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Review Article

Plant Nutrition Management Strategy: A Policy for Optimum Yield

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Abstract

Plant nutrition is simply a study of chemical compounds which is required for optimum plant growth as well as metabolism. The nutrition of green plant is therefore, solely inorganic. It is, in fact, commonly called mineral nutrition. Thus, elements absorbed from the soil by roots are called as plant nutrients or mineral nutrients. The plant requires 17 essential nutrients which is required for their growth and optimum development. It is called insufficient whether the amount of essential plant nutrient is below which required for optimum yields. It is called toxic when the concentration of essential elements is sufficiently high which may inhibit plant growth to a greater extent. It is called excessive if the concentration of the essential nutrient is sufficiently high.

Keywords: Plant Nutrition; Metabolism; Essential Nutrients; Optimum Yield; Deficiency Symptoms

Introduction

Plants contain small amounts of 90 or more elements, only 17 of which are known to be essential to plants. The primary nutrients/major nutrients/macro nutrients which are required by plants in larger amount for plant growth are nitrogen, phosphorus, and potassium (known as NPK). Secondary nutrients required by plants in small quantity are calcium, magnesium and sulphur. Micronutrients are required in trace for the proper functioning of plant metabolism [1,2]. The absence of any of these nutrients can hamper plant growth. On the other hand too high a concentration can be toxic to the plant metabolic system. The plant nutrients generally occur in the soil phase. Their normal pathway to the plant system is through the surrounding liquid phase preferably soil solution. Then to the plant roots and plant cells. Under favourable condition, plants require larger amount of nutrients, then the situation of nutrient supply rare to plants become a limiting factor, mostly at the critical stages of growth. Thus resulting in a low crop yield [2]. Visual clues of plant nutrient deficient symptoms can alert farmers and other service providers on the type of nutrient deficiencies in soil. If it is identified early, to correct the negative impact of such deficiencies corrective measures can be taken during the growing season Plant nutrient element classification has been presented in table 1.

Essential plant nutrients	Form of uptake	Biochemical functions
1st group (C, H, O, N, S)	CO_2, HCO_3, H_2O,O_2, NO_3^-, NH_4^+, N_2, SO_4^{-2}, SO_2	Major constituents of organic matter, essential elements of atomic groups which are involved in enzymatic process
2nd group (P, B, Si)	Phosphates, boric acid, silicate from soil solution	Esterification with native alcohol groups in plants. Phosphate esters are involved in energy transfer reactions.
3rd group (K, Na, Mg, Ca, Mn, Cl)	Ionic form from soil solution	Non-specific functions establishing osmotic potentials. Bridging of the reaction partners. Balancing anions. Controlling membrane permeability and electro potential.
4th group (Fe, Cu, Zn, Mo)	Ions or chelates from soil solution	Present predominantly in a chelated form incorporated in prosthetic groups. Enable electron transport by valency change.

Table 1: Plant nutrient element classification [3].

Forms of nutrient elements absorbed by plants

Plant absorb nutrients from the soil as i) single nutrient elements i.e. uncombined with other nutrients and ii) essential nutrient element, combined with other elements to form nitrate, phosphate, sulphate etc. Different form of nutrient element absorbed by plants has shown in table 2.

Sources of plant nutrients

Plants are supplied with nutrients mainly from: soil reserves; mineral fertilizers; organic sources; atmospheric nitrogen through biological fixation; aerial deposition caused by wind and rain; irrigation, flood or groundwater, and sedimentation from runoff [3,4]. Functions and deficiency symptoms of essential plant nutrients are discussed below.

Nutrient elements	Forms absorbed by plants	Nutrient elements	Forms absorbed by plants
Absorb as a single element			
Potassium	K^+	Copper	Cu^+ and Cu^{+2}
Calcium	Ca^{+2}	Zinc	Zn^+
Magnesium	Mg^{+2}	Chlorine	Cl^-
Iron	Fe^{+2} and Fe^{+3}	Silicon	$Si(OH)_4$
Manganese	Mn^{+2} and Mn^{+4}	Cobalt	Co_{+2}
Absorbed as a combine form			
Nitrogen	NH_4^+ and NO_3^-	Molybdenum	MoO_4^{-2}
Phosphorus	HPO_4^{-2} and $H_2PO_4^-$	Carbon	CO_2
Sulphur		Oxygen	O^{-2}, OH^-, CO_3^{-2}
Boron	H_3BO_3 and $H_2BO_3^-$	Hydrogen	HOH, H^+

Table 2: Different form of nutrient element absorbed by plants [3].

