Chapter 1

Integrated Nutrient Management in Corn Production: Symbiosis for Food Security and Grower's Income in Arid and Semiarid Climates

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Additional information is available at the end of the chapter

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Abstract

Soil fertility and corn productivity is continuously declining due to removal of essential plant nutrients from the soils. The deficiencies of essential plant nutrients, organic matter, and beneficial soil microbes in soils had negative impact on soil fertility, corn productivity, and grower's income, which has increased the problem of food insecurity under arid and semiarid climates. Best management practices including the proper use of plant nutrients increase (1) soil fertility and health, (2) yield per unit area, and (3) grower's income (profitability). Our long-term field experiments on maize crop indicated that a significant increase in yield per unit area occurred with the integrated nutrient management (combined use of chemical fertilizers + organic fertilizers + biofertilizers). The integrated use of major plant nutrients (nitrogen, phosphorus, and potash) along with different organic carbon sources (animal manures and plant residues) plus biofertilizers (beneficial microbes) significantly improves maize growth, yield and yield components, and grower's income.

Keywords: maize, corn, integrated nutrients management, organic fertilizers, chemical fertilizers, bio-fertilizers, yield, grower's income

1. Economic importance of maize

Corn or maize (*Zea mays* L.) is an important cereal crop in the world. It provides staple food to many populations. Maize is the third most important cereal crop in Pakistan after wheat and rice. In Khyber Pakhtunkhwa it ranked second after wheat in its importance [1, 2]. In developing countries, maize is a major source of income to farmers among whom many are poor. Corn is used as animals feed and industrial raw material in the developed countries, while in developing countries mostly used as food for human and feed for animals (http://cornindia.com/importance-and-utilization-of-maize/). Because of its worldwide distribution and relatively lower price, maize has wider range of uses. For example, it is used directly for human consumption, as livestock and poultry feed, and in nonfood products such as starches, acids, and alcohols. Recently, there has been interest in using maize for production of ethanol as a substitute for petroleum-based fuels. Nutritionally, maize seeds contain 60–68% starch and 7–15% protein. The embryo of corn seeds which forms about 12% of the whole grain is the source of protein, fats, and sugars. Yellow maize is the richest source of vitamin A. Maize contains 1.2–5.7% edible oil. Varieties developed particularly for oil production contain as much as 14%. Maize oil is widely used as a cooking medium and for manufacturing of hydrogenated oil. The oil has the quality of reducing cholesterol in the human blood like sunflower oil. Maize acts as a source in the manufacture of starch, syrup, dextrose, oil, gelatin, lactic acid, etc. Corn flour is used as a thickening agent in the preparation of many edibles like soups, sauces, and custard powder. Corn syrup is used as an agent in confectionary units. Corn sugar (dextrose) is used in pharmaceutical formulations and as a sweetening agent in soft drinks, etc. Corn gel on account of its moisture retention character is used as a bonding agent for ice-cream cones and as a dry Dustin agent for baking products (http://cornindia.com/importance-and-utilization-of-maize/). Integrated nutrient management improves corn growth, leaf area index and light interception, dry matter accumulation and distribution, grain and fodder quality, yield components, grain and biomass yields, harvest index, shelling percentage, and grower's income.

2. Maize response to chemical fertilizers (N, P, and K)

Commercial fertilizers are applied to maize crop to improve its growth and yield [1–7]. Maize (cereal) is an exhaustive crop and produces high biomass [7–14] and therefore has a high requirement for nutrients especially nitrogen [15], phosphorus [1, 7, 10, 16], and potassium [2, 14, 17–19].

