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Effect of Nitrogen, Phosphorus and Sulfur Nutrients on Growth and Yield Attributes of Bread Wheat

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Abstract

Wheat is one of the most important cereals cultivated in Ethiopia. The production and productivity of bread wheat are mainly constrained by the removal of soil nutrients from the soil, application of unbalanced fertilizer treatments and traditional farm management practices. Soil is one of the most important natural resources and medium for plant growth. It is a major source of nutrients needed by plants for growth. The objective of this review was design to pay attention to guide the effect and deficiency of Nitrogen, Phosphorus and Sulfur nutrients in plant growth of bread wheat. Nutrients are the essential components influence proper growth, development and quality of plants just like all other living organisms. Nitrogen is highly valuable plant nutrient and it is found in all plant cells, in plant proteins and hormones, and in chlorophyll. Phosphorous is an essential component of major cell proteins and nucleotides that are mainly responsible for development of different plant structures and helps transfer energy from sunlight to plants, stimulates early root and plant growth, and activate the maturity period. Sulfur is a ingredient of amino acids in plant proteins and is involved in energy-producing processes in plants and responsible for many flavor and odor compounds in plants. The deficiency and unbalanced application of nutrients are highly affected the growth, yield and quality of bread wheat. The use of right amount of fertilizer application based on crop requirement has a significant result for sustainable crop production.

Keywords: Bread Wheat; Nutrient; Soil; Nitrogen; Phosphorus; Sulfur

Introduction

Wheat is one of the most important crop plants in the world. It grows under a wide range of latitudes and altitudes; it is not only the most widely cultivated crop but also the most consumed food crop all over the world [1]. Ethiopia is the largest producer of wheat in sub- Saharan Africa (SSA), over 1.8 million hectares annually [2]. It ranks fourth after maize, tef and sorghum both in area coverage and production [3]. Wheat production in the country is adversely affected by low soil fertility and suboptimal use of mineral fertilizers in addition to diseases, weeds, erratic rainfall distribution in lower altitude zones, and waterlogging in the Vertisols areas [4].

In the complex landscapes of Ethiopia, the position of fields within soil catena will probably influence the observed responses to fertilizer application as observed in other places [5,6]. The increasing benefits of fertilizer application requires the development of reasonable fertilizer recommendation domains targeted at specific systems, landscapes and farm typologies, and management practices [7,8]. The realization of site-specific fertilizer recommendations is elusive in Ethiopia as it is in other parts of SSA [9]. In Ethiopia, agriculture is still characterized by low productivity, a high level of nutrient mining, low use of external inputs, traditional farm management practices and limited capacity to respond to environmental shocks [10-12].

Nutrient mining due to sub optimal and unbalanced fertilizer uses have favored the emergence of multi-nutrient deficiency in Ethiopian soils [13,14]. Further, the type of cropping system influences the soil nutrient status; the availability of nutrients to succeeding crops require context-specific targeting of fertilizer application using conditions and systems that optimize fertilizer use efficiency [15]. Di ammonium phosphate (DAP) and urea have been the only chemical fertilizers used for crop production with initial understanding that nitrogen and phosphorus are the major limiting nutrients of Ethiopian soils. However, in addition to N and phosphorus (P), sulfur (S), boron (B) and zinc (Zn) deficiencies are widespread in Ethiopian soils, while some soils are also deficient in potassium (K), copper (Cu), manganese (Mn) and iron (Fe) which all potentially limit crop productivity [16].

Wheat Production in Ethiopia

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops of the world and is a staple food for about one third of the world's population [17]. Ethiopia's agriculture constitutes 46% of gross national production, employs 85% of its population, and creates 75% of export commodity value [18]. Despite its large scale, the agricultural sector is largely formed by smallholder subsistence farms burdened by dependence on erratic rain-fed systems. In all smallholders account for 96% of total area cultivated [19]. In the country Rain dependent agricultural system is particularly vulnerable to shifts in climate and weather, with less than 3% of households having access to irrigation (or less than 1% of cereal acreage) [19]. These vulnerabilities are further exaggerated by extensive use, land degradation, and household poverty.

