritive value then termed 'Biofortification' lately. A number of biofortification programmes are running all over the globe to counter malnutrition and hidden hunger some in consortia mode and most of them in a project mode. Biofortification was thought to one of strategy to give nutritional security to the poor who cannot afford balance diet.

Overview of global malnutrition and hidden hunger

Infant mortality and post partum morbidity is an important parameter for Human Development Index. Globally, there are many countries where the HDI is low due to hidden hunger and protein energy malnutrition. Biofortification of staple food crops is a new public health approach to control vitamin A, iron, and zinc deficiencies in poor countries. Global statistics on malnutrition shows a horrifying picture. About 2 million children globally affected by iron and zinc deficiency. Globally, about 127 million pre-school children are vitamin A deficient. Every year, up to half a million preschool children go blind from lack of vitamin A, and about as many die within months of going blind. Close to 20 million pregnant women in developing countries is also vitamin-A deficient. About one-fifth of the world's population is at high risk of zinc deficiency.

Zinc deficiency can cause stunting and worsen diarrhea and pneumonia (the most common causes of death among children in developing countries). Almost half a million children die every year from infections that could have been easily overcome if they had enough zinc. Iron deficiency is the most common micronutrient deficiency in the world. Anemia (often due to iron deficiency) affects more than 1.6 billion people. Almost half of preschool children and pregnant women in developing countries are iron deficient. Iron deficiency impairs mental development and learning capacity in children. It reduces adults' capacity for physical labor and, when severe, increases the risk of mothers dying in childbirth.

Strategies countering malnutrition

There are strategies formulated and practiced to counter malnutrition and hidden hunger. The government addresses issues with the policies like the Food security bill in India (2013). Common salt is fortified with Iodine to reduce the risk of hypothyroidism. Awareness programs about the healthy foods and balanced diet for pregnant women and children below five years through *Aanganwadis* and etc. The health department provides doses of Vitamin A to infants along with vaccines in primary health centers (PHCs) free of cost. The pregnant women are given folic acid, iron and calcium tablets to prevent anemia and calcium deficiency. But, to give a holistic approach to a healthy diet to all people biofortification of staple crops is important.

Biofortification has four main advantages when applied in the context of the poor in developing countries. First, it targets the poor who eat large amounts of food staples daily. Second, biofortification targets rural areas where it is estimated that 75 percent of the poor live mostly as subsistence or smallholder farmers, or landless labourers. These populations rely largely on cheaper and more widely available staple foods such as rice or maize for sustenance. Despite urbanization and income growth associated with globalization, diets of the rural poor will continue to be heavily based on staple foods like cereals and tuber crops in many regions. Expected increases in food prices, exacerbated by climate change, are likely to increase this reliance on staple foods. Supplements or fortified food products are often not widely available in rural areas; in fact, coverage of fortified foods in rural areas may be less than one-third (Msangi *et al*., 2010). Therefore, locally produced, more nutritious staple food crops could significantly improve nutrition for the rural poor who eat these foods on a daily basis. Third, biofortification is cost effective. After an initial investment in developing biofortified crops, those crops can be adapted to various regions at a low additional cost and are available in the food system, year after year. *Ex ante* research that examined the cost effectiveness of a variety of staple crops biofortified with provitamin A, iron, and 30–50 percent of the daily nutrient requirement, biofortified crops can significantly improve public health in countries where hidden hunger is widespread (poor consumers in most cases will already be consuming 50 percent of requirements). Transgenic approaches can be used to improve the nutrient content of crops where natural variation in germ plasm is limited. However, transgenic crops also face more regulatory hurdles compared to their conventionally bred counterparts. Whether conventionally or transgenically bred biofortified crops should shift significant numbers of people that are receiving a little less than their estimated nutrient requirement, into a state of nutritional adequacy, for that nutrient. Fourth, nutritionists now focus on the 9 to 24 month age group, when micronutrients are crucial for healthy development. Infants consume relatively low amounts of staple foods and yet have relatively higher micronutrient requirements, making biofortification's contribution to micronutrient adequacy in this group limited.

Biofortification in maize

QPM and overview

It was long known that maize was a poor source of the critical amino acid lysine (Osborne and Mendel, 1914). The source of this problem is that the primary storage proteins in the maize endosperm are the lysine-poor zeins. Mertz et al. (1964) demonstrated that maize homozygous for the *opaque-2* mutation had greatly elevated levels of lysine, due to a shift from zeins to other lysine-rich proteins.

Initial excitement ebbed since *opaque-2* maize had poor grain characteristics, poor yield and storage problems.

Poor agronomic traits and kernel characteristics of the originally identified high lysine mutant were overcome over several decades of concerted breeding efforts to produce advanced lines known as Quality Protein Maize (QPM) (Prasanna *et al*., 2001; Vasal, 2002). QPM represents one of the notable successes, as defined above, of a nutritionally-enhanced staple food crop that has found wide production. QPM is recognized as superior food relative to other maize varieties that can benefit some individuals, specifically young children, at risk of severe malnutrition. The greater direct impact of increased availability of lysine and tryptophan in maize is on animal nutrition and productivity (Qi *et al.*, 2004). Success of QPM came from two major reasons first, the development of high-yielding QPM lines only came from one organization, CIMMYT (International Maize and Wheat Improvement Center). Second, production of such lines ultimately was due to government intervention in developing countries, where public health is dependent on nutritious grains and legumes. Maize varieties with enhanced levels of lysine and tryptophan developed to internationally. Indirectly, it therefore has potential positive benefits for human nutrition at the population level. However, the recessive nature of the trait and the fact that its presence is not easily verifiable by farmers or consumers requires replacing the breeding population with the desired variety, isolating it from other maize or alternatively supplying certified seed to farmers. In many cases, biofortified crop varieties will require considerable investment in seed distribution, labeling, packaging and consumer education to ensure that they are used appropriately as foods in existing diets and food cultures.

During 2004 QPM has got another chance to enter the main stream of cultivation In India. The previously released QPM composites Shakti-1, Shakti, Protina, and Rattan could not make impact what the QPM hybrids have done. A series of hybrids were released after Shaktiman-1 like Shaktiman-2, HQPM-1, Shaktiman-3, Shaktiman-4, HQPM-5 and HQPM-7 etc. Among the released hybrids HQPM-1 is popular across India. Huge quantity of seeds is been produced by NSC and Dept. of Agriculture and Cooperation receives huge indent for these hybrids from various State Seed Corporations. The QPM hybrids, HQPM-1, HQPM-5, and HQPM-7 are high yielding, tolerant to abiotic stress and is resistant to many diseases. Vivek QPM-9 which was developed through marker assisted selection is recommended for high altitude regions of Himalayan range. This is the major reason for the impact it has made in over years. The farmers growing QPM is supplied to feed industries of poultry and piggery majorly.

Vitamin A rich maize

Maize displays considerable natural variation for carotenoid composition, including vitamin A precursors a-carotene, β-carotene, and β -cryptoxanthin. Through association analysis, linkage mapping, expression analysis, and mutagenesis, show that variation at the lycopene epsilon cyclase (*lcyE*) locus alters flux down α-carotene versus β-carotene branches of the carotenoid pathway. Four natural *lcyE* polymorphisms explained 58% of the variation in these two branches and a threefold difference in provitamin A compounds. Selection of favorable *lcyE* alleles with inexpensive molecular markers will now enable developing-country breeders to more effectively produce maize grain with higher provitamin A levels.

A limited number of carotenoids, including α-carotene, β-carotene (βC) and β-cryptoxanthin (βCX), can be converted to vitamin A through animal metabolism (Fierce *et al*., 2008). The favorable *lcyε* alleles increase the proportion of βC, but a large amount is hydroxylated to βCX and zeaxanthin (Z), which have 50% and 0% of the provitamin A activity of βC, respectively. Thus, the identified maize *lyce* naturally occurring allelic variation was well studied to establish the molecular basis for reduced β-Carotene conversion. Another gene *crtRB1* favorable allele is effective, increasing average β-carotene concentrations. The provitamin A mean of the most favorable combined class (8.57 ± 0.89 μg g−1) represents 57% of the 15 μg g−1 provitamin A target value set by Harvest Plus. The rarity of certain genetic variants is such that the most favorable haplotypes of crtRB1 and lcyε do not naturally occur together. Experiments to combine the best haplotypes for both loci to evaluate the combined genetic effects in breeding crosses are continuing.

Maize is staple food in many African countries and some parts of India it used as food. Harvest Plus is concentrating on increasing Vitamin A in maize targeting African countries. In Zambia Vitamin A biofortified maize is released in 2012. The Government of Nigeria released two Vitamin- A rich maize hybrids in 2012, Ife Maizehyb-3 and Ife Maizehyb-3 which is second important staple food crop. These varieties were developed by in partnership with IITA led project on high Vit A maize. These new maize varieties are also well suited to the tropical lowlands of many West African countries and are expected to spread beyond Nigeria's borders.

Other nutritional quality improvement in maize

Cereals make the bulk of the household diets in developing countries and hence are an ideal tool for Fe biofortification. The conventional approach to cereal mineral biofortification has been to work at three levels. These are to increase the density of the mineral nutrient of interest, to decrease the density of anti-nutritive compounds (nutrient inhibitors), and to increase the density of compounds that enhance bioavailability of the specific nutrient. The best example from conventional breeding is a study from the International Rice Research Institute (IRRI), where a new rice variety was developed with substantially more Fe concentration than varieties typically consumed in Asia. A high Fe variety chosen for a feeding study contained 2.6 μg per gram dry weight more Fe than a standard commercially available rice variety.

Enhancing Fe and Zn in maize is reportedly going on across the world though no cultivar is released till date. Apart from FE and Zn there are ongoing programs enriching maize with Selenium (Chilimba *et al*., 2012), methionine and low phytate.

Harvest Plus, a CGIAR organization is addressing this important challenge of biofortification of staple food crops targeting specific countries. They have lot of success stories in many crops including maize.

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19. Botany of maize plant

Bhupender Kumar, S.L. Jat, Ganapati Mukri and Yatish K. R.

Maize (*Zea mays* L.) is the world's leading crop and is widely cultivated as cereal grain. Its domestication was started from Central America. It is one of the most versatile emerging crops having wider adaptability. Globally, maize is known as queen of cereals because of its highest genetic yield potential. It is the only food cereal crop that can be grown across different seasons and ecologies. It is grown for diverse purposes because of its vast genetic diversity and types like yellow/white grain, sweet corn, baby corn, popcorn, waxy corn, high amylase corn, high oil corn and quality protein maize. In recent years it is also being cultivated commercially as an industrial crop as maize is being used a raw material in several food/feed and non-food processing industries thus providing large opportunities for value addition. Globally, it is cultivated in more than 170 m ha area across 166 countries having wider diversity of soil, climate, biodiversity and management practices.

Maize (*Zea mays* L.) belongs to the tribe maydeae of the grass family *Poaceae*. Tribe maydeae comprises seven genera which are recognized, namely old and new world group. Genera *Zea* and *Tripsacum* are belong to new world group. "*Zea*" was derived from an old Greek name for a food grass. The genus *Zea* consists of four species of which *Zea mays* L. is economically important. The other *Zea sp.*, referred to as teosinte, is largely wild grass native to Mexico and Central America. It is accepted that, corn originated from teosinte. The number of chromosomes in *Zea mays* is 2n = 20 (Chopra, 2001). The transformation of maize from teosinte involved evolutionary forces such as mutation, hybridization, genetic drift and selection aided by the activities of human beings, who selected useful variants out of large populations of teosinte and concentrated them into isolated evolutionary pools. This resulted in the differentiation of maize into large number of races. The races gradually got adapted to different agro-climatic regions in America, away from the centre of origin. On the basis of morphological data, several authors suggested that there has been extensive gene flow between maize and teosinte and that the genetic constitution of teosinte has been greatly altered by maize germplasm (Sleper and Poehlman 2006). Recent molecular studies confirm that there is a two-way gene flow, but at a lower level. Consequently, maize and teosinte maintain distinct genetic constitutions despite sporadic introgression (Doebley, 1990). On the basis of molecular analysis, Doebley and his colleagues suggested that only five regions of the genome accounted for most of the variation between maize and teosinte. Transfer of teosinte-cytoplasm-associated miniature trait from the wild teosintes such as *Z. Perennis*, *Z. diploperennis* and *Z. luxurians* was also found in some inbred lines of maize.

Origin and Evolution

Maize is one of the oldest human-domesticated plants. Its origins are believed to be dates back to at least 7000 years ago when it was grown in the form of a wild grass called *teosinte* in Central Mexico. Recognizing its early potential as a major food crop, over a time the *Mesoamerican* natives managed to improve the crop, by systematically selecting certain varieties for their desired traits. This process led to the gradual transformation of *teosinte* to its present day form known as maize.

The exact processes of evolution into maize and its progenitor's species are still a matter of investigation. However, it now seems to be generally accepted that corn originated from teosinte, which is the only known nearest relative of corn. There is still controversy exist as whether corn was originated by a single domestication from the vessel branching teosinte subspecies *Zea mays* L. spp. *parviglumis*, or from the lateral branching sub species *Z. mays* L. spp. *maxicana*, or by dual domestication from the two subspecies. The archeological and molecular data indicates that modern maize was domesticated from annual teosinte (*Zea mays ssp. parviglumis*) in southern Mexico between 6,600 and 9,000 years ago. The selection was also followed immediately after selection leading to fixation of favourable alleles at loci controlling plant morphology and kernel nutritional quality around at least 4,400 years ago. The further selection by Native Americans facilitated maize adaptations to varied environments. In contrast to other major grain crops, the corn plant has monoecious condition i.e. separate male and female flowering parts on the same plant at different locations and it possesses C_4 photosystem (plants that use **C_4 photosynthesis** to fix atmospheric carbon dioxide) like sorghum and sugarcane. Since the initial product of photosynthesis is four carbon compound (oxaloacetate) so it is called C_4 photosynthesis. The C_4 photosynthesis essentially eliminates the oxygenase activity of Rubisco via anatomical, biochemical and ultra structural modifications of leaves (Brown *et al*., 2005).