2.1. Nitrogen management

Nitrogen is an essential nutrient for plant and microbial growth and one of the key limiting nutrients in many natural ecosystems all over the world. In many developing countries, the imbalance use of nitrogen in crop production results in nitrous oxide (N_2O) which is considered much stronger greenhouse gas than carbon dioxide. The integrated use of chemical and organic N fertilizers can improve plant growth, increase yield and yield components and grain quality, and reduce environmental pollution. Nitrogen-rich organic manures (animal manure, poultry manure, plant residues, etc.) can be served as an effective substitute to chemical N fertilizers (urea, ammonium sulfate, nitrate, etc.) to reduce the costs of chemical fertilizers, reduce environmental pollution, and increase grower's income [20]. Increase in N rate and number of split applications at high density improve light interception contributing to the remarkable increase in the crop growth rate and yield [21]. The increase in light interception at high-density plots was due to the increase in leaf area index [17, 22]. The efficient use of nitrogen is also important for increasing grain quality (Amanullah and Shah [13]), partial factor productivity (PFP), and agronomic N use efficiency (NUEA) in maize [23]. Amanullah [24] compared the agronomic N use efficiency (NUEA) and harvest index response of different maize genotypes to different N-fertilizer sources (urea, calcium ammonium nitrate (CAN) and ammonium sulfate (AS)) at various levels (0, 50, 100, 150, and 200 kg ha^{-1}). The results revealed that NUEA had negative relationship with increase in N rate, while harvest index had positive relationship with increase in N rate up to 150 kg ha^{-1}. Both NUEA and harvest index ranked first with the application of AS (AS > CAN > urea). The maize hybrid produced higher NUEA and harvest index than local cultivars (Pioneer-3025 > Jalal > Azam). Khan et al. [15] reported that nitrogen application yielded 41 and 26% more grain than the check (control) in year 1 and year 2, respectively. The hybrid (P-3025) yielded 30 and 24% more grain than the local cultivars in years 1 and 2, respectively. The application of urea at 150 and 200 kg N ha^{-1}, CAN at 100 and 150 kg N ha ha^{-1}, and AS at 50 and 100 kg N ha ha^{-1} was economical in terms of NR in both years ([15]). Seed protein contents in corn increased with the application of higher N rates (150 and 200 kg ha^{-1}) as compared with the lower N rates (50 and 100 kg ha^{-1}), while application of ammonium sulphate increased seed oil contents as compared to urea and CAN [25]. Yield components (number of rows ear^{-1}, seeds row^{-1}, seeds ear^{-1}, ears per 100 plants), and both grain and stover yields in corn increased with higher N rate [5]; ammonium sulfate at the highest rate of 200 kg N ha^{-1} was found beneficial in terms of higher productivity & profitability for hybrid maize [5].

2.2. Phosphorus management

Phosphorus is second to nitrogen in total application to crops yet is used by plants in much lower quantities. Unlike N, soil P readily forms weakly soluble mineral compounds in the soil, thus resulting in poor mobility. The major problems under semiarid condition in Northwest Pakistan are (1) low soil moisture and (2) low soil fertility especially P unavailability ([26–28]). Highest level of 90 kg P ha^{-1} 10 days before sowing (DBS) had marked an increase in ear length, grain weight, grain yield, shelling percentage, and net returns [29]. Among the sources of P-fertilizers, diammonium phosphate (DAP) and single super phosphate (SSP) improved growth, dry matter partitioning, and grain yield than Nitrophos (NP) and control [27]. The highest level of 90 kg P ha^{-1} at 10 DBS increased plant height, number of leaves per plant, mean leaf area, dry weight of leaf, stem and ear as well as biomass yield, and harvest index [28]. Amanullah et al. [26] also reported that application of DAP and SSP resulted in higher partial factor productivity (PFP) (63.58 and 61.92 kg grains kg^{-1} P), agronomic efficiency (AE) (13.01 and 13.71 kg grains kg^{-1} P), and net returns (NR) (Rs. 16,289 and 16,204 ha^{-1}), respectively, as compared with NP with lower PFP (57.16 kg grains kg^{-1} P), AE (8.94 kg grains kg^{-1} P), and NR (Rs. 4472 ha^{-1}). Increase in P rate (90 > 60 > 30 > 0 kg P ha^{-1}) and tillage depth (45 cm) increased maize productivity and profitability [6]. Earlier, Amanullah et al. [28] reported that phosphorus level and its time of application are considered as some of the most important factors affecting crop growth, dry matter accumulation, and harvest index in maize.

2.3. Potassium management

Asif et al. [18] reported that tasseling, silking, and physiological maturity were delayed when potash levels were increased up to 60 kg ha^{-1}, while further increase in K level up to 90 kg ha^{-1}

enhanced tasseling, silking, and maturity. Tasseling, silking, and physiological maturity showed positive relationship with increase in the number of splits. Maximum grain yield was recorded when K was applied at the highest rate of 90 kg ha^{-1}, while minimum grain yield of 1898.8 kg ha^{-1} was recorded when K was not applied. The highest grain yield was recorded in those plots which received 100% of K at sowing time, while the lowest grain yield was recorded when K was applied in three splits, i.e., 33.3% at sowing time, 33.3% at 15 DAE, and 33.3% at 30 DAE. Amanullah et al. [2] reported that potassium fertilizer management is beneficial for improving growth, yield, and yield components of maize under moisture stress condition in semiarid climates. The results confirmed that increasing the rate of soil applied K up to 90 kg P ha^{-1} in two equal splits (50% each at sowing and knee height) improve growth and maize productivity under semiarid climates.

