A Review Article on Mineral Nutrition and Fertilizer Management of Cereal Crops

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Abstract

This article was conceptualized to provide the readers other options and easy access to review the basics aspects of plant nutrition and fertilizer management of cereal crops. This article provided a brief overview of the plant mineral nutrition and fertilizer management in cereal crops. The concept behind the 17 essential elements the macronutrients and the micronutrients needed by the cereal crops. The nutrient elements are absorbed by plants primarily in ionic form from the soil. Nutrients can be taken up and distributed equally in straw and grain of the cereal crops. Thus, soils must therefore be replenished with those nutrient elements in the form of fertilizers. To have a basis for fertilizer application, the fertility status of the soil must be determined. Once the soil test results indicate the need for supplemental fertilizer, one must know how to calculate the amount of fertilizer needed and select the right one to avoid wastage and minimize costs. It needs to familiarize the fertilizer recommendation rate that will fit specific cereal crops and their ecosystems. Its cropping season, the effectiveness of the crop to use specific kind and availability of fertilizers in the market and financial resources of the farmer.

Keywords: Mineral nutrition, cereal crops, crop development, and nutrient essentiality

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INTRODUCTION

Worldwide, cereal crops are mostly grasses grown for their edible seeds and cultivated in more significant quantities than any other type of crops. It can provide more food energy to the human population and feeds to the animals. Examples of cereal crops are rice (*Oryza sativa* L.), wheat (*Triticum* L.), barley (*Hordeum vulgare*), oats (*Avena sativa*), rye (*Secale cereale*), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), and millet (*Pennisetum glaucum*). These cereal plants need essential nutrients to live and grow healthy, just as the human body needs vitamins and minerals. There are 17 mineral nutrients supplied solely by the soil.

They are divided intotwo groups according to the amounts required, namely, the macronutrients, which are Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), P hosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg) and Sulfur (S), and the micronutrients which are Boron (B), Copper (Cu), Iron (Fe), C hlorine (Cl), Manganese (Mn), Molybdenum (Mo), Nickel (Ni) and Zinc (Zn) (Roy et al., 2006).

Under natural conditions, these mineral nutrients are dissolved in water and absorbed through the plant's roots, and recycled to the soil through plants` herbage. However, crops demand more nutrients under crop production than natural vegetation (Biller et al., 2017). Supplemental nutrients are needed to satisfy the plant's needs, which canbe achieved by applying fertilizers.

Fertilizers, which can be organic or inorganic, provide plants with nutrients needed to grow healthy and strong. However, they contain different ingredients, and the number of nutrients present is in different ways. To have a basis for fertilizer application, the fertility status of the soil must be determined. Once the soil test results indicate the need for supplemental fertilizer, one must know how to calculate the amount of fertilizer needed and select the right one to avoid wastage and minimize costs. This paper was conceptualized to provide the reader's options and easy access to review plant nutrition in cereal crops.

THE CONCEPT OF CROP`S MINERAL NUTRITION

In plants, nutrition is defined as a synthesis of food, its breakdown, and utilization for various functions in the body. The chemical substances in food are called nutrients, *e.g.,* carbon dioxide, water, protein, fats, carbohydrates, and minerals. The elements present in the food chemical substances can be subdivided into macro and microelements. Macro-elements are required in relatively large quantities for the normal physiological processes of the plant, while microelements are required in relatively small quantities or trace amounts. Macro-elements include carbon, hydrogen, nitrogen, potassium, sodium, calcium, chloride, magnesium, phosphorus, and sulfur, while microelements include boron, chlorine, copper, iron, manganese, molybdenum, and zinc.

Table 1. presents the chemical elements that can be further divided into two main groups: non-mineral elements (C, H, O) absorbed from air and water or in the atmosphere as a component of compounds. The remaining elements are under the mineral elements, whichare absorbed by plants primarily in ionic form from the soil. Therefore, mineral nutrition can be defined as the collective processes involved in plant assimilation and metabolism of all chemical elements, except for carbon, hydrogen, and oxygen (Mattson, 2018).

