CURRENT APPROACHES FOR SMART AGRICULTURE

Editors

Dr. Satybhan Singh

Dr. Himanshu Trivedi

Dr. Virendra Singh

AkiNik Publications

New Delhi

Published By: *AkiNik Publications*

AkiNik Publications
169, C-11, Sector - 3,
Rohini, Delhi-110085, India
Toll Free (India) – 18001234070

Editors: *Dr. Satybhan Singh, Dr. Himanshu Trivedi and Dr. Virendra Singh*

Edition: *1st*

Publication Year: *2022*

Pages: *528*

ISBN: *978-93-5570-290-6*

Book DOI: *https://doi.org/10.22271/ed.book.1833*

Price: *₹ 1795/-*

Chapter - 42
Nutrient Management Strategies for Improving Maize Productivity

Authors

Anil Nath
Department of Agronomy, College of Agriculture, GBPUA & T, Pantnagar, Uttarakhand, India

Richa Khanna
School of Agricultural Sciences & Engineering, IFTM University, Moradabad, Uttar Pradesh, India

Arvind Kumar
Department of Agronomy, College of Agriculture, GBPUA & T, Pantnagar, Uttarakhand, India

Chapter - 42

Nutrient Management Strategies for Improving Maize Productivity

Anil Nath, Richa Khanna and Arvind Kumar

Maize (*Zea mays* L) is one of the most versatile and multi utility crops, having wider adaptability in diverse ecologies. Maize, also known as corn, is a cereal grain that was first grown by people in Central America. Globally, it is known as queen of cereals because of its highest genetic potential among the cereals. It is the major source of food, feed, fodder and industrial raw material for the industry for production of starch for textile, pharmaceutical, cosmetic industries, high quality corn oil, protein, alcoholic beverages, food sweeteners etc. and also provides enormous opportunity for crop diversification, value addition and employment generation.About 15 million farmers are engaged in maize cultivation in India which generates employment for more than 650 million people at farm (FICCI & PWC,2018).It is used as an ingredient in more than 3000 products. 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. Maize is the third most important cereal crop in the world as well as in India. The importance of corn is due to its wide diversity of uses. It is used both as staple food for human and quality feed for animals. Corn is nearly directly consumed as feed. Corn is converted in to a variety of foods such as popped snack food and staple alkali-cooked “Mexican” foods. It is also fractionated by either dry or wet milling into food and industrial ingredients. The starch, the major constituent of the corn kernel, is used in foods and industrial products. The starch is also converted into glucose/ fructose for use as food sweetness. Glucose can be fermented in to ethanol for fuel or beverages. Maize has a nutritional value for both animals and humans. Table 1 gives the nutritional details of maize.

Table 1: Nutrition value of Maize

Content	Percentage dry matter basis
Starch	71-72
Protein	9-10
Fat	4-45

Fibre	9-10
Sugar	2-3
Minerals (Ash)	1.4

Global Maize Production

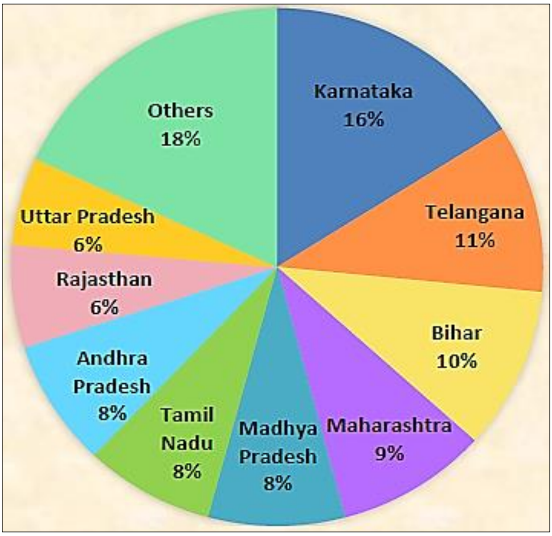
Maize is cultivated in about 196 mha area, producing ̴1110 mt grains with 5.66 t/ha productivity across the world (FAOSTAT, 2018-19). The world's maize production has been growing at a CAGR of about 3% since 2005. The area has been grown at a CAGR of 1.8% and the yield has grown at a CAGR of 1.2% since 2005.(NCoMM Report,2017)The United States of America has the highest production of maize in the world i.e. around 375 mt which is 36% of the total maize production in the world. USA has the highest productivity in the world i.e. around 10.5 t/ha which is almost double of the global productivity. Other top producing countries are China, Brazil, Mexico, Argentina & India. India is standing at the sixth position in case of production. India is producing only 2.5 % of the world maize production.

Maize Production in India

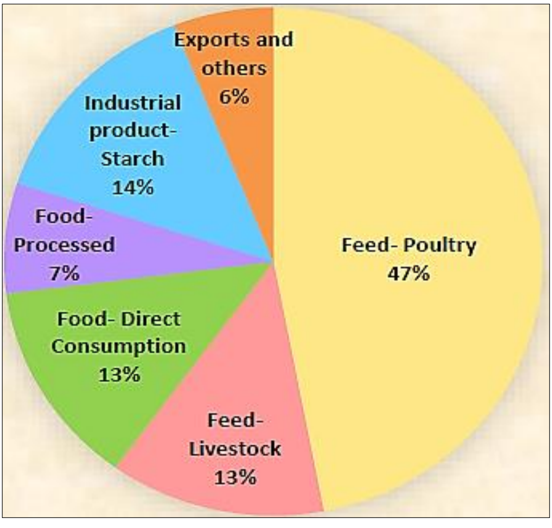
In India, Maize is grown in about 9.20 mha area and producing around 27.23 mt grains with 2.95 t/ha productivity and 3-4 % annual growth rate (MOA&FW,2018-19). India produces about 2.5% the world's maize produce. Karnataka is the leading producer of maize in India producing around 16% of India's total Maize production. Karnataka is followed by Telangana & Bihar which together contribute 20% to India's maize production basket. Maharashtra, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Rajasthan and Uttar Pradesh are other maize producing states of India. About 71% of maize in India is produced in the Kharif season. Karnataka, Madhya Pradesh, Tamil Nadu, Maharashtra, Telangana, UP & Rajasthan produce Kharif Maize, with Karnataka being the leader. Bihar, Andhra Pradesh & Tamil Nadu are states which produce *rabi* maize crop. Rabi is the primary crop of Bihar and Andhra Pradesh.