Nitrogen (N)

In plant system nitrogen is mobile. Its mobility in soil is generally dependent on the chemical form of the element used. The main function of nitrogen are- It is a part of proteins, enzymes, chlorophyll, and growth regulators. Nitrogen is needed by plants for the production of proteins, nucleic acids (DNA and RNA) and chlorophyll [5,6]. It is also needed for vigorous vegetative leaf and dark green leaf color and stem growth.

Nitrogen deficiency is observed in plants grown on soils low in organic matter (< 0.4% organic C). If plants contain less than 1.0% N then they are generally deficient in N. As N is mobile in plant they translocate from older to newer leaves and thus symptoms of its deficiency first appear on the older leaves which then advance towards upper leaves, while the new leaves remain green. Nitrogen deficiency causes yellowish-green plants with spindly stalks and pale. Symptoms appear on leaves as a V-shaped yellowing. It starts at the tip and progressing down the midrib toward the base of leaf [6]. The condition is favored by cold or saturated soil; dry soil, particularly after mid-season; large amounts of low-nitrogen residue; sandy soil; inadequate fertilization; leaching from heavy rainfall; and flooded soil when the temperature is warm. Excess of N produces leathery dark green succulent leaves or crop which delays maturity, adversely affect the quality of produce and increases susceptibility to diseases and lodging.

Phosphorus (P)

About 49% of Indian soils are deficient in P. It is stored in fruit and seeds. It is most readily available to plants if pH is 6 to 7.5. But it is unavailable in very acid or alkaline soil. Thus found in greatest concentration in new cell growth. It is necessary to stimulate early root growth and formation. It hasten crop maturity as well as stimulate flowering and also seed production. It give winter hardiness to fall plantings and seedlings. Thus promote vigorous start by cell division to plants [5,7]. It play a great role in hydrogen, oxygen, fat metabolism. It has a role in respiration, and in photosynthesis.

Phosphorus is basically very mobile in plants system. But it is relatively immobile in soil system which allows it not to leach down. Its absorption can be reduced at low soil temperatures. In P-deficient soils the plants develop visual deficiency symptoms, viz. they fail to make a quick start, develop poor root-system, remain stunted. Being mobile nutrient in plants, it is easily translocated from older tissues or leaves to the meristematic or new leaves and hence the older leaves develop characteristic symptoms of dark to blue-green coloration starting from the tip towards the base, which later turn reddish brown [5,8,9]. P deficiency symptoms show reduced flowering, purplish or red color in leaves. Death of tissue or necrosis may follow under severe condition. Under severe deficiency plants develop spindly growth, reddish purple in the nodes and internodes due to increase in sugar content and show formation of anthocyanin.

Potassium (K)

Potassium is generally highly mobile in plant system. But it is generally immobile in soil. This nutrient is deficient in 20% Indian soil. It promotes disease resistance, helps development of root system and vigor. It also improves plant quality along with increasing in winter hardiness. This is due to carbohydrate storage in roots. It increases protein production. It is essential to sugar, oil and starch formation.

Potassium deficiency is noticed in plants growing in soils inherently low in total or non-exchangeable K or on coarse textured leached soils or soils under intensive cultivation with N and P fertilizers alone. Potassium deficiency causes its translocation from older to new tissues or leaves, thereby resulting in characteristic visual symptoms on older leaves [8,9]. The symptom of chlorosis starts from the leaf margins, followed by scorching and browning of tips and margins. K-deficient plants are stunted in growth with pronounced shortening of internodes, and they develop shriveled seeds and fruits. Another indication of K deficiency is reduced straw or stalk strength in small grains and corn, resulting in lodging problems, reduced disease resistance.

Calcium (Ca)

It is an important constituent of calcium pectate. It is important for maintaining cell wall integrity and also an enzyme activator. It is required for osmoregulation and maintenance of cation–anion balance in cells.

Symptoms appear first on younger leaves. Its deficiency may resemble to boron deficiency. The tips of youngest leaves become (white) rolled and curled necrotic tissue may develop along the lateral margins of leaves, and old leaves turn brown and die. The young growth and fast growing tissues are affected first [9,10]. Acute deficiency result is stunting and death of the growing point. Possible occurrence of Ca deficiency in soils are coarse textured sandy soils, acid, acid sulphate soils with high leaching and low CEC, soils derived from respective rocks.

Magnesium (Mg)

Magnesium has an important role in photosynthesis as it forms the central atom of chlorophyll. If its amount is not sufficient then plants start to degrade the chlorophyll content in the old leaves. It affects protein synthesis and CO_2 assimilation. It also affects several cellular pH, enzymes activities and the cation-anion balance. Magnesium deficiency is common in rainfed lowland and upland [11,12]. It is also a necessary activator for many enzymes like ribulos-bi-phosphate carboxylase (RuBisCO) and phosphoenolpyruvate carboxylase (PEPC) which are very essential for carbon fixation.