Table 1. Essential elements and their functions (Adapted from NIOS, 2012)

Elements	**Form in which the element is taken in**	**Region of the plant that requires the element**	**Function**
The basic Nutrients are derived from air and water			
Carbon	$C0_2$	Stem and young leaves of the plant	Forms the backbone of most plant biomolecules, including proteins, starches and cellulose. Carbon is fixed through photosynthesis; this converts carbon dioxide from the air into carbohydrates which are used to store and transport energy within the plant.
Hydrogen	H_20	All tissues	Necessary for building sugars and building the plant. It is obtained almost entirely from water. Hydrogen ions are imperative for a proton gradient to help drive the electron transport chain in photosynthesis and for respiration.
Oxygen	H_20, 0_2	Leaves and root tips of the plant	A component of many organic and inorganic molecules within the plant, and is acquired in many forms. These include: O_2 and CO_2 (mainly from the air via leaves) and H_2O, NO^{-3}, H_2PO^{-4} and SO_2^{-4} (mainly from the soil water via roots). Plants produce oxygen gas (O_2) along with glucose during photosynthesis but then require O2 to undergo aerobic cellular respiration and break down this glucose to produce ATP.
The macronutrients which are needed by the plants in a larger amount			
Nitrogen, N	$NO2^-$, $NO3^-$ or $NH4^+$ ions	All tissues, particularly in meristematic tissues	Required for the synthesis of amino acids, proteins, nucleic acids, vitamins, hormones, coenzymes, ATP and chlorophyll.
Phosphorus, P	$H_2PO_4^-$ or HPO_4^{2-}	Young tissues from the older metabolically less active cells	Required for the synthesis of nucleic acids phospholipids, ATP, NAD, and NADP. Constituent of cell membrane and some proteins.

Potassium, K	K^+	Meristematic tissues, buds, leaves, and root tips.	Activates enzymes associated withK^+/Na^+ pump in active transport, anion-cation balance in the cells. Brings about the opening and closing of stomata. Common in cell sap in the plantcell vacuole and helps in turgidity of cells.
Calcium, Ca	Ca^{2+}	Meristematic and differentiating	Present as calcium pectate in the middle lamella of cell walls that join the adjacent cells together. Activates
Magnesium, Mg	Mg^{2+}	Leaves of the plant	Forms part of the chlorophyll molecule. Activates enzymes of phosphate metabolism. Necessary for the synthesis of DNA and RNA. Essential for binding of ribosome subunits.
Sulfur, S	SO_4^{2-}	Stem and root tips, young leaves of the plant	As a constituent of amino acids, cysteine and methionine, and someproteins. Present in coenzyme A, vitamin thiamine, biotin, and ferredoxin. Increases root development. Increases the nodule formation in legumes.
The micronutrients which are needed by the plants in a lesser amount			
Iron, Fe	Fe^{3+}	Leaves and seeds	Needed for the synthesis of chlorophyll. As a constituent of ferredoxin and cytochromes. Activates the enzyme catalase.
Manganese, Mn	Mn^{2+}	All tissues. Collects along the leaf veins.	Activates many enzymes of photosynthesis, respiration, and N2 metabolism. Acts as an electron donor forchlorophyll b. Involved in decarboxylation reactions during respiration.
Molybdenum, Mo	MoO_2^{2+}	All tissues, particularly in roots	Required for nitrogen fixation. Activates the enzyme nitrate reductase.