Maize Consumption in India-

Maize consumption in India can broadly be divided into three categories *Viz*. Feed, food and Industrial non-food products (mainly starch). Feed accounts for about 60% of the maize consumption in India. The most important use and demand driver of maize is poultry feed which accounts 47% of total maize consumption. Livestock feed accounts for 13%. The food consumption accounts for 20% of Maize consumption, with direct consumption being 13% and that in form of processed food being 7%. The non-food industrial products account for the remaining 20% of India's maize consumption. Starch is the most important in this category accounting for 14% of the total maize consumption. The remaining 7% is accounted for by exports and other industrial non-food products, for instance, Maize is used as a feedstock for the production of ethanol fuel.



Maize Production Shares in India (%)



Maize consumption pattern in India (%)

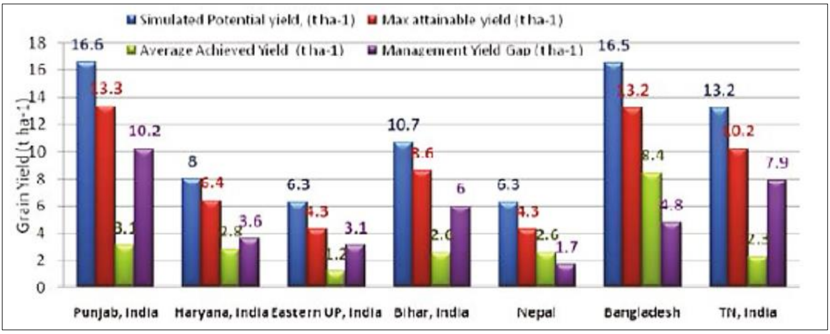
NCoMM Report, 2017

Maize productivity in India

If we compare India's productivity with the world, India's corn productivity is about half the world's average, 1/5th of the productivity of the US and less than half of China. Constraints for low productivity are

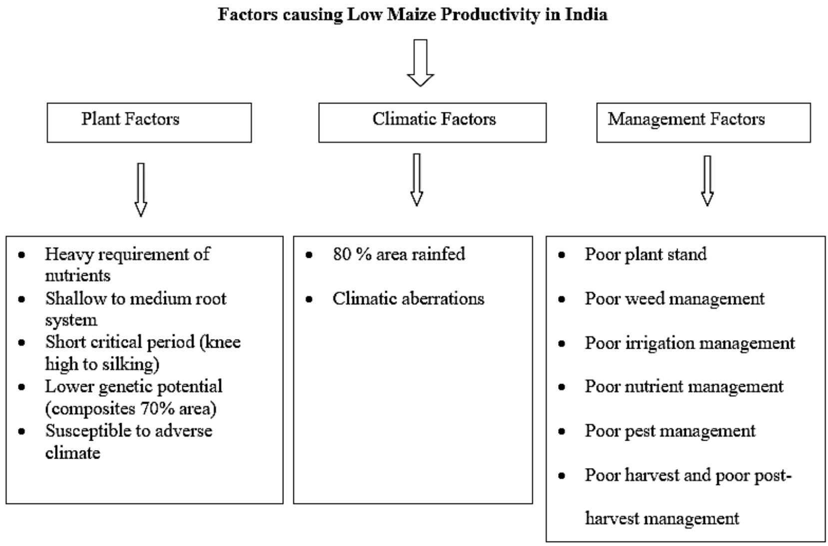
- Climatic conditions resulting in drought/excess water associated with increased pressure of disease/pets.
- Cultivation is mainly in rain-fed conditions on marginal lands with inadequate irrigation.
- Only about 30 percent of area is under Hybrid. Lack of development of single cross hybrid technology, which is key to higher productivity gains in USA, china and other countries.
- Limited adoption of improved production–protection technology.
- Deficiencies in the production and distribution system of quality seed.
- Small farm holdings and limited resource availability with farmers.
- Presence of very large yield gaps between potential yield, attainable yield and actual yield.

Yield potential (Yp) of any crop cultivar/ hybrid for a site and for a given planting date is the yield achieved when grown in environments to which it is adapted, with nutrients and water non-limiting and pests and diseases effectively controlled. Timsina *et al.*(2010) using hybrid maize models, estimated yield potential of four maize hybrids in India that ranged from 7.1 to 19.7 t/ha. Attainable yield (Yat), generally set at 80–90% of Yp, is average grain yield in farmers' fields with best management practices and without major limitations of water and nutrients. Attainable yield can be limited by variety, planting density, water and nutrient management, soil-related constraints (acidity, alkalinity, salinity, etc.), and climate-related constraints (flooding, drought, etc.). Actual yield (Yac) is the yield farmers receive with their average management under all possible constraints. Attainable yield of maize in farmers' fields, achieved under optimal conditions, can vary significantly across the agro-ecologies mainly due to genotype x environment interactions but also due to confounding influence of biotic and abiotic stresses and agronomic management. Dass *et al.*(2008) reported Yat and Yac of maize from experiments conducted in 13 representative locations in various agro-environments for 9 years (1995–2003) under the All India Coordinated Research Project (AICRPM) on maize. The selected locations were first divided into two categories: locations having lower productivity than the national average (Banswara, Udaipur, Godhra, Varanasi, Kanpur and Chhindwara) and locations (Mandya, Arbhavi, Ludhiana, Dhaulakuan, Bajaura, Dholi and Hyderabad) with greater productivity as compared to national average. Data indicated that the Yac is always less than Yat under all the agro-environments due to limited availability of agronomic inputs and their scheduling. Potential for improving Yat was more at the locations of the first group as compared to the locations of the second group. Except Banswara, other locations of the first group showed the potential for achieving Yat of 4–6 t ha-1, while Yac at all the locations of this group was less than half (1-2 t ha-1) of the Yat. It has also been reported that present average Yac at farmers' fields is only about 50% of the Yat, which could be increased through adoption of improved technology. On the other hand, Yat for most locations was about 4.0 t ha-1 except for Arbhavi (5.9 t ha-1) in the high productivity group, whereas, Yac at most of the locations of this group was more (1.2–3.4 t ha-1) as compared to the low productivity group. The data reveal that Yat of maize can be quite large, and so yield gap between Yp and Yat, between Yat and Yac, and that between Yp and Yac can be minimized. These gaps are ascribed mainly to three major factors, (i) low yielding genotypes, (ii) poor crop establishment due to random broadcasting and (iii) inadequate and inappropriate fertiliser nutrient applications as 15-45% maize acreage remains unfertilised and the rest of the acreage has imbalanced nutrient applications.