3. Maize response to foliar nutrition

Amanullah et al. [30] studied the response of maize to urea spray (U0 = control, U1 = 2, U2 = 4, U3 = 6, and U4 = 8% urea) at different growth stages (T1 = V9, T2 = V12, T3 = VT, and T4 = R1 stages) assigned to subplots. It was concluded from the study that urea spray at the rate of 6% at V12 stage improves the grain yield and yield components of maize. Foliar application of nitrogen (2%) from different sources (e.g., urea, ammonium sulfate (AS), and calcium ammonium nitrate (CAN)) and its application time (15, 30, 45, and 60 days after emergence (DAE)) were studied on maize. It was concluded from the results that late foliar-N application (urea, CAN, or AS) about 1 week before tasseling up to silking could increase maize productivity in the study area [31]. Amanullah et al. [12] reported that foliar nutrient management not only applies nutrients to the hungry crops, but it could also be beneficial in terms of providing water to the thirsty crops under moisture stress condition. They conducted field experiment to investigate effects of foliar NPK (2% each) applied alone and in various combinations (N, P, K, N + P, N + K, P + K, and N + P + K) and their application time (one split at 30 and 60 days after emergence (DAE) and two equal splits at 30 + 60 DAE) on the growth and yield of maize (*Zea mays* L., cv. Azam) under moisture stress condition. It was concluded from the results that combined foliar application of the three major nutrients (N + P + K) at the rate of 1% each in two equal splits at 30 and 60 DAE increased maize productivity under moisture stress condition. In our recent study (Amanullah et al. [4]), response of dryland maize was investigated to foliar phosphorus (1, 2, and 3% P) and zinc levels (0.1, 0.2, and 0.3% Zn) and their application time (T1 = at boot stage and T2 = at silking stage). It was concluded from this study that the application of 3% foliar P + 0.3% foliar Zn at boot stage improves growth and increases maize productivity and profitability under moisture stress condition in semiarid climates.

4. Maize response to organic matter

Soil organic matter (SOM) is a key indicator of soil health because of its vital functions that affect soil fertility, productivity, and the environment. Soil organic matter plays a key role in supplying plants with the nutrients they require. Organic matter improves soil physical (texture, structure, bulk density, and water-holding capacity), soil chemical (nutrient availability, cation exchange capacity, reduced aluminum toxicity, and allelopathy), and soil biological (nitrogen mineralization bacteria, dinitrogen fixation, mycorrhizae fungi, and microbial biomass) properties. SOM adsorb heavy metals in the soils, which reduce toxicity of these metals to plants and reduce their escape to ground water. SOM also adsorbs herbicides, which may inhibit contamination of surface and groundwater. Furthermore, SOM also functions as a sink to organic carbon and mitigates carbon dioxide escape to the environment. SOM stabilize soil aggregates, making soil easier to cultivate, increasing soil water-holding and buffering capacities, and releasing plant nutrients upon mineralization [32]. Adequate amount of SOM maintains soil quality (health), preserves sustainability of cropping systems, and reduces environmental pollution [33].

4.1. Animal manures

Farhad et al. [34] reported maximum plant height, leaf area index, leaf area, number of leaves plant^{-1}, and transpiration with composted poultry manure. Delayed tasseling resulted in Monsanto-919 with fresh poultry manure at 75% FC, whereas early tasseling resulted in FH-810 with same treatment at 100% field capacity. Ahmad et al. [35] reported that the use of poultry manure at the rate of 2.50 t ha^{-1} with inorganic fertilizer 200–150–125 kg NPK ha^{-1} resulted in higher grain yield due to the enhancement in grains per cob and cobs per m^{-2}. Baloch et al. [36] reported that combined application of manures and inorganic fertilizers significantly increases the growth and yield of maize crop. Amanullah and Khalid [10] Studied the impact of animal manures (poultry, cattle, and sheep manures) on hybrid maize "CS-200." They concluded that application of poultry manure delay phenological development, improve growth, and increase total corn biomass. Amanullah and Khalid [1] reported that the application of poultry manure increased yield and yield components of maize.

4.2. Plant residues

Adejumo et al. [37] reported that application of compost significantly increased maize biomass and decreased lead concentration in soil as compared to control and inorganic fertilizers. It was concluded that compost enhance soil fertility and crop productivity and increase plant resistance to heavy metals. Nziguheba et al. [38] studied the effects of residue incorporation and inorganic fertilizers on nutrient availability and maize yield. Plant residue incorporation increased P uptake and soil P as compared to inorganic fertilizer treatments in 3 years. Schiemenz et al. [39] studied the effectiveness of various types of ashes obtained after burning of different plant biomasses like rape meal, straw, and cereal residues. Ash application increased P uptake and soil P content, and the fertilizing effect of ash was comparable to triple super phosphate (TSP, a chemical fertilizer). Amanullah and Khan [16] studied the impact of compost application times ((30, 15, and 0 days before sowing (DBS)) on maize yield. The results confirmed that compost applied at sowing time significantly increased yield and yield components of maize under semiarid condition. Amanullah et al. [3] reported that application of compost tremendously improved growth and increased yield and yield components of maize when grown alone in mono-cropping or inter-cropped with common bean. The land equivalent ratio (LER) was higher in plots treated with compost than without compost-treated plots.