Boron, B	BO_3^{3-} or $B_4O_7^{2-}$	Leaves and seeds	Increases the uptake of water and calcium. Essential for meristem activity and growth of pollen tube.
Silicon (Si)			They are involved in the translocation ofcarbohydrates.
Copper, Cu	Cu^{2+}	All tissues	Component of oxidase enzymes and plastocyanin. Involved in electrontransport in photosynthesis.
Zinc, Zn	Zn^{2+}	All tissues	Component of indoleacetic acid – aplant hormone. Activates dehydrogenases and carboxylases. Present in enzyme carbonic anhydrase.
Chlorine, Cl	Cl^-	All tissues	Essential for oxygen evolution in photosynthesis. Anion-cation balance in cells.

NUTRITIONAL DISORDERS IN PLANTS

Nutritional disorders are physiological disorders in plants that affect the productivity and quality of the grain or fruit. If the minerals are not available at the right amount to plants, specific symptoms (some disease-like) appear due to the deficiency of a particular element or the presence of nutrients at levels toxic to the plant (Figure 1).

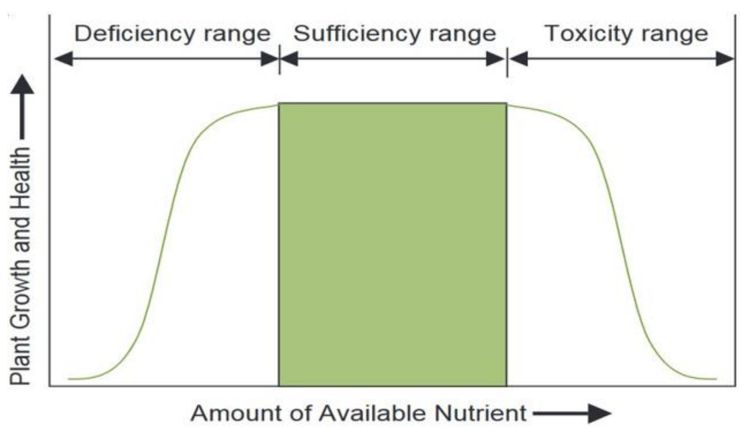

Figure 1. Relationship between plant growth and health and amount of nutrients available (Brady and Weil, 1999).

Hence, identifying between nutrient and disease disorder and preventi n g plant nutrient deficiencies and toxicities is an integral part of crop production. Symptoms are first seen in older leaves for some deficiencies and in young leaves and tissues for others (Table 2). This depends on the mobility of the nutrient. For mobile nutrients (N, P, K and Mg), deficiencies are first seen in older leaves; for immobile nutrients (Ca, B, Cu, Zn and Fe), deficiencies are first seen in the youngest leaves and growing tissue.

Table 2 . Typical nutrient deficiency symptoms and general information for corrective orpreventive actions (AUSVEG, n.d.)

Nutrient Deficiency	Symptoms	Action
Nitrogen (N)	Poor plant growth; older leaves are pale green to yellow, and they eventually dry anddrop; fruit and tubers are small.	Add N fertilizer, for examples a side dressing before irrigation; regular foliar sprays; improve irrigation management.
Phosphorous (P)	Poor germination, seedling establishment, and plant growth; leaves may be dull bluish/greyish-green or have red pigment in leaf bases and dying leaves; oldest leaves may turn yellow and drop.	Application of phosphorus fertilizers and manure, particularly from grain-fed animals.
Potassium (K)	Older leaves have yellowing and scorching ofedges and interveinal region; lettuce heads are loose; leaves may cup; fruit maybe unevenly colored or distorted.	Increase K fertilizer rate; improve irrigation management
Calcium (Ca)	Retarded growth; roots usually affected first, becoming brown; young leaves become yellow and distorted; blossom end rot in cucurbits and tomatoes; can be confused with the physiological disorder tip burn.	Side dress with a Ca fertilizer; foliar spray susceptible crops at critical growth stages; apply lime or gypsum; existing damage is permanent.
Magnesium (Mg)	Growth retarded; chlorotic patches between the veins of older leaves; a triangle of green remains at the leaf base; leaf margins may burn.	Application of fertilizer or weekly foliar sprays; primary sources of Mg are dolomite and Epsom salts.
Sulfur (S)	Yellowing of young leaves while older leaves remain dark green; growth stunted.	Application of sulfate compounds.
Boron (B)	Bushy stunted growth and dying growing tips; corky markings on plant parts; cankered patches on roots; internal brown rot; planttissue can become brittle and split easily; hollow areas in stems.	Application of boron-amended fertilizers or boron foliar fertilizer; existing damage is permanent.