Jat *et al*. (2013)

Fig 1: Potential, attainable and actual yields and management yield gaps under different ecologies across South Asia



Nutrient use in maize

Nutrient removal is far excess of their replenishment under intensively cropped cereal systems in India, which has led to widespread multi-nutrient deficiencies in soils. Due to soils with decreasing fertility levels, coupled with higher yielding maize hybrids, farmers have not sufficiently matched nutrient uptake and removal with accurate maintenance fertiliser applications. Timsina and Majumdar (2012) indicated that maize grain yields in Bangladesh have been decreasing where maize was grown on the same land for the last 5 to 10 years. The authors attributed the yield decline to imbalanced and inadequate nutrient application by farmers. Maize with the yield potential of less than one t/ha removes about 90-100 kg/ha of nutrients from the soil. With the introduction of improved cultivars, the productivity has increased up to 4.0 t/ha with nutrient removal of around 220 kg/ha. Introduction of single cross hybrids, the productivity further increased to 7.0 t/ha and total nutrient removal has also increased to 420 kg/ha. In several states of the country particularly hill ecologies (North Eastern Himalayas, Uttarakhand, Himachal Pradesh) and rainfed and tribal states (Madhya Pradesh, Chhattisgarh, Rajasthan, Orissa, and West Bengal), large area under maize production still remained untreated with fertilisers. The extent of area was up to 90 % especially in areas where farmers are not sure to harvest their crop due to abiotic stresses, particularly during monsoon season. Besides, the current nutrient use in the high input maize systems indicates imbalance plant nutrition with very high use of N and less use of P and negligible use of K fertilisers and micro nutrients. This has led to nutrient imbalances in soils and lower nutrient use efficiency and economic profitability. This warrants adequate and balanced use of plant nutrients not only for specific farm and ecology but also in production systems using nutrient best management practices adapted to local situations and farm typologies to achieve better efficiency and nutrient stewardship.

Problems with Nutrient Management in Maize

Cultivation of high yielding maize hybrids will likely exacerbate the problem of secondary and micronutrient deficiencies, not only because larger amounts are removed, but also because the application of large amounts of N, P, and K to achieve higher yield targets often stimulates the deficiency of secondary and micronutrients. High yielding maize hybrids with very high biomass production, extracts higher amount of mineral nutrients from the soil than the other cereal crops.

However, breeding and agronomic advancement has increased maize yield to a new height but with little guidance about nutrient management strategies for the modern maize hybrids to achieve the maximum yield potential. There is a large information gape on appropriate nutrient management strategies for maize. Farmers are still applying the fertilisation practices which are developed decades ago and they are not matching uptake requirement of modern hybrids which are grown at population densities higher than ever before. Thus nutrient management practices under such scenario are still not well developed. So it is important to determine right rate of nutrients and plant response to applied nutrients.

Soils of the major maize growing areas in India are inherently low in soil organic matter and nitrogen is the major limiting plant nutrient. While managing plant nutrients in maize crop, nitrogen (N), phosphorus (P), and potassium (K) remain the major ones for increased and sustained productivity. Yield of maize is increasing with N fertilisation but the AE of N (Kg grain/kg N) is only 12.5 which indicates the low NUE. Though N plays an important role in governing the yield of crops, lack of awareness on improved strategies of N management, coupled with relatively lower prices of N fertilisers (especially urea), encourages imbalanced use by farmers. Therefore, N management strategies that consider the yield response, agronomic efficiency of N (AEN), coupled with appropriate timing and splitting, may be used not only for minimizing the losses of N from agricultural fields but also for increasing the yield and profitability from N use. P response is highly variable and is influenced by soil characteristics and growing environment of the crop. P application rate, therefore, must be based on expected response of a particular location. P application based on yield response alone does not take into account the nutrient removal by crops where response is low or negligible. In such scenarios, nutrient removal by the crop would not be replenished adequately by external application, which may lead to nutrient mining and decline in soil fertility. One way to counter that would be to apply a maintenance dose that replenishes part of the nutrient exported out of the field with harvested crop part (grain and straw). This will ensure that soil fertility levels that can support intensive production systems are maintained. Finally, management of P fertiliser for maize systems must take account of residue and organic amendments applied to the soil. Indian soils, despite often having relatively large total K content, resulted in variable yield and economic loss to the farmers with skipping application of K. Long term use of N and P in the absence of K illustrates the seriousness of nutrient imbalance of a region. Li *et al.* (2012) demonstrated the effect of K fertilisation on maize production within a region that has typically relied on N and P alone. They reported that balanced use of N, P, and K fertiliser generated an average yield increase of 1.2 t/ha and improved farm income by USD 300/ha when compared to common farmer practice. Grain yield response to fertiliser K is highly variable and is influenced by soil, crop and management factors. Majumdar *et al.* (2012) reported that the average yield loss of maize in Indo-Gangetic Plains due to omission of K application was 700 kg ha-1. These observations were in contrary to the general perception that omitting potash for a season will not adversely affect maize production in the country. The results also demonstrate clearly the low K supply levels of most maize growing soils in India. Therefore, improved K management will have great potential for improving the overall productivity of maize systems in India. N, P, K, and Zn are the most limiting nutrients for maize growth in Tamil Nadu and relative yields are 57, 63, 71, and 75% of the optimum when N, P, K, and Zn are omitted. Also, maize yields and responses to applied nutrients varies considerably across farmer fields, mainly because of small and marginal landholdings that result in high variability in soil nutrient availability over small distances. The generally high variability in maize nutrient responses across fields and establishment practices suggests that spatial and temporal differences of nutrient availability needs to be accounted for while formulating nutrient management strategies in maize. Besides, large variability in crop response to all nutrients indicates the need to develop fertiliser recommendation tools that consider more than just a soil test. In other words, best bet approaches for nutrient management like site-specific nutrient management and decision support tools like Nutrient Expert for Hybrid Maize, based on realistic estimates of indigenous nutrient supply and nutrient requirements for a targeted crop yield for individual farmers' fields, will be required to improve yield and nutrient use efficiencies in maize. So keeping all this view, It is important to discuss on best nutrient management strategies for higher maize productivity.

