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NUTRIENT MANAGEMENT PRACTICES FOR ENHANCING SOYBEAN (*Glycine max* L.) PRODUCTION

Prácticas de gestión de nutrientes para mejoramiento en la producción de soja (*Glycine max* L.)

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ABSTRACT

Soybean (*Glycine max* L.), is the most important pulse crop in the world. Soybean is a very energy-rich grain legume containing 40 percent protein and 19 percent oil in the seeds. The magnitude of soybean yield losses due to nutrient deficiency also varies among the nutrients. Deficiencies of N, P, Fe, B and S nutrients may cause yield losses up to 10 %, 29-45 %, 22-90 %, 100 % and 16-30 %, respectively, in soybean depending on soil fertility, climate and plant factors. Soil salinity is one of the major limiting factors of soybean production in semiarid regions, and chloride salinity has a more depressive effect on yield than sulphate salinity. The goal of nutrient management is to maximize soybean productivity while minimizing environmental consequences. Balanced and timely nutrient management practices applied for soybean contributes to sustainable growth of yield and quality, influences plant health and reduces environmental risks. Balanced nutrition with mineral fertilizers can assist in integrated pest management to reduce damage from infestations of pests and diseases and save inputs required to control them. Balanced fertilization generates higher profits for the farmers, not necessarily through reduced inputs. The role of education and extension in delivering the up-to-date knowledge on nutrient management is crucial, challenging, and continuous.

Keywords: bean, fertiliser, plant nutrition, yield.

RESUMEN

La soya (*Glycine max* L.), es el cultivo de legumbres más importante en el mundo. La magnitud de las pérdidas en el rendimiento de la soya debido a deficiencias varía dependiendo de los nutrientes. Las deficiencias de N, P, Fe, B y S pueden causar pérdidas en rendimiento de hasta 10 %, 29-45 %, 22-90 %, 100 % y 16-30 %, respectivamente, en la soya dependiendo de la fertilidad del suelo, clima y factores intrínsecos a las plantas. La textura de los suelos utilizados en el cultivo de soya varía entre arenosa y arcillosa. La salinidad del suelo es uno de los mayores factores limitantes en la producción del cultivo en regiones semiáridas, y la salinidad por cloro tiene un mayor efecto en la disminución del rendimiento que la salinidad por sulfatos. Los granos de soya son una gran fuente de energía que contienen 40 % de proteína y 19 % de aceite. El éxito del manejo de nutrientes es maximizar la productividad del cultivo mientras se minimizan los impactos ambientales. Las prácticas de manejo de nutrientes balanceadas y reguladas en el tiempo contribuyen a un crecimiento sostenido del rendimiento y la calidad, influencian la salud de las plantas y reducen los riesgos ambientales. Una nutrición balanceada con fertilizantes minerales puede ayudar en el manejo integrado de plagas para reducir los daños causados por las infestaciones de pestes y enfermedades y reducir los insumos requeridos para su control. Una fertilización balanceada genera mayores ganancias para los agricultores, no necesariamente por reducción de los insumos. El papel de la educación y la extensión en la difusión del conocimiento actual sobre manejo de nutrientes es crucial, desafiante y continuo.

Palabras clave: fríjol, fertilizante, nutrición vegetal, rendimiento.

INTRODUCTION

Soybean (*Glycine max* L.), is the most important pulse crop in the world. The magnitude of soybean yield losses due to nutrient deficiency also varies among the nutrients (Ali *et al.*, 2002). Deficiencies of N, P, Fe, B and S may cause soybean yield losses up to 10 %, 29-45 %, 22-90 %, 100 % and 16-30 %, respectively, depending on soil fertility, climate and plant factors. Yield is also limited by nutrient toxicities, which are more common with micronutrients. However, studies on this aspect are limited. Soybean, which is a hardy crop, has the ability to grow well even in marginal soils. It is grown on a wide range of soils varying in texture and soil fertility. The soil texture varies from sandy to clay. Soil salinity is one of the major limiting factors of soybean production in semiarid regions, and chloride salinity has a more depressive effect on yield than sulphate salinity. High exchangeable sodium percentage (ESP) and resultant deficiency of Fe, Cu and Zn in sodic soils causes poor crop establishment and performance. Therefore, selection of salt-tolerant genotypes for cultivation in soils with electrical conductivity (ECe) > 4 dS/m is recommended. The ability to exclude Na and Cl from shoots has been used as a criterion for selecting salt-tolerant genotypes. *Rhizobium* inoculation, mineral N fertilization and gypsum application have also been found effective in alleviating salinity problems. The nutrient related limitations of soybean productivity and their management are discussed in the following sections.

The goal of nutrient management is to maximize soybean productivity while minimizing environmental consequences. Nutrient management plans document available nutrient sources, production practices, and other management practices that influence nutrient availability, crop productivity and environmental stewardship. Many factors contribute to stagnating or declining yields in spite of farmers' efforts to achieve higher output. Production under adverse conditions faces many natural obstacles, e.g. insufficient and unreliable rainfall, poor or eroded soils, low soil fertility, shortage of irrigation water, crop-damaging and soil-eroding typhoons in humid regions or dust storms in arid regions, and rapidly spreading pests and plant diseases. In addition, there are often economic issues such as high prices for inputs like fertilizers, low market prices, and poor infrastructure. A combination of some of these factors diminishes the possibility for higher yields and discourages production beyond subsistence level.

SOYBEAN PRODUCTION

Soybeans (*Glycine max*) serve as one of the most valuable crops in the world, not only as an oil seed crop and feed for livestock and aquaculture, but also as a good source of protein for the human diet and as a biofuel feedstock. World soybean production increased by 4.6 % annually from 1961 to 2007 and reached average annual production of 217,6 million metric tons in 2005-07. World production of soybeans is predicted to increase by 2.2 % annually to 371,3 million metric tons by 2030 using an exponential smoothing model with a dampened trend (Masuda and Goldsmith, 2009). Soybean oil is used directly in food and preventing high blood pressure caused by arteriosclerosis. It also contains lot of the essential vitamins for the body. Soybean cultivation in Egypt started in 1976. Soybean production in Egypt has increased to about 966 ha. Yield levels have stabilized at about 2895 metric ton per hectare (El -Agroudy *et al.*, 2011).