Iron (Fe)	Leaves turn yellow/bleached between veinmargins; stunting and abnormal growth; fruit may not mature.	A weekly foliar spray of iron sulfate or chelate; reduce soil pH below 7.5.
Manganese (Mn)	Yellow patches between veins; reduced flowerformation.	Root drench or weekly foliar sprays with manganese sulfate;do not over-lime.
Molybdenum (Mo)	Stunting and pale green or yellowish-green color between the veins and along the edges ofleaves; leaf tissue of margins dies; older leaves more severely affected.	Lime the soil to increase soil pH (to about 6.5, measured in water); soil or foliar applications of sodium or ammonium molybdate.
Zinc (Zn)	Plants appear stunted and pale with the creamy yellow interveinal area, death of leaf margins, deformed young leaves.	Application of a basal fertilizer Containing Zn at sowing; application of a Zn foliar spray.
Copper (Cu)	Chlorosis in young leaves; tips of leaves distorted; stunted growth.	Apply a copper fertilizer

On the other hand, an excess amount of an element may also cause nutritional plant disorders. But toxicity in plants may not always be the direct effect of the element in excess, but the effect of the excess element on one or more other essential elements. For example, an excessive level of K in the plant can lead to either an Mg and Ca deficiency, excess P can result in Zn deficiency, and excess Zn to Fe deficiency (Table 3).

Table 3. Generalized symptoms of nutrient toxicity in crops (Jeyakumar and Balamohan, n.d.)

Element	Visual Symptoms
Nitrogen (N)	Plants will be dark green, and new growth will be succulent; susceptible, if subjected to disease and insect infestation and subjected to drought stress, plants will easily lodge. Blossom abortion and lack of fruit set will occur.
Phosphorus (P)	Phosphorus excess will not directly affect the plant but may showvisual deficiencies of Zn, Fe, and Mn. High P may also interfere with normal Ca nutrition, with typical Ca deficiency symptoms occurring.
Potassium (K)	Plants will exhibit typical Mg and possibly Ca deficiency symptoms due to cation imbalance.

Calcium (Ca)	Plants may exhibit typical Mg deficiency symptoms, and when in high excess, K deficiency may also occur.
Magnesium (Mg)	Results in cation imbalance showing signs of either a Ca or K deficiency.
Sulfur (S)	Premature senescence of leaves may occur.
Boron (B)	Leaf tips and margins will turn brown and die.
Chlorine (Cl)	Premature yellowing of the lower leaves with the burning of the leaf margins and tips. Leaf abscission will occur, and plants will quickly wilt.
Copper (Cu)	Fe deficiency may be induced with prolonged growth. Roots maybe stunted.
Iron (Fe)	Bronzing and tiny brown spots on the leaves.
Manganese (Mn)	Older leaves will show brown spots surrounded by a chlorotic zone and circle.
Molybdenum (Mo)	Not of common occurrence.
Zinc (Zn)	Fe deficiency will develop.

Fertilizer Management in Cereal Crops

Soil fertility and light, moisture, weeds, pests, and diseases are also an essential part of cereal production as they can affect crop yield. The fertilizer application rate must be carefully considered in fertilizer management as applications overcrop needs may pose harmful effects from environmental and economic viewpoints. The number of nutrients to be applied to suffice the recommended rate can be derived from soil testing and determining nutrient removal by grains and straw. For example, in rice production, a sufficient amount of nutrients must give the maximum economic return.

