Advances in Agricultural Technology & Plant Sciences
ISSN: 2640-6586
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Review Article *Volume 4 Issue 1*

Effect of Blended Fertilizer (NPS) on Yield and Yield Component of Soybean (Glycine Max L.)

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Received Date: June 11, 2021; **Published Date:** June 30, 2021

Abstract

Soybean (Glycine max L) is among the most important legume crops produced in Ethiopia. However, declining soil fertility and poor soil fertility management practices decrease yields. Nitrogen fertilization is necessary to improve yield and quality of soybean at certain application times or rates. In order to achieve high yield potential, soybean must maintain high photosynthesis rates and store large amounts of N in seeds Sulfur (S) is among the 17 essential nutrients for healthy plant growth and is a requirement for soybean. With N, phosphorus, and potassium being primary macronutrients, S is a secondary macronutrient. In order to achieve maximum plant growth and high yield, nutrients must be at adequate levels. Phosphorus along with nitrogen and potassium is a primary nutrient required by plants to complete their life cycle. It's especially important during the early stages of growth and development. One important role of P in plants is to store and transfer energy produced by photosynthesis which is then used for growth and reproduction. If P is limiting, plants cannot grow adequately, which limits their ability to cope with stress. Slow root and shoot development results in delayed maturity and reduced yields although soybean yields have increased over the past decade, even greater improvement is in demand. Nontraditional practices such as applying nitrogen (N) to soybean for yield optimization might be one way to meet this demand. Also, sulfur (S) is becoming a more important limiting nutrient in production due to higher yielding crops.

Keywords: Sulfur; Nitrogen; Phosphorus; Yield; Blended Fertilizer

Abbreviations: IDC: Iron Deficiency Chlorosis; SOM: Soil Organic Matter.

Introduction

Soybean was first introduced to Ethiopia in 1950's because of its nutritional value, multipurpose use and wider adaptability in different cropping systems [1]. It is a crop that can play major role as protein source for resource poor farmers of Ethiopia who cannot afford animal products. Besides, it can also be used as oil crop, animal feed, poultry meal, for soil fertility improvement and more importantly as source of foreign exchange earnings for the country [NSRL 2007]. In Ethiopia, soybean has adapted to diverse ecological niches and provided wider yield range [1]. Soybean was produced on about 38,166.04 ha of land and 81241.833 tons produced in 2015/16 main cropping season with the productivity of 2.1 t ha-1; which is low as compared to world average of 2.6 t ha-1 [2]. This low yield may be attributed to a combination of several production constraints among which low soil fertility, periodic moisture stress, diseases and insect-pests, weeds and poor crop management practices play a major role [3].

Soybean is known for its wide adaptability coupled with its higher productivity per unit area compared to other grain legumes [4]. However, it is mostly cultivated in tropical and subtropical areas, where the soils are often deficient in phosphorus (P) and nitrogen (N) due to intensive erosion, weathering, and P fixation by free Fe and Al oxides [5]. Therefore, low P availability is often a major constraint to soybean growth and production [6]. Use of P efficient soybean varieties with efficient P acquisition ability from both native and added P sources in the soils would be a sustainable and economical approach [5]. Legumes require P for adequate growth and N fixation and their effectiveness in soil improvement can be hindered by P deficiency [7]. Phosphorus deficiency can limit nodulation by legumes and P fertilizer application can overcome the deficiency [8]. N2 fixation apparatus could not meet N demand [9]. However, yield response of soybean to fertilizer N has been inconsistent at economically acceptable levels [10,11].

However, the soil fertility mapping project in Ethiopia reported the deficiency of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils and thus recommend application of customized and balanced fertilizers [12]. This emphasizes the importance of developing an alternative means to meet the demand of nutrient in plants by using of blending NPS that contains S in addition to the commonly used N and P fertilizers. However, there is limited information on responses of soybean varieties to rates of blended NPS fertilizer rates in Ethiopia.