Developmental Stages (Life Cycle)

Typical corn plant develops around 18 to 22 total leaves and their silks appear between 45-60 days after emergence while plant matures by 80-125 days after emergence depending upon the maturity groups and type of corn. However, the specific time interval can vary among hybrids, environments, planting date, and locations. For example, an early maturing hybrid may produce fewer leaves or progress through the different growth stages at a faster rate than described here. In contrast, a late-maturity hybrid may develop more leaves and progress through each growth stage at a slower phase. Maize view at different growth stages has been given in Figure 1. Almost all pest management decisions for corn are based on the vegetative stage. Therefore this is very important to know for all maize growers. The different maize growth stages identified by Iwoa state University (www.agronext.iastate.edu/corn) are explained below:

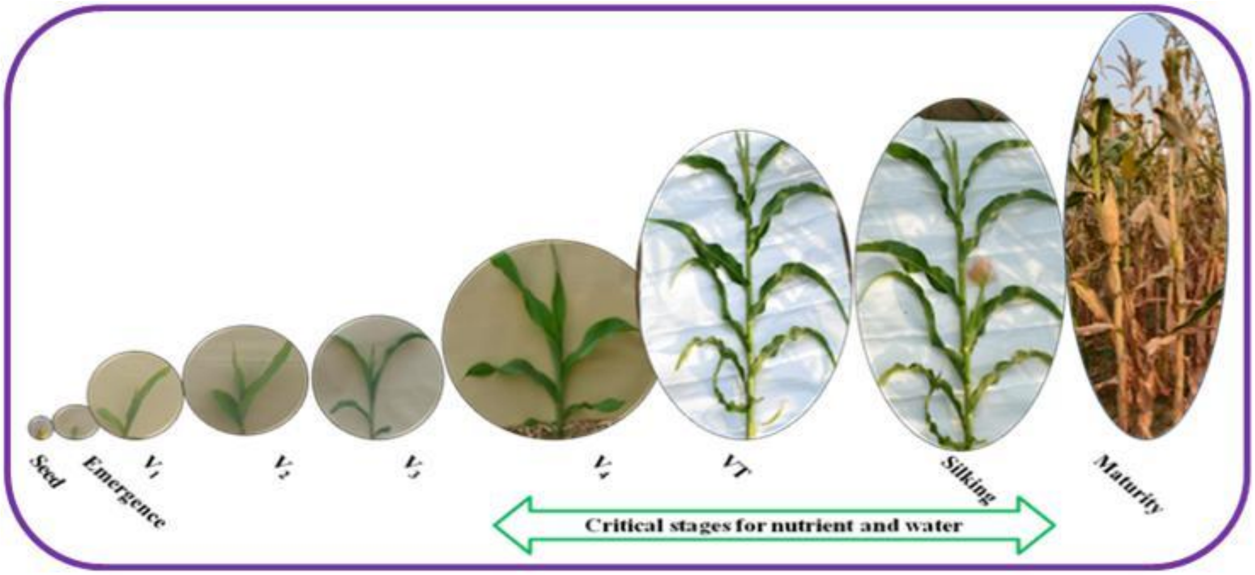

Figure 1. Maize at different growth stages

VE - Emergence

Coleoptile reaches the soil surface and exposure to sunlight causes elongation of the coleoptile and mesocotyl to stop. The growing point, located just above the mesocotyl, is about 0.75 inches below the soil surface. Embryonic leaves rapidly develop and grow through the coleoptiles tip. Seminal root growth begins to slow and nodal roots are initiated at the crown.

V1 - First leaf collar

Lowermost leaf (short with rounded tip) has a visible leaf collar. Nodal roots begin its elongation.

V3 - Third leaf collar

The growing point remains below the soil surface as little stalk elongation has occurred. Lateral roots begin to grow from the nodal roots and growth of the seminal root system has ceased. All the leaves and ear shoots that the plant will produce are initiated at this stage. Since the growing point remains below the soil surface, lower soil temperatures may increase the time between leaf stages, increase the total number of leaves formed, delay the tassel formation, and reduces nutrient uptake.

V7 - Seven leaf collar

During the V7 and V8 growth stages the rapid growth phase and kernel row determination begins. Senescence of lower leaves may occur if plant is stressed, but must still it must be counted as one of the growth stage.

V10 - Ten leaf collar

At the V9 and V10 growth stages the stalk is in a rapid growth phase accumulating dry matter as well as nutrients. The tassel has begun growing rapidly as the stalk continues to elongate. Many ear shoots are easily visible when the stalk is dissected.

VT - Tasseling

Initiation of the VT stage begins when the last branch of the tassel is visible and silks have not emerged. This stage begins about 2-3 days before silk emergence. The plant is almost at its full height and anthesis begins. Anthesis typically occurs in the morning or evening hours. Plants at the VT/R1 are most vulnerable to moisture stress and leaf loss.

R1 - Silking

This stage begins when silk is protruding from the husk. When pollen fall on the stigmatic surface, pollen tube will grow through the silk over a 24 hour period ultimately fertilize the ovule, which becomes a kernel up on maturity. It takes three days for all silks on a single ear to be exposed and pollinated. The number of fertilized ovules is determined at this stage. If an ovule is not fertilized, it will not produce a kernel and it eventually it gets degenerates. Environmental stress at this stage is detrimental to pollination, fertilization and seed set, with moisture stress causing desiccation of silks and pollen grains. Nutrient concentrations in the plant are highly correlated with final grain yield as nitrogen and phosphorous uptake are rapid.

R6 - Physiological Maturity

Physiological maturity occurs approximately 45-50 days after silking, all kernels on the ear have attained maximum dry weight. A black or brown layer has formed where the kernel attaches to the cob indicating attainment of physiological maturity. The stalk of the plant may remain green, but leaf and husk tissue has losses its green colour at this stage. Kernel moisture content ranges from 30-35% at this stage, however it will vary among hybrids and environmental conditions.

Botanical Features

Maize is a tall, determinate annual C_4 plant varying in height from <1 to >4 metres producing large, narrow, opposing leaves, borne alternately along the length of a solid stem (Fig. 2). The botanical features of various plant parts are as follows:

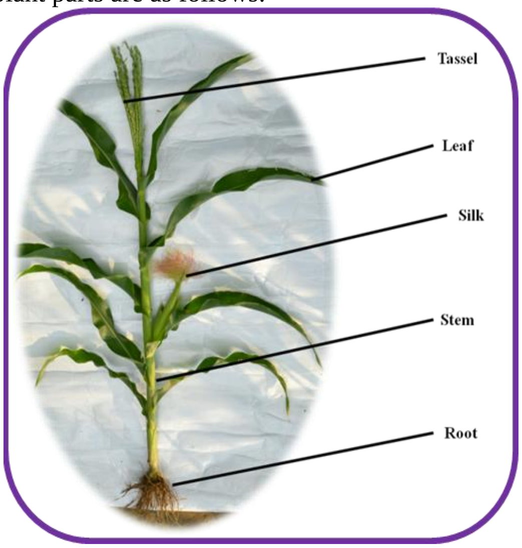

Figure 2. Maize plant parts

Root

Normally maize plants have three types of roots, i) seminal roots - which develop from radical and persist for long period, ii) adventitious roots, fibrous roots developing from the lower nodes of stem below ground level which are the effective and active roots of plant and iii) brace or prop roots, produced by lower two nodes. The roots grow very rapidly and almost equally outwards and downwards. Suitable soils may allow corn root growth up to 60 cm laterally and in depth.

Stem

The stem generally attains a diameter of three to four centimetres. The internodes are short and fairly thick at the base of the plant; become longer and thicker higher up the stem and then taper again. The ear bearing internode is longitudinally grooved, to allow proper positioning of the ear head (cob). The upper leaves in corn are more responsible for light interception and are major contributors of photosynthate to grain.

Flower

The apex of the stem ends in the tassel, an inflorescence of male flowers and the female inflorescences (cobs or ears) are borne at the apex of condensed lateral branches known as shanks which protrudes from leaf axil. The male (staminate) inflorescence, a loose panicle, produces pairs of free spikelets each enclosed by a fertile and a sterile floret. The female (pistillate) inflorescence, a spike, produces pairs of spikelets on the surface of a highly condensed rachis (central axis, or "cob"). The female flower is tightly covered over by several layers of leaves, and so closed in by them to the stem that they don't show themselves easily until emergence of the pale yellow silks from the leaf whorl at the end of the ear. The silks are the elongated stigmas that look like tufts of hair initially and later turn green or purple in colour. Each of the female spikelets encloses two fertile florets, one of those ovaries will mature into a kernel once sexually fertilized by pollen.

Floral Biology

Maize is a monoecious plant, that is, the sexes are partitioned into separate pistillate (ear), the female flower and staminate (tassel), the male flower. It has determinate growth habit and the shoot terminates into the inflorescences bearing staminate or pistillate flowers. The main shoot terminates in a staminate tassel. Maize is generally protandrous, that is, the male flower matures earlier than the female flower. Within each male flower spikelet, there are usually two functional florets, although development of the lower floret may be slightly delayed in comparison to the upper floret. Each floret contains a pair of thin scales i.e. lemma and palea, three anthers, two lodicules and rudimentary pistil. Pollen grains per anther have been reported to range from 2000 to 7500. Each tassel on an average produces around 7000 anthers and each anther produces on an average 3500 pollen grains, thus each tassel could produce around 2.45 crores of pollen grains. It appears that each ear requires about 1000 pollen grains for fertilization, if pollination was 100 percent efficient. However, in terms of the ratio of pollen grains produced to per ovules fertilized, there are about 20,000 pollen grains per kernel in excess of what is actually needed. The pollen grains are very small, barely visible to the naked eye, light in weight, and easily carried by wind. The anemophilic and protandry nature lead to cross-pollination, but there may be about 5 per cent self-pollination.

The female flower initially small but protrude soon to form rows. The basal protuberances are formed first later the development advances towards the tip of the ears. The part above the attachment of the carpel develops a single sessile ovule, which consists of a nucellus with two integuments or rudimentary seed coats. The united carpel's, which will form the ovary wall or pericarp of the mature kernel, grow upward until they completely enclose the ovule. The two anterior carpel, which face the ear tip form outgrowths, which develop into the style i.e. long thread, know as silks. Silks are covered with numerous hairs, trichomes which form an angle with the silk where pollen grains are harboured. The base of the silk is unique, as it elongates continuously until fertilization occurs. The cobs bear many rows of ovules that are always even in number. The female inflorescence or ear develops from one or more lateral branches (shanks) usually borne about half-way up the main stalk from auxillary shoot buds. Since the internodes of the shanks are condensed, the ear remains permanently enclosed in a mantle of many husk leaves. Thus the plant is unable to disperse its seeds in the manner of a wild plant and instead it depends upon human intervention for seed shelling and propagation. The explanation for each maize male and female floral organ has been given below:

Male Inflorescence

Tassel

The tassel consists of several long, indeterminate branches bearing short determinate branches (spikelet pairs) bear two spikelets. This is considering as inflorescence of male flowers.

Stamen

Pollen-producing reproductive organs which are collectively referred as androecium. Stalk/ filament; the part of the stamen on which anther develops.

Anther

The terminal part of a stamen in which the pollen grains are produced.

Microspore

Smaller of the two types of spore produced in heterosporous plants; develops in the pollen sac into a male gametophyte.

Male gametophyte

Microspores divide twice to produce 3 cells pollen grain/tube (a male gametophyte); two of them are sperm; other is called vegetative cell, or tube cell.

Sperm cell

Two sperm cells are produced; one sperm cell fuses with the egg resulting in zygote; other sperm cells fuses with central cell giving start to development of triploid tissue called endosperm which surrounds the embryo and serves an absorbtive/nutritive function in seed.

Tube cell

Haploid cell that comprise two sperm cells and facilitates delivery of the sperm into ovary.

Female Inflorescence

Ear

Inflorescence of female flowers; it consists of a single spike with short branches each producing two single-flower spikelets.

Pistil

It consist of style, a slender part of a pistil, situated between the ovary and the stigma (main part of silk) and stigma, the receptive apex of the pistil of a flower, on which pollen is deposited at pollination.

Ovary

It mainly consists of ovule having megaspore also called macrospore, which gives rise to female flowers in maize. The female gametophyte also called mega gametophyte or embryo sac consists of 7 cells.

Egg one of small 6 cells, which fuses with the sperm cell giving rise to the plant embryo; Central cell large cell, which has 2 haploid, or polar nuclei; it fuses with the second sperm cell giving rise to triploid tissue called endosperm.

Sex determination in maize is complex process involving interplay between genetic determinants, environment and hormones (Dellaporta and Calderon, 1984). Uni-sexuality of flowers is achieved by the process of selective arrest and abortion of the inappropriate organ primordial within a bisexual floral meristem. Masculinising genes [Such as *tassel seed 2*(*ts2*)] are required for gynoecial abortion, ferminizing genes [such as *Anther ear 1*(*An1*) and *Silkless* (*Sk1*) arrest stamen development, and both types also control secondary traits involving morphological characteristics of floral tissues (Chopra, 2001).

Mating Systems

Maize under natural condition reproduces only by seed production. Pollination occurs with the transfer of pollen from the tassels to the silks of the ear; about 95% of the ovules are cross-pollinated and about 5% are self-pollinated (Sleper and Poehlman, 2006); although plants are completely self-compatible. There is no asexually reproductive maize, but cell/tissue culture techniques can be used to propagate calli and reproduce tissues or plants asexually.

Pollination and Fertilization

Formation of the female flowers or cobs is the first reproductive stage and occurs 2-3 days after tasseling stage. This stage begins when any silks are visible outside the husk. These are auxillary flowers unlike tassels that are terminal. Pollination occurs when these new moist silks catch the falling pollen grains. In maize, the pollen shedding usually begins two to three days prior to silk emergence and continues for five to eight days. The silks are covered with fine, sticky hairs which captures and anchor the pollen grains. Pollen shedding stops when the tassel is too wet or too dry and begins again when temperature conditions are favourable. Under favourable conditions, pollen grain remains viable for only 10 to 18 hours. Lower temperature and high humidity favour pollen longevity. The interval between anthesis and silking under optimal conditions is around one to two days, however under any stress situation this interval increases. Fertilization occurs after the pollen grain is received by the silk and pollen tube grows through the length of the silk within few minutes and enters the embryo sac in 12 to 28 hours. Pollen is light and is often carried considerable distances by the wind. However, most of it settles within 20 to 50 feet. Pollen of a given plant rarely fertilizes the silks of the same plant. Under field conditions 97% or more of the kernels produced by each plant are pollinated by other plants. Fertilization of ovules begins at about one third of the way up from the base of the ear.

Maize, being a cross-pollinated crop, various reproductive isolation methods are used by plant breeders and seed producer to obtain genetically pure seed. The isolation of crops using separation distances and physical barriers are common techniques for restricting gene flow and ensuring seed purity for maize seed production. Various experimental practices mostly used to maintain reproductive isolation in maize are as follows:

Maintaining isolation distance: Cross-pollination is controlled by separating two maize plots involving two different lines/cultivars. The Minimum Seed Certification Standards require a minimum 500m isolation distance..

Detasseling

Mechanical removal of tassels is another effective method in corn. It is possible to eliminate entire source of genetic material from the male flower that can be transferred via pollen. Isolation distance can be reduce to some extent by using physical barriers.

Out crossing and gene flow

Gene flow from maize can occur by two means: pollen transfer and seed dispersal. Seed dispersal can be readily controlled in maize as domestication has all but eliminated any seed dispersal mechanisms that ancestral maize may have previously used. Kernels are held tightly on the cobs and if the ear falls to the ground, one competing seedlings will grow till maturity. Pollen movement is the only effective means of gene escape from maize plants. As maize is mainly cross pollinated, wind speed and direction affects pollen distribution. Maize pollen measures about 0.1 mm in diameter is the largest pollen among members of the grass family, has been reported to be disseminated by wind from a comparatively low level of elevation. Further, due to its large size, maize pollen settles at a rate that is approximately 10 times faster than pollen from other wind-pollinated plants. It indicates that maize pollen will not transported as far by the wind as smaller pollen grain/does not disperse as widely either horizontally or vertically, and settles to earth more quickly, much of it within the source itself. Insects, such as bees, have been observed to collect pollen from maize tassels, but they do not play a significant role in cross-pollination as there is no incentive to visit the female flowers. However, in the commercial maize cultivation if differences in flowering dates between adjacent maize fields are narrower then cross-pollination between them may occur at relatively high rate. Cross-pollination is also affected by the concentration of maize pollen released i.e. pollen load; pollen produced by a crop will successfully compete with foreign pollen sources when present in higher concentrations. Gene flow from maize (*Zea mays*) to other species in the same genus (inter-specific) and between genera (inter-generic) first requires the formation of a viable intermediate hybrid that is capable of producing fertile progeny which can survive till it gives the next generation. Assuming sexual compatibility exists, other factors like proximity of the crop, relatedness of a species with each other, environmental conditions, and overlapping flowering periods also contribute to the likelihood of hybridization. The introgression of genes from maize to other plant species may require several generations of recurrent backcrossing.