Nutrient Management Strategies for improving Maize Productivity-

Nutrient management in the crop like maize which extracts large amount of nutrient from soil is a complex process. In maize, nutrient uptake is whole season process. Most of the nutrient (N and K) uptake is done during vegetative stage while P,S and Zinc uptake is greater during grain filling. Similarly micronutrients have narrow period of nutrient uptake than macro nutrients. Thus in maize the nutrient uptake time is different for different nutrients. In maize, season long supply of nutrients is critical for balanced crop nutrition. Thus matching nutrient supply with plant needs is the major concern in nutrient management strategies. That’s why the 4 R approach is very important. Optimizing nutrient management in maize includes using the right source at the right time at the right place with the right method. The fertiliser source and method that supply nutrients at the rate and time that match maize nutritional needs is very critical for optimizing NUE in maize. Proper nutrient management of exhaustive crop like maize should be based on the supply of adequate fertilizer as per the crop demand and use of such application methods that minimize the loss and maximize the efficiency of applied nutrient. One better way is to give a maintenance dose that replenishes part of the nutrient exported out of the field with harvested crop part. This will ensure that sure fertility level is maintained. Emphasis should be given to the exact nutrient requirement for the target yield and nutrient supply by integrated use of indigenous source, soil organic matter, FYM, Compost, crop residue etc to achieve high yield and NUE. Improving understanding of nutrient uptake time and rate provide opportunity to optimize rate, source and time. The spatial and temporal differences of nutrient availability needs to be counted while formalizing nutrient management strategies. While developing fertiliser recommendations for maize, two major aspects of plant nutrition are important to understand for managing high yielding maize production systems. This includes:

1) The amount of a given mineral nutrient that needs to be acquired by the plant during the growing season, referred to as “total nutrient uptake,” or nutrients required for production.

2) The amount of the nutrient transported out of the field with grain and straw/stover, referred to as “removed with harvested product”.

Providing the nutrients as and when required by the crop and replenishing the exported nutrient out the field with harvested products ensures sustainability of production systems. Further improvement of fertility practices require matching in-season nutrient uptake with availability, a component of the right source, which is interconnected with the other components of 4R Principle. The maximum rate of nutrient uptake coincides with the greatest period of dry matter accumulation during vegetative growth for most nutrients. Unlike the other nutrients, P, S, and Zn accumulation are greater during grain-filling than vegetative growth fertiliser sources that supply nutrients at the rate and time that match maize nutritional needs are critical for optimizing nutrient use efficiencies. Effectively minimizing nutrient stress requires matching nutrient supply with plant needs, especially in high-yielding conditions. Sulphur and N, for example, are susceptible to similar environmental challenges in the overall goal of improving nutrient availability and uptake. However, the timing of N uptake in comparison to S is surprisingly different In case of Nitrogen, two-thirds of the total plant uptake is acquired by VT/R1 crop physiological stage of maize, whereas S accumulation is greater during grain-filling stages with more than one-half of S uptake occurring after VT/R1. Similarly, potassium, like N, accumulates two-thirds of total uptake by VT/R1 and greater than one-half of total P uptake occurs after VT/R1 season-long supply of P and S is critical for maize nutrition while the majority of K and N uptake occurs during vegetative growth. Unlike N, P, K, and S, which have a relatively constant rate of uptake, micronutrients exhibit more intricate uptake patterns. Uptake of Zn and B, for example, begins in the early vegetative stages and reaches a plateau at VT/R1 stage of the crop. Thereafter, Zn exhibits a constant uptake rate similar to that of P and S, while B uptake follows a major sigmoidal uptake phase concluding around R5 stage of maize. Zinc and B follows shorter periods of more intense uptake in comparison to macronutrients. Late vegetative and reproductive growth, constituting only one third of the growing season, accounts for as much as 71% of Zn uptake by maize. A similar trend is also noticed for B where, as much as 65% of B uptake occurred over only one-fifth of the growing season (Bender *et al*., 2013). This also indicates that matching micronutrient needs of maize in high- yielding conditions clearly requires supplying nutrient sources and rates that can meet crop needs during key growth stages. Therefore, the 4R approach (right source, right time, right amount and right place) holds merit not only attaining higher yields but efficiency, profitability and environmental stewardship.The major considerations while formulating nutrient management strategies for higher maize productivity are listed below-

1. Careful application of nutrient /Balanced fertilization
2. Split application of Nitrogen with simultaneous Earthing up

3. Micronutrient application
4. Legume intercropping
5. Legume based crop rotation
6. INM
7. SSNM-NE
8. Precision and Real time Nutrient management

1. Careful application of nutrient/Balanced fertilization

To increase the NUE in maize, it is important to apply nutrients carefully specially nitrogen as N is subjected to various kinds of losses like volatilisation, denitification, nitrate leaching and losses of surface applied urea etc. Thus N scheduling is needed to be midified in such a way so that its losses could be minimized to improve NUE. Normally, the nitrogen is applied in three splits in maize i.e. 33% basal, 33% at knee high stage and 33% at tasseling stage but there is a scope to apply nitrogen in more splits to avoid nitrogen deficiency and improve N availability during critical crop growth stages. Pal and Bhatnagar, (2015) conducted an experiment in Tarai region of Uttarakhand during two consecutive kharif season of 2007 and 2008 to find out the optimum nitrogen schedule for higher maize productivity. The experiment consisted of four nitrogen schedules (1) T_1 33% basal, 33% at four leaf and 33% at 8 leaf stages;(2)T_2 10% basal,30% at four leaf,30% at 8 leaf, 20% at tasseling and 10% at early grain filling stage; (3) T_3 5% basal, 30% at four leaf,40% at 8 leaf,15% at tasseling and 10% at early grain filling stage; (4) T_4 20% basal,25% at four leaf,30% at 8 leaf,20% at tesseling stage and 5% at early grain filling stage. The significant higher grain yield, fodder yield and NUE were recorded with T_4.The reason behind this enhanced productivity and NUE is the better utilisation of Nitrogen even after the grain filling stage, which maintained the plant green even at harvesting stage. Thus balanced fertilisation in form of more split application of nitrogen is helpful in increasing productivity and NUE in maize.