Ethiopia is the second largest wheat producer in Africa next to South Africa. It is one of the major cereal crops grown in the highlands of Ethiopia, and the country is regarded as the largest wheat producer in Sub-Saharan Africa [20]. Out of the total grain crop area, wheat ranked 4th after *tef* (*Eragrostis tef*), maize (*Zea mays*) and sorghum (*Sorghum bicolor*), while third in total production after maize and *tef* [21]. Wheat is modeled here due to its relative importance as well as its wide scale adoption throughout the four main regions (Oromiya, Amara, SNN and Tgraye) of Ethiopia. Wheat grows mostly in the range between 1500-3000 m above sea level in Ethiopia, where the need for chilling temperature is satisfied [22]. About 4.7 million small holder farmers were engaged in wheat production and closed to 4.6 million ton was produced in 1.7 million ha with average productivity of 2.74 t/ha [3]. Mean wheat yields increased from 1.3 t ha^{-1} in 1994 (CSA, 1995) to 2.54 t ha^{-1} in 2015 [21], which is well below experimental yields of over 5 t ha^{-1} [23,14]. However, Ethiopia's current wheat production is insufficient to meet domestic needs, forcing the country to import 30 to 50% of its wheat to fill the gap [24-26]. The yield gap of over 3 tha^{-1} suggests that there is potential for increasing production through improved soil and crop management practices, particularly increased use of fertilizers and an adequate soil fertility maintenance program.

Soil Fertility Status and challenges in Ethiopia

In Ethiopia, agriculture is the mainstay of the majority of the population and major driver of the national economy. Agricultural production has been highly dependent on natural resources for centuries [27]. However, increased human population and other factors have degraded the natural resources in the country thus seriously threatening sustainable agriculture and food security [28,14]. Continuous cropping and inadequate replacement of nutrients removed in harvested materials or lose through erosion and leaching has been the major causes of soil fertility decline [29]. This is particularly evident in the intensively cultivated areas, traditionally called high-potential areas that are mainly concentrated in the highlands of Ethiopia. To tackle this problem, the country initiated community-based participatory watershed management [30], and to date, it has rehabilitated millions of hectares of degraded land.

According to the Soil Fertility Status and Fertilizer Recommendation Atlas, Ethiopian soil lacks macro- and micronutrients (N, P, K, S, Cu, Zn and B) [16]. Soil fertility can be defined as the capacity of soil to provide physical, chemical and biological needs for the growth of plants for productivity, reproduction and quality, relevant to plant and soil type, land use and climatic conditions [31]. Ethiopia faces a wider set of soil fertility issues beyond inorganic fertilizer use which has historically been the major focus for extension workers, researchers, policy makers and donors. These issues interact and include loss of soil organic matter, macronutrient (N, P, K and S) and micronutrient (Fe, Mn, Zn, Cu, B, Mo and Cl) depletion, topsoil erosion, acidity, salinity and deterioration of other physical soil properties [14].

However, the sector is characterized by low productivity and the prevalence of a fragmented smallholder/subsistence farmer population that is relegated to highly degraded/marginal land due to loss of soil fertility. Low productivity can be attributed to limited access by small farmers to agricultural inputs such as in organic fertilizer, poor attitude on organic fertilizer, financial services, improved production technologies, irrigation and agricultural output markets and, more importantly, to poor land management practices that have led to severe land degradation in some areas. According to Cobo [32], in the Sub Saharan countries with highest rates of nutrient depletion due to lack of adequate synthetic fertilizer input, limited return of organic residues and manure, high biomass removal from farm lands, high soil erosion rate and leaching loss of nutrient elements. The annual nutrient deficit in the country is estimated at 41kg N, 6 kg P, and 26 kg K $ha^{-1}yr^{-1}$. Low soil fertility is recognized as a constraint to increased food production and farm incomes in many parts of Sub-Saharan African [33].