Literature Review

Nitrogen Fertilization

Nitrogen is an essential plant nutrient, as it is an important component of chlorophyll. It is also a key part of amino acids, the building blocks of protein molecules, and DNA, without which there would be no life on earth [13]. The earth's atmosphere is approximately 78% N in the form of nitrogen gas (N2) [14]. Nitrogen in this form, however, is not available for plant use. Soybean requires a large amount of N because of the high protein concentration of the seed, approximately 35-40% [15]. Nitrogen application to soybean has significantly increased yields in ND, but the revenue increase did not outweigh the cost of fertilizer (H. Kandel, personal communication, 2015). Salvagiotti, et al. [16] reported that N fertilization may satisfy the additional N required to attain maximum yield of soybean when soil and BNF provide an inadequate N supply. Soybean acquires only between 25% and 75% of its required N by fixation [17]. This matches a range of 50-60% of average total N demand obtained through BNF reported by Salvagiotti, et al. [16]. Kaiser and Lamb [18] also reported that certain environmental conditions limit the ability of soybean nodules to supply adequate N late in the growing season, indicating that N fertilizer may be beneficial.

High N levels in the soil, specifically nitrate (NO3-), are associated with high expression of iron deficiency chlorosis (IDC) in soybean [19,18]. Chlorosis is known to cause plant stress and presents itself as interveinal yellowing of leaves. Iron deficiency chlorosis can cause substantial yield loss in soybean [20], The soybean plant must take Fe from the soil in the Fe2+ form. High soil NO3--N concentrations also decrease N fixation [21]. Nitrogen as incorporated AMS and broadcast incorporated urea at planting may not increase soybean yield in certain environments and certain soil conditions [22,23,24]. However, low rates of N at seeding have increased soybean yield and nodulation in some regions [25,26], possibly due to low N fixation at the beginning of the season. Zapata, et al. [27] stated that the main source of N during vegetative development is the absorption of NO3--N from the soil, which can be from soil mineralization or application of fertilizer.

Timing may be an important factor when considering N fertilizer application to soybean. Applying N at reproductive stages may increase yield by supplying N at a vital time when N supply may be limited. Barker and Sawyer [11] concluded that fertilizing soybean at the beginning of reproductive stage with 45 and 90 kg N ha-1 in the form of broadcast urea or band placement polymer-coated urea in Iowa only increased yield 49 kg ha-1 over the control (0 kg N ha-1), which was not significant. Kinugasa, et al. [28] also reported that N fertilization after flowering significantly increased soybean seed number plant-1 (100%).

Applying Nitrogen to Nitrogen Fixers

Nitrogen fertilization is necessary to improve yield and quality of soybean at certain application times or rates [29,10,30]. According to Salvagiotti, et al. [31] in order to achieve high yield potential, soybean must maintain high photosynthesis rates and store large amounts of N in seeds. Thus, an ideal crop canopy must enable full light interception and adequate storage of N in leaves to maintain photosynthesis for converting incoming radiation into new biomass and, eventually, grain yield. Dinitrogen fixation and mineral soil or fertilizer N is the main sources of meeting the N requirement of high yielding soybeans. Many factors will affect the response of the soybean to N fertilization, such as temperature, soil type, soil water and organic matter content, and genotype [32]. Maximum N2 fixation occurs between the R3 and R5 stages of soybean development, and any deficiencies between crop N demand and N supply by N fixation must be satisfied by N uptake from other sources [31]. When adequate soil N is available then N fixation is inhibited, but there are some situations when N fertilization is helpful to the plant development. Hardason, et al. [33] suggests that during the early period of plant growth, when nodules have not fully developed, the young plant depends on soil N and N stored within the cotyledons for normal growth. If the soil N is inadequate to meet the needs for the seedling, growth can be stunted. Therefore, a low rate of N might be beneficial to encourage both growth and N2 Fixation. Furthermore, as soybean roots and nodules age, their ability to fix N can be significantly reduced compared to that of early season N2 fixation levels. Thus, foliar applications of N could possibly supplement an N deficit, particularly in a high yield situation. Hodgins, et al. (2015) stated that increasing soybean yield goes hand in hand with a larger N demand. The ability to maintain N fixation by the rhizobia during the late season can be difficult and can impede the crop's ability to supply all of the N required for maximum grain filling and seed N content. Although Hodgins, et al. (2015) did not significantly increase soybean yield with late season foliar N applications, there is justification for further research to investigate the effects of N applications on a soybean crop.