5. Maize response to biofertilizers (beneficial microbes)

Biofertilizers (beneficial microbes) are known to play many vital roles in soil fertility, crop productivity, and profitability. Beneficial microbes reduce the use of chemical fertilizers and thereby reduce environmental pollution caused by chemical fertilizers. Beneficial microbes reduce cost of production and so increase grower's income and profitability [40]. Our recent publications [1, 10, 16] indicated significant ($P \leq 0.05$) differences in growth, yield components, yield, and harvest index between the seeds treated with PSB (+) and without PSB (−). Amanullah and Khan [16] conducted field trial to study the effects of P levels, compost application times, and seed inoculation with phosphate-solubilizing bacteria (PSB) on the yield and yield components of maize (*Zea mays* L., cv. Azam). Maize seed inoculated with PSB (+) had tremendously increased yield and yield components of maize over PSB-control plots (−). Amanullah and Khalid [10] conducted field experiment to investigate impact of P levels (40, 80, 120, and 160 kg P ha^{-1}) and animal manures (poultry, cattle, and sheep manures) with (+) and without (−) phosphate-solubilizing bacteria (PSB) on phenological development, growth, and biomass yield of hybrid maize "CS-200." The plots with PSB (+) produced significantly taller plants with higher mean single leaf area and leaf area index and produced the highest biomass yield. Amanullah and Khalid [1] conducted a field trial to investigate the impact of the integrated use of different animal manures and phosphorus levels on yield and yield components of hybrid maize (CS-200) with (+) and without (−) phosphate-solubilizing bacteria (PSB). Maize seeds treated with PSB (+) before sowing had produced higher yield and yield components than untreated seeds (−). We concluded from this study that combined application of 160 kg P ha^{-1} + poultry manure + seed treatment with PSB (+) could improve corn productivity and profitability under semiarid condition.

6. Maize response to integrated nutrient management

The basic concept underlying integrated nutrient management (INM) is the maintenance and possible improvement in soil health for sustained crop productivity and sustainability. Amanullah et al. [7] reported that application of 120 kg N ha^{-1} + 2 t compost ha^{-1} under deep tillage system (45 cm) could improve spring maize yield and yield-contributing traits. Amanullah et al. [9] reported that application of the highest level of sulfur at 40 kg S ha^{-1} + N level at 160 kg N ha^{-1} increased maize productivity. Amanullah and Khan [16] reported that compost applied at sowing time + P applied at the two higher rates (75 and 100 kg P ha^{-1}) + PSB (phosphate-solubilizing bacteria) tremendously increased yield and yield components of maize. Application of 120 kg P ha^{-1} + poultry manure along with seed treatment with PSB improved growth and total biomass [10] and increased yield and yield components of maize [1]. According to Iqbal et al. [14], application of K at the highest rate of 90 kg ha^{-1} in two equal splits (50% at sowing +50% at V9 stage) along with cattle dung (5 t ha^{-1}) could improve number and area of leaves, dry matter partitioning, biomass yield, and harvest index under limited irrigation condition. Amanullah [41] reported that integrated use of organic carbon sources, plant nutrients and bio-fertilizers is key to improve field crops productivity under arid and semiarid climates.

7. Conclusions

Soil fertility and corn productivity are continuously declining due to the removal of essential plant nutrients from the soils. The deficiencies of essential plant nutrients, organic matter, and beneficial soil microbes in soils had negative impact on soil fertility, corn productivity, and grower's income that have increased the problem of food insecurity globally. Best management practices including the proper use of plant nutrients increase (1) soil fertility and health, (2) yield per unit area, and (3) grower's income (profitability). Our long-term field experiments on maize crop indicated that a significant increase in yield per unit area occurred with integrated nutrient management (combined use of chemical fertilizers + organic fertilizers + biofertilizers). The integrated use of major plant nutrients (nitrogen, phosphorus, and potash) along with different organic carbon sources (animal manures and plant residues) plus biofertilizers (beneficial microbes) significantly improves maize growth, yield and yield components, and grower's income.

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