Acid soils, low in CEC, acid sulphate soils, coarse textured sandy soils are very much prone to Mg deficiency. The symptoms of Mg deficiency are pale-colored plants with orange-yellow interveinal chlorosis on older leaves and later on younger leaves, chlorosis progresses to yellowing and finally necrosis in older leaves in severe cases, greater leaf number and length, wavy and droopy leaves and reduced grain quality [11-13]. Its deficiency may be confused with chlorine or zinc deficiencies, natural aging or viruses. Fe toxicity is more pronounced in Mg deficient plants.

Sulphur (S)

Plants can use S only in SO_4^{2-} form. Most of the sulphur in soil contained in organic matter as proteins, amino acids and other compounds not immediately available to plants. It affects protein synthesis, chlorophyll production as well as plant structure and function. It also affects some oxidation-reduction reactions, reduces cysteine and methionine content in rice, delayed plant development and maturity, affects yield if deficiency occurs at vegetative stage.

Generally crops grown on coarse textured soils, low in organic matter or leached acid soils under intensive cultivation suffer from its deficiency. Depending upon the crop and variety, plants having less than 0.1 to 0.02% S content suffer from its deficiency. Crop plants having more than 16:1 N:S ratio ca be suspected to be deficient in sulphur. Unlike nitrogen, sulphur deficiency symptoms generally appear first on the younger leaves. It persist even after nitrogen application due to its immobile mechanism in plant system [14,15]. The plants deficient in S are spindly and small with very slender stalks and short. Their growth is retarded, modulation in legumes may be poor, maturity in cereals is delayed and nitrogen fixation is reduced. The fruits remain light-green in colour and mostly do not mature fully. Oilseeds, pulses and other crops having high requirement of S suffer most from its deficiency. Rice plants having S-deficiency have less resistance at adverse condition.

Zinc (Zn)

Zinc deficiency is the most widespread micronutrient disorder in rice. It is often combined with P deficiency. Under prolonged submergence due to increase availability of Cu, Fe, Mn, Ca, Mg and P zinc availability as well as uptake hampered by the crops. Zinc is essential for cytochrome and nucleotide synthesis. It is also important for chlorophyll production, enzyme activation, increase rate of seed, maintenance of membrane activity.

Zinc deficiencies mainly occur at high organic matter in soil, high soil pH and also calcareous soils, intensively cropped soils. On younger or middle aged leaves the symptoms are very common [16,17]. Due to immobilization of zinc the symptoms are prolonged at early growth stages. Fe/Mn deficiencies sometimes resembles to the symptoms of zinc deficiency. A Mg : Ca ratio in soils > 1 promotes zinc deficiency which is associated with high bicarbonate content. Another reasons are use of high yielding cultivars, intensive cropping and alkaline water in irrigation system.

Iron (Fe)

Iron content in soil varies from 1% to 20%. But the average content is 3.2% and its normal concentration in plants is only 0.005%. Iron deficiency is very common in high pH, upland condition and aerobic soil. The toxicity is the major constraints to lowland rice cultivation [17]. The main reason for iron deficiency are coarse textured soil (sany), low iron concentration in upland and increased rhizosphere pH etc.

Deficiency of iron resulted chlorosis between the veins of leaves. The deficiency symptom show first in the younger leaves. Its deficiency symptoms are chlorosis of emerging leaves, interveinal yellowing, less dry matter production. The plants become stunted with narrow leaves along with reduced sugar metabolism enzymes,.

Boron (B)

Boron is concerned with precipitating excess cations. It has regulatory effect on other nutrient elements for the development of new cells in meristematic tissue. It is able for translocation of sugars, phosphorus and starches etc. which are essential for formation of cell wall.

Deficiency occurs under dry condition and moister stress condition which cause reduced plant height. At panicle formation stage plants fail to produce panicles if they are affected by boron deficiency. The tips of emerging leaves are white and rolled.

Excess of boron appears to inhibit the formation of starch from sugars. Sometimes it results in the formation of B-carbohydrate complexes. This results in retarded grain formation. Boron toxicity symptoms are dark brown elliptical spots on leaves, brownish leaf tips and necrotic spot at panicle initiation stage [18]. Excessive application of boron, use of boron rich ground water, and high temperature are some of the main reason for boron toxicity.