Effect of Nitrogen Rate and Timing on Soybean (Glycine max L.) Growth, Development, and Yield

Nitrogen is necessary for a variety of plant growth and development processes. The most important of these processes is stimulating vegetative growth, being a main factor in chlorophyll production, and assisting in environmental stress, injury, and disease recovery [34]. Also, N is a component of amino acids for proteins, balances the uptake of other nutrients, and is a key element in critical compounds, such as nucleic acids and enzymes [35]. If the N level is deficient in the soil solution and not supplied through N fixation, the result will be decreased plant productivity of legumes, decreased photosynthetic capacity and food production, slow injury recovery time, and reduced tolerance to stresses [34]. With the higher yield potential of modern legume cultivars, more N is required from the bacterial relationship and soil solution; thus, supplementing the difference between crop demand and N supply with mineral fertilizers may be necessary to reach modern yield goals. Some researchers have proposed that N fertilization is not needed for a normal inoculated soybean crop [31], but others have suggested that biological N fixation and soil uptake of N is not enough to meet crop demand [32]. For soybean to reach higher yield goals, the crop must sustain high photosynthetic rates and accumulate large amounts of N in the seeds [31]. Maximizing canopy development permits full light interception and sufficient storage of N in leaves to manage photosynthesis that is not limited by N to transform solar radiation into new biomass and ultimately grain yield [31].

Sulfur Fertilization

Sulfur is one of the 16 essential elements for plant growth and is a component of amino acids needed for protein synthesis [36]. Following the enactment of the Clean Air Act in 1963, more soils show S deficiencies possibly relating to lower sulfur dioxide emissions.

Sulfur is becoming deficient in soils due to the introduction of high yielding varieties, the use of high grade S free fertilizers, and the reduced emission of S from industrial processes (Scheerer, 2009). Soil S levels have decreased as S removal and crop yields have increased and deposition of SO4-S via rainfall, fertilizer, and pesticides has decreased [37]. Sulfur deficiencies not only reduce yield, but also decrease the feed value of soybean [38]. Unfortunately, it is difficult to measure soil S levels because of highly variable soil test results [19,18]. Soils typically at risk for S deficiency include coarse-textured soils, soils low in organic matter, soils experiencing large amounts of rainfall in the fall or spring, and soils located on higher landscape positions [39]. Sulfur also seems to have an effect on the root system of soybean. Zhao, et al. [40] reported that S supply as elemental sulfur can promote the growth of the soybean root and enhance the plants ability to absorb nutrients. When fertilized in pots with 60 mg S kg-1 soil, the average number of nodules plant-1 increased by 36%, the plant dry weight increased by 76%, and the seed yield increased by 12.8% compared to the control (0 mg S kg-1 soil) [40].