PLANT ANALYSIS FOR TESTING NUTRIENT LEVELS IN SOYBEAN

Plant analysis is a common method to determine soybean nutrient deficiencies. As with corn, wheat, and other crops, there are two primary ways plant analysis can be used: as a routine monitoring tool to ensure nutrient levels are adequate in the plant, and as a diagnostic tool to help explain some of the variability in soybean growth and appearance we see in fields. The following Table (1) gives the range of nutrient content considered to be "normal" or "sufficient" for top fully developed soybean leaves at flowering. Keep in mind that these are the ranges normally found in healthy soybean plants (Mengle, 2008).

NUTRIENT UPTAKE BY SOYBEAN

Soybean is a very energy-rich grain legume containing 40 % protein and 19 % oil in the seeds. The crop is adapted to a wide range of climate conditions. The highest soybean yields

Table 1. Nutrient content of soybean leaves at flowering stage.

Elements	Content %	Elements	Content ppm
Nitrogen	4.25-5.50	Copper	10-30
Phosphorus	0.25-0.5	Manganese	20-100
Potassium	1.70-2.50	Zinc	20-50
Calcium	0.35-2.00	Boron	20-55
Magnesium	0.26-1.00	Molybdenum	1.0-5.0
Sulfur	0.15-0.50	Aluminum	<200

Source: Mengle (2008)

are produced in near neutral soils but good yields can be obtained also in limed acid soils. Under good growing conditions with adequate N fixation, grain yields of 3-4 metric ton/ha can be obtained. Total nutrient uptake by the plants per metric ton of grain production are as follows (IFA, 1992): 1. Macronutrients (kg): N 146, P_2O_5 25, K_2O 53, MgO 22, CaO 28 and S 5; 2. Micronutrients (g): Fe 476, Zn 104, Mn 123, Cu 41, B 55 and Mo 13. Under conditions favorable for N fixation, a significant part of the N uptake can be derived from nitrogen fixation. Inoculation with *Rhizobium japonicum* (now known as *Bradyrhizobium japonicum*) culture is often recommended particularly where the crop has been introduced recently or the native *Rhizobium* population is inadequate and ineffective. However, once soybean has been grown in a field for a number of years, *Rhizobium*, inoculation is not required, unless the field has been out of soybean production for five or more years. Under good conditions, the soybean crop will fix 100 kg N/ ha or more. Most or all of the nitrogen required by a soybean crop at this yield level will be supplied from the soil (as residual nitrogen and nitrogen derived from mineralized organic matter) and from symbiotic fixation from the atmosphere. Table 2 shows nutrient uptake for a typical soybean (Ferguson *et al.*, 2006)

NUTRIENT FUNCTION OF SOYBEAN

Nutrient functions of soybean include macro, secondary and micronutrients reported by Oldham (2011).

Nitrogen

Nitrogen (N) is required for protein production in plants and animals and is a component of the nucleic acids DNA and RNA. It is a component of chlorophyll, which gives the green color to plants and is vital for photosynthesis. Crops do not use N very efficiently, and significant quantities are often lost to leaching, volatilization, or denitrification. The bacteria infect their roots and convert nitrogen in the air into a form the plants can use. It is important to inoculate legumes with proper N-fixing bacteria if that particular crop has not been grown in the field for several years. Therefore, legumes that has active N-fixing bacteria do not need additional N fertilization. The bacteria will produce less N if it is provided.

Hardarson *et al.* (1984) reported that the % N derived from atmosphere was much more affected when the soybean were inoculated with *B. Japonicum* strain RCR 3412 compared to inoculation with 61A24a, when 20 or 100 kg N ha^{-1} were applied to the soybean and the N2 nitrogen fixation measured using ^{15}N methodology. In this context, starter N doses as low as 20-40 kg of N ha^{-1} may decrease nodulation and N2 fixation rates, with no benefits to yield. Indeed, in more than 50 experiments where inoculation and fertilization with 200 kg of N ha^{-1} have been compared (split application of N at sowing and flowering), no increases in yield due to N-fertilizer use have been observed. Similarly, there were no benefits when N-fertilizer was applied at a rate of 400 kg N ha^{-1}, split across ten applications (Hungria *et al.*, 2006). However, Afza *et al.* (1987) found that foliar application of N may slightly increase soybean yields without significantly decreasing biological N2 fixation. They carried out a field experiment, which shown that it is possible to increase soybean yields by applying 40 kg N ha^{-1} as a foliar spray without significantly reducing the amount of N_2 fixed. Clearly, biological nitrogen fixation (BNF) is the most sustainable and lowest cost source of N, and in many cases there is no response to added N. Hence, the issues of when, where and why soybean sometimes responds to applied N remains an important research issue.

Phosphorus

Phosphorus (P) enables plants to convert solar energy into chemical energy, and plants need chemical energy to synthesize sugars, starches, and proteins. Phosphorus is relatively immobile in soils. Substantial loss normally occurs only with erosion. Therefore, P may build up over time if more P is present in the soil than the amount removed by harvested crops. Plants may have deficient P early in the season if P is too far away from the roots or if root growth is inhibited. Phosphorus fertilization is inefficient, as it reacts in the soil with iron, aluminum, and calcium and becomes unavailable for plant use. Therefore, the amount of plant-available phosphorus is much lower than the total quantity of phosphorus in the soil. Soil testing is the best way to assess available P.

Table 2. Nutrient uptake for typical soybean yield.

Nutrients	Removed by Seed	Removed by Stover	Total uptake
		Pounds per acre	
N	188	127	315
P_2O_5	44	30	74
K_2O	66	576	142
S	5	15	20
Zn	0.05	0.3	0.35

Source: Franzen and Gerwing (1997).