The use of Nutrients for Growth, Yield and Quality of Bread Wheat

Several elements take part in the growth and development of plants, and those absorbed from the soil are generally known as plant nutrients. Besides these, the plant takes up carbon, oxygen and hydrogen, either from the air or from the water absorbed by roots. A total of 16 elements have been identified and are established to be essential for plant growth. There are carbon (C), hydrogen (H), Oxygen (O), nitrogen (N), phosphorus(P), potassium(K), calcium(Ca), magnesium (Mg), iron (Fe), sulfur(S), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine(Cl) [16].

Soil analyses and site-specific studies also indicated that elements such as K, S, Ca, Mg, and micronutrients (e.g. Cu, Mn, B, Mo, and Zn) are becoming depleted and deficiency symptoms are observed in major crops in different parts of the country [34,35]. Several factors contribute to reducing the fertility status and quality of soil in Ethiopia. The major ones being land degradation because of massive deforestation, human and livestock population pressure, limited use of crop residue and animal dung and little or no use of modern technologies to restore soil fertility, high price of mineral fertilizer and low use of organic nutrient sources.

Effect of nitrogen fertilizer on yield and yield related attributes of Bread Wheat

After carbon, hydrogen and oxygen, nitrogen (N) is one of the essential elements in plants due to its key role in chlorophyll production, which is fundamental for the photosynthesis process. In addition, nitrogen is part of various enzymatic proteins that catalyze and regulate plant-growth processes**.** Nitrogen is the most limiting nutrient in plant growth. It is a constituent of chlorophyll, plant proteins, and nucleic acids and useful for vegetative development. Nitrogen plays a key role in agriculture by increasing of crop yield [36]. Nitrogen not only enhances the yield but also improves the food quality [37]. Optimum, rate of N increases photosynthetic processes, leaf area production, leaf area duration as well as net assimilation rate [38]. Nitrogen plays a most important role in various physiological processes. It imparts dark-green color in plants, promotes leaves, stem and other vegetative part's growth and development. Moreover, it also stimulates root growth. Nitrogen produce rapid early growth, improve fruit quality, enhances the growth of leafy vegetables, increases protein content of fodder crops; It encourages the uptake and utilization of other nutrients including potassium, phosphorous and controls overall growth of plant [39,40].

According to Gooding and Davis [41] variability in grain protein can be attributed to environments that differ across locations and years with respect to seasonal temperatures, moisture, and soil type. Variability on grain protein can also be attributed to differences to cultivar genetic potential and to management decisions [42,43]. Among the most important management practices influencing grain protein content is N fertilizer application rate and timing. Increasing N fertilizer rates can result in higher grain protein content [44,45].

Nitrogen is an essential element required for successful plant growth. Although inorganic nitrogen compounds (*i.e.*, NH_4^+, NO_2^-, and NO_3^-) account for less than 5% of the total nitrogen in soil [46], they are the main form of the element absorbed by most plants. Once nitrogen fertilizers are applied to agricultural systems, the fertilizers are absorbed directly by plants or converted into various other forms through the oxidation process. Excess nitrogen is lost in ionic or gaseous form through leaching, volatilization, and denitrification [46,47]. Soil nitrogen (N) is frequently deficient in continuous cereal cropping systems, and this is commonly encountered in soils on which crops are cultivated more than once annually [48]. In Kenya, N is the first limiting macro-element on farms where bread wheat (*Triticum aestivum*) has been grown continuously for more than a decade [49].

The major sources include biological N fixation by soil microorganisms, mineralization of organic matter and industrial fixation of N gas and fixation as oxides of N by atmospheric electrical discharge. The availability of N through biological N fixation is influenced by soil pH and its mineral nutrient status, photosynthesis, climate and crop management. Similarly, mineralization of organic N to inorganic forms depends on temperature, level of soil moisture and supply of oxygen.

However, there is quantitative relationship between crop yield and accumulation of N by plants, i.e., when the soil cannot supply with adequate N, the crop yield will be constrained. This indicates that yield can be considered as a good measure of the collective impact of environment on plant growth, (i.e., the more favorable the environment, the more the effective N applied is and hence the greater the yield). Thus, properly applied nitrogen fertilization has a positive effect on crop yield. At a high level of such fertilization, it is advantageous to apply it twice or three times to plants at different stages of crop development [50].