Manganese (Mn)

Manganese influences auxin levels in plants. The high concentrations of Mn favour the breakdown of Indole Acetic Acid (IAA). It takes part in electron transport in photosystem-II.

It is very common in degraded soil having high Fe content, upland condition. Other reasons are acid sandy or acid sulphate soil, accumulation of H_2S and excessive liming in acid soil. Often confused with, and occurs with, iron deficiency. Most common in low e organic matter soil and poorly drained soils. Symptoms include smallest leaf veins remaining green to produce a chequered' effect having yellowing of leaves. On leaf surfaces brown spots may appear and severely affected leaves turn into wither and brown [19]. In lower leaves manganese toxicity shows brown spots on the veins of leaf sheath and leaf blade. Cause less number of tillering and plant growths are stunted.

Silicon (Si)

Silicon is considered a plant nutrient 'anomaly'. The main reason is that this nutrient is presumably not essential for plant development and growth. The beneficial effects of silicon have been attributed to soil toxicities correction arising due to high levels of available Fe, Mn as well as active Al. Silicon provides greater stalk strength. It helps in resistance to lodging. It increased availability of phosphorus and reduce transpiration in plant [20]. The major deficiency symptoms of Si are lodging of plant soft droopy leaves along with severe pest-disease attack. Deficiency generally occurs due to small mineral reserves in old soils of subtropical, organic soil as well as cold climates.

Copper (Cu)

During chlorophyll synthesis copper helps in the utilization of iron. Copper deficiency causes iron to accumulate in the nodes of plants. It has an unique involvement in terminal oxidation by cytochrome oxidase, oxidase enzymes, photosynthetic electron transport generally mediated by plastocyanin. In enzymes it also acts as "electron carrier". This brings about oxidation-reduction reactions in plants. Lateritic soil, calcareous, high in organic matter, induce Cu deficiency in soil.

Main important deficiency symptoms of copper are bluish green leaves, chlorotic leaves, leaf tips give needle like appearance, reduced tillering, and less pollen viability [21]. Yellowing of leaves, dieback of stems and twigs, pale green leaves and stunted growth are some of the symptoms.

Molybdenum (Mo)

In plants molybdenum is an essential component of nitrate reductase. Its requirement of plants is influenced by either nitrite (NO_2^-) or ammonium (NH_4^+). It has great role in iron absorption and translocation in plants.

Nitrogen deficiency sometimes resembles to Mo resembles to where the older leaves become chlorotic. Necrotic spots are seen at leaf margins because of NO_3 accumulation. Other symptoms of Mo deficiency include pale leaves that may be scorched, cupped, or rolled. Leaves may also appear thick or brittle, and will eventually wither, leaving only the midrib [21].

Sodium

Sodium is essential for halophytic plant species that accumulate salts in halophytes in vacuoles to maintain turgor and growth. The beneficial effect of sodium on plant growth is often observed in low-K soils, because Na+ can partially substitute for K^+. Many plants that possess the c4 dicarboxylic photosynthetic pathway require Na as essential nutrient. Sugar beets appear to be particularly responsive to Na and it increases the resistance of the crop to drought.

Cobalt

Cobalt is essential for microorganisms fixing nitrogen. Co is thus needed in the nodules of legumes and nitrogen fixing algae. Co forms a complex with nitrogen important for synthesis of vitamin B12 coenzyme. It plays a remarkable role in ruminant nutrition. Its deficiency in ruminants is often associated with forage produced on soils containing less than 5.0 ppm of total Co. Soils in which Co deficiency can occur are acidic, calcareous and peaty soils [22].

Selenium

Selenium is not needed by plants, but it must be present in forage since it is essential for animals. A greater frequency of livestock nutritional disorder caused by low Se has been observed after cold, rainy summer than after hot, dry ones. Plants such as the crucifers which require large amount of sulphur absorb intermediate amounts of Se, while grasses and grain crops absorb low to moderate amounts [22].

Nickel

Nickel is essential for plants supplied with urea and for those in which ureides are important in N metabolism. Nodule weight and seed yield of soybeans have been stimulated by Ni. High level of Ni may induce Zn and Fe deficiency because of cation competition.

Vanadium

Low concentrations of V are beneficial for the growth of microorganisms, animals, and higher plants. Vanadium may partially substitute for Mo in nitrogen fixation by microorganisms such as the *Rhizobia*.

Sources of plant nutrients

A large number of diverse materials can serve as sources of plant nutrients. These can be natural, synthetic, recycled wastes or a range of biological products including microbial inoculants. Nutrient sources are generally classified as organic, mineral or biological. Organic nutrient sources are often described as manures, bulky organic manures or organic fertilizers. The majority of nutrient input to agriculture comes from commercial mineral fertilizers [23].