Seed dispersal

Seed dispersal of individual kernels naturally does not occur because of the structure of the maize ears. Maize, as a thoroughly domesticated plant, has lost all ability to disseminate its seeds and relies entirely on the aid of man for its distribution. The kernels are tightly held on the cobs. In case ears fall to the ground, so many competing seedlings emerge then the likelihood of any seedlings to grow till maturity is extremely low. Corn variation may be artificially defined according to kernel type likes: dent, flint, flour, sweet, pop and pop corn (Brown and Darrah, 1985). Except for pod corn, these divisions are based on the quality, quantity and pattern of endosperm composition in the kernel and are not indicative of natural relationships.

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20. Development of single cross hybrids in maize for different ecosystem

Bhupender Kumar, Abhijit Dass, Vishal Singh and Sai Dass

Maize (*Zea mays* L.) is the third largest planted crop after wheat and rice. It is mostly used as feed crop but is also an important food staple. In addition to food and feed, maize has wide range of industrial applications as well; from food processing to manufacturing of ethanol. It is grown in more than 166 countries of the world in different agro-climatic condition up to 50^0 N and S from the equator to more than 3000 masl. It is one of the most versatile emerging crops having wider adaptability. Maize can be grown in all type of soils and season; however it is sensitive to moisture stress (high as well as low), so soil having poor water retention as well as stagnate the water should be avoided. Under high moisture, the sowing should be done preferable on ridges as compare to on flat. Under low moisture stress, genotypes of early to medium maturity having deeper root system and better nutrient use efficient are more preferable. Apart from normal maize it has many other types' *viz*. Quality Protein Maize (QPM), sweet corn (SC), baby corn (BC), pop corn (PC), waxy corn (WC), high oil (HO) and high amylase maize etc.

Maize breeding in India has gone through many phases since the inception of AICRP on maize in 1957: from double cross hybrids to double top crosses, 3-way crosses, synthetic and composite varieties to present-day single cross hybrids. With the cultivation of less productive OPVs and multi parent crosses, area, production and productivity remained stagnant (around 1.0t/ha) for many years in this country. However, the strategy to switch over to single cross hybrids in 2005-6 has paid rich dividends. There has been tremendous increase in acreage, production and productivity over the years. Being most productive, single cross hybrids have shown better adaptability to new set of cropping systems and management practices. The growing demand for maize in future will easily be met as research agenda at national level has been focused on high yielding single cross hybrids (SCH) for different agro-ecological regions of the country.

Sustaining of maize yield stability over the year and locations is the big challenge in the era of climate change. There are various types of biotic and abiotic stresses in maize viz., drought, water logging, cold stress, heat stresses, nutrients stress and salinity stress etc. Single Cross hybrids are better tolerant under all kind of abiotic stresses than OPVs/DCH/MPH. Deeper root system, shorter ASI, stay green, erect leaves, and early maturity character are the important traits generally available in single cross hybrids and associated with both moisture and nutrient stress. Flowering and grain filling are the most sensitive stages for moisture stress.

Different zones in maize

Based on the agro-ecological conditions, the entire India is divided in five major zones – Zone I, Zone II, Zone III, Zone IV and Zone V (Fig.1), for effective evaluation and identification of suitable hybrids as well as breeding materials of the maize. The details of maize growing states included in these zones are given below:

Zone(s)	State(s)
Zone I	Jammu and Kashmir, Himachal Pradesh, Uttarakhand (Hill region), North Eastern Hill Regions (Meghalaya, Sikkim, Assam, Tripura, Nagaland, Manipur, Arunachal Pradesh
Zone II	Punjab, Haryana, Delhi, Uttarakhand (Plain), Uttar Pradesh (Western UP)
Zone III	Bihar, Jharkhand, Odisha, Uttar Pradesh (Eastern UP)
Zone IV	Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu
Zone V	Rajasthan, Madhya Pradesh, Chhattisgarh, Gujarat

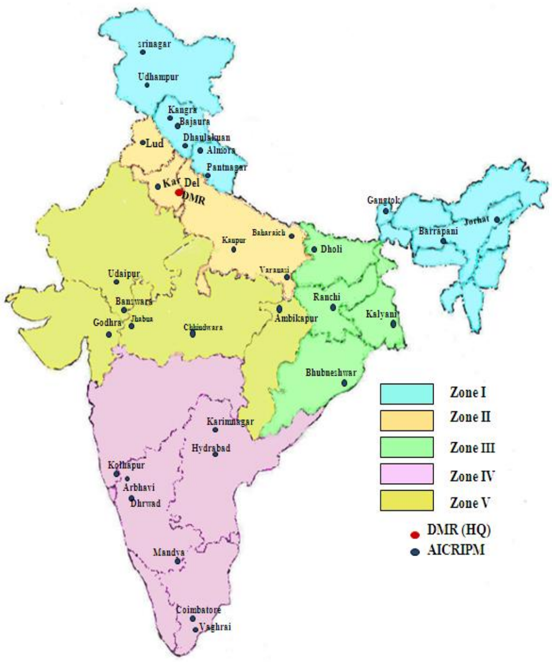

Figure 1. Zones and centres of AICRP (Maize)

Hybrids priority for different region

In the low to medium average rainfall sub-region viz., central part, part of northern India and western region of the country, moisture stress is the key constraint to maize production, and aggressive breeding efforts to overcome the drought problem are needed, as they are thought to be more relevant than water-saving or water management technologies. Development of early and medium maturity hybrids can be the one of important component of breeding strategies for these regions. The use of biotechnology to develop transgenic maize for drought management would benefit poor and resource-scarce farming communities of theses region (Joshi *et al*., 2005). Non-traditional maize growing areas viz., Karnataka, Andhra Pradesh, Tamil Nadu, which are now emerging in big, mostly grow maize for commercial purpose and supply goes to feed industries (Poultry, livestock and fisheries). They are comes under more favourable production environments, therefore, breeding efforts will be mostly emphasise for development of full as well as medium maturity maize hybrids having tolerance to biotic stresses viz. Stem borer, turcicum leaf blight and post flowering stalk tot (Joshi et al., 2005).

In the high and medium rainfall regions of Eastern Uttar Pradesh and Bihar, the development of medium and full-season cultivars for high rainfall regions is the priority. Now winter maize is coming in a big way, therefore, full season maize hybrids, which should be cold tolerant are needed for winter season. In spring season early and medium maturity hybrids, which need to be heat stress tolerant are more preferable compare to late maturity. The objectives of single cross hybrids development are therefore based on the zonal and season requirements. Generally, zone I requires early and medium drought tolerant hybrids, zone II requires early, medium and late maturing drought tolerant during *kharif*, heat tolerant in spring and cold tolerant single cross hybrids during *rabi* season. Zone III requires water logging tolerant in *kharif* and late cold tolerant hybrids in *rabi* season, in zone IV all maturity groups hybrids can be grow with more preference to full season maturity, because it comes in secure environment where irrigation facility are available, in zone V early, medium drought tolerant during *kharif* and late cold tolerant hybrids during *rabi* season are requires.

Under the All India Coordinated Research Project on Maize (AICRIP), research projects focusing on improvement of promising cultivars, advanced agronomic practices, nutrient management, and diseases and pests are being carried out for the overall development of the country's maize sector. Recently, efforts are also being geared up for minimizing post-harvest losses and exploring alternative uses of maize, especially for mal and undernourished segments of society.

Maize single cross hybrids breeding

Development of inbred lines

Inbred development in maize hybrids breeding is one of the most important components. A pure inbred line is a homozygous and homogeneous population developed by continuous inbreeding, usually by self pollination, followed by selection during subsequent segregating generations. Complete self cob of the selected plant should be grown in long row of length 25 to 30 m in field for effective and efficient evaluation during the segregating generations. Preference should be given to select more progenies of a cross having less inbreeding depression than that of selecting more crosses carrying progenies having high inbreeding depression. It will help to use the land, water and nutrient resources very efficiently. Further, this will give the clear view of all the plants of a progenies in single row, which will help in effective selection of the transgressive segregants in family.

The choice of base population to obtain elite inbred lines in breeding programme is very important. Various source materials which can be use for inbred line development are single cross hybrids, elite line synthetics, composites, back cross populations, pedigree populations, pools, heterotic populations groups, landraces, farmer varieties and obsolete varieties. Populations originating from maize single cross hybrids by selfing may be the one of the better option as compared to less improved populations viz., land races and other open pollinated varieties/populations because later are less improved and may carry more unfavourable alleles in hidden form. Single cross hybrids have the advantage of being tested extensively across the environments and are developed from elite inbred lines already carried favourable alleles. Beside it, synthetic populations backcross and pedigree populations developed involving elite inbred lines are the better alternate option to extract potential inbred lines. Single seed descent, pedigree, self progeny selection, self progeny bulk method, recycling maize inbred, double haploid etc. are various breeding approaches may be followed during extraction of elite inbred lines from various source populations.

Testing of inbred lines

Fixed inbred lines are need to be characterized for use as good pollen, seed parent and both (pollen as well as seed parent) before their use in hybrids development. Good pollen parent should have lax tassel with long main branch and profuse secondary branches. It should be long pollen shedder, preferably taller than female, should have attractive grain colour, good yield potentials, better root system and resistant to various abiotic and biotic stresses. However good seed parent should be productive, strong, with preferably low cob placement, shorter ASI, nutrient responsive, stay green trait, erect leaves, strong root and shoot system and should also be resistant to various abiotic and abiotic stresses. Selected inbred lines are needed to be evaluated in all the seasons (*kharif, rabi* and spring). This will help the breeders to identify the lines perform better across the seasons. Use of inbred lines in hybrids breeding programme is also depends upon their combining ability with other parental lines. Only selective inbred lines are prove to be good combiners. Therefore testing of lines for their combining ability is another important activity in maize hybrids breeding which can be done in early generation of development (S_2 to S_4) or at later stages when breeding lines are fixed and becomes inbred lines. Early testing of breeding lines can be conduct during S_2 to S_4 generations of selfing, which help the breeders to discard the lines show poor performance in hybrid breeding programme. S_3 generation of selfing is the more common stage being use and help the breeders to discard the lines showing poor combing ability. Based on the early testing of breeding lines, about 50% lines are rejected, which further help to make the inbred lines development programme very efficient. During testing of lines for their combining ability, they are cross in specific mating design viz., line x tester, diallel, partial diallel and crosses progenies are evaluated for their *per se* performance in replicated trials, which help to know the combining ability of the breeding lines. Based on the top cross progenies performance of breeding lines in replicated trials, they are selected or rejected. Finally selected inbred lines are use for crossing programme to develop hybrids.

Development of single cross hybrids

One of the major achievements in plant breeding has been the exploitation of heterosis through commercial cultivation of maize hybrids. Inbred found better combiner (specific or general) are crossed in specific combination to develop hybrids. There are different types of hybrids viz., single cross (I_1 x I_2, I denoting an inbred), modified single cross [(I_1 X I'_1) X I_2, I' denoting the sister lines], three way cross [(I_1 X I_2) X I_3] , modified three way cross [(I_1 X I_2) X (I_3 X I'_3)] and double cross [(I_1 X I_2) X (I_3 X I_4)] (Sleper and Poehlman, 2006) are beings developed and cultivated in maize in contrast to other crops. A cross between two varieties is a varietal hybrid and between variety and an inbred line is a top cross hybrid. Among all types of hybrids, at present single cross hybrids are mostly been used commercially. Large number of single cross hybrids developed finally can be tested in a station trials using augmented design. Station trials can be repeatedly evaluated across all the seasons (kharif, spring and rabi) against the identified national and zonal checks. High yielding hybrids can be further entered into national system of testing under AICRP trials.

Testing of experimental hybrids under AICRP trials

Before identification, release and notification, all the varieties (single cross hybrids, open pollinated varieties, synthetic etc.) have to undergo three years of multi-locations testing [(Initial Varietal Trial (IVT), Advance Varietal Trial-I (AVT-I) and Advance Varietal Trials –II (AVT-II)] under all India coordinated research project (AICRP),(DMR, 2013) in which varieties are evaluated for their *per se* performance against the recommended checks in various trials. In each maturity trial (late, medium, early and extra early), the latest released hybrids for a zone along with the national checks shall be used for the comparison of the performance of test entry. The entry found superior (5% in late maturity, 10% in medium, early and extra early) over the best check shall be promoted for next phase of testing. The entry belonging to quality protein maize (QPM), baby corn, sweat corn and popcorn, will be evaluated in specific trials of quality protein maize (QPM), baby corn, sweat corn and popcorn.

Advantages of single cross hybrids

Single cross hybrids are highest in yield potential, genetically uniform, most acceptable to farmers and farmers cannot be cheated. Generally, single cross hybrids shows better adaptation under climate change, tolerant to biotic and abiotic stresses, quick and higher percentage of germination, easy seed production and low cost of production, export potential and employment generation. The adoption of this technology has made maize a global productive crop. The cultivation of high yielding, stress resistant/tolerant single cross hybrids offers viable, sustainable and profitable option for Indian farmers.

Seed production

Production of hybrid seed in maize is an unique and dynamic industry worldwide. The productive inbred lines are the base of efficient hybrid seed production in maize. Therefore sufficient time and resources must be allocated for productive inbred lines development. Good field management practices as well as adequate site selection is also an important part of hybrid seed production. Proper plant protection, timely visit of field at critical stages, effectively removing off types, required male and female ratio and proper detasseling of female parent must be done at appropriate time. Proper isolation distance of at least 400-500m must be maintained in the field. There should be no any maize varieties or genotypes with in the area of 400 to 500m. Male and female ratio in the field is depending upon pollen shedding ability and duration of pollen parent. Based on pollen shedding ability and duration, this ratio varies from 1 (male):2 (female); 1 (male):3 (female); and 1 (male):4 (female).

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21. Genetic engineering in maize improvement

Pranjal Yadava

The improvement of crops with the use of genetics has been occurring for years. Traditionally, crop improvement was accomplished by selecting the best looking plants/seeds and saving them to plant for the next year's crop. Once the science of genetics became better understood, plant breeders used what they knew about the genes of a plant to select for specific desirable traits. This type of genetic modification, called traditional plant breeding, modifies the genetic composition of plants by making crosses and selecting new superior genotype combinations. Traditional plant breeding has been going on for hundreds of years and is still commonly used today. The "sharing" of DNA among living forms is well documented as a natural phenomenon. For thousands of years, genes have moved from one organism to another. For example, *Agrobacterium tumefaciens*, a soil bacterium known as 'nature's own genetic engineer', has the natural ability to genetically engineer plants. Crops developed through genetic engineering are commonly known as transgenic crops or more commonly as genetically modified (GM) crops. GM crops have been developed for various traits like herbicide tolerance, insect resistance, virus resistance, drought tolerance, nutritional enrichment, etc.