Potassium

Plants use potassium (K) to photosynthesize, transport sugar, move water and nutrients, synthesize protein, and form starch. Adequate K improves disease resistance, water stress tolerance, winter hardiness, tolerance to many plant pests, and uptake of other nutrients. Under good growing conditions, crops remove quite a bit of potassium from the soil. K uptake is often equal to N uptake, and several times the uptake of P. Where levels of soluble K in the soil are high, plants may take up more K than needed as a "luxury consumption" that does not increase yields. Potassium mobility is strongly related to soil texture, and movement is greatest in soils with high sand content. K is most likely to build up in clay soils, followed by loam and coarse-textured sands.

Sulfur

Sulfur (S) is a component of some amino acids used in building proteins. Plants need about the same quantity of S as they do P. The amount reported is based on the soil organic matter content and is not a separate analysis. Like N, S is mobile in soils and can be lost by leaching. Within plants, however, S is immobile. Therefore, S deficiency symptoms are first found in younger tissue, while N deficiency symptoms are found in older tissues. Many older fertilizers contained both S and the primary nutrient, and for many years, rainfall deposited about 25 pounds of S per acre on the state annually. Thus, the only soils with S problems were coarse, sandy soils prone to leaching and containing low organic matter levels.

Calcium and Magnesium

Calcium makes up part of the cell wall and stabilizes cell membranes. Calcium deficiencies are usually found in growing points of the plant at the fruit, stem, leaf, and root tips. Calcium deficiency is rare in soils, but some crops, such as peanuts, may use more calcium in one season than the soil can supply. Magnesium is the central part of the chlorophyll molecule, where photosynthesis occurs. It also helps the plant metabolize energy and form protein. Magnesium deficiency is rare but has been diagnosed on sandy soils with low cation exchange capacities and high soil test potassium. Magnesium deficiencies in the soil may lead to magnesium deficiencies in grazing animals.

Micronutrients

Copper (Cu) is involved in respiration, protein synthesis, seed formation, and chlorophyll production. It is immobile in soils and thus can accumulate when more is applied than used. Organic matter holds copper tightly. Zinc is (Zn) necessary for starch formation, protein synthesis, root development, growth hormones, and enzyme systems. As is copper, Zn is relatively immobile in soils and tends to accumulate. Zinc deficiencies are most common on sandy soils that have low organic matter and high pH and P levels, especially under cool, wet conditions. Zinc deficiency symptoms are evident on small plants as interveinal light striping or a whitish band beginning at the base of the leaf.

Manganese (Mn) is involved in chlorophyll formation, nitrate assimilation, enzyme systems, and iron metabolism. Manganese deficiency is generally caused by a high soil pH, whereas Mn toxicities occur at low soil pH. Boron (B) is involved in sugar and starch balance and translocation, pollination and seed production, cell division, N and P metabolism, and protein formation. Boron, like N and S, is highly mobile, especially on sandy surface soils. Because of this mobility, B must be added annually for crops sensitive to deficiencies of it. Boron is recommended for all alfalfa production and for cotton production in all non-delta areas. In delta areas, B may boost yields on non-irrigated soils in dry weather, particularly if the soil has been recently limed. However, excessive rates of B should be avoided.

Molybdenum (Mo) is involved in protein synthesis, legume N fixation, enzymes systems, and N metabolism. Deficiencies of Mo generally occur on acidic soils with high levels of iron and aluminum oxides. Soil pH largely controls the availability of Mo to the plant. Iron is used in chlorophyll and protein formation, enzyme systems, respiration, photosynthesis, and energy transfer. Iron deficiency is believed to be caused by an imbalance of metallic ions, such as Cu and Mn; excessive amounts of P; and a combination of high pH, high lime, cool temperatures and high levels of carbonate in the root zone. Chlorine (Cl) is involved in photosynthesis, water-use efficiency, crop maturity, disease control and sugar translocation. While chloride leaches quite readily in coarse-textured soils, deficiencies are not very common. Plants require Nickel (Ni) for proper seed germination. Ni is also a component in urease, which helps convert urea to ammonium. Nickel is relatively newly defined as an essential element, so specific deficiency symptoms are unclear beyond chlorosis.

SYMPTOM OF NUTRIENT DEFICIENCIES ON SOYBEAN

Soybeans may begin showing signs of chlorosis or other leaf discoloration in all or parts of the field. There may be many causes of discoloration. Nutrient deficiencies are one possibility. Plant symptoms can be used to differentiate and identify crop nutrient disorders. Symptoms of nutrient deficiency vary with variety, growing conditions, and plant age. Similar symptoms may be caused by other abiotic or biotic stresses. Use the following key to help identify nutrient disorders observed in soybean (Ferguson *et al.*, 2006, Mengle, 2008, Crop watch, 2013). The following is a brief description of the symptoms of some of the most common nutrient deficiencies in soybeans (Fig. 1).

Nitrogen

Lower leaves are chlorotic or pale green (Fig. 1A). Within the plant, any available nitrogen (N) from the soil or from nitrogen fixation within nodules on the roots goes to the new growth first. Soybeans prefer to take up N from the soil solution as much as possible, since this requires less energy than the nitrogen fixation process. Both sources of N are important for soybeans since they are a big user of N.

Phosphorus

Phosphorus deficiency may cause stunted growth, dark green coloration of the leaves, necrotic spots on the leaves, a purple color to the leaves, and leaf cupping (Fig. 1B). These symptoms occur first on older leaves. Phosphorus deficiency can also delay blooming and maturity. This deficiency may be noticeable when soils are cool and wet, due to decrease in phosphorus uptake.

Potassium

Soybean typically requires large amounts of potassium. Like phosphorus deficiency, potassium deficiency occurs first on older leaves. Symptoms are chlorosis at the leaf margins and between the veins. In severe cases, all but the very youngest leaves may show symptoms (Fig. 1C).

Sulfur

Stunted plants, pale green color, similar to nitrogen deficiency except chlorosis may be more apparent on upper leaves. Young plants first turn pale and then turn severely chlorotic. Chlorosis starts from the leaf margins and spread towards the midrib (Fig. 1D). Plant-available sulfur is released from organic matter. Deficiency is most likely during cool wet conditions or on sandy soils with low organic matter content.