2. Split application of Nitrogen with simultaneous Earthing up

Earthing up is an essential operation in maize crop which prevents the plant from lodging with better stand ability. Moreover, it also provides anchorage of the lower whorls of adventitious roots above the soil level which then function as absorbing roots. Thakur *et al*. (2003) reported significant increase in grain and straw yield owing to earthing up. Earting up and sowing on ridge may provide better condition for aeration and also require less irrigation water. Top-dressing of fertilizer in maize and other row crops is done by broadcasting method manually which results in low fertilizer-use efficiency. Broadcasting of fertilizers, especially P and K, results in fixation problems due to more soil contact while applied N is lost due to volatilization (Jat *et al*., 2014). Regular supply of nitrogen in adequate amount is necessary to enhance the productivity of maize (Singh *et al.*, 2003). Urea applied by farmers on soil surface is subjected to various losses and causes poor nitrogen use efficiency (Jat *et al*., 2016). Placement of urea below the soil surface may prove an effective way to enhance nitrogen-use efficiency and thus may be helpful in reducing nitrogen dose (Jat *et al.*, 2014). Earthing up ensures better aeration and fine tilth in root zone and thus makes favourable conditions to the development of roots. These conditions might result in higher water and nutrient uptake by roots from soil and favoured shoot growth. A field experiment was conducted by Bhatnagar and Kumar,(2017) during the rainy season (*rabi*) of 2011–12 and 2012–13 at Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar, to study the effect of mechanized earthing, conventional earthing and nitrogen dose on productivity and profitability of maize (*Zea mays* L.). The experiment included 4 earthing treatments in main plots, *Viz*. no earthing, manual earthing, inter-cultivation by cultivator and earthing by Pant fertilizer band placement-cum-earthing machine) and 4 levels of nitrogen, i.e. 90, 120, 150 and 180 kg/ha as subplots was arranged in splitplot design. The Pant fertilizer band placement cum earthing machine was designed and developed at the Department of Farm Machinery and Power Engineering, College of Technology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The machine was designed to perform continuous placement of fertilizer along the row crop, earthing-up and weed cutting operation simultaneously. Pant fertilizer band placement-cum-earthing machine is tractor-drawn machine which can perform the 3 main functions: (i) loosening of the soil up to 200 mm depth and cutting the weeds, (ii) placement of chemical fertilizers on the surface of the soil near the plant at a distance of 50– 100 mm sideways, and (iii) earthing-up the plant and covering the fertilizer. Significantly higher productivity and monetary advantage was noted under earthing by Pant fertilizer band placement-cum-earthing machine.The reason is the more availability of nutrients through out the crop growth period which results into higher NUE and productivity in maize.

Pant fertilizer band placement cum earthing machine

Field condition during operation of machine in maize

3. Micronutrient application

Micronutrients are trace elements which are needed by the maize crop in small amounts and play an active role in the plant metabolic functions in shortage of which show deficiency symptoms and crop yields are reduced, they are therefore to be added into the soil before crop planting or applied directly to the crop to increase maize productivity. Adhikari *et al.* (2010) revealed in order to evaluate the effects of micronutrients (B, Zn, Mo, S and Mn) on the grain production of maize (var. Rampur Composite), series of field experiments were conducted during the winter season of three consecutive years (2007 to 2009) in the acidic soil condition (5.1 pH) at National Maize Research Programme (NMRP), Rampur. The highest grain yield (5.99 t ha-1) was recorded with the crop which was supplied with micronutrients (B, Zn, S, Mn and Mo) applied in combination with NPK fertilizers at 120:60:40 kg ha-1 which produced almost 171% higher grain yield than those with control plot (2.21 t ha-1) and 3.78 t ha-1 of additional grains over NPK treated crop.Also the field experiment was conducted by Paramasivan *et al.* (2010) at farmers' field with maize (COHM 5) as a test crop. The highest grain yield (7908 kg ha-1) was recorded in the treatment with 250:70:150:9.6 kg of NPK and Zn ha-1. Archana *et al.* (2012) reported that among the iron treatments, 50 kg FeSO4 + 0.5% FeSO4 foliar spray showed the highest grain yield and it was comparable with 25 kg FeSO4 + 0.5% FeSO4 foliar spray. Borase *et al.*(2018) conducted a field experiment on experimental farm of National Agricultural Research Project, Aurangabad during *kharif* season 2015 and revealed that highest grain yield was recorded by T8-RDF + ZnSO4 + FeSO4 + Borax (4890 kg ha-1) followed by T9-RDF + Foliar application of Micronutrient (4791 kg ha-1). Thus, for securing maximum grain yield maize crop should be sown by supplying recommended dose of NPK along with ZnSO4 20 kg ha-1, FeSO4 20 kg ha-1 and borax 5 kg ha-1.

4. Legume intercropping

The main concept of intercropping is to get increased total productivity per unit area and time, besides equitable and judicious utilization of land resource and farming inputs including labour, with the insurance against crop failure. Maize (*Zea mays* L.) crop is normally grown at wider row spacing and inter row space can profitably be utilized for higher returns. Though intercropping is an age-old practice, it has attracted worldwide attention owing to yield advantages. One of the main reasons for higher yield in intercropping is that the component crops are able to use growth resources differently, so that when grown together, they complement each other and make better overall use of growth resources than grown, separately. Legumes in an intercropping system not only provide nitrogen to the associated crops but also increase the amount of humus in the soil due to decaying crop remains. Legumes as intercrop with maize instead of showing any adverse effect maize increase its yield. Legume as an intercrop can increase crop yields and economic benefits of intercropping systems. Maize in association with legumes gives higher total yield and net returns. To study the productivity of intercropping in maize with urd bean under different spatial arrangement, a field experiment was conducted by Bhatnagar and Pal,(2014) at G.B.P.U.A. & T. Pantnagar. The intercropping system of maize with urdbean in raw ratio (1+1) was found beneficial over sole cropping of maize and gave the maximum maize equivalent yield, LER and net return. Thus intercropping of maize with legumes in additive series is beneficial due to balanced competition and additional bonus yield of intercrop.