Status of GM maize

Every year, farmers of more than 15 countries grow various GM maize cultivars in an area of about 55.1 million hectares *i.e*. 35% of its global maize acreage. Maize is the crop with maximum number (75) of transgenic events approved for commercial cultivation. It is the crop with maximum number of stacked genes being deployed. The world's first drought tolerant GM crop to be approved is maize. More than 80% of area planted in USA, Canada and Argentina is under GM cultivars. GM traits like multiple insect resistance, herbicide tolerance, drought tolerance, enhanced lysine, modified amylase and male-sterility are already available to maize growing farmers of many countries for cultivation. Other important traits like next generation of insect resistance, nitrogen-use efficiency, low phytate, high oil, bio fortification, etc. are in advanced R&D pipeline. It is clear that the Indian farmers would lose the competitive edge *vis-a-vis* their global peers, if such traits are not made available to them at the earliest. In India, multi-locational field trials of GM maize for insect resistance and herbicide tolerance traits were conducted till 2012. Stem borer resistant GM maize developed by the Directorate is also undergoing greenhouse trials. There are several opportunities for public-funded research institutes, to come up with trait specific 'non-proprietary' GM cultivars, especially for resource poor small and marginal farmers.

The regulatory process for GM maize field trials in India and the role of state departments of agriculture

India has a well established regulatory process for conduct of genetic engineering research. Since agricultural research is a state subject as per the Constitution of India, the state departments of agriculture are playing an important role in conduct of the field trials of all GM crops, including maize. Field trials are an important component of the process for approval of any GM crop cultivar for commercial cultivation. These trials represent the first controlled introduction of a GM crop into the environment falling in between experiments in contained facilities and commercial release to farmers.

The activities involving GM crops are regulated under the "Rules for the manufacture, use/import/export and storage of hazardous microorganisms/genetically engineered organisms or cells" notified under the Environment (Protection) Act, 1986, commonly referred as Rules, 1989. These rules and regulations are implemented by the Ministry of Environment and Forests (MoEF) and Department of Biotechnology (DBT) and State departments of agriculture. Six competent authorities and their composition have been provided for in the Rules to handle various aspects i.e., Recombinant DNA Advisory Committee (RDAC), Review Committee on Genetic Manipulation (RCGM), Genetic Engineering Approval Committee (GEAC), Institutional Bio safety Committee (IBSC), State Biotechnology Coordination Committee (SBCC) and District Level Committees (DLCs).

While the RDAC is advisory in function, the IBSC, RCGM, and GEAC are of regulatory function. IBSC keeps a close watch on all GM research from conception to commercialization at the institute level. SBCC and DLC are for monitoring purposes. In addition to the above, a Monitoring cum Evaluation Committee (MEC) has been set up by the RCGM to monitor the field performance of GE crops.

The initial assessment of an application for a confined field trial begins at the institutional level itself. Based on information generated by the applicant in the laboratory and the greenhouse, an application is made to the IBSC for permission to conduct a confined field trial. The IBSC evaluates the proposal for conducting a field trial and, if recommended by the IBSC, the applicant may submit the application to RCGM.

RCGM, functioning in the DBT, is the Regulatory Authority for Bio safety Research Level I (BRLI) trials. These trials are limited in size to no more than 1 acre (0.4 ha) per trial site location and a maximum cumulative total of 20 acres (8.1 ha) for all locations for each plant species/construct combination (e.g., one or more events originating from transformation of a plant species with the same genetic construct), per applicant, per crop season.

GEAC, functioning in the MoEF, is the Regulatory Authority for Bio safety Research Level II (BRLII) trials. These are limited in size to no more than 2.5 acres (1 ha) per trial site location and number of locations to be decided on a case by case basis for each plant species/construct combination (e.g., one or more events originating from transformation of a plant species with the same genetic construct), per applicant, per crop season. An application to GEAC for the environmental release of a new event will not be considered unless the applicant has completed:

- First crop season of confined field trials at the level of Bio safety Research Level I to be followed by;
- Second crop season of confined field trials at the level of Bio safety Research Level I or Bio safety Research Level II.
- Third crop season of confined field trials at the level of Bio safety Research Level II.

Since, 2010, the applicant cannot conduct field trials even after approval of GEAC, unless given a No Objection Certificate (NOC) by the state department of agriculture of the concerned state. Therefore, now it is necessary for officials of the state departments of agriculture to know the detailed scientific aspects of GM crops for better regulation and monitoring.

22. Popular Agricultural Extension Methods

Shailesh Kumar Mishra

Field days/visits, campaigns, exhibitions and *kisan melas* are the popular agricultural extension methods which are commonly used by extension workers.

Field days/visits

It is a method in which a group of interested farmers accompanied and guided by an extension worker, goes on tour to see and gain first-hand knowledge of improved practices in their natural setting. The purpose of field days is

- To stimulate interest, conviction and action in respect of a specific practices.
- To impress the group about the feasibility and utility of a series of related practices.
- To induce a spirit of healthy competition by showing the accomplishments in other villages.

Procedure

- Provide for field trips at opportune time in the overall teaching plan.
- Prepare an outline of specific aims of the trip.

Conduct of visit

- Give guide sheet in a simple language.
- Focus attention on the purpose of the trip.
- Let everyone see, hear, discuss and if possible participate in activities at the places of visit.
- Allow time for questions and answers.
- Help them to make notes of interesting information.
- Follow the general instructions regarding conversation applicable to all direct contact methods.
- Avoid accidents.
- Adhere to schedule all through.

Characteristics of quality field visits/days

- Field Visit should be highly structured and organized.
- Trainees are required to turn in a written description of what they experienced.
- Trainees did not just listen the field visit/tour. They should actively involve in the learning experiences.
- The field visit/tour should directly relate to learning objectives and previous and future lessons.

Advantages

- Participants gain first-hand knowledge of improved practices, and are stimulated to action.
- Eminently suited to the "show me" type of people.
- Percentage of "takes" to exposure is high.
- Widens the vision of farmers.
- Caters to group psychology and leadership.
- Have incidental values of entertainment and sight-seeing.

Campaign

Campaign is an intensive teaching activity undertaken at an opportune time for a brief period; focusing attention in a concerted manner on a particular problem, with a view to stimulate the widest possible interest in a community, block or other geographical area.

Procedure

Determine the need for a campaign. Be clear about the purpose.

Make sure that it fulfills the need of local people.

Conduct the Campaign

- Ensure that campaign is carried out as per plan.
- Work with and through local leaders.
- Watch the campaign closely throughout.
- Avoid failures.

Advantages

- Especially suited to stimulate mass scale adoption of an improved practice in the shortest time possible.
- Facilitates exploitation of group psychology for introducing new practices.
- Successful campaigns create conductive atmosphere for popularizing other methods.
- Builds up community confidence.
- This method is of special advantage in the case of certain practices which are effective only when the entire community adopts them.

Exhibitions

An exhibition is a systematic display of models, specimens, charts, posters etc. in a sequence so as to convey some significant information or idea in an easily understandable way to the onlookers.

Purpose

The purpose of an exhibition is to catch attention, convey an idea and stimulate action on the part of the farmers looking at the displays.

Objectives

- To acquaint people with better standards.
- To create interest in a wide range of people.
- To motivate people to adopt better practices.

General suggestions for preparing effective exhibits and displays

- Keep very few elements in an exhibit and focus only on one idea or theme.
- Use a combination of real objects, models, focus illustrated material and written words.
- Keep written material to a minimum. Use only enough captions and words to tell the idea clearly. Vary size, colour and style of lettering to create interest. But keep the lettering simple, clear and bold.
- Use two or three vivid colours against a neutral background.
- Place the centre of interest near eye-level i.e. about five feet above ground level.

Advantage of an Exhibition

- Exhibitions are one of the best media for reaching large audience and illiterates.
- Exhibition has publicity value where a new project or activity is being initiated.
- Exhibitions have an imaginative appeal.
- Exhibitions cater to the needs of a mixed group.
- Exhibitions fit into festive occasions and can serve recreational requirements.
- Exhibitions promote creative ability.
- Exhibitions can stimulate healthy competitive spirit when intended for the purpose.

Kisan melas

The following are some of the activities that must be arranged:

- Effective field demonstrations of improved practices related to crop production, subsidiary occupations along a well-laid-out and convenient route.
- Arrangements for providing guided visits to all demonstrations sites, standing crops, orchards, etc.
- Arrangements for collection and testing of soil and water samples brought by the farmers.
- Setting up an agricultural clinic.
- Setting up agro-home-industrial exhibitions.
- Organizing a question answer session.
- Sale of improved seeds in small packets.
- Sale of extension publications.
- Provision of farm machinery-use competition and home craft competitions.
- Organizing a produce competition in which farmers being their produce samples and are awarded prizes or certificates.
- Arrangements for a select number of rural sports, that are popular among rural people of the area and are easy to organize.
- Providing some basic amenities such as cloak room, drinking water, arrangements for food and night stay etc.

Points to be kept in mind while organizing Kisan Melas

- Co-ordinate efforts of a number of departments, organizations and persons. Develop a theme for each fair, set up an organizational committee to prepare and issue policy guidelines, and to set up a number of committees for each major function or activity. Co-ordination of all such committee should be done by organization.
- Adequate publicity through radio, television, newspapers and posters is a prerequisite to ensure a large attendance at the mela.
- On the day of the mela, a control room may be setup for the various organizers. An information counter may also be set up for farmers to seek information.
- During the mela, efforts should also be made to know the extent and kind of farmers' participation, their reactions and the knowledge and skills they obtained from the fair.
- Farmers should be treated as the most distinguished visitors at such fairs.

23. Maize AGRI *daksh:* A web based expert system

V.K. Yadav, K.P. Singh, S.L. Jat, J.C. Sekhar, Laxmi Saujanya, Abhijit Kumar Das and Robin Gogoi

Maize is the third most important cereal in India after paddy and wheat. The national productivity is 2.47 t/ha, whereas the world average productivity is 5.07 t/ha during 2011-12 (Anonymous, 2011). The reason for low productivity is cultivation of low yielding local varieties/ composites/ double cross hybrids in majority of areas. Moreover lack of access to seed and other inputs, underdeveloped markets, and low investment in research and extension worsen farmers' marginalization. With the growing population and high farmer to extension worker ratio, there is a great need for an intuitive knowledge based system, which may suggest suitable solutions to the farmers. Conventional extension approaches has not been able to fulfill the ever increasing expectations of farming communities due to time and money constraints. The use of computer based information system may meet the socio-economic and information need of farming community. Expert system on maize attempts to capture the knowledge of human experts and make it available through computer programme.

An "Expert System" is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require human expertise for their solution (Feigenbaum, 1982). The knowledge necessary to perform at such a level plus the inference procedures used can be thought of as a model of the expertise of the best practitioners in the field. Expert system is designed to simulate the problem-solving behavior of a human who is an expert in a domain or discipline. An expert system is normally composed of a knowledge base (information, heuristics, etc) inference engine (analyzes the knowledge base), and the end user interface (accepting inputs, generating outputs).

Developing an expert system in a specific knowledge domain is quite a difficult task as it requires team of experienced knowledge engineers, programmers as well as domain experts. Agriculture, being a very vast and varied domain of knowledge with over a hundred crops distributed in different geographic regions having varied climatic conditions, building such a team in every domain of knowledge of agriculture is itself a challenging and huge task. Knowledge engineers gather knowledge from domain experts and put it in such a form that system can use for inferring and reasoning using a knowledge representation technique. Programmers then build an online interface so that the end users can use the system over the Internet.

AGRI*daksh* is a tool for building online expert system. With its use, it is possible to build online expert system for each and every crop in significantly less time and resources. Online expert systems have the capability to transfer location specific technology & advice to the farmers efficiently and effectively. The specific objective is to develop information and expert system of maize that can give solutions to the farmer's queries and can reduce losses due to diseases and pests infestation, improve productivity with proper variety selection and increase in income of the farmer.

Development of information and expert system of maize

For developing Expert System of Maize, the already existing Expert System of Extension (Marwaha, *et al*., 2002) was strengthened for the maize crop. The path that leads to the development of expert systems is different from that of conventional programming techniques. The concepts for expert system development come from the subject domain of artificial intelligence (AI), and require a departure from conventional computing practices and programming techniques. A conventional program consists of an algorithmic process to reach a specific result. An AI program is made up of a knowledge base and a procedure to infer an answer. One of the most powerful attributes of expert system is the ability to explain reasoning. Since, the system remembers its logical chain of reasoning, a user may ask for an explanation of a recommendation and the system will display the factors it considered in providing a particular recommendation.

Expert System of Extension was designed using n-tier architecture. The system have browser based user interaction layer, the server side application logic layer (ALL), the inference engine layer and the RDBMS knowledgebase. Expert System of Extension was built using Java technology. The user interaction layer was built using HTML, CSS and JavaScript while knowledgebase was in SQL Server 2000. Application Logic Layer was built using Java Server Pages (JSP). It contains all the necessary logic for interaction among front end (knowledge acquisition & explanatory interface), inference engine and the knowledge base. It also hides all the implementation level details of the inference procedure and knowledge fetching and thus provides formatted result to the user interface.

The main focus was to build a web based tool named 'AGRI*daksh*' for developing expert systems of various crops. The AGRI*daksh* was in turn used to develop information and expert system for maize crop called Maize AGRI*daksh*. Administrator of AGRI*daksh* can create multiple users with different authorization rights. There are five types of users in AGRI*daksh* viz. Administrator, Crop Administrator, Domain Expert with Validation Rights, Domain Experts and Farmers. Creation of new expert system for a specific crop say maize starts with building a Knowledge Model for that crop. Knowledge Model can be build by Administrator or Crop Administrator only by selecting various attributes specific to that crop. Once, the main attributes are selected from the comprehensive list provided in the system which is also expandable, one can enter various attributes values corresponding to varieties of that crop. The system also has capability to store and manage extensive information on diseases, pests, nematodes, weeds and physiological disorders etc. The system has modules for post harvest technologies and farmer's question & feedback.

For building the Expert System of Maize, the knowledge was captured as per the activity chart from the domain experts. The knowledge was stored in text format as well as in decision tree format. The acquired knowledge was validated after entering it in the system. The expert system was then tested for any possible errors or shortcomings. The Expert System of Maize was demonstrated in different workshops and made available to the farmers and other stake holders through Internet.

Keeping in mind the user friendliness, Maize AGRI*daksh* was designed in the following modules:

- Knowledge Model Creation
- Knowledge Acquisition
- Problem identification
- Knowledge retrieval
- Ask Questions to Experts Administration

Knowledge model creation

First step for building an expert system of a crop through AGRI*daksh* was to build its knowledge model. Knowledge model was built by selecting the desired attributes from the Attributes List and moving them to Selected Attribute List. Once the desired attributes are chosen, domain experts can enter the values of these attributes for each and every variety of the crop.

Knowledge acquisition

Knowledge Acquisition module was used for entering knowledge about various entities such as crop varieties, diseases, insect-pests, weeds, nematodes, physiological disorders and post harvest technology.