Magnesium

Lower leaves will be pale green, with yellow mottling between the veins. At later stages, leaves may appear to be speckled bronze. Symptomology may also include pale green plants with interveinal yellow mottling of the leaves followed by interveinal necrosis or necrosis along the underside of the main veins (Fig. 1E).This deficiency may occur on very sandy soils.

Calcium

The deficiency symptoms of Ca include arrested development of the rachis and browning of the leaflets of young expanding leaves. Leaflets also show necrosis. While older plant parts remain dark green, the death of growing points enhances development of auxiliary buds.

Boron

The deficiency symptoms of appear as yellowing of the leaves (Fig. 1F). Because of its poisonous nature, excessive amounts of B may show drying and shedding of leaves.

Zinc

Pale green plants; interveinal mottling (or interveinal chlorosis in drybean) of older leaves leading to bronze necrosis; green veins (Fig. 1G).

Manganese

Stunted plants with interveinal chlorosis. Pale yellow leaves with mottled interveinal chlorosis leading to dark brown necrosis (Fig. 1H). Can be a problem in soils with high pH (>7), or on soils that are sandy or with a high organic matter content. Symptoms are hard to distinguish from iron chlorosis.

Iron

Iron chlorosis, occurs in calcareous soils with high soil pH. The classic symptom is chlorosis (yellowing) between the veins of young leaves. Iron is not mobile within the plant. Symptoms are prominent interveinal chlorosis or necrosis; veins are prominent over length of leaf (Fig. 1I). A side effect of iron deficiency can be N deficiency, since iron is necessary for nodule formation and function. If iron is deficient, N fixation rates may be reduced. Iron deficiency occurs on calcareous soils because at high levels of calcium, iron molecules become tightly bound to the soil particle and unavailable for plant uptake.

NUTRIENT MANAGEMENT GUIDELINES FOR SOYBEAN

Practical recommendations and guidelines on nutrient management for specific soybean crops are usually provided by the local research and extension services in each country. This is logical and also necessary because of the crop- and area-specific nature of such recommendations.

Nitrogen

Soybean, which is a legume, has the inherent ability to fix atmospheric nitrogen (N_2) in symbiotic association with *B. japonicum*. The rich N content of soybean grain coupled with soil N meets the seedling stage demand, while biologically fixed N takes care of the needs at later crop stages under favourable conditions. Thus, the crop rarely shows N deficiency symptoms, but it does show the symptoms of deficiency with failure of biological nitrogen fixation (BNF) and in N-deficient soils. To alleviate N deficiency arising between the exhaustion of seed N and effective nodule formation, 20 kg N/ha is recommended as a starter dose. This starter dose is more essential in sandy loam soils, which have low soil N content. Temperatures as high as 30 °C in the top 10 cm of the soil profile may hinder early development of nodules (Rawsthorne *et al.*, 1985).

Over the years there has been interest in using N fertilization as a means to increase soybean yield due to the recognition of the large N requirement by soybean for high productivity. Despite the fact that soybean is a legume, research has shown soybean readily utilizes soil inorganic-N and at high yield levels results in net N removal from soil. Depending upon the amount of residual soil inorganic-N and soil mineralization characteristics, from 40 to 75 % of the N in a mature soybean plant is derived from the soil (Shibles, 1998). Soybean appears to require this soil-derived N component of total plant N for