5. Legume based crop rotation

The practice of growing cereal after cereal coupled with use of intensive tillage led to decline in factor productivity (Dwivedi *et al*., 2003), stagnation in crop yield and depression in farm income. Increasing demand for pulses has further prompted farmers to use legume based crop rotation with maize. Yadav *et al*. (2017) evaluated the long term effect of legume intensified maize based crop rotations. The experiment consisted of four crop rotations (MWMb; maize-wheat-mungbean, MCS; maize-chickpea-*Sesbania*, MMuMb; maize-mustard-mungbean, MMS; maizemaize- *Sesbania*) as sub plot treatments. Results revealed that maize grain and stover yield were invariably higher in MCS and MWMb systems compared to MMuMb and MMS rotations. The higher maize yield with MCS might be due to inclusion of two legumes (one winter and another in summer) compared to only summer legume in other cropping systems. The inclusion of legumes have improved the soil fertility; particularly the N availability thereby improved growth and yields of maize. The maximum N, P and K content in maize stover was observed in MCS sequence plots as compared to other cropping sequences the inclusion of deep rooted legumes with shallow rooted cereals in the cropping systems might help in extraction of sub-surface nutrients. This in turn increases the nutrient availability in surface soil layers where maximum concentrations of maize roots existed. The higher nutrient availability might help in higher uptake of N, P and K which in turn leads to higher content of these nutrients in maize stover. The enhancement of NPK content due to inclusion of legumes has been earlier reported by Parihar, (2014) and Aziz *et al*., (2015).

6. Integrated Nutrient Management

The disproportionate use of chemical fertilizer has widened soil imbalance in terms of NPK ratio. The occurrence of nutrients deficiencies and overall decline in productive capacity of soil has been widely reported due to non-judicious fertilizer use (Chhonkar, 2008). Crop nutrients in generally low fertility situations in the state accompanied by the high cost of non-renewable chemical forms of nutrients and concern about environmental degradation and pollution, the need for supplementary cheaper source of nutrients is recognized. The use of vermicompost helps in maintaining soil fertility since the mineral elements contained in it get changed to available forms that could be readily taken up by plants such as nitrates, exchangeable phosphorous, soluble potassium, calcium, manganese *etc*. The recent concept of integrated nutrient management involving organic, inorganic and bio-fertilizers has developed to meet the growing need for nutrients under intensive cultivation. In integrated nutrient management system, the basic goal is to maintain or possibly improve the soil health and plant nutrient supply to an optimum level for sustaining the desired crop productivity by through optimization of the benefits from all the possible sources of plants nutrients in an integrated manner. The different INM options for maize are –

- Crop Residue Incorporation
- FYM/Compost/Vermicompost
- Green mauring
- Biofertilizer
    - Nitrogen fixing – *Azotobacter chroococcum*
    - Phosphorous solubilising

Bacteria: *Bacillus polymyxa, Bacillus megaterium Pseudomonas striata*

Fungi: *Aspergillus awamori, Penicilleum digitatum*

- K solubilizer *Bacillus mucilaginous*

Plant growth promoting -*Pseudomonas fluorescence*

Tomar *et al*. (2017) revealed that maize can be successfully grown under Indo-Gangetic plain zone on 100% NPK + 5 t FYM+ Azotobactor + PSB and harvest maximum productivity and profitability besides, improving used efficiency of nitrogen.It might be due to better effect of inorganic and organic sources on the adequate nutrients supply for longer period, which will affects crop growth and photosynthetic activity. Similar results were found by Sharma *et al.* (2013) and Kokani *et al*. (2014). Significantly higher removal of NPK were also noticed under 100% NPK + 5 t FYM+ Azotobactor + PSB. Higher uptake of N, P and K was may be due to favorable effect of incorporation of organic sources together with inorganic nutrients which was earlier reported by Sharma *et al*. (2013). Moreover, Decomposition of organic source is accompanied by the release of appreciable amount of Co2 which dissolve in water to form carbonic acid being capable of decomposition of certain primary minerals and release of nutrients, besides favors higher biomass production and nutrient uptake (Chandravanshi, 2014).

7. Site Specific Nutrient Management-Nutrient Expert

Being a heavy nutrient and water required crop, maize needs intensive management on these inputs. Increasing the cost of inputs especially fertilizers, site specific nutrient management (SSNM) in different crops is most effective way to the farmers to enhance crop productivity and sustaining soil fertility because it aims to supply required nutrients to a crop for a specific field or growing environment. Site-specific nutrient management gathered the informations from different scales to make field-specific decisions on various essential nutrients management. At present many tools have been using by farmers for applying required nutrients on targeted crop and field. Nutrient expert (NE), a simple nutrient decision support tool can also be used to develop fertilizer recommendations on a farmers filed. Nutrient expert for hybrid maize is new, computer based decision support tools developed to assist local experts to quickly formulate fertilizer guidelines for tropical hybrid maize based on the principles of site-specific nutrient management (SSNM). Adopting NE-based field specific fertilizer recommendations a significant increase in fertilizer efficiency and productivity of maize can be achieved (Satyanarayana *et al.,* 2013). Nutrient Expert (NE) for hybrid maize was evaluated by Singh *et al*. (2017) against farmers fertilizer practice (FFP) in three years maize-wheat rotation. Results revealed that nutrient expert-decision support system based nutrient management gave higher yield, nutrient uptake and profits and sustained soil properties over other practices.

8. Precision and Real time Nutrient management

Blanket recommendations based on fixed-time application of fertiliser N doses at specified growth stages do not consider the dynamic soil nutrient supply and crop nutrient requirements, and lead to untimely application of fertiliser nutrients. Therefore, need based fertiliser management in maize can help to improve recovery efficiency and to reduce nutrient losses. In-season N application adjustments of maize can be accomplished using leaf colour charts (LCC), SPAD and Green-Seeker sensors. Improved N management using the

LCC has consistently shown to increase yield and profit as compared to FFP (Rajendran *et al*., 2010). Applying right rate of N (240 and 150 kg/ha in maize and wheat), coupled with the right timing for N fertiliser (3-split applications) using LCC-based real time N management proved to be beneficial in increasing the yield and profitability of maize-wheat farmers of Northern Karnataka (Biradar *et al*.,2012). Singh *et al.*, (2011) evaluated different need based fertiliser N management strategies in maize and confirmed the usefulness of LCC 5 as threshold during vegetative growth stages for improving fertiliser N recovery efficiency and for obtaining high yields. They also observed that there was no response to fertiliser N application at R1 stage following different LCC threshold values. The authors further recorded that using LCC 5 as threshold of N application led to equivalent grain yield achieved with fixed time application of 150 kg N ha-1 but with the application of only 90 kg N ha-1. The recovery efficiency was increased by 19.8–22.8 along with grain yield production improvement by 7.1–8.5 kg grain per kg applied fertiliser N.