Application of 105 kg N ha-1 gave the highest mean values of all yield and its components compared as control treatment such increments might be attributed to the favorable role of nitrogen in encouraging in catabolic processes in wheat plants [51]. At higher N application rates, top-dressing of N fertilizer significantly increased grain yield, improved grain protein content, and grain N uptake. The increase in grain N uptake and protein content led to an improvement in wheat grain quality [52]. Ejaz reported that increasing levels of nitrogen fertilizer improved grain yield, which seems to be the result of enhanced tiller production and increased kernel number per spike. However, N rate beyond the optimum prolongs the vegetative stage and thereby reducing yield and quality. Nitrogen fertilizer applications that exceed crop N requirements lead to environmental pollution including nitrate N leaching and gaseous N emissions [53].

Nitrogen Deficiency on Growth of Bread Wheat

Symptoms of N deficiency are general chlorosis of lower leaves, stunted and slow growth and necrosis of older leaves in severe cases [54]. N deficient plants will mature early and crop quality and yield are often reduced [55]. In cereals, yellow discoloration from the leaf tip backward in the form of a 'V' is common [56]. Insufficient amounts of N in cereals will result in few tillers, slender stalks, short heads, and grain with low protein content. Leaf curling and small tubers are common in potatoes deficient of N. Fields deficient in N can be either uniform or patchy in appearance, depending on the cause of the deficiency [54]. N deficiency have general chlorosis, slow and delayed growth and plants show a stunted appearance.

Effect of phosphorus on yield and yield related attributes of Bread Wheat

Phosphorus (P) is an essential hetero element in compounds such as ATP, NADPH, nucleic acids, sugar phosphates, and phospholipids, all of which play important roles in photosynthesis [57]. The source of mineral P fertilizers, is a finite natural resource, and known reserves are projected to last less than a few hundred years at current rates of consumption [58-61]. Phosphorus is a critical nutrient for plant growth, since it is involved in cellular energy transfer, respiration, and photosynthesis. Phosphorus plays an important role in energy transformations and metabolic processes in plants [62]. Phosphorus is an important nutrient element on crop production. However, the fact is that phosphorus is one of the main limiting factors for the world wheat production [63,64].

Phosphorus plays an important role in an array of cellular processes, including maintenance of membrane structures, synthesis of bio molecules and formation of high-energy molecules. It also helps in cell division, enzyme activation/inactivation and carbohydrate metabolism [65]. It is also a structural component of the nucleic acids of genes and chromosomes and of many coenzymes, phosphoproteins and phospholipids. In order to maintain its role under inorganic phosphate (Pi-deprived conditions), plants undergo various morphological, physiological and biochemical adaptations. These include alterations in root architecture, formation of cluster roots, shoot development, organic acid exudation and alternative glycolytic and respiratory pathways [66]. Phosphorus enhances cell division, fat formation, flowering, fruiting, seed formation, and development of lateral and fibrous root systems. Phosphorus is an important nutrient element on crop production. However, the fact is that phosphorus is one of the main limiting factors for the world wheat production [63,64].

An adequate quantity from available source of phosphorus is vital for the growth, reproduction, yield and quality of wheat. An emphasis should be given on the efficient use of P fertilizer in order to maintain sustainable wheat production [67-69]. Application of adequate amount of phosphorus improves wheat grain yield. Thus, there is a need to apply the adequate level of phosphorus for obtaining higher yield with good quality product of wheat. In many parts of Northwestern and Northern Ethiopia, applying P fertilizer at the highest rate has significantly enhanced yield and yield components of wheat, maize, barley and teff [70].

Phosphorus Deficiency on Growth of Bread Wheat

Phosphorus deficiency in plants can be visually identified at the early vegetative stage as an abnormally dark green or reddish purple color along the edge of the lower plant leaves [71]. Due to deficiency of phosphorus, growth of root and shoot is restricted, plants become thin and spindly, premature shedding of leaves and flowering occur, yields are consequently decreased. The dark-green color of leaves is one of the first symptoms of P deficiency in many species, growth is reduced and, in conditions of severe deficiency, plants become dwarf.