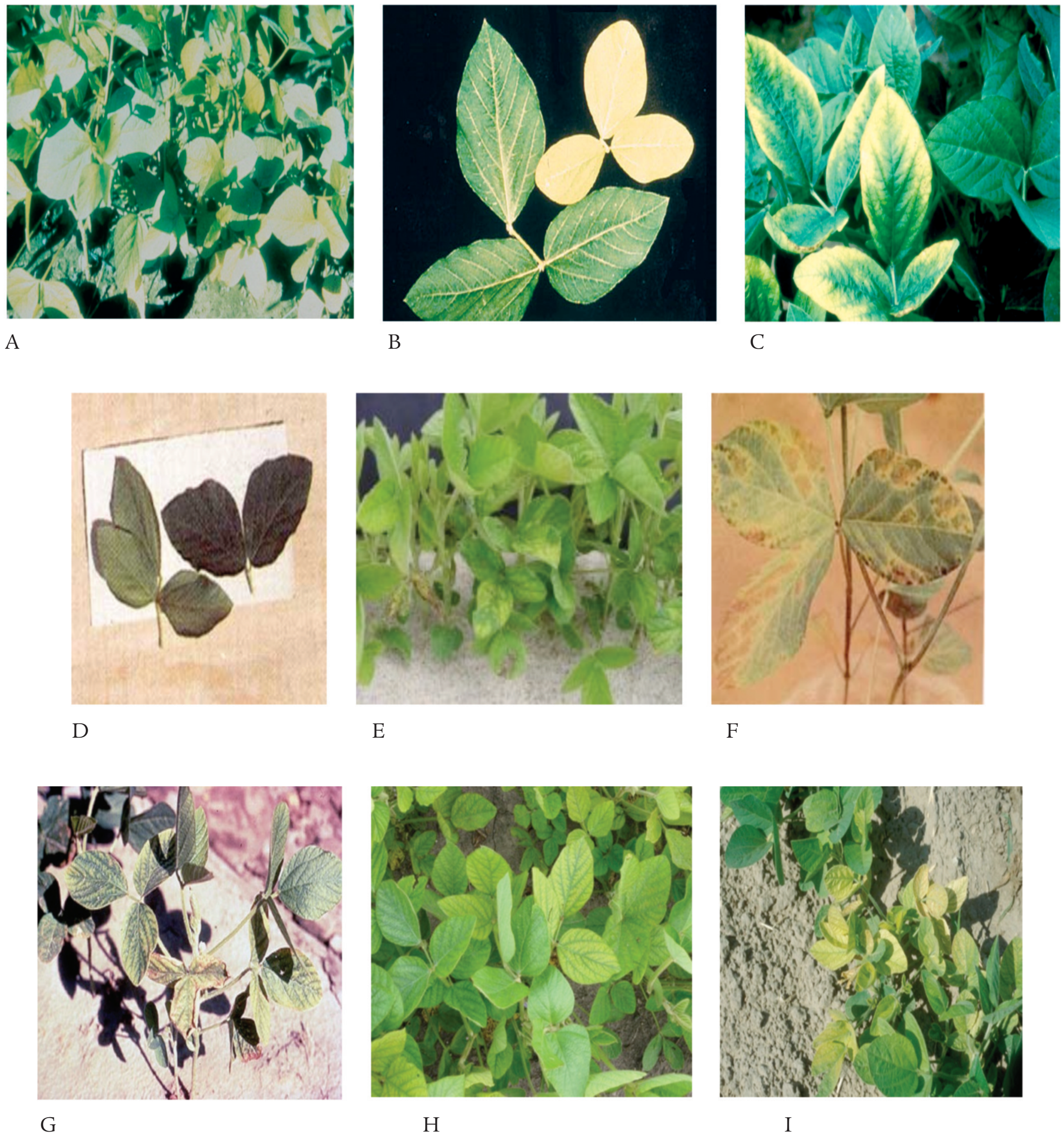

Figure 1. Nutrient deficiency symptoms in soybean (*Glycine max* L.). A. Nitrogen, B. Phosphorus, C. Potassium, D. sulfur, E. Magnesium, F. Boron, G. Zinc, H. Boron, I. Manganese.

high yield. Recognition of this soil N use, as well as other physiological aspects of soybean N metabolism, has sustained interest in enhancing N supply and use by soybean in hopes of increasing yield and grain protein.

The relative nitrogen supply from these two sources can vary widely depending on the soil nitrogen supply and conditions for nodule development. Nitrogen supplied from symbiotic fixation can range from 25 % to 75 % of the total nitrogen in the plant depending on these conditions (Varco, 1999). The least expensive means of supplying adequate nitrogen to soybean is to ensure adequate nodulation by inoculating the seed at planting. For fields in which soybean has not been previously grown, inoculation is essential. For such fields, a soil-applied inoculant may provide greater yield potential than a seed applied inoculant. For fields in which soybean has been previously grown, either a soil-applied or seed-applied inoculant is good insurance for providing adequate nitrogen for the crop. N fixation can meet a large part of the N requirement of the crop. The crop may respond up to the application of 100 kg N/ha in the absence of poor nitrogen fixation.

As discussed in the review article by Shibles (1998), soybean has two N acquisition systems, inorganic-N from soil and symbiotic N_2-fixation. What is interesting is the negative impact soil nitrate supply has on *Bradyrhizobia* infection and symbiotic fixation (that is, delayed infection and reduced nodulation and N_2-fixation in response to increased soil nitrate). This interrelated N acquisition presents a significant difficulty to increasing total plant N through fertilization.

Phosphorus

Soybean is more efficient at producing good yield at low soil phosphorus (P) levels than other major agronomic crops. Phosphorus is the most critical nutrient limiting soybean production, and is deficient in the majority of soybean - cultivated tracts. Legume fertilization is often P-based, since it is highly essential for intensive N fixation. Thus, P, by way of its role in energy transformation and enhancing root growth, is essential for nodulation and effective N fixation. The response to P fertilization depends on soil moisture status, as soil moisture stress may decrease the availability of applied P, resulting in poor biomass production and reduced P uptake. The need for P fertilization is usually more in acidic soils than in others due to higher P fixation. In general, all the sources of P are equally effective in soybean, except rock phosphate. Rock phosphate is a poor source of P in neutral to alkaline soils, but a fairly good source for acidic soils.

Yield increases from phosphorus fertilization will probably not occur when the Bray-1 P test is greater than 12 ppm. Subsoil levels of phosphorus usually are not an issue when making recommendations for phosphorus fertilization. Generally, no great advantage exists for using a starter-applied fertilizer with soybean. The producers plant soybean later than corn, when soil temperatures are higher and the growing point of soybean is above ground, versus below for corn, so soil temperature has less influence on soybean growth. With low soil test phosphorus levels, band application of fertilizer is more efficient than broadcasting. The producer should space fertilizer bands 10 to 15 inches apart and three to six inches deep. If the farmer applies phosphorus at planting, he should band at least one inch away from the seed. The producer should not place fertilizer with the seed due to the risk of seedling injury during germination (Ferguson *et al.*, 2006). Phosphorus fertilizer recommendations for soybean are provided in Table 3.

Phosphorus is an important plant nutrient involved in several energy transformation and biochemical reactions including biological nitrogen fixation. Nandini (2012) conducted field experiments to study the effect of different sources and levels of phosphorus on productivity of soybean. The treatments consisted of four sources of phosphorus [Single super phosphate (SSP), Diammonium phosphate (DAP), Single super phosphate (SSP)+Phosphate solubilizing bacteria (PSB), Diammonium phosphate (DAP)+Phosphate solubilizing bacteria (PSB)], four levels of phosphorus (20, 40, 60 and 80 kg P_2O_5 ha^{-1}) and one absolute control(without any fertilizer and PSB). Maximum grain yield and total phosphorus uptake were also recorded when using SSP+PSB. Yield attributing characters, grain and stover yield were increased with increasing levels of phosphorus. Regarding evaluation of various efficiency fractions of soybean, agronomic efficiency, physiological efficiency and phosphorus use efficiency had more pronounced effects on combined application of SSP+PSB. However, apparent recovery of phosphorus was higher in DAP+PSB due to higher stover yield and higher phosphorus uptake. Among the different levels the efficiency fractions increase up to 60 kg P_2O_5 ha^{-1} and declined at 80 kg P_2O_5 ha^{-1}.

Potassium

Potassium (K) requirement of soybean varies from 14.3 to 57.7 kg / t of grain depending on soil type, but its use is limited due to sufficient levels of soil K in most regions to support the crop. Clay soils seldom need K fertilizer for soybean production. For soils that are not high in exchangeable

Table 3. Phosphorus fertilizer recommendations for soybean in Nebraska based on Bray-1 or Olsen phosphorus tests.