Conclusion

Maize is an important crop for food and nutritional security in India. Strong market demand, modern high yielding maize hybrids with lesser water requirement have increased the area and production of maize in the country over the past decade. But productivity of maize has not increased proportionately and significant yield gaps are evident across maize growing areas in the country. Maize is an exhaustive crop and removes large amounts of plant nutrients from the soil to support high biomass production. Regular supply of nitrogen in adequate amount is necessary to enhance the productivity of maize Adoptation of proper fertilizer application method is also important to increase the nutrient use efficiency and maize productivity. Micronutrients are also needed by the maize crop in small amounts and should be added in the soil before planting or applied directly to the crop to increase maize productivity. Inclusion of legumes in maize system as intercrop has been found to augment the productivity and profitability.Different INM options can also be used to enhance the maize productivity. Different nutrient-management approaches such as leaf-colour chart (LCC), Nutrient Expert, a computer-based decision support tool, Variable Rate Technology (VRT) etc. are the better options to increase fertilizer efficiency and productivity of maize.

The 4R Principles of applying right source of nutrients, at the right rate, at the right time and at the right place is expected to increase nutrient use efficiency, productivity and farm profit from maize production and provides opportunity for better environmental stewardship of nutrients. Adaptation of 4R Principle-based site-specific nutrient management decision support tools provides the opportunity for large-scale adoption of improved nutrient management across maize ecologies.

Way Forward

- Future research must build on the present approach of SSNM to develop a more practical way for achieving similar benefits across large areas without site-specific modeling and with minimum crop monitoring.
- Development of N management recommendation compatible with newly emerging resource conservation technologies (CA, Bed planting).
- There is need to develop crop rotations involving legumes to tap the benefits of BNF for enhancing NUE.
- Research should be done to develop Nutrient-efficient cultivar with high Nutrient uptake, assimilation and partition.
- Creating awareness amongst farmers regarding balanced fertilization in Maize is also very important to increase the maize productivity.

References

1. Adhikari, B.H, Shrestha, J. and Baral, B.R.,(2010).Effects of micronutrients on growth and productivity of maize in acid soil. *International Research Journal of Applied and Basic Sciences*, 1(1):8-15.
2. Archana, J., Amanullah, M.M., Manoharan, S. and Subramanian, K.S.,(2012) Influence of iron and arbuscular mycorrhiza inoculation on growth and yield of hybrid maize in calcareous soil. *Madras Agric. J*.,99(1-3):65-67.
3. Aziz, I., Bangash, N., Mahmood, T. and Islam, K.R. (2015). Impact of no-till and conventional tillage practices on soil chemical properties. *Pakistan Journal of Botany* 47: 297–303.
4. Bender, R. R., Haegele, J. W., Ruffo, M. L. and Below, F. E., (2013). *Better Crops with Plant Food*, 97(1): 7-10.
5. Bhatnagar,A. and Kumar,A.,(2017). Fertilizer band placement-cum-earthing machine effects on growth, productivity and profitability of maize (*Zea mays*) under varying nitrogen levels. *Indian Journal of Agronomy*,62(1):65-69.

6. Bhatnagar,A. and Pal,M.S.(2014).Evaluation of Intercropping systems in spring maize with sunflower and urdbean in North Western plain of India.*SAARC J.Agri.*,12(1):26-32.

7. Biradar, D. P., Aladakatti, Y. R., Shivamurthy, D., Satyanarayana, T. and Majumdar K. (2012). *Better Crops- South Asia*, 6(1): 19-21.

8. Borase C.L.,Lomte,D.M.,Dr.Thorat S.D. and Dr.Dhonde,A.S.,(2018). Response of *Kharif* maize (*Zea mays* L.) to micronutrients. *Journal of Pharmacognosy and Phytochemistry*; 7(3): 482-484.

9. Chandravanshi P, Chandrappa H, Hugar AY, Danaraddi Vijay S, Kumar NBT, Pasha A.,(2014). Effect of integrated nutrient management on soil fertility and productivity for sustainable production in rice-maize cropping system under Bhadra command area of Karnataka Proceedings of National Conference on Harmony with Nature in Context of Environmental Issues and Challenges of the 21st Century, Special issue, The Ecoscan, 6:385-390.

10. Chhokar, P. K. (2008). Organic farming and its relevance in India. Organic agriculture. Indian Society of Soil Science, Jodhpur PP 5-33.

11. Dass, S., Jat, M. L., Singh, K. P. and Rai, H. K., (2008). *Indian J. Fert.,* 4 (4): 53- 62.

12. Dwivedi, B.S., Shukla, A.K., Singh V.K. and Yadav, R.L. (2003). Improving nitrogen and phosphorus use efûciencies through inclusion of forage cowpea in the rice–wheat systems in the Indo-Gangetic plains of India. *Field Crops Research* 84:399–418.

13. FAOSTAT,(2018-19),Food and Agriculture Organisation of United Nations. http://www.fao.org/faostat/en/#home

14. FICCI & PWC,(2018), Maize Vision 2022: A Knowledge Report, Federation of Indian Chambers and Commerce of Industry & Pricewaterhousecoopers. http://ficci.in/spdocument/22966/India-Maize-Summit.pdf

15. Jat, H.S., Jat, R.K., Singh, Yadvinder, Parihar, C.M., Jat, S.L., Tetarwal, J.P., Sidhu, H.S. and Jat, M.L., (2016). Nitrogen management under conservation agriculture in cereal-based systems. *Indian Journal of Fertilizers* 12(4): 76–91.

16. Jat, S.L., Parihar, C.M., Singh, A.K., Kumar, A. and Sharma, S., (2014). Nitrogen management under conservation agriculture for enhancing resource-use efficiency in intensified maize systems. (In) *Abstracts of*

12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security" at Bangkok, Thailand, p. 98.