Problem Identification:

This module has two sub modules viz., Rule based problem identification and Ontology based problem identification. First sub module allows the domain experts to define the problem and develop decision tree to solve the problem. Once the tree is developed, farmers can get the solution about the problem in their situation. The second sub module allows the farmers to identify the diseases and insects affecting their crops as well as select varieties according to their location and conditions.

Knowledge Retrieval

Knowledge Retrieval module is the most important module as far as farmers are concerned. Through this module, a farmer can get information about everything that domain experts have entered e.g., plant protection sub module allows farmers to retrieve knowledge about diseases, insects, weeds, nematodes and physiological disorders.

Ask questions to experts

Using this module a farmer can ask a question directly to domain experts. The system transfers the question to relevant domain experts and sends answer to the farmer through email. The same is displayed in the system for the benefit of other farmers.

Administration

This module is for the administrator for controlling the overall functionality of the system. Using this module administrator can create different type of users such as end users, domain experts, domain expert validators, and crop administrator. One can add a new crop and assign a crop administrator for that crop.

How users can access expert system of maize

Website of expert system of maize (maize AGRI*daksh*) is www.agri*daksh*.iasri.res.in . It is also linked with website of DMR (www.dmr.res.in) and IASRI (www.iasri.res.in). Internet users can easily open it by typing www.agri*daksh*.iasri.res.in in google (or any other search engine) followed by clicking enter button. Maize Directory, technical bulletins of DMR, value addition in maize, etc. are uploaded in the system which can be easily accessed by clicking respective icon. Farmers can select suitable variety for their locality by clicking *varieties* icon (Map 2). They can also access information related to diseases, insects, weeds, etc by clicking *problem identification* icon. Users can see questions and reply given by experts by clicking *expert response* icon. They can provide feedback or ask questions by clicking feedback/ask questions icon. Users will get answer in their e-mail through system.

Conclusion

AGRI*daksh* acts as one system for all crops with ability to create knowledge models for new crops. Maize AGRI*daksh* gives location specific variety information with the ability to add multiple pictures for each variety. It has comprehensive plant protection sub module with Diseases, Insects, Weeds, Nematodes and Physiological disorders. It facilitates the domain experts to define problems and create decision trees to solve the problems through Ontology based diseases and insects identification and variety selection and also has ability to add static web pages. It is very useful system for speedy dissemination of information, technology, etc to the farmers at global level.

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24. Frontline demonstrations and their impact on maize productivity

V.K. Yadav, Avinash Singode, Manohar B. Dhadwad, Rachna Choudhary, Kailash Chand Kalvaniya and H.S. Tripathi

The Directorate of Maize Research is disseminating maize technologies and providing extension service to the nation through frontline demonstrations. Under this programme maize technologies are demonstrated at farmers' field by the farmers under close supervision of scientist in unit acre of land for increasing production and productivity of maize. The ultimate aim of this programme is to accelerate the adoption of maize technologies by the farming community. This programme is financed by Ministry of Agriculture, Government of India under Integrated Scheme of Oilseeds, Pulses, Oil palm and Maize (ISOPOM).

Genesis of frontline demonstration

Efforts are being constantly made by the maize scientists for development of improved technologies. They developed many technologies so far. Developing only the technology is not solution of problems faced by farmers but its dissemination to the end-users is equally important. For effective dissemination of technologies, Ministry of Agriculture, Government of India commenced Frontline Demonstration (FLD), which is financed by Ministry of Agriculture, Government of India. It is conducted at farmers' field by the farmers under close guidance of maize scientists of state agricultural universities/ICAR institutes/ non-governmental organizations with coordination of Directorate of maize research.

Concept of FLD

The concept of FLDs was introduced with the purpose of improving the adoption behavior of farmers related to improved maize production technologies and to harvest the maximum yield potential in real farm conditions. It ensures free supply of essential farm inputs, guidance by scientific community to avoid partial and non-adoption of recommended technologies, monitoring the performance of the crop at critical stages, extending the cultivation of improved varieties, getting the feedback from farmers involved in FLD trials regarding constraints in adoption of recommended improved technologies for further research and to maximize the technology dissemination process among the farming community. The ultimate aim of this programme is to accelerate the adoption of maize production technologies by the farming community through multiplier effect generated by these demonstrations.

Seeing is believing and learning by doing are the basic tenets of frontline demonstrations. The FLDs provide an effective learning situation as the farmers observe the technologies, practice it and interact with the scientists and extension functionaries. Successful demonstrations motivate farmers for adoption of demonstrated technologies. Availability of essential inputs, marketing facility and technical guidance helps in confidence development among farmers in using the technologies.

Frontline Demonstration is a participatory research, emphasizing scientist-farmer interaction, refine and validate research findings with the help of ICAR institutes, SAUs and NGOs, bring knowledge equity, develop leadership amongst farmers for multiplier effect to horizontally disseminate technology.

Objectives of FLDs

- To demonstrate and convince the farmers about production potential and benefits of adopting the latest maize production technologies under real farm situation.
- Assessing the performance of the technologies in the socio-economic conditions of the farmers.
- To provide feedback to maize research system about the constraints in adoption of the new technologies by the farmers and to enable the maize research system to take corrective measures and generates relevant technologies accordingly.

Steps involved in conducting FLD

For conducting FLDs in maize four steps involved (Figure 1) and are described below:

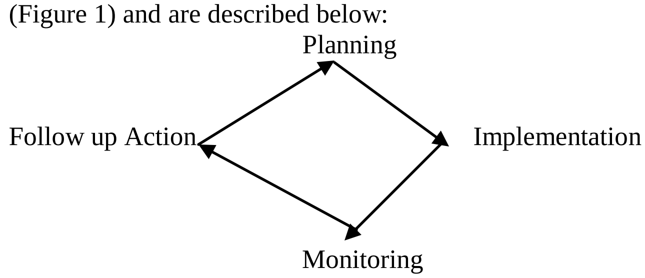

Figure 1. Steps involved in FLD

Planning for FLD

Survey should be conducted to know:

- The socio-economic conditions of the farmers.
- Farming situations under which crop is grown.
- The existing level of adoption of technologies. This will serve as broad benchmark for planning of demonstration work.
- Demonstration site and demonstrating farmers should be selected. Site should be easily accessible.
- Critical inputs for the demonstration of technologies should be identified and arranged in time.

- An orientation training may be organized for half a day for all the participating farmers about all aspects of technologies and methodologies including aims and objectives of the demonstrations so that there is clarity for how to do demonstrations.

Implementation of Demonstration

- Prior to the implementation of the demonstrations, all participating agencies may be informed and invited well in advance about the date and venue including the demonstrating farmers. On this occasion, the neighboring farmers may also be invited and should be educated about the details of the technologies, objectives of the demonstration etc.
- All the important farm operations may be carried out by the demonstrating farmers under the close supervision and guidance of the scientist(s)-in-charge of the demonstrations. The concerned scientists may also be invited and should be educated about the details of the demonstration. Sowing of the crop must be done in the presence of scientists and participating farmers.
- When the demonstration plot is at maturity, the “Field Day” may be organized. Neighboring farmers including farm women and extension workers may be invited. A question-answer session among the scientists, farmers and extension workers may be organized.
- The concerned scientist/expert is expected to keep record of all necessary data and various expenditure incurred on inputs.

Monitoring

It is required for recording observation, getting the feedback from the farmers and the extension workers. Scientists / Officers of the ICAR system, SAUs, Ministry of Agriculture and the State Department should make occasional visits to such demonstration for getting direct feedback and offering suggestion and guidance.

Follow up Action

- The results of the demonstration may be properly documented, reported and circulated among all the concerned personnel, demonstrating farmers etc.
- A success story may be published in newspapers / magazine preferably in local language for the benefit of other farmers.
- Impact assessment of FLDs may be conducted to find out progress, reasons of rejection, discontinuance of technologies etc. Effective measure may be taken up for improving the demonstrations.

Major Technologies demonstrated in FLDs

- High yielding hybrid and composite varieties
- Production Technologies a. Kharif maize b. Rabi maize c. Spring maize d. Quality protein maize e. Specialty corn (Baby corn, Sweet corn, Pop corn)
- Intercropping
- Seed Production
- Maize for green cob
- Conservation agriculture (e.g. zero tillage, bed planting, etc.)
- Integrated Pest Management, etc.

Impacts of FLDs

The data of Table 1 and Figure 2 indicate yield gain in FLDs over national average yield and state average yield of maize. It shows that Average yield of maize in FLD plots is almost double than national average yield of maize. It indicates scope of doubling productivity of maize. Area, production and productivity of maize have increased over the years. FLDs may be one important contributing factor for spread of improved maize technologies.

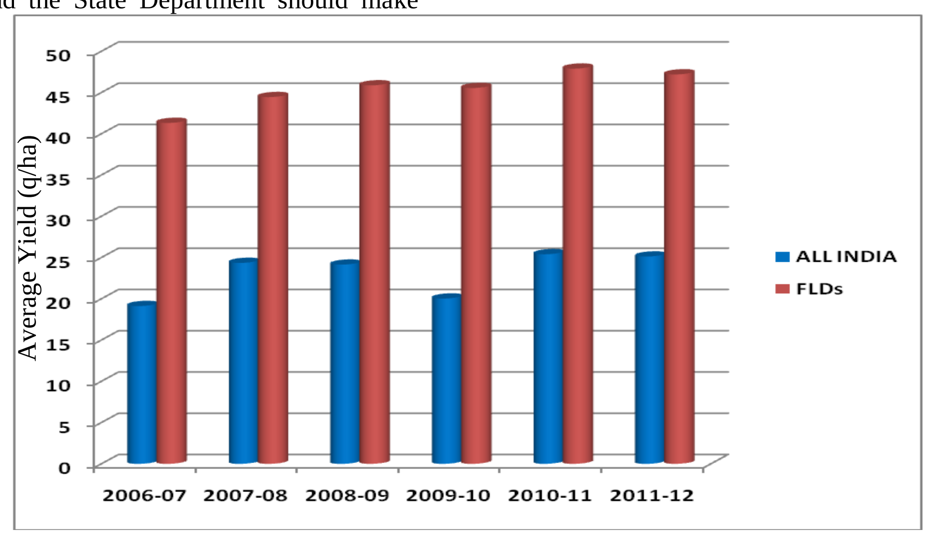

Figure 2. Yield Gain in FLDs over National Average

Table1. Yield gain in FLDs over state average

State	Years	Farmers' Yield/ State Average Yield (kg/ha)	Average Yield of FLDs (kg/ha)	Yield Gain (%)
Andhra Pradesh	2008-09	4873	5847	19.99
	2009-10	4123	6120	48.44
	2010-11	3527	6423	45.09
	2011-12	5317	5363	0.86
Arunachal Pradesh	2011-12	2540	5405	138.5
Assam	2011-12	722	4763	559.70
Bihar	2008-09	2676	5270	96.94
	2009-10	2892	3960	36.93
	2010-11	2341	5324	127.42
	2011-12	2230	5000	124.21
Chhattisgarh	2008-09	1402	4515	222.04
	2009-10	1399	3906	179.20
	2010-11	1399	4258	204.36
	2011-12	1807	4230	134.09
Gujarat	2008-09	1481	3947	166.51
	2009-10	985	2940	198.48
	2010-11	1072	3391	216.32
	2011-12	1637	2905	77.46
Haryana	2011-12	1900	4980	162.10
Himachal Pradesh	2007-08	2873	3496	21.68
	2008-09	2273	3932	72.99
	2009-10	1233	3698	199.92
	2010-11	1839	3812	107.29
	2011-12	2263	3640	60.85
Jammu & Kashmir	2008-09	2005	4248	111.87
	2009-10	1894	2566	35.48
	2010-11	1566	4739	202.62
	2011-12	1712	4455	160.22
Jharkhand	2011-12	1215	2369	94.98
Karnataka	2007-08	2924	6121	109.34
	2008-09	2833	5995	111.61
	2009-10	2647	5320	100.98
	2010-11	2430	5930	144.03
	2011-12	3450	5815	68.55
Madhya Pradesh	2007-08	1288	4463	246.51
	2008-09	1361	3404	150.11
	2009-10	1106	4022	263.65
	2010-11	1256	3236	157.64
	2011-12	1266	4464	252.84
Maharashtra	2007-08	2664	5113	91.93
	2008-09	2382	4957	108.10
	2009-10	1980	4730	138.89
	2010-11	2302	4560	98.09
	2011-12	2920	5141	76.06
Manipur	2011-12	2540	3414	34.41
Meghalaya	2011-12	2540	3780	48.82
Nagaland	2011-12	2540	3014	18.66
Odisha	2007-08	1986	3150	58.61
	2008-09	2007	4410	119.73
	2009-10	2158	-	-
	2010-11	2156	4651	115.72
	2011-12	2550	3971	55.72

State	Years	Farmers' Yield/ State Average Yield (kg/ha)	Average Yield of FLDs (kg/ha)	Yield Gain (%)
Punjab	2007-08	3405	5737	68.49
	2008-09	3404	4409	29.52
	2009-10	3417	-	-
	2010-11	3417	5041	47.53
	2011-12	3692	4764	29.04
Rajasthan	2007-08	1860	2943	58.22
	2008-09	1736	3283	89.11
	2009-10	1045	2836	171.39
	2010-11	1044	3423	227.87
	2011-12	1796	3350	86.52
Sikkim	2011-12	25.40	44.96	77.01
Tamil Nadu	2007-08	3627	5750	58.53
	2008-09	4389	5403	23.10
	2009-10	3951	4950	25.28
	2010-11	4686	6146	31.16
	2011-12	4458	6910	55.00
Tripura	2011-12	2540	2789	9.80
Uttar Pradesh	2007-08	1443	5144	256.48
	2008-09	1499	4815	221.21
	2009-10	1438	4086	184.14
	2010-11	1465	4567	211.74
	2011-12	1477	5276	257.21
Uttarakhand	2011-12	1503	3554	136.46
West Bengal	2010-11	3943	4928	36.61
	2011-12	3974	4824	21.39

How farmers can get benefit from FLD Programme?

Government of India is implementing FLD Programme in different crops (e.g. paddy, wheat, maize, pulses, oilseeds, etc.). Frontline demonstration in maize is being implemented throughout country by the Directorate of Maize Research with help of different centers of All India Coordinated Research Project (AICRP) on maize and nongovernmental organizations (NGOs). As per norms of Govt. of India, technical guidance along with essential critical inputs (e.g. Seed) is being provided to the FLD farmers free of cost. Interested farmers may consult local maize scientists of AICRP on maize / experts of NGOs / extension scientist of DMR, New Delhi for getting FLD programme for that location. Contact address of AICRP centre on maize is mentioned in maize Directory in website of DMR (www.dmr.res.in).

Conclusions

Maize technologies are being transferred from lab to field through FLDs in collaboration of AICRP centres on maize, Krishi Vigyan Kendras and nongovernmental organizations. Area under hybrid and national productivity of maize are increasing through adoption of improved technologies by farmers. More emphasis should be given on poorest of the poor, farmers in tribal areas, hilly areas, neglected areas, etc. so that they would also be benefitted through available technologies. There is need to work hand in hand with all partners (e.g. seed companies, NGOs, researchers, farmers etc.) of technology dissemination for increasing maize production, removing hunger and malnutrition, generating employment opportunities and augmenting income level of farmers.