Phosphorus soil test			P_2O_5 to apply
Bray-1 P	Olsen-P	Relative level	Pound per acre
0-5	0-3	Very low	60
6-10	4-5	Low	20
11-15	6-7	Medium	0
16-24	8-14	High	0
> 24	> 14	Very high	0

Source: Ferguson *et al.*, 2006.

Table 4. Potassium fertilizer recommendations for soybean in Nebraska, based on soil test levels.

Exchangeable K soil test		K_2O to apply
ppm	Relative level	Pound per acre
0 - 40	Very low	60
41 - 74	Low	40
75 - 124	Medium	20
> 124	High	0

Source: Ferguson *et al.*, 2006.

potassium, producers should apply potassium fertilizer in the amounts shown in Table 4. Broadcasting and incorporating potassium prior to planting is the most efficient method (Ferguson *et al.*, 2006).

Fertilizer P and K requirements of soybean should be based on soil test values. Typical application rates for soils of low nutrient status are 50-70 kg P_2O_5/ha and 60-100 kg K_2O/ha. In the soybean-growing areas of the United States of America, for an expected grain yield of 2.5-2.7 tonnes/ha, the recommended rates of P on low-fertility soils are 40-60 kg P_2O_5/ha, and 100-150 kg K_2O/ha on soils with a low to normal clay content. Application rates are higher at higher yield levels in soils with high clay content. As an example, for each additional tonne of grain yield, an extra 10-15 kg P_2O_5/ha and 20-30 kg K_2O /ha is recommended (Roy *et al.*, 2006).

Potassium fertilization in Egyptian irrigated agriculture has become very important since the completion of the High Dam in Aswan, which prevented the continuous deposition on farmers' fields of the Nile silt-rich in K bearing minerals (Abdel Hadi, 2004). In addition, Nile alluvial soils with high clay content can have a high K fixing capacity. Thus, even with a high Kex level there might not be sufficient available K for various crops (El-Fouly and El-Sayed, 1997). In addition, the newly reclaimed soils (approximately 800,000 ha, 25 % of the total cultivated land) are sandy and calcareous, and poor in organic matter and macro- and micronutrients (El Hadi, 2004).

During this period, potash consumption (input of K) in Egypt was only 57000 mt K_2O. This means that the negative balance for potash was between 183000 and 433000 mt K_2O, or between 3 and 8 times the amount of potash used. This calculation is valid for 75 % of the cultivated land in Egypt. The production of fruit and vegetables is considerable and therefore very significant in K_2O consumption. We estimate that currently these crops are responsible for approximately half of the K_2O removed in Egypt. In future, with increased production of fruit and vegetables on the newly reclaimed land, with its poor K supplying capacity, there should be a need for higher K_2O consumption (FAO, 2005).

Sulfur, Calcium and Magnesium

The importance of sulphur (S) in soybean, which requires ~9 kg for producing 1 t of grains, arises due to the fact that legumes are rich in S-containing amino acids (methionine, cystine and cysteine), and because it is a constituent of the nitrogenase enzyme, which aids nitrogen fixation. Thus, S has become the fourth most important nutrient of crop production. The need for S fertilization has also been identified because of the increased use of S-free fertilizers and higher productivity of crops associated with greater uptake of S. Soybean need forS fertilizer is very unlikely. Soybean is tolerant of low sulfur levels in the soil, so it is not likely to respond to sulfur fertilization. Soybean responds to the application of Mg and S depending on soil fertility status and crop growth conditions. Significant responses of soybean to S application have been found in many field trials in India. In several cases, it may be advisable to apply phosphate through SSP so that the crop also receives an S application. Where DAP is used, gypsum can be applied to the soil before planting at the rate of 200-250 kg/ha (Roy *et al.*, 2006).

The base elements, calcium (Ca) and magnesium (Mg), are generally deficient in acidic soils. Soils with <1.5 meq exchangeable Ca /100 g soil or <25 % of cation exchange capacity (CEC), and <1.0 meq exchangeable Mg /100 g soil or <4-15 % of CEC are usually considered as Ca- and Mg-deficient. The Mg requirement of legumes is generally higher than that of cereals and oilseeds. In neutral soil with 1.6 cmol (p+) Mg/kg soil, Mg fertilization increased soybean yield by 22.5%.

Zinc

Zinc deficiency is common among soybean -growing regions of the world. Zn fertilization enhances water use efficiency (Khan *et al.*, 2004), amino acid (lysine, histidine and arginine) and crude protein contents of soybean (Nayyar *et al.*, 1990). The critical concentrations of Zn in soils vary from 0.48 ppm in noncalcareous soils to 1.75-2.5 ppm in loams. Critical Zn concentration in plants is 15-20 ppm at 45 days after sowing in top leaves. The critical limit of Zn concentration in both soil and plant decreases with advancement of crop growth stage. Soybean is more tolerant to low levels of zinc in the soil than corn is, but zinc fertilizer may be beneficial when soil zinc levels are low.

Intensive cropping coupled with high crop yields has gradually led to micronutrient deficiencies. Although these nutrients are micro in terms of uptake, their contributions are as important as those of macronutrients. The necessity of all the six micronutrients in soybean and their extent of yield limitations have been well established in pot/solution culture and in some cases under field situations. The micronutrients limiting soybean productivity in the order of importance are: Zn > Fe > B. Depending on soil fertility status and crop growth conditions, responses have been obtained to the application of Zn and Mn. Application of 5 kg Zn /ha on coarse-textured soils and 10 kg Zn /ha on clay soils can remedy Zn deficiency. On Mn-deficient soils, the application of manganese sulphate at a rate of 15 kg/ha to the soils or 1.5 kg through foliar spray increases yield. Table 5 shows the recommended zinc fertilizer rates for soybean (Ferguson *et al.*, 2006).