According to Roy et al. (2006), to produce 1 ton of paddy rice (rough rice), it needs to absorb an average of 20 kg N, 11 kg P2O5, 52 kg Si. Out of the total uptake, about 50% N, 55% K, and 65% P are absorbed by the early panicle-initiation stage, while about 80% N, 60% K and 95% P uptake are completedheading stage. Higher N and P are taken by grain than in straw (3:1), whereas K, Ca, Mg, Si, Fe, Mn, and B remains in more significant proportions in the straw.

On the other hand, nutrients taken up and distributed equally in straw and grain were S, Zn, and Cu (Yoshida, 1981). The soils must therefore be replenished with those nutrient elements in the form of fertilizers. However, there is no single fertilizer recommendation rate that will fit all cereal crops and their ecosystems. It depends on the cropping season, the effectiveness of the crop to use a specific kind of fertilizer, and availability of fertilizers in the market, and the financial resources of the farmer. For example, the dry season requires more nitrogen input in terms of the cropping season because nitrate ions carry negative charges that cause them not to bind to soil particles. Thus, they easily volatilize, particularly at soils with moist and warm temperatures. Thus, the application of urea fertilizers when soil and air temperatures are cool and incorporating the fertilizer into the soil will reduce volatilization (Schwenke, 2014).

Nitrogen-use efficiency by crops can also be improved by splitting the application of N fertilizer. For instance, part of the crop N requirement can be applied as starter fertilizer that can be top-dressed beside the crop rows. This helps the first stages of crop growth without applying significant N that could only volatilize before the crop requires it. The rest of the crop N requirement can be applied to other stages of the crop. It requires more during early tillering, mid-tillering, panicle initiation, and heading to 1st flowering (Maguire et al. 2009).

Its kind also influences the efficient use of fertilizer by the plant. Hamissa et al. (1997) found that, as regards nitrogen, field experiments carried on cotton, wheat, maize, and rice indicate that calcium nitrate and urea are near equal effectiveness. Furthermore, on rice, sulfur-coated urea and super urea granules were superior to urea and ammonium sulfate, while iso-butidylin di-urea was the least effective. Moreover, high cost and unavailability of fertilizers and other farm inputs like seeds, pesticides, etc. most especially when the season starts, cause delays in implementing agricultural activities, which in turn reduce the number of crops planted in a specific area per year and, ultimately, reduce the potential net income of the farmer (Herrera, 2014). Therefore, the ability of the farmer to identify the right kind of fertilizer to use and to follow the appropriate way of fertilizer application and the application schedules must also be considered in fertilizer management. The farmer must choose the fertilizer materials available locally and the least expensive per unit of needed plant nutrients by computing possible combinations of a single, compound, or complete type of fertilizers. For example, a recommended rate of 90 - 60-60 can be made up of complete fertilizer and urea, urea, solophos, and muriate of potash. The option to choose will depend on which combination costs less. The chosen fertilizer must also be well-suited to the farm soil conditions because some slightly acidic soil requires fertilizer with less residual effects (Xuan and Ross, 1972).

Proper timing of the fertilizer application also increases yields, reduces nutrient losses, increases nutrient use efficiency, and prevents environmental damage. But applying fertilizers at the wrong timing might result in nutrient losses, waste of fertilizer, and even damage to the crop. The mechanisms by which losses occur depend on the properties of the nutrient and its reactions with the surroundings (Sela, n.d.). Also, a nutrient loss can be reduced through basal application wherein fertilizer will be buried and incorporated in the soil than broadcasting where fertilizers were only applied over the field uniformly (Manna and Singh, 1991).