25. Integrated farming systems for livelihood security of small and marginal farmers

U.K. Behera

To meet the multiple research objectives of poverty reduction, food security, competitiveness and sustainability, several researchers have suggested farming systems approach *(*Byarlee *et al.*, 1982*;* Shaner *et al*. 1982 and *Goldsworthy* and Vries, 1994*)*. A farming system is the result of complex interactions among number of interdependent components, where an individual farmer allocates certain quantities and qualities of four factors of production namely, land, labour, capital and management to which he has access *(*Mahapatra, 1994*)*. Farming system research is considered as a powerful tool for the natural and human resource management in developing countries including India. This is a multidisciplinary whole farm approach and very effective for solving the problems of small and marginal farmers *(*Gangwar, 1993*)*. This approach aims at increasing income and employment from small-holdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Behera and Mahapatra, 1999). With this approach, the synergy among interacting components of farming systems is explored. Under the gradual shrinking of land holding, it is required to integrate the land based enterprises like fishery, poultry, duckery, apiary, field and horticultural crops *etc*. within the bio-physical and socio-economic environment of the farmers to make farming more profitable, dependable and environmentally sustainable (Behera *et al*., 2004).

Indian economy is predominantly rural and agriculture oriented where the declining trend in the size of land holding poses a serious challenge to sustainability and profitability of farming. In view of the decline in per capita availability of land from 0.5 ha during 1950-51 to 0.15 ha by the turn of the century and further decline to less than 0.1 ha by 2020 AD, it is imperative on the part of National Agricultural Research System to develop such strategy and agricultural technology to be able to generate adequate employment and income, specially for small and marginal farmers who constitute more than 80% of the farming community (Jha, 2003). Devendra (2002) emphasized on farming system analysis and multidisciplinary research for the development of small farmers. Much of the research conducted by National Agricultural Research System in Asia lacks farming system perspective and disciplinary barrier exists in all institutions. No single farm enterprise shall be able to sustain predominantly small and marginal farmers in the country, without resorting to integrated farming systems for generation of adequate income and gainful employment round the year (Mahapatra, 1992 and 1994). The farming system research, therefore, is a potential approach to address the problems of small farmers and management of natural resources in an eco-friendly manner for sustainable economic growth of farming communities of developing countries including India in the 21st century.

Why farming systems research

During the last 4-5 decades of agricultural research and development in India, major emphasis was given for component/commodity based research involving developing animal breed, farm implement, crops' variety and farm machinery which were mostly in isolation and at institute level. This component, commodity and discipline-based research proved inadequate to address the multifarious problems of small farmers (Jha, 2003). Due to such approaches, several ills in farming appeared, such as decreasing factor productivity, declining resource use efficiency, declining farm profitability and productivity (Sharma and Behera, 2004, Chopra, 1993). Environmental degradation including ground water contamination and entry of toxic substances in the food chain became the major problems.

The emerging problems in Indian agriculture call for a holistic approach to research and development efforts. It has been largely recognized farming system research, a holistic approach for the efficient management of the available resources with the small and marginal farmers and to overcome the above mentioned problems (Jha, 2003; and Gangwar, 1993). In the FSR, small farmers are considered to be clients for agricultural research and development of technology (Chambers and Ghildyal, 1985). Integrated farming systems are often less risky, because if managed efficiently, they benefit from synergisms among enterprises, a diversity in produce and environmental soundness (Lightfoot, 1990; Pullin, 1998; Prein *et al*., 1998).

Improved agricultural technologies, even when considered as technically sound, are of limited value if they are not adopted by the farming community. In the absence of adequate attention to the understanding of the agro-climatic and socio-economic milieu in which the farmers operate, generated and transferred technologies are found inappropriate to the needs and circumstances of the practicing farmers. The potential beneficiaries, particularly those farmers with limited resources, operating in less favorable natural environment, often do not adopt the new technologies due to various reasons:

- Lack of awareness about the new technology,
- Ineffective extension services,
- Non-representation of their conditions by the research stations where the technologies are developed,

- Lack of resources to invest on the required inputs, and Non-availability of inputs in time,

A less frequently heard explanation is that the recommended technologies themselves are simply not appropriate to farmers and their environment. Farmers, generally, seek those technologies, which increase their income while keeping risks within reasonable bounds under their own circumstances and management practices.

The green revolution strategy mainly concentrated on "better-off" farmers and "better-endowed" areas with greatest potential for increasing agricultural production. The traditional technology generation and transfer models adopted have been found inadequate to meet the specific needs of a vast majority of farmers in developing countries. Research is mostly conducted at research stations under the conditions not representative of farmer's fields, with little or no farmer involvement. Hence is the necessity to conduct Farming Systems Research.

Core Characteristics

Many of the core activities of FSR/E can be operational zed in different ways. The approach is open to multiple interpretations. In spite of the variations in their perceptions about FSR/E among the practitioners, the approach has certain distinctive core characters. These are:

It is problem solving As an applied problem solving approach, it emphasizes on developing and transferring appropriate technologies to overcome production constraints through diagnosis of biophysical, socio-economic and institutional constraints that influence technological solutions.

It is holistic

The whole farm is viewed as a system encompassing interacting sub-systems, and no potential enterprise is considered in isolation.

It acknowledges the location specificity of technological solutions

Recognizing the location specific nature of agricultural production problems, it emphasizes on testing and adaptation of technological solutions based on agro ecological and socio-economic specificities.

It defines specific client groups

Emphasis is made on the identification of specific and relatively homogeneous groups of farmers with similar problems and circumstances for whom technology is to be developed as the specific client groups. On the basis of common environmental parameters, production patterns and management practices, relatively homogeneous recommendation domains need to be identified.

It is farmer participatory it revolves round the basic principle that successful agricultural research and development efforts should start and end with the farmers (Rhoades and Booth, 1982). Farmer participation is ensured at different stages of technology generation and transfer processes such as system description, problem diagnosis, design and implementation of on- farm trials, and providing feedback through monitoring and evaluation.

It gives weightage to ITK system The Indigenous Technical Knowledge (ITK), which is time tested at the farmer's level for sustainability through a dynamic process of integrating new innovations into the system as they arise, has to be properly understood by the scientists and utilized in their research activities.

It is concerned with 'Bottom-up' research strategy it begins with an understanding of existing farming system and the identification of key production constraints.

It is interdisciplinary

It lays greater emphasis on interdisciplinary cooperation among the scientists from different areas of specialization to solve agricultural problems that are of concern to farmers.

Integrated farming

Integrated farming is defined as biologically integrated system, which integrates natural resources in a regulation mechanisms into farming activities to achieve maximum replacement of off-farm inputs, secures sustainable production of high quality food and other products through ecologically preferred technologies, sustain farm income, eliminates or reduces sources of present environment pollutions generated by agriculture and sustains the multiple function of agriculture. It emphasizes a holistic approach. Such an approach is essential because agriculture has a vital role to play that is much wider than the production of crops, including providing diverse, attractive landscapes and encouraging bio-diversity and conserving wild life. Sustainable development in agriculture must include integrated farming system with efficient soil, water crop and pest management practices, which are environmentally friendly and cost effective.

The future agricultural system should be reoriented from the single commodity system to food diversification approach for sustaining food production and income. Integrated farming systems, therefore, assume greater importance for sound management of farm resources to enhance farm productivity, which will reduce environment degradation and improve the quality of life of resource poor farmers and to maintain agricultural sustainability. The aims of the integrated farming system can be achieved by

- Efficient recycling of farm and animal wastes.
- Minimizing the nutrient losses and maximizing the nutrient use efficiency.
- Following efficient cropping systems and crop rotations and Complementary combination of farm enterprises.

The various enterprises that could be included in the farming system are crops, dairy, poultry, goat rearing, fishery, sericulture, agro-forestry, horticulture, mushroom cultivation etc. Thus it deals with whole farm approach to minimize risk and increase the production and profit with better utilization of wastes and residues. It may be possible to reach the same level of yield with proportionately less input in the integrated farming and the yield would be more sustainable because the waste of one enterprise becomes the output of another, leaving almost no waste to pollute the environment or to degrade the resource base. To put this concept into practice efficiently, it is necessary to study linkages and complementarities of different enterprises in various farming system. The knowledge of linkages and complementarities will help to develop farming system (integrated farming) in which the waste of one enterprise is more efficiently used as an input in another within the system.

Goals of Integrated Farming System

The four primary goals of IFS are

- Maximization of yield of all component enterprises to provide steady and stable income at higher levels
- Rejuvenation/amelioration of system's productivity and achieve agro-ecological equilibrium.
- Control the buildup of insect-pests, diseases and weed population through natural cropping system management and keep them at low level of intensity.
- Reducing the use of chemical fertilizers and other harmful agro-chemicals and pesticides to provide pollution free, healthy produce and environment to the society at large.

Sustainable integrated farming system models for different agro-ecosystems

Small farmers are the core of Indian economy. Single farm enterprise is not sufficient to sustain these small and marginal farm families in the country. They have to go for multi-enterprise integrated farming system, which will ensure them adequate income and employment. Number of IFS studies in the different agro-ecosystem in the country reveals that IFS provides higher income, spread or minimize risks, brings better resource use efficiency, and the technologies are eco-friendly in nature.

Rice-poultry-fish-mushroom integration

On-station studies were conducted during 1987-92 (Rangaswamy *et at.,* 1996) taking the marginal farmers' situations in to considerations. Economic analysis of the study of the system under lowland coastal agro-ecosystem of Tamil Nadu in India revealed that a net profit of Rs. 11755/year was obtained from rice-poultry-fish-mushroom integrated farming system (IFS) in 0.4 ha area while in conventional cropping system (CCS) with rice-rice-green manure/pulses gave a net income of Rs 6334/year from the same area. Integrated farming system increased the net income and employment from the small farm holding and provided balance diet for the resource poor farmers.

On-station studies were conducted by Behera and Mahapatra (1999) to develop integrated farming system model for small farmers in eastern Indian with the objectives to bring self sufficiency in farmers' requirement of food and cash; increased income and employment opportunity; recycling of farm wastes and by-products and increasing resource use efficiency through efficient management of resources. The land based enterprises such as dairy, poultry; fishery, mushroom, biogas etc were included to complement the cropping programme to get more income and employment, thus leading to higher social and economic up-liftment. The philosophy of such integrated farming system revolved around better utilization of time, money, resources and family labourers of farm families. The farm family gets scope for gainful employment around the year thereby ensuring good income and higher standard of living. The economic analysis of such studies revealed that from a small farm piece of 1.25 ha area, a net return of Rs 58,367 could be realised from an investment of Rs 49,286 generating 573 man days of employment and with a resource use efficiency of Rs 2.18 per rupee invested.

Singh *et al.* (2006) in their efforts to develop sustainable integrated farming system models for irrigated agro-ecosystem of north-eastern plain zone revealed that rice-pea-okra was the most remunerative cropping sequence with highest rice equivalent yield of 17.88 t/ha and net return than rest of sequences (Rice-Wheat, Rice-Berseem-Sorghum, Rice-Wheat-Moong, Rice-Pea-Onion, Rice-Mustard-Sorghum, Sorghum-Berseem - Maize). The rice based integrated farming system comprising of crop components (Rice-Pea-Okra and Sorghum-Berseem-Maize), dairy, poultry and fishery was the most suitable and efficient farming system model giving the highest system productivity and net return under irrigated agro-ecosystem of eastern Uttar Pradesh. This model generated significantly higher levels of employment than the rice-wheat system only.

Study conducted in farmers field by Gill *et al.* (2005) to develop sustainable integrated farming system models for irrigated agro-ecosystem of north-western plain zone revealed that rice based integrated farming systems involving rice-wheat + poultry + dairy + piggery + poplar + fishery produced significantly higher rice equivalent yield and net return (Rs. 73,973/ha) than conventional practice of rice-wheat, where a return of Rs. 53,221 was obtained. Integrated rice-based farming system also generated an additional income of 48 man days/ha in comparison to only rice-wheat. The additional income and overall profitability of the system was due to the synergistic effect of integration of different enterprises within the system.

For restoration of the degraded ecologies in Hill and Mountain ecosystem in Koraput district of Orissa, Horti-Silvi-pasture system was recommended. This system consisted planting of mango tree along with teak for timber and grasses for fodder purposes. This system was ideal to generate enough income and employment as well as checking the degradation of ecology, and was a suitable alternative to shifting cultivation.

Interactions and resource recycling

Farming system in many of the developed world has become an issue of managing a set of individual enterprises. Individual farm enterprises driven by advancing technology have developed almost in isolation. Industrial inputs in to farming have almost broken the subsystem (enterprise) interaction in farming systems. Certain dependencies between enterprises, of course remain; these are related to the need to distribute scarce resources within the farm business. The management of farm as a system has been neglected to resource acquisition and an allocation problem between (almost) independent enterprises (Dent, 1990).

The farming systems in India and other developing countries are mostly subsistence in nature. The enterprises are existed more in a natural form based on there complimentarity. For example, in fish-duck farming system, a lot of complementarities is observed between duck enterprise and pond ecosystem. The on-station study conducted by Behera and Mahapatra (1999) involving enterprises such as crop, fishery, poultry, duckery, apiary and mushroom production revealed that there is chain of interaction among these enterprises. The by-product of one enterprise may be effectively utilized for the other enterprise, thus ensuring higher and efficient resource use efficiency. A close examination of resource recycling indicate the interdependence of the different components of the total farming system to make the farmer self sufficient in terms of ensuring the family members a balanced diet for leading healthy life and also making farm self sufficient through recycling of by products/wastes. The by-product of dairy (cow dung) forms a major raw material for bio-gas plants. Digested slurry of bio-gas forms a major part of feed of pisciculture for increasing plankton growth as well as supplying valuable manure to raise the productivity of field crops/enrich the soil. The by-product of field crops like paddy straw forms a major raw material for mushroom cultivation. Straw after use in mushroom production is utilized as cattle feed and compost preparation. Similarly, the poultry droppings form an important ingredient of pisciculture for increasing the plankton growth as well as increasing the fertility of land. Even apiary played a role of improvement in pollination, apart from giving a wholesome product like honey to farmers. Therefore, it is dangerous to deal separately in such linked agricultural system. The entire philosophy of integrated farming system revolves round better utilization of time, money, resources and family labourer of farm families. The farm family gets scope for gainful employment round the year, thereby ensuring good income and higher standard of living.

"Farming Systems" represent the integration of farm enterprises such as cropping systems, horticulture, animal husbandry, fishery, agro-forestry, apiary etc. for optimal utilization of farm resources bringing prosperity to the farmers. A judicious mix of cropping systems with associated enterprises to like fruits, vegetables, dairy, poultry, duckery, piggery, goatary, fishery, apiary, sericulture etc. suited to the given agro-climatic conditions and socio-economic status of the farmers shall be able to generate additional employment and income for the small and marginal farmers both under rainfed and irrigated conditions.