17. Jat,M.L.,Satyanarayana,T.,Majumdar K., Parihar,C.M.,Jat,S.L.,Tetarwal,J.P.,Jat,R.K. and Saharawat Y.S.,(2013).Fertiliser Best Management Practices for Maize Systems. *Indian J. Fert.,* 9 (4): 80- 94.

18. Kokani, J.M., Shah, K.A., Tandel, B.M. and Nayaka,P.(2014) Growth, yield attributes and yield of summer blackgram (Vigna mungo l.) as influenced by FYM, phosphorus and sulphur. Proceedings of National Conference on Harmony with Nature in Context of Environmental Issues and Challenges of the 21st Century, Special issue, The Ecoscan,VI:429-433.

19. Li, S., Jin, J., Duan, Y., Guo, T., Zhang, Y. and Li, Y., (2012). *Better Crops Plant Food*, 96(4): 18-20.

20. Majumdar, K., Jat, M. L., Pampolino, M., Kumar, A., Shahi, V., Gupta, N., Singh, V., Satyanarayana, T., Dwivedi, B.S., Singh, V.K., Kumar, D., Kamboj, B.R., Sidhu, H.S., Meena, M.C. and Johnston, A., (2012). *Indian J. Fert*., 8(5): 44- 53.

21. MOA & FW, (2018-19), Ministry of Agriculture & Farmers' Welfare. http://agriculture.gov.in/

22. NCoMM Report, (2017), Special report on Maize, National Collateral Management Services Limited. http://www.ncml.com/Upload/New/Pdf/c7495fab-54d7-4b03-a04a-47c2da337039.pdf

23. Pal,M.S. and Bhatnagar,A.,(2015).Effect of nitrogen scheduling on productivity, profitability and Nitrogen use efficiency in maize (Zea mays L.) under Tarai region of Uttarakhand. *International Journal of Basic and applied Agricultural Research*,13 (1):5-9.

24. Paramasivan, M., Kumaresan, K.R., Malar*Viz*hi, P., Mahimairaja, S. and Velayudham K., (2010). Effect of different levels of NPK and Zn on yield and nutrient uptake of hybrid maize (COHM 5) (*Zea mays* L.) in Mudhukkur (Mdk) series of soils of Tamilnadu. *Asian J Soil Sci*., 5(2):236-240.

25. Parihar, M.D. (2014). Studies on green house gas emissions and carbon sequestration under conservation agriculture in maize based cropping systems. Department of Agronomy, CCSHAU, Hisar, India.

26. Rajendran, R., Stalin, P., Ramanathan, S. and Buresh, R.J., (2010). *Better Crops-South Asia*, 4(1):7-9.

27. Satyanarayana, T., Majumdar, K., Pampolino, M., Johnston, A.M., Jat, M.L., Kuchanur, P., Sreelatha, D., Sekhar, J.C., Kumar, Y., Maheswaran, R., Karthikeyan, R., Velayutahm, A., Dheebakaran, G., Sakthivel, N., Vallalkannan, S., Bharathi, C., Sherene, T., Suganya, S., Janaki, P., Baskar, R., Ranjith, T.H., Shivamurthy, D., Aladakatti, Y.R., Chiplonkar, D., Gupta, R., Biradar, D.P., Jeyaraman, S. and Patil, S.G., (2013). Nutrient Expert: A tool to optimize nutrient use and improve productivity of maize. *Bettr Crops-South Asia,* 4-7.

28. Sharma GD, Thakur R, Som R, Kauraw DL, Kulhare PS.,(2013). Impact of intergated nutrient management on yield, nutrient uptake, protein conttent of wheat (Triticum astivum) and soil fertility in a typic Haplustert.*The Bioscan*.8(4):1159-1164.

29. Singh, R.N., Sutaliya. R., Ghatak, R. and Sarangi, S.K., (2003). Effect of higher application of nitrogen and potassium over recommended level on growth yield and yield attributes of late sown winter maize (*Zea mays* L.). *Crop Research* 26(1): 71–74.

30. Singh, V., Singh, Y., Singh, B., Thind, H. S., Kumar, A. and Vashistha, M. *Field Crops Res.*, 120: 276–282 (2011).

31. Singh,V.,Pant,A.K.,Bhatnagar,A. and Bhatt,M.,(2017). Evaluation of Nutrient Expert Based Fertilizer Recommendation for Growth, Yield and Nutrient Uptake of Maize Hybrids and Soil Properties in Maize- Wheat Cropping System in Mollisol. *Int.J.Curr.Microbiol.App.Sci.,6*(10): 3539-3550.

32. Thakur, H.S., Girothia, O.P., Holkar, S. and Sharma, R.A. (2003). Effect of land treatments on productivity of rainfed maize (*Zea mays* L.) varieties grown on Vertisols of Madhya Pradesh. *Crop Research* 26(1): 75–78.

33. Timsina, J. and Majumdar, K., (2012).*Better Crops-South Asia*, 6(1): 25-26.

34. Timsina, J., Buresh, R. J., Dobermann, A., Dixon, J. and Tabali, J., (2010). IRRICIMMYT Alliance Project **"**Intensified Production Systems in Asia (IPSA)**"**,IRRI-CIMMYT Joint Report, IRRI, Philippines.

35. Tomar,S.S.,Singh,A.,Dwivedi,A.,Sharma,R.,Naresh,R.K.,Kumar,V.,Tyagi,S.,Singh,A.,Siddhart,Y.,Rahul,N. and Singh,B.P.,(2017). Effect of integrated nutrient management for sustainable production system of

maize (*Zea mays* L.) in indo-gangetic plain zone of India. *International Journal of Chemical Studies*, 5(2): 310-316.

36. Yadav,M.R.,Parihar,C.M.,Jat,S.L.,Singh,A.K.,Kumar,R.,Yadav,R.K.,Kuri,B.R.,Parihar,M.D.,Yadav,B.,Verma,A.P. and Jat,M.L.(2017). Long term effect of legume intensified crop rotations and tillage practices on productivity and profitability of maize *vis-a-vis* soil fertility in North-Western Indo-Gangetic Plains of India. *Legume Research***,** 40 (2) : 282-290.