Fertilizer Calculation

The International Rice Research Institute and partners across Asia begun and led the development of site-specific nutrient management (SSNM) for rice which eventually provides scientific principles on field-specific management of N, P, and K for other cereals (Doberman et al., 2004; Buresh et al., n.d.). The fertilizer N required by a cereal crop (FN, expressed in kg N ha^{-1}) to achieve an attainable target yield is determined from the anticipated yield gain to the application of fertilizer N and a targeted efficiency of fertilizer N use to attain the targeted yield;

$$FN = (GY - GY_{0N})/(AE_N/1000)$$

$GY - GY_{0N}$ is the increase in grain yield due to fertilizer N, which is the difference between the attainable target yield (GY) expressed in t ha^{-1} and yield without fertilizer N (GY_{0N}) expressed in t ha^{-1}. The GY_{0N} is the N-limited grain yield, which reflects the yield attainable from only non-fertilizer sources of N referred to as the indigenous N supply. AE_N is the targeted agronomic efficiency of fertilizer N expressed as kg grain yield increase per kg of fertilizer N applied. The targeted AE_N is adjusted for crop and crop response to N based on the field trials conducted across Asia in the development and verification of SSNM principles.

The total supply of P or K from sources other than fertilizer is estimated through a nutrient balance. The requirement of a crop for fertilizer P (FP, expressed in kg ha^{-1}) or fertilizer K (FK, expressed in kg ha^{-1}) to achieve a targeted yield (GY, expressed in t ha^{-1}) is estimated from the deficit in the nutrient balance with each input expressed in kg ha $^{-1}$ (Buresh et al., 2010): where RIE_P is reciprocal internal efficiency for P expressed in kg plant P at maturity per ton of grain produced, RIE_K is reciprocal internal efficiency of K expressed in kg plantK per ton of grain, P_{CR} and K_{CR} are P and K inputs with retained crop residues, P_{OM} and K_{OM} are P and K inputs from organic materials, K_W is K input with irrigation water, K_L isK loss by percolation or leaching in kg ha^{-1}. P_S and K_S are threshold limits for the drawdown of soil P and K reserves expressed in kg ha^{-1}. The input of P in irrigation water, loss of P by percolation and leaching, and inputs of P and K with rainfall are treated as negligible. Loss of K by percolation or leaching (K_L) is treated as negligible except on sandy soils. For simple and general computation of fertilizer recommended rate, the following formulamay be utilized, and Table 5 shows a list of fertilizer materials with respective percent nutrient analyses.

$$\text{Weight of Fertilizer Material (kg)} = \frac{\text{Recommended Rate (kg N, } P_2O_5\text{, } K_2O\text{/ha}}{\text{Percent nutrient in fertilizer material}}$$

Table 5. Common basic fertilizer materials used for blending and their nutrient contents

Material	Analysis	N (%)	P_2O_5 (%)	K_2O (%)
Complete	14-14-14	14	14	14
Urea [$CO(NH_2)_2$]	46-0-0	46	0	0
Solophos	0-18-0	0	18	0
Ammonium phosphate [$(NH_4)_3PO_4$]	16-20-0	16	20	0
Ammonium sulfate	21-0-0-24S	21	0	0
Muriate of potash [KCl]	0-0-60	0	0	60

RECOMMENDATION

Some good agricultural practices for fertilizer management, for example in corn, which could also be imposed on other cereal crop production, are enumerated by the Bureau of Product Standards (2008) under the Department of Trade and Industry as follows:

1. Use only fully decomposed organic materials. Raw and slightly decomposed animal manure should be confined in a designated area for treatment.
2. Use only registered commercial fertilizers. Observe the appropriate method and time of application of the recommended combination and amount of fertilizers based on soil analysis.
3. Seed inoculant may be used to supplement part of the corn plant nutrient requirement.
4. Fertilizers should be stored separately from pesticides in a clean and dry area (preferably slightly elevated above the ground on pallets).
5. The storage area of fertilizers should be isolated from corn drying and storage areas to prevent contamination due to leaching, runoff, or wind drift.
6. A complete set of records of fertilizers and fertilizer preparation should be kept. Information includes the source of fertilizer materials, details of the composting procedures, dates, amounts, and methods of applying the fertilizer, as well as the person responsible for the application.

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