The FSR views the farm in a holistic manner and considers interactions (between components and of the components with the environment) in the system. This type of research is most appropriately carried out by the interdisciplinary team of scientists who in association with the Extension Officers continuously interact with the farmers in the identification of the problems and finding their solutions. Farming system approach to agricultural research and development efforts would definitely help in sustainable development of small farmers and accelerate agricultural growth in the country and thereby providing leverage for transforming poverty prone rural India to a prosperous India by strengthening rural economy. Certainly this will play a key role in agricultural revolution in the 21st Century, which is very much important to make India a developed nation.

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26. Rhizospheric management for improved nutrient availability

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The rhizosphere is defined as the volume of soil around living plant roots that is influenced by root activity. A whole range of root activities make the rhizosphere a unique environment. The underlying changes in biochemical, chemical and physical properties of soil surrounding the root, compared with the bulk soil, arise from either processes for which roots are directly responsible, and /or activities of microorganisms that are stimulated in the vicinity of the roots as a consequence of the release of rhizodeposits by roots (Jones *et al.*, 2004). This is the so-called rhizosphere effect–stimulation of microorganisms that may be either beneficial or deleterious (e.g. pathogenic microorganisms).

Roots are widely acknowledged to be major contributors to ecosystem nutrient cycles. However, live roots may have very different effects than dead roots, the quality of the soil surrounding the roots may itself affect the influence of the roots, and the nature of the soil profile may modify all of these interactions. The soil-plant system is one of the most important components in agricultural and natural ecosystems. Nutrient dynamics in soil-plant systems not only reflect the pattern of nutrient flow but also influence food production and quality, and the contaminant pathways in agricultural and natural ecosystems.

Rhizosphere is regarded as a special habitat with intense nutrient interactions and biological activities. All mechanisms of nutrient interactions in bulk soil are also applicable to the rhizosphere, but some aspects of nutrient interactions in the rhizosphere are distinct from bulk soil due to specific rhizosphere processes. Evidence of the profound chemical changes that occur in the rhizosphere has accumulated, as reviewed by Darrah (1993), and Marschner *et al.* (1995). Chemical conditions in the rhizosphere can thus be drastically different from those in bulk soil. This should alter the quality of the diagnosis of nutrient bioavailability, which is commonly deduced from the analysis of bulk samples of soil. A better prediction of nutrient bioavailability and mineral nutrition would thus take into account the chemical state and physical extent of the rhisosphere. These factors are either a direct effect of root activity itself or an indirect effect of the roots, i.e., the effect of the root-stimulated rhisosphere microflora. Even though the latter effect may be of prime importance, especially for major nutrients such as N and P. Various processes and their relative contributions to the changes in the bioavailability of soil nutrients that can occur in the rhizosphere can considerably vary with plant species, plant nutritional status, ambient soil conditions, as well as by soil management and other factors.

Rhizospheric processes of individual plants have been widely investigated; however, little attention has been paid to rhizosphere effects at an agro-ecosystem level. Intercropping between maize and faba bean (*Vicia faba* L.) was found to improve nitrogen and phosphorus uptake in the two crops compared with corresponding sole crop. There was a higher land equivalent ratio (LER) in the intercropping system of maize and faba bean than the treatment of no root interactions between the two crops. The increased yield of maize intercropped with faba bean resulted from an inter-specific facilitation in nutrient uptake, depending on inter-specific root interactions of the two crops.

Plant roots and rhizospheric flora

The root system is fundamentally important for plant growth and survival because of its role in water and nutrient uptake. It attracts many soil organisms in its vicinity. Major rhizospheric flora are bacteria, fungi, actinomycetes and algae, etc. In general, root growth leads to substrate loading in the root zone, which in turn promotes rhizobacterial proliferation, leading to further root growth, a concomitant increase in root exudation that leads to substrate loading, and so on. All root–microbial exchanges can be considered a form of *allelopathy* (Barazani and Friedman, 1999) and include those biochemical interactions, both inter- and intraspecifically, that involve microbial- or plant-produced secondary metabolites (allelochemicals) that influence growth and development of biological systems in the soil. Consequently, phyto-microbially governed plant growth is a form of beneficial allelochemical response that shares many of the characteristics of a "feedback" system. The plant initiates an allelopathic cascade of which it is also the final recipient. An analogous process can be found in *autotoxicity*, where phytochemical auto-inhibitors collect in the root zone and inhibit same or other species' growth and development (Singh *et al*., 1999).

The term *allelopathy* was originally introduced to describe the injurious effects of one plant upon the other (Molisch, 1937). However, the term has now been generally accepted to include both inhibitory and stimulatory effects, and the definition has been extended to include "any process involving secondary metabolites produced by plants, microorganisms, viruses and fungi that influence the growth and development of agricultural and biological systems (excluding animals), including positive and negative effects" (Torres *et al*., 1996). As a class of relationship between organisms, allelopathy is considered to be one where no direct contact occurs, the effect of any interaction being a consequence of some indirect event controlled by an allelochemical. Thus in its broadest sense "plantdirected" microbial communities can provide the host plant with a distinct ecological advantage through the cultivation of *beneficial allelopathies* (Sturz and Christie, 2003). Microbially generated secondary metabolites have been shown to aid plant growth (Glick *et al*., 1999; Mathesius, 2003), increase availability of minerals and nutrients (Hinsinger, 1998), improve nitrogen economy (Ladha *et al*., 1997; Yanni *et al*., 2001), change plant susceptibility to frost damage (Xu *et al*., 1998), enhance plant health through the direct biocontrol of phytopathogens induce systemic forms of plant disease resistance (Van Loon *et al*., 1998), and secure plant establishment (Burd *et al*.,1998).

Positive root-microflora Interactions

Nodulation of legumes by rhizobia

Rhizobia form symbiotic associations with leguminous plants by fixing atmospheric nitrogen in root nodules. Scientists have always wondered whether plants outside the Fabaceae family might be manipulated to form associations with rhizobia. However, rhizobia-legume interactions are very specific, allowing specific rhizobial strains to nodulate with specific host legumes. *Sinorhizobium meliloti* effectively nodulates species of the *Medicago, Melilotus*, and *Trigonella* genera, whereas *Rhizobium leguminosarum bv. viciae* induces nodules in the *Pisum, Vicia, Lens*, and *Lathyrus* genera. Interestingly not all members of the legume family form nodules. Of the three subfamilies of legumes, *Caesalpinoideae, Mimosoideae*, and *Papilionoideae*, members of the basal subfamily *Caesalpinoideae* are mainly non-nodulating. The signal components largely responsible for these specific host-microbe relationships belong to a class of compounds termed flavonoids (Peters *et al*., 1986)). More than 4000 different flavonoids have been identified in vascular plants, and a particular subset of them is involved in mediating host specificity in legumes (Perret *et al.*, 2000).

Mycorrhizal associations

Unlike the selective legume-rhizobial associations, arbuscular mycorrhizal fungi (AMF) and plant roots form associations in more than 80% of terrestrial plants. This symbiotic relationship increases nutrient uptake, improving plant fitness, and in turn, the associated fungi extract lipids and carbohydrates from the host root (Bago *et al*., 2003). AMF may recognize the presence of a compatible host through root exudates, similar to recognition by rhizobia (Tamasloukht *et al*., 2003). The ability of AM fungi to enhance host–plant uptake of relatively immobile nutrients, in particular P, and several micronutrients, has been the most recognized beneficial effect of mycorrhiza. Rhizospheric interactions occur between AM fungi and other soil micro-organisms with effects on plant nutrient balances, such as nitrogen-fixing bacteria and plant growth-promoting rhizobacteria (Paula *et al*., 1993). AM colonization may furthermore protect plants against pathogens. AM fungi interact with heavy metals/micronutrients. They can restore the equilibrium of nutrient uptake that is misbalanced by heavy metals (Carneiro *et al*., 2001). AM fungi can alleviate Al toxicity. AM fungi improve water relations, especially under nutrient limitation. The extra-radical hyphae of AM fungi contribute to soil aggregation and structural stability. Therefore, mycorrhizas are multifunctional in (agro) ecosystems, potentially improving physical soil quality (through the external hyphae), chemical soil quality (through enhanced nutrient uptake), and biological soil quality (through the soil food web).

Plant growth–promoting bacteria

Bacteria thrive on abundant nutrients in the rhizosphere and some of these rhizobacteria provide benefits to the plant, resulting in plant growth stimulation (Gray and Smith, 2005). Bacteria are likely to locate plant roots through cues exuded from the root, and root exudates such as carbohydrates and amino acids stimulate PGPB chemotaxis on **root** surfaces (Somers *et al*., 2004). Root exudates also influence flagellar motility in some rhizospheric bacteria. Some PGPB produce phytostimulators, which directly enhance plant growth. In addition to fixing atmospheric nitrogen, *Azospirillum* spp. secrete phytohormones such as auxins, cytokinins, and gibberellins (Steenhoudt *et al*., 2000). There is the exciting possibility that most PGPB are capable of producing growth regulators continuously, provided that precursors of phytohormones are available in the rhizosphere.

Other rhizobacteria create "suppressive soils" by controlling plant diseases caused by soil fungi and bacteria. The mechanisms responsible for this biocontrol activity include competition for nutrients, niche exclusion, induced systemic resistance (ISR), and the production of antifungal metabolites. The biocontrol agents that are best characterized at the molecular level belong to the genus *Pseudomonas.* Most of the identified *Pseudomonas* biocontrol strains produce antifungal metabolites, of which phenazines, pyrrolnitrin, 2,4-diacetylphloroglucinol (DAPG), and pyoluteorin are most frequently detected. However, antifungal metabolites belonging to the class of cyclic lipopeptides, such as viscosinamide (Nielsen *et al*., 1999) and tensin (Nielsen *et al*., 2000), have also been discovered. Viscosinamide prevents infection of *Beta vulgaris* L. (sugarbeet) by *Pythium ultimum* (Thrane *et al*., 2000). *Arabidopsis thaliana* ecotype Columbia plants (Col-0) treated with the PGPBs *Serattia marcescens* strain 90–166 and *Bacillus pumilus* strain SE34 developed minor disease symptoms upon infection with the Cucumber mosaic virus (CMV) (Ryu *et al*., 2004). Also, it was reported that some of the known gram-positive biocontrol PGPBs (such as *B. subtilis* 6051 strain) assist plants in evading a gram-negative plant pathogen, *Pseudomonas syringae pv. tomato* DC3000, by forming a protective biofilm on *A. thaliana* roots limiting pathogen access to the root surface and by producing an antimicrobial cyclic lipopeptide surfactin (Bais *et al*., 2004a).

Negative root-microflora interactions

Antimicrobial effects

Plant root exudates substantially increase microbial activity in the rhizosphere. The role root exudates play in pathogenesis of root-infecting bacteria and fungi, however, has not been fully appreciated, in part because of inadequate methods available for analysis. Just as symbiotic root-microbe interactions depend on secondary metabolites in root exudates for initiation and development of beneficial associations, the survival of physically vulnerable root cells under continuous attack from pathogenic microorganisms depends on "underground chemical warfare" mediated by plant secretion of phytoalexins, defense proteins, and other as yet unknown chemicals (Bais et *al*., 2004b, Flores *et al*., 1999). *Arabidopsis*, rice, corn, soybean, and the model legume *Medicago truncatula*, which have been subject to intensive sequencing efforts, are, collectively, rich sources of antimicrobial indole, terpenoid, benzoxazinone, and flavonoid/isoflavonoid natural products. The unexplored chemodiversity of root exudates in all these genetically tractable species is an obvious place to search for novel biologically active compounds, including antimicrobials.

Influence of microflora on plant roots

Mycorrhizae

Unlike *Arabidopsis*, more than 80% of higher plants associate with mycorrhizal fungi, which elicit profound changes in the root morphology of host plants (Hetrick, 1991). In particular, ectomycorrhizae suppress root elongation and induce dichotomous branching of short lateral roots, culminating in the formation of coralloid structures resulting from higher-order dichotomous branching. All of these anatomical structures are variable depending on the plant and fungal species. Once the fungus is established, root branching is suppressed, which makes the plant more dependent on the nutrients provided by the fungus (Hetrick, 1991; Price *et al*., 1989). Whether this modification of root system architecture (RSA) is a direct consequence of symbiosis or an indirect effect of improved nutrient status of the plant is not clear. However, it appears that symbionts can trigger RSA changes by promoting lateral root initiation very early in the interaction (Harrison, 2005). Moreover, the maize mutant *lrt1* normally lacks lateral roots, but displays extensive lateral root development following inoculation with the mycorrhizae *Glomus mosseae* (Paszkowski *et al*., 2002). Notably, many microorganisms that interact with plants can produce plant hormone analogs. Thus, symbiotic association might employ hormone signaling pathways to regulate RSA.

Nodulation

The second most important symbiosis of plant roots is their association with N-fixing bacteria in legumes, a process termed nodulation. Nodules and lateral roots share some common features. For instance, both organs form adjacent to xylem poles, develop meristems, and break cell layers to emerge. In support of this idea, the lateral root organ-defective mutant of Medicago truncatula initiates both nodule and lateral root formation, but does not complete either process. Moreover, nodule formation shares common molecular processes with lateral root development (Hirsch *et al*., 2001)

Rhizodeposition and soil microflora (root-microflora interaction)

Among the many processes occurring in the rhizosphere, rhizodeposition has received considerable attention, given its major impact on soil microorganisms and on the fate of carbon in terrestrial (and even aquatic) environments (Lynch, 1990; Jones *et al.*, 2004). Plant roots exude an enormous range of potentially valuable small molecular weight compounds into the rhizosphere. Some of the most complex chemical, physical, and biological interactions experienced by terrestrial plants are those that occur between roots and their surrounding environment of soil (i.e., the rhizosphere). Interactions involving plants roots in the rhizosphere include root-root**,** root-insect, and root-microbe interactions. Chemical components of root exudates may deter one organism while attracting another, or two very different organisms may be attracted with differing consequences to the plant. A concrete example of diverse meanings for a chemical signal is the secretion of isoflavones by soybean roots, which attract a mutualist (*Bradyrhizobium japonicum*) and a pathogen (*Phytopthora sojae*) (Morris *et al.*, 1998).

Root-microflora interactions can positively influence plant growth through a variety of mechanisms, including fixation of atmospheric nitrogen by different classes of proteobacteria (Moulin *et al*., 2001)), increased biotic and abiotic stress tolerance imparted by the presence of endophytic microbes and direct and indirect advantages imparted by plant growth–promoting rhizobacteria (Gray and Smith, 2005). Bacteria can also positively interact with plants by producing protective biofilms or antibiotics operating as biocontrols against potential pathogens, or by degrading plant- and microbe-produced compounds in the soil that would otherwise be allelopathic or even autotoxic. However, rhizosphere bacteria can also have detrimental effects on plant health and survival through pathogen or parasite infection. Secreted chemical signals from both plants and microbes mediate these complex exchanges and determine whether an interaction will be malevolent or benign.

Root colonization is important as the first step in infection by soil-borne pathogens and beneficial associations with microorganisms. In addition to providing a carbon-rich environment, plant roots initiate cross talk with soil microbes by producing signals that are recognized by the microbes, which in turn produce signals that initiate colonization. Chemical attraction of soil microbes to plant roots, or chemo taxis, is a well understood mechanism involved in initiating cross talk between plant roots and microbes (Bais *et al*., 2003).