Different plant nutrient interaction

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- Low levels of N, S and Mg exhibited high Mn and low Fe uptake
- P induced Zn deficiency: High level of available P in soil
    - $ZnSo_4$ application @15 - 20 kg/ha
- Application of K decrease Mn and Fe content in plant
- Increase in pH by lime application reduce Zn availability to plants
- Application of Zn depress extractable Fe but increase Mn in submerged soil
- Application of Cu decrease Fe and Mn in submerged soil
- Mn inhibit Zn absorption by root, but favored Zn translocation within plants
- Mn interferes with translocation of Fe from root to shoot
- Calcareous soil + high pH: Iron chlorosis due to iron remaining in ferric (oxidized state)
    - Inundation for 2 - 3 days or foliar application of iron
- Iron toxicity: In acidic soil (liming is the best way)
- Zinc deficiency: Normal and saline-sodic soils- $ZnSo_4$ application @40 kg/ha.

Management of plant nutrients

The proper use of fertilizers has become an accepted and necessary part of farm operation to increase the nutrients status of soil for getting higher yield. However, there are some other factors of importance in nutrient management like physical condition of the soil to supply plant nutrients; inhibitory factors present in the soil, like acidity, alkalinity and salinity; moisture in soil; use of inorganic and organic fertilizers and biofertilizers

Positive effects of nutrient management on the environment

Efficient use of plant nutrients ensures that yields are higher than those obtained on the basis of inherent soil fertility by correcting either an overall deficiency or an imbalance of nutrients. Nutrients removed from the soil through harvesting and export of produce can be largely replenished through various types of recycling in order to maintain and enhance the production potential of the soil. By increasing yields per unit area from suitable arable land, application of plant nutrients allows land of low quality, e.g. land susceptible to erosion, to be withdrawn from cultivation. This reduces the overall pressure on land, including deforestation and overgrazing on non-cropped areas. Balanced plant nutrition also results in an increased addition of organic matter through greater leaf residues, and root and stubble biomass. INM promotes the correct management of all plant nutrient sources on the farm and helps reduce the losses of plant nutrients to the environment.

Negative effects of nutrient management on the environment

The constant removal of crop produce without sufficient replenishment of plant nutrients exported by the crop causes a steady decline in soil fertility. This mining of plant nutrients, leading to severe depletion of soil fertility, is also a kind of soil degradation and a major environmental hazard in a number of developing countries. The use of low levels of input places additional stress on soil nutrient supplies, resulting in excessive mining of soil nutrients and in depletion of soil fertility, leading to land degradation [23,24]. To the extent that land and labour resources are available, low crop yields resulting from nutrient depletion force farmers to cultivate land under forests or marginal soils that are subject to erosion or desertification and, therefore, not normally fit for cropping. Bringing unsuitable land into cultivation promotes land degradation.

Policies for effective plant nutrition

Long-term planning and monitoring of the use of plant nutrients needs to aim at reconciling four objectives: (i) agronomic as well as economic efficiency to maximize yield from all the available nutrient sources; (ii) proper maintenance and enrichment of the production capacity of the natural resource base; and (iii) safeguarding livelihood-earning capability of the rural populations [24]. Timely consideration of these issues is essential to planning and implementing a consistent and comprehensive policy both in the short term and the long term. Site specific nutrient management practices should be adopted. Nutrient should be applied as and when required by the crop plants. Promotion of biofertilizers based products should be enhanced by Govt. as well as private sector. Agronomic practices are important for increasing of nutrient use efficiency. To improve nutrient use efficiency we have to use adequate rate, effective source, timing, and methods of application of nutrients. Decreasing abiotic and biotic stresses is another way to increase nutrient efficiency. Use of nutrient efficient crop species is also important in increasing nutrient use efficiency. Acid tolerant or alkaline tolerant crops should be used as and when required. Split applications of nutrients are better than basal application. Deep placement can increases crop yields as well as income and thus decreases pollution and less consumption of nitrogen per hectare. Thus judicious use of nutrients is the only way for management of nutrient for getting optimum yield.

Conclusion

More information on the availability and transformation of nutrients for different soils need to be studied. Besides there is a need to study on the effect of manipulating the soil physical environment and its moisture regimes on plant available nutrients. Continuous use of organic sources of nutrients arrests the depletion of available nutrient pools from soils. Using available organic sources development of integrated nutrient technology is needed. This is not only for increase use efficiency of nutrient but also to decrease the use of inorganic nutrient. For a cropping system the residual availability of various sources of nutrients needs to be worked out.

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