Yasari (2012) studied the effects of applying the micronutrients zinc, manganese, and boron, and to compare the effects that incorporating them in the soil and spraying them on the soybean crop on seed oil and protein contents and percentages. The study was conducted based on the factorial design with the two factors of incorporating these micronutrients in the soil and spraying them on the crop. Results obtained showed that the highest seed oil percentage (25.03 %) was achieved by spraying zinc on the crop, and that the biggest seed oil yield (359.31 Kg h^{-1}) was obtained by applying manganese

Table 5. Zinc fertilizer recommendations for soybean.

DTPA-Zn		Zinc to apply	
Ppm	**Relative level**	**Calcareous soil**	**Noncalcareous soil**
		Pound per acre	
0 - 0.4	Low	1 row or 10 broadcast	1 row or 5 broadcast
0.4 - 0.8	Medium	0	0
0.8	High	0	0

Source: Mengle (2008)

to the soil. The highest seed protein content (36.12 %) was achieved by spraying boron on the crop, and the greatest seed protein yield (545.54 Kg h^{-1}) was obtained when manganese was added to the soil. These results also showed that the largest number of total pods per plant (71.05), and the biggest seed yield (152.9 g m^{-2}) were achieved by applying manganese to the soil. It was also shown that, although the highest seed oil percentage belonged to the spraying of zinc on the crop, yet the greatest seed yield among all the treatments (170.7 g m^{-2}) was that of the treatment of adding manganese to the soil plus spraying zinc on the crop, in which the greatest number of pods per plant (77.87) and the highest seed protein yield (631.1 Kg h^{-1}) and the highest seed oil yield (284.5 Kg h^{-1}) were obtained.

Iron

Iron deficiency is a complex physiological disorder of plants grown in calcareous soils with high pH that have low available Fe and inadequate uptake or because of impaired transport and metabolism of Fe induced by other ions. The problem is difficult and it requires a specific management program, which includes selecting appropriate varieties, properly adjusting seeding density, applying materials with the seed, and using foliar sprays. Applying Fe-EDDHA directly with the seed at planting is the most effective and consistent treatment. The amount needed depends on the degree of chlorosis, but the most common rate is between one and four pounds of product per acre. Fe-EDDHA is a dry powder that mixes easily with water. The producer should dissolve the powder in 20 to 25 gallons of water per acre and apply it directly with the seed, without the addition of any other fertilizer (Ferguson *et al.*, 2006).

Soybean yield response following foliar application of iron-containing materials is often inconsistent. Frequently, chlorosis will be advanced beyond the stage where foliar iron application will help. High air temperature and wind erosion also reduce foliar application effectiveness. To fully correct the problem, two to three applications may be necessary using a 1 % solution of ferrous sulfate ($FeSO_4$). Two pounds of ferrous sulfate or four pounds of ferrous sulfate heptahydrate ($FeSO_4$ $7H_2O$) in 25 gallons of water makes a 1 % solution. A greater-than-1% solution can lead to leaf burning. The farmer can also use iron chelates for foliar application. Adding a commercial wetting agent or a cup of mild household detergent to 100 gallons of solution can improve plant coverage. Adding five pounds of urea fertilizer per 100 gallons of spray solution also may improve foliar spray performance (Ferguson *et al.*, 2006).

Boron, Manganese and copper

Boron (B) toxicity is a major concern in arid and semiarid regions of the world (Hobson *et al.*, 2001). The importance of molybdenum in legumes in general and soybean in particular arises from the fact that it is a constituent of nitrate reductase and nitrogenase enzymes, which play an important role in N fixation. Soils with 1 ppm DTPA-extractableMn may support crop growth successfully. In coarse-textured soils where rice is grown continuously, Mn gets leached, and crops after rice usually experience Mn deficiency. Copper deficiency has been reported in newly cleared soils of South-west Australia with neutral to alkaline pH.

Application of organic manure and biofertilizer

Application of organic manure, biofertilizer and yeast (*Candida tropicales*) on growth, yield and seed quality of soybean (*Glycine max* L.). The results indicated that application of organic manure at a rate of 20 ton per acre as a sole treatment and also when it is associated with biofertilizer as one treatment had more plant height and dry weight per plant. Seed yield (g per plant), pods weight (g per plant), as well as, number of pods per plant, seeds per pod and 1000-seed weight were decreased by adding biofertilizer singly, but when it was associated with organic manure it showed the highest seed and pods weight. Application of organic manure+yeast as one treatment resulted in increased yield and yield attributes of soybean plants. P concentration was only increased when plants received yeast only and also when yeast was associated with biofertilizer. Zn concentration tended to increase as plants were treated by bio.+ organic manure+yeast followed by bio.+ organic as one treatment. Mn concentration was high when plants received yeast singly or when it was associated with biofertilizer, while Fe concentration tended to increase due to adding bio.+ organic manure + yeast followed by bio.+ organic as one treatment (Mekki *et al.*, 2005).

Most countries have traditionally utilized various kinds of organic materials to maintain or improve fertility and productivity of their agricultural soils. However, several decades ago organic recycling practices in some countries were largely replaced with chemical fertilizers that were applied to high yielding cereal grains that responded best to high level of fertility. Compost utilization as manure is becoming more widely accepted in recent years as a consequence of the rise in price of conventional fertilizers. Beneficial effects of organic fertilizer applications on growth and yield of some field crops were shown by Radwan and Hussein (1996), Mekki *et al.* (1999) and El-Kholy and Gomaa (2000). Currently, emphasis has already been placed on research and development activities that led to the concept of multistrain biofertilizers i.e. the application of soil microorganism groups, having a definite beneficial role in supporting bio-control of soil born disease (Saber and Gomaa, 1993). Bread yeast (candida) has demonstrated a large on growth and yield of millit crop (El-Kholy and Gomaa, 2000).