Agronomic management for rhizosphere flora interactions

Crop rotations/ diversification

Different crops exploit soil resources in different ways. Maximizing the diversity of cropping systems in both time and space (by rotations, intercropping, and so on) creates a mosaic of soil resources and niches which in turn enhances belowground biodiversity and improves the resilience of the system as a whole. Certain cropping sequences, for example, favor the build-up of various beneficial bacteria that promote plant growth, while the availability of the host crop is known to be the biggest single factor influencing the number and diversity of plant parasitic nematodes in the soil (SP-IPM, 2004). Differences in root morphology and biomass, and in patterns of root exudation and carbon allocation, can all influence the population density and activity of other members of the soil biota. Furthermore, maintaining some kind of continuous plant cover through the use of living crops or mulches moderates fluctuations in soil temperature and moisture, and further enhances stability (SP-IPM, 2004).

The increased use of cereal/legume crop rotation has been advocated as a strategy to increase cereal yields. Research at multiple sites has suggested a complex interaction of chemical and biological factors, including increased mineral N, available P, elevated pH and arbuscular mycorrhizal infection, and a decrease in plant parasitic nematodes as causal mechanisms for rotation-induced increases in cereal yields (Alvey *et al*., 2000.) In principle, these chemical and biological changes should be accompanied by concomitant changes in the rhizosphere microflora. However, it is unknown how cropping systems affect the composition and structure of rhizosphere microbial communities. In subsistence agricultural systems, crop yields are directly dependent on the inherent soil fertility and on microbial processes that govern the mineralization and mobilization of nutrients required for plant growth. Furthermore, the impact of different crop species that are used in various combinations is likely to be an important factor in determining the structure of plant beneficial microbial communities that function in nutrient cycling, the production of plant growth hormones, and suppression of root diseases.

During the colonization of plant roots by soil bacteria, microorganisms from the bulk soil undergo selective enrichment in the plant rhizosphere in response to different root exudate components. Because different plant species release different types and quantities of exudates, plants exert species-specific effects on the soil microbial community that result in broad shifts in the microflora (Lynch, 1990). In practice, crop rotations have been explicitly used to disrupt disease or in the case of legumes to fix atmospheric N_2 for the subsequent non-leguminous crop (Baldock *et al*.,1981; Pierce and Rice, 1988). When examined at the community level, crop rotations can cause changes in substrate utilization patterns, which suggest that soil bacterial communities under crop rotation have greater species diversity than under continuous cultivation with the same crop (Lupwayi *et al.*, 1998). Therefore, crop rotation can cause significant shifts in rhizosphere bacterial communities.

Alvey *et al.* (2003) concluded that the cropping system had a highly significant effect on community structure ($P <0.005$), irrespective of plant species (maize, pearl millet, sorghum, cowpea and groundnut) or sampling time. Continuous cereal-soil grown plants had highly similar rhizoplane communities across crop species and sites, whereas communities from the rotation soil showed greater variability and clustered with respect to plant species. Similarly, Bagayoko *et al.* (2000b) reported higher AM colonization in cereals (sorghum, pearl millet (*Pennisetum glaucum*) in rotation with legumes (cowpea, peanut) than in continuous cropping. Nematode densities on cereals also were decreased in rotation with legumes.

Crop rotation effects on mycorrhizal functioning have repeatedly been observed. Harinikumar and Bagyaraj (1988) observed a 13% reduction in mycorrhizal colonization after one year cropping with a non-mycorrhizal crop and a 40% reduction after fallowing. Lack of inoculum or inoculum insufficiency after a long bare fallow (especially in climates with an extended dry, vegetation less season) may result in low uptake of P and Zn and in plants with nutrient deficiency symptoms that have been described as long-fallow disorder. Sanginga *et al*. (1999) found evidence for increased mycorrhizal colonization of soybean if the preceding crop was maize, and increased colonization of maize if the preceding crop was bradyrhizobium-inoculated soybean in the savanna of Nigeria.

Tillage and crop residue management

Conventional tillage immediately changes the structure of the soil microbial community, even if total microbial biomass is little affected. Under conventional tillage regimes, bacteria-based food webs predominate, and flushes of mineralization related to cultivation can lead to increased losses of nutrients and organic matter from the soil. In this way, tillage can increase the potential both for nitrate leaching and the emission of greenhouse gases such as carbon dioxide and nitrous oxide. In the long term, it can have deleterious effects on soil structure and biodiversity (SP-IPM, 2004).

The use of tillage techniques in seed bed preparation and land use management not only impose a physical stress on the soil structure but also on the soil microbial communities that inhabit that soil. In an effort to minimize such stresses, modern arable farming systems are attempting to reduce excessive cultivation in favour of limited or strategic tillage practices. Conventional tillage system is a preliminary deep primary operation followed by some secondary tillage system for seedbed preparation. In contrast, conservation, or reduced tillage, can encompass any tillage practice that reduces loss of soil and water as compared to unridged or clean tillage. This can include (1) minimum tillage, considered to be the minimum amount of tillage required for seed bed preparation and plant establishment; (2) no-tillage/zero- tillage/direct drilling, which involves no seedbed preparation other than chemical preparation and soil opening for seed placement (Baeumer and Bakerman, 1973); and (3) high-residue mulched beds (Morse, 2000).

Compared to conventional tillage systems, reduced-tillage practices offer not only long-term benefits from soil stability, reduced soil erosion, and sustainable agriculture (Lal, 1991), but they can also enhance soil microbial diversity (Lupwayi *et al*., 1998; Phatak, 1998; Phatak *et al*., 2002). Thus, minimizing the mechanical upheaval associated with tillage operations tends to maximize soil microbial diversity because the disruption of food substrate at the trophic level, desiccation and soil compaction are reduced, and optimum pore volume is maintained (Giller, 1996). Paradoxically, fallow periods in a crop rotation can reduce soil microbial diversity (Zelles *et al*., 1992), an effect probably associated with food substrate depletion over time. Thus, heterogeneity in soil microbial populations tends to coincide with heterogeneity of food resources, which is often greatest in crops under conservation or zero tillage management, where the residue of the preceding year's crops adds sequentially to the variety of food substrates available for utilization. Clearly, while the act of mixing soil during tillage increases seedbed homogeneity, it will simultaneously destroy the diversity of trophic microsites that occur down the soil profile together with the assemblages of soil microorganisms that occupy them. The result is a reduction in both the structural and functional diversity of the soil microbial community (Beare *et al*., 1995) and the efficiency of those microbially mediated processes that sustain the agricultural productivity of soils, e.g., nutrient recycling, degradation of toxic residues, maintenance of soil structure, and aggregation (Sparling, 1997).

Tailoring amendments and cultural practices to promote beneficial soil microbes has been an underappreciated area of crop production science that offers potential for increasing agricultural productivity in a natural and sustainable manner. It is already well established that sugars and amino acids are released by decomposing plant material and can serve as carbon sources for soil microbes (Gregory *et al*., 2004). However, in modern crop production monocultures that rely on mineral fertilizers, carbon sources can become limited, especially where crop residues are removed from fields and soil organic matter is kept low. Consequently, the diversity of microbial activity is likely to be reduced. This is not meant to imply that soil applications of N-P-K primarily intended to provide essential nutrients to crop plants do not also benefit soil microbes. The point is that traditional fertilizer inputs are intended primarily for crop plants and not the microbes that sustain them. Even when soil organic matter is low, relatively few agriculturalists would fertilize their fields specifically to benefit soil microbes (Gregory *et al*., 2004).

Mineral nutrition and fertilization

Plants modify their environment at many spatial scales; the global, the ecosystem, the soil horizon, and the rhizosphere. In all ecosystems, plants transform the surrounding soil making and maintaining a habitat more favourable for growth (Marschner, 1995). Root mediated changes to the soil are mainly associated with ways to increase their potential for nutrient and water acquisition. Plants have evolved an array of mechanisms to increase the solubility, diffusion potential and uptake of nutrients from soil. These mechanisms are particularly important in low nutrient environments where plant demand can only be met by mobilizing nutrients from non-soluble sources.

Fertilization is one of the major factors controlling the population densities and activity of soil organisms (Bünemann *et al.* 2006). Application of inorganic and organic fertilizers can indirectly but positively affect soil microbes and animals by increasing plant growth and stimulating root exudation, both of which lead to a greater input of organic substrates. Community structure and body size of soil organisms are also affected by fertilization. Most fertilizers can inhibit local microbial activity, especially when they are applied in high concentrations. Some nitrogenous fertilizers can produce biocidal levels of ammonia. Furthermore, high levels of inorganic fertilizer, particularly in tropical soils, tend to reduce populations of mycorrhizal fungi (SP-IPM, 2004). Some species may even disappear under such circumstances. For example, root nodulation in legumes by rhizobium is highly influenced by N supply in soil. It is a strongly suppressive effect of combined N (especially NO_3^-) which legumes will utilize as a N source in preference to forming the N-fixing symbiosis. Nitrate inhibition of nodulation has been one of the clearest and most intensively studied examples of the nutritional control of plant development. Unlike other factors that inhibit nodulation (such as pH, temperature or toxicity), NO_3^- does so in a very specific way without interfering with plant growth (Carroll and Mathews, 1990). However, the sensitivity of nodulation to NO_3^- is strongly dependent on the plant species and genotype.

Inoculation of legumes by rhizobia

Legume inoculation with root-nodule bacteria is an established and successful practice. When a new legume is introduced into a region, few of the soils will contain appropriate rhizobia, and inoculation will usually be needed. Under soil conditions of low nitrogen, yield increases following inoculation can then exceed 50%, with clear differences evident between inoculated and uninoculated plants. With rare exceptions (Vargas and Hungria, 1997), reinoculation in subsequent years will not be needed, and over time even uninoculated soils will tend to accumulate rhizobia, limiting inoculation response. A consequence, as shown by Hall and Clark (1995) for soybean in Thailand, is that there will be greater interest m inoculation and inoculant technologies in the newer areas of production than in regions where the crop has been grown for some time. Where inoculation is needed, the inoculant must both supply adequate numbers of rhizobia and use inoculant-quality strains having the following characteristics (Thompson, 1991) the ability to form highly effective nodules with all commonly used cultivars and species for which it is recommended; be competitive in nodule formation and persistent in the soil; the ability to tolerate soil environmental stresses such as acid soil pH and temperature; display good growth in simple, inexpensive culture media; be genetically stable and not be subject to mutation; and the ability to survive well on the seed prior to seed germination.

Inoculant strains are required to survive in stressful soils in sufficient numbers to provide a population able to nodulate under environmental constraints such as pH, temperature and competition from less effective indigenous and naturalized strains. This last problem of competition is significant in many areas, not the least in soils of the tropics and sub-tropics. Several research programs around the world are addressing the problems of stress tolerance in root-nodule bacteria. Improvements in our understanding of the molecular and physiological mechanisms of stress-sensitivity in both symbionts will be important if we are to increase legume nitrogen fixation and productivity. In addition, there will be clear benefits to legume production from increasing the survival of the inoculant root-nodule bacteria on seed, or when delivered directly into soil. Enhanced formulations, granular inoculants, and seed coating techniques that protect the bacteria from environmental stress or physically separate them from toxic chemicals, such as fungicides applied to seed, offer new research directions (Singleton *et al*., 2002).

Addition of organic matter

Organic matter can help modify soil structure and is of fundamental importance to many soil functions, including carbon cycling and sequestration and nutrient storage. Incorporation of rich and varied sources of organic matter not only supplies plant nutrients, but also helps to increase below-ground biodiversity by providing an array of substrates capable of supporting diverse soil organisms. Increased biodiversity in turn contributes to the ability of the soil to suppress plant pests and diseases. Suitable sources of organic matter include animal wastes, green manures, crop residues, and composted vegetation. It is important to note, however, that the effects of organic amendments can vary not only with the nature of the material added, but also with soil pH (SP-IPM, 2004).

Mulching

Mulch has been defined as any form of covering applied to the soil surface. By this broad definition, it includes crop residues, weeds, green manures, and other plant material cut and carried in from elsewhere, as well as artificial materials such as paper and plastic. The organic mulches, which are more relevant to resource-poor farmers in developing countries, are quite common in the traditional farming systems of the humid tropics. Besides reducing soil erosion and improving nutrient cycling, mulching can also help suppress weeds, pests, and diseases. Herbicide use or time spent weeding by hand may be significantly reduced by mulching, and notable successes have been achieved by using mulches to suppress soil-borne plant pathogens (SP-IPM, 2004).

In Kenya, for example, black rot of cabbage caused by the bacterium *Xanthamonas campestris* was controlled by grass mulch applied immediately after transplanting (SP-IPM, 2004). In such cases, it is thought that the effect of the mulch is due to a combination of its role as a physical barrier (reducing rain splash of the pathogen onto the crop), together with its ability to change the microclimate at the soil surface and enhance the activity of beneficial soil microorganisms capable of suppressing pathogens. Mulching has also been used to divert termites from crops, and in various parts of Africa, mulching with the weed *Tithonia diversifolia* has been shown to reduce nematode damage and improve crop growth. In Uganda, mulching of banana plantations appeared to reduce numbers of the nematode *Radopholus similis*, possibly because the mulch reduced soil temperatures, thereby slowing nematode feeding and reproduction. Conversely, the presence of crop residues on the soil surface may enhance the biological control of insect pests by entomopathogenic nematodes. It has been shown, for example, that such residues increase the persistence of *Steinernema carpocapsae*, probably by protecting it from desiccation or ultraviolet light (SP-IPM, 2004).

Conclusion

Soil flora resources are indispensable for establishing sustainable agriculture. Abuse and a scientific use of microbial resources seem to hamper the wholesome popularization of them. We need to understand the utility and limit of their effects in agriculture scientifically. Too few data have been accumulated with agronomic practices *vis-à-vis* soil micro flora. Importance is the accurate, scientific evidence of the fate of microbial resources as well as of its effect on plant growth. The knowledge of soil micro flora can be successfully utilized in managing the field crops through suitable and appropriate agronomic practices.

Crop nutrition is frequently inadequate as a result of the expansion of cropping into marginal lands. Elevated crop yields placing increasing demands on soil nutrient reserves, environmental and economic concerns about applying fertilizers. Over application of chemical fertilizer can result in considerable decreases of microorganism population and friendly insects, crop susceptibility to disease attack, acidification or alkalization of the soil or aggravation of soil physical properties, and pollution of water resources through leaching — causing irreparable damage to the overall system. Hence, designing sustainable management practices that focus on rhizosphere soil is more efficient and cost-effective for improving crop productivity with lesser agrochemical inputs, reduces fertilizer application, increases yields, decreases fertilizer residues in the soil, and is simple to apply.

The diversity of cropping systems in India provides a unique field for investigation rhizosphere processes at an agro-ecosystem level. In cropping systems, rhizosphere is not only an interface between root and soil for an individual plant, but also is a center of interaction for plant community, soil, nutrients, microorganisms and their environment (Zhang *et al.*, 2002). The understanding of mechanisms of rhizosphere interactions with respect to nutrient transformation in various cropping systems of the county is an important step for better understanding of advantages for efficient resource use in cropping systems and thus fully utilizing these advantages and avoiding disadvantages to optimize crop productions. However, little attention has been paid to rhizosphere effects at an agro-ecosystem level for the management of plant nutrition in India.

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