Effect of Sulfur on yield and yield related attributes of Bread Wheat

Sulfur (S) is one of the essential nutrients for plant growth and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis. It is required in similar amount as that of Phosphorus [72]. Sulphur is an essential nutrient for plant growth due to its presence in proteins, glutathione, phytochelatins, thioredoxins, chloroplast membrane lipids, and certain coenzymes and vitamins [73]. The amino-acids, methionine (21%S), cysteine (26%S) and cystine (27%S), that impact nutritional value of human food and feeds, contain sulfur [74]. Without adequate sulfur, crops can't reach their full potential in terms of yield, quality or protein content; nor can they make efficient use of applied nitrogen [75]. The sulphur is a component of organic matter released after their mineralization [76]. Sulfur is reported to be a macro-nutrient that is taken-up by crops in amounts similar to and sometimes exceeding those of P, 10-30 kg/ha [77], and considered to be one of the most limiting nutrient element for crop production. It is essential not only for plant growth and quality produce, but also enhances other nutrients use efficiency and ranks second only to N in importance for optimum crop yield/quality [78].

S and N nutrition interact at many levels, as the uptake and assimilation of NO_3 and SO_4^{2-} have much in common, and there are many common products of N and S metabolism. For assimilation of sulphate to occur, plants must contain adequate levels of this precursor, and as an amino acid its concentration is dependent on N nutrition. When nitrogen and sulfur fertilizers were applied simultaneously, flour protein content and dough strength, swelling and extensibility were increased [79]. Sulfur does not affect only nitrogen utilization and grain quality, but it also plays an important part in the formation of the baking quality.

N and S are both important constituents of protein, and adequate supplies of both nutrients are important for optimum crop yield. A synergistic effect between the applied nitrogen and sulfur fertilizers appears to increase nitrogen and sulfur assimilation in wheat grain and may improve bread making qualities. When nitrogen and sulfur fertilizers were applied simultaneously, flour protein content and dough strength, swelling and extensibility were increased [79]. The increase in grain yield in response to S addition was associated with a higher N uptake rate before anthesis confirming the positive interaction between both nutrients. Sulfur (S) is another essential nutrient for successful rapeseed growth [80].

Timms [81] showed that increasing protein content correlated with a lower proportion of the sulfur amino acids like cysteine and methionine. Applied sulfur positively affects the quality of wheat flour by increasing gluten and protein concentration. Furthermore, sulfur positively affects the development, stability, softening, and quality of dough as well as bread volume. Wheat fertilization with sulphur and nitrogen affects sulphur content and N : S ratio in grain [82].

Sulfur Deficiency in Growth of Bread Wheat

Sulfur deficiency had a significant influence on the yield and yield components of wheat [83]. It is clear that protein rich cereals like wheat are likely to suffer from concealed S deficiency [84]. Sulfur deficiency decreases grain size and bread baking quality because of formation of disulfide bonds formed from the sulphydryl groups of cysteine. This effects the visco elasticity of dough. The baking quality of wheat was improved by sulfur application, showing high correlation between loaf volume and the sulfur content of grain and thus improving rheological properties (extensibility) of dough [85]. Sulfur deficit may result in harder grain; the dough made from such grain is usually stiff and is not elastic.

Low S values (< 0.15 %) were reported from Shewa, Sidamo (southern zones) and Arsi (south eastern zone) (Weil, 2011). The author reported some foliar symptoms of S deficiency in farmers' fields in Oromia, Amhara and Tigray regions. Generally, for young wheat plants, S content of 0.15-0.40 % is considered sufficient but values < 0.15 % or a N/S ratio > 17 are considered to be deficient [86-92].

Conclusion

The production of wheat is highly affected by the removal nutrients from the soil, use limited fertilizers for a long period of time and unbalanced application of fertilizer treatments in the field area. Application of appropriate and balanced amounts of Nitrogen, phosphorus, sulfur and other nutrients are important for keep the soil health, increase the production and productivity and improve the quality of bread wheat. Therefore, in order to ensure wheat cultivars possessing high productivity of specific quality attributes nutrient management practice is crucial.

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