Sharief *et al.*, (2010) conducted field experiments at El-Semblawin, Dakahlia Governorate, Egypt to investigate the effect of soybean cultivars (Giza 111, Crawford, Giza 35 and Giza 21) as well as organic and inorganic fertilization treatments (farmyard manure, poultry manure, urea, 75% farmyard manure + 25 % urea and 75 % poultry manure + 25 % urea) on growth, yield and yield components as well as seed oil and protein contents. Application of 75 % N from poultry manure + 25 % N from urea as a source of nitrogen ha-1 significantly enhanced all the studied characters in both seasons and combined analysis. It could be concluded that relevance of the combination of 75 % of recommended N from poultry manure (67.5 kg N ha^{-1}) + 25 % recommended rate of N from urea (22.5 kg N ha^{-1}) with sowing soybean Giza 21 cultivar, should be the optimal treatment to minimizes soil and water pollution and more successfully enhance seed production and its quality under the environmental conditions of Dakahlia region.

Mehasen and Saeed (2005) studied the effects of bacterial inoculation as well as mineral and organic fertilization on the yield and yield components of soybean Giza 22 and Giza 111 cultivars. They concluded that there is a significant effect for the interaction between soybean cultivars and fertilization treatments on seed weight per plant only.

Cropping Systems and nutrient management

Soybean, mainly a summer crop, is also grown in autumn and spring seasons in different parts of the world in various sequential and intercropping systems. The residual effect of previous crops and differential requirement of nutrients of component crops demand efficient management for higher system productivity.

The crop has made radical improvement in the farming community. It is considered as an exhaustive crop demanding heavy nutrition. This has resulted in a decline in crop productivity and deterioration in soil health and productivity. Use of organic manures may prove a viable option for sustaining the productivity of soybean and adds life to the soil. Normally only 35 to 40 per cent of N from organic manure added is available for the use of crop. The rest of it is available to the succeeding crops. Hence, the nutrient management of a cropping system is based on the residual effect of organic matter. This will affect the succeeding crop of wheat after wheat in the rabi system. Wheat is one of the most important cereal crops of the world on account of its wide adaptability to different agro-climatic and soil conditions. In India it stands next only to rice and contributes about 35 per cent to the national food basket, with an area of 26.5 million hectare and a production of 72 million tonnes (2004-05) with a productivity of 2718 kg per ha (FAI, 2006).

Shwetha (2007) studied nutrient management through organics in a soybean-wheat cropping system. The experiment was comprised of 12 treatment combinations of organic manures (*viz.*, compost, vermicompost, GLM) and fermented organic manures (beejamrut, jeevamrut, panchagavya), with RDF + FYM as control. Nutrient uptake by both the crops was significantly higher with the application of RDF + FYM and organic manures + beejamrut + jeevamrut + panchagavya. Soil properties *viz.*, organic carbon and available soil nutrients (N, P_2O_5 and K_2O) after harvest of soybean and wheat crops were significantly higher with organic manures alone or in combination with fermented organics. The study reveals that compost + vermicompost + GLM, helps in increasing yield, net return and benefit per rupee investment comparable to RDF + FYM in soybean-wheat cropping system. Next best combinations were organic manures + beejamrut + jeevamrut + panchagavya. Whereas, fermented organic manures alone are not able to support crop yield.

Xiang *et al.*, (2012) conducted a field experiment to determine the effect of Phosphorus (P) application (0, 8.5, 17.0 and 25.5 kg ha^{-1}) and Potassium (K) application (0, 37.5, 75.0 and 112.5 kg ha-1) on growth and yield of soybean (*Glycine max* (L.) Merr.) in a relay strip intercropping system. Applying K from 0 to 112.5 kg K ha^{-1}, plant height, lodging rate, unfilled pod ratio, and 100 seeds weight were significantly reduced, while pods per plant, seeds per pod, and harvest index increased greatly. The highest benefit in growth and seed yield was obtained at rates of 17.0 and 112.5 kg ha^{-1} for P and K, respectively. Application of 17.0 kg P ha^{-1} at the rate of 112.5 kg K ha^{-1} gave 18.5, 13.7, and 4.0 % higher seed yield than its application at rates of 0, 37.5, and 75 kg K ha^{-1}, respectively. In conclusion, the findings suggested that the combination of P (17.0 kg ha^{-1}) and K (112.5 kg ha^{-1}) can maximize productivity of soybean in the relay strip intercropping system.

Salinity and nutrient management

Salinization of land has threatened civilization from ancient to modern times. Soybean is a major food and oil crop in most countries where salinity problems exist or might develop. Abd-Alla and Omran (2002) recorded that soybean cultivars had a wide range of variation in growth and yield as well as its attributes; also varietal differences were detected among soybean cultivars in efficiency and to soybean nematodes. Hussein *et al.* (2006) found that soybean Giza 21 *cv.* surpassed Giza 22 and Giza 111 cultivars in 100-seed weight (g) and seed yield (t ha^{-1}) by 64 and 15 % in the first season and 26 and 12.8 % in the second season, respectively. Abdelhamid *et al.* (2010) carried out experiments to examine how inoculation with *Rhizobium* sp., *Azospirillum* sp. and ascorbic acid solely and/or combined mitigate the negative effects of salinity on soybean growth and yield. A randomized complete block design with three different sites of soil salinity levels (3.13, 6.25, 9.38 dS m^{-1}), with two soybean cultivars (*Giza* 22 and *Giza* 111) and 7 treatments (biofertilizer and ascorbic acid solely and their combinations) with three replications were used. Soil salinity significantly reduced ascorbic acid, total indoles, amylase activity and polyphenoloxidase activity while it increased total soluble phenols, total soluble sugars and free proline. Soil salinity decreased significantly the concentration of N, P, K, Fe, Mn, Zn and Cu while it increased Na and Cl. Soil salinity reduced all seed yield parameters in addition to seed yield quality (protein and oil contents). Biofertilizer associated with ascorbic acid at 100 and 200 ppm, treatment resulted in the best results compared with the other treatments.

CONCLUSIONS

Balanced and timely nutrient management practices applied for soybean contributes to sustainable growth of yield and quality, influences plant health and reduces environmental risks. Balanced nutrition with mineral fertilizers can assist in integrated pest management to reduce damage from infestations of pests and diseases and save inputs required to control them. Balanced fertilization generates higher profits for the farmers, not necessarily through reduced inputs. The role of education and extension in delivering the up-to-date knowledge on nutrient management is crucial, challenging, and continuous.

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