Role of Sulfur in Soybean

Among the 17 essential nutrients for plant growth, sulfur (S) is a requirement for all crops. It is a secondary macronutrient, behind N, phosphorus, and potassium. A balance of these nutrients is essential in accomplishing optimum plant health and yield goals. Soybean requires 0.0058 kilograms S per hectoliter (Mosaic, 2014; Davidson, 2015). As stated by Place, et al. [41] in the soil, S can exist as organic S compounds, sulfides (S-), elemental sulfur (S), and sulfate (SO42-). Most of the S in the soil is found in soil organic matter (SOM), which is not readily available to plants; therefore, it must undergo a mineralization process to be converted to sulfate for plant uptake [41]. In the sulfate form, it plays an important role in protein synthesis and is essential for many different plant processes since it is a main component of amino acids, proteins, and peptides. Also, S is important for the formation of chlorophyll as well as the success of nodulation and N fixation in soybeans. According to Davidson (2015), S is a component of ferredoxin, an iron-S protein found in the chloroplasts. Ferredoxin also plays a metabolic role in both N fixation and sulfate reduction and in the absorption of N by rhizobacteria living in the nodules. Root nodules are high in protein, and nitrogenase has iron and S cofactors. Therefore, S, being a component of two amino acids, can limit N fixation and, ultimately, yield in legumes [42].

Effect of Sulfur Rate on Soybean (Glycine max L.) Yield

Sulfur (S) is among the 17 essential nutrients for healthy plant growth and is a requirement for all crops. With N, phosphorus, and potassium being primary macronutrients, S is a secondary macronutrient. In order to achieve maximum plant growth and high yield, nutrients must be at adequate levels. With the majority of S in the soil being found in organic matter, S exists as organic compounds, sulfides (S2-), elemental S (S), and sulfate (SO42-). Similar to nitrogen (N), S in soil organic matter is not readily available for plant uptake. In warm, well aerated soils, organic S slowly goes through a process known as mineralization to form sulfate S which is available to plants [41].

According to Davidson (2015), S plays a critical role in protein synthesis and is crucial for various plant processes since it is a key component of amino acids, proteins, and peptides. In addition, S is essential for the development of chlorophyll by being a dominant component of one of the enzymes needed for the formation of the chlorophyll molecule [43]. Also S is necessary for the success of nodulation and N fixation in legumes such as soybean. Development of vegetative growth would be impossible without chlorophyll production; and without S, chlorophyll production would be impossible. Sulfur is a key ingredient of ferredoxin, which is an iron-S protein found in chloroplasts. Further, ferredoxin also contributes to the metabolic role in both N fixation and sulfate reduction and the consumption of the N by the rhizobacteria living in the root nodules (Davidson, 2015). Sulfur and iron cofactors are components of root nodules, which are high in protein and the enzyme nitrogenase.

Thus, being an integral component of two amino acids, S deficiency can limit N fixation and, eventually, yield [42]. Sulfur can be depleted from the soil profile by plant uptake, leaching, and volatilization; and these processes can increase in tilled soil [41]. Consistent tillage discourages overall soil heath by depleting soil aggregates, infiltration, and soil tilth. Also, tillage promotes soil erosion, which is a main reason for nutrient loss in a cropping system. Plants that are deficient in S or N may display similar symptoms. Both appear as interveinal chlorosis and stunted plant growth. Sulfur is a less mobile plant nutrient than N. When a deficiency occurs, the plant cannot easily move S to younger tissue; therefore, deficiency symptoms will be seen in the younger tissue first. In contrast, N is very mobile in the plant tissue, resulting in symptoms being observed in the older tissue before the younger. An optimal N:S ratio of 15:1 [44] assures optimum N use efficiency, plant vigor, water use efficiency, phosphate use, carbohydrate production and utilization, rate of grain fill, and maturity [45]. Therefore, this N: S ratio basically emulates the correlative relationship that N and S have in producing key plant proteins [45].

In recent years, S has become a more limiting nutrient in crop production for various reasons, including higher crop yields that require more S, minimal S amounts in modern phosphorus fertilizers, less use of S containing pesticides, reduced S emissions to the atmosphere, and soil organic matter levels that are too low to provide enough S [42]. According to Morrison [46] less than half the amount of S reached the soil as acid rain in recent years compared to in the 1980s. Therefore, crop responses to S fertilizer application could become more common. The Clean Air Act in 1970 reduced S emissions significantly, causing a reduction in S deposition in many areas [41]. Other conditions that can cause S deficiency in the soil are cold temperatures and water-logged soils (Further Agriculture Solutions, 2012), where low oxygen conditions reduce available sulfate S into sulfide, which is unavailable for plant uptake.

Sulfur and Nitrogen

Like N, S can leave the soil solution by plant uptake, leaching, and volatilization, which soil disturbance increases [41]. Deficiency symptoms of N and S are often mistaken for each other. Both deficiencies exhibit interveinal chlorosis and stunted plant growth. However, S is considered an immobile nutrient inside the plant, meaning that the plant cannot easily move it to where it is needed the most, i.e. younger tissue. Thus, S deficiency symptoms will be seen in the younger tissue before the older tissue. Conversely, N is very mobile in the plant, and symptoms will be seen in the older tissue before the younger. According to Agrisolutions [45] an adequate balance between N and S is vital to maintain maximum N use efficiency, plant vigor, water use efficiency, phosphate use, carbohydrate production and utilization, rate of grain fill, and maturity. The ratio is a result of the close relationship between S and N in the production of key plant proteins.

Role of Phosphorus

Phosphorus along with nitrogen and potassium is a primary nutrient required by plants to complete their life cycle. It's especially important during the early stages of growth and development. One important role of P in plants is to store and transfer energy produced by photosynthesis which is then used for growth and reproduction. If P is limiting, plants cannot grow adequately, which limits their ability to cope with stress. Slow root and shoot development results in delayed maturity and reduced yields. Phosphorus is also a component of cell membranes and is part of the structure of DNA. Relatively large amounts of P are required by plants compared to most other nutrients.

Phosphorus (P) is a key nutrient used in fertilizer due to its role in energy transfer, photosynthesis and growth in plants [47]. Phosphorus is a nutritional requirement in soybean for nodule development and functioning (Sa and Israel, 1991). There are a wide variety of influences in the soil that affect P availability. The nutrient requirement of plants depends on many coexisting factors including plant type, yield goal, soil nutrient status, soil type, climatic conditions and land management. A significant amount of P and other nutrients are removed atharvest in the grain. Phosphorus cycling in soils is a complex phenomenon and depends on environmental factors including soil moisture and temperature. The amount of labile or available P available to plants in solution is low and is influenced by soil, plants and microorganisms. Labile P has to be constantly replenished to replace plant needs over the course of a plant's life so that P in solution is available to the plant at every growth stage. Contribution and bioavailability of organic P in soil solution is not completely understood. Further, mechanisms controlling rate of P exchange and availability are not completely understood [48].

Phosphorus is taken up as an inorganic anion (H2PO4 - and HPO4 2-) and therefore, organic P must be mineralized prior to plant uptake. Because P transport to the root is predominantly through diffusion, uptake can be decreased by soil drying or increased by practices that increase root length [49]. Rate of diffusion is affected by temperature and moisture; therefore it is not the quantity of P applied that affects availability, but the rate at which P in solution can be replenished. Most P in soils is derived from the weathering of apatite [48]. As apatite is broken down, the P has potential to bind with metals or salts and become unavailable to plants [48]. Soils with high clay content will adsorb more P because of the large surface area. Adding inorganic P fertilizers to soil will likely cause an increase in the concentration of P in soil solution [48]. Fertilizer recommendations will be higher for soils that have a fine texture, high clay content and high pH [49]. Anthony, et al (2012) reported that soil pH has a large influence on soil test P, and that at high levels it can form calcium phosphates. After fertilization, more than 80% of the P may become immobile due to the soil pH and other soil physiological processes.

Conclusions

Soybean yield is low compared to other legume crops due to many factors affecting its production which include suitable varieties, poor agronomic practices such as fertility management including appropriate fertilizer rate and time of application, untimely and inappropriate field operations, rainfall variability and diseases and insect pests. Therefore, field experiment should be conducted to assess the effect of rates of blended NPS on yield and yield components of soybean varieties and to determine economically appropriate rates of blended NPS fertilizers for soybean production.

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