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Role of Nitrogen on Potato Production: *A Review*

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Abstract: Potato (*Solanum tuberosum* L.) is a perennial plant of the *Solanaceae* family and the world's most important and widely grown tuber crop ranking fourth after rice, wheat and maize. In terms of human consumption, it ranks third after rice and wheat. It could be one of the most important crops to be introduced in the area where the population experiences recurrent malnutrition due to heavy dependence on cereal crops and poor crop productivity for the reason that its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle as compared to the major cereal crops. To increase potato production Nitrogen (N) among others is the mineral nutrient most commonly deficient in agricultural soils. The optimal response to N fertilizer application differs by cultivar and soil type; hence it needs critical consideration for different cultivars at specific location. Fertilizer requirement varies across locations due to numerous reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety. Ensuring the optimum husbandry including nutrient management is very important because soil-plant system inefficiencies prevent complete utilization of the N, leaving residual N in the soil, which is a waste of natural resources and cause for environmental concern. This needs due attention since the crop demands high level of soil nutrients due to relative poorly developed and shallow root system in relation to yield. Generally, concerning nutrient, optimum yield can be obtained by improving nutrient management (provided that other issues e.g. improved variety are fulfilled) since tuber yield and tuber quality are directly impacted by quantity and timing of nutrient applications. Split application (each on a vital time) of N is important in order to avoid loses through leaching, volatilization, denitrification, utilization by weeds, erosion by running-off water and sedimentation.

Keywords: Nitrogen, *Solanum Tuberosum* L, Management, Response, Quality

1. Introduction

Potato (*Solanum tuberosum* L.) is a perennial plant of the *Solanaceae* family and the world's most widely grown tuber crop ranking fourth after rice, wheat and maize; and 40% of the world potatoes are grown in Europe, 35% in other developed countries and 25% in the rest of the world [17]. It is one of the most important food crops worldwide, and ranks third after rice and wheat in terms of human consumption [25]. As it is has been indicated, potato tubers are the subterranean swollen, starchy tubers of the potato plant (*Solanum tuberosum* L.) and are of utmost importance as staple food for hundreds of millions of people in the world. Apart from utilization as food, potatoes can be used in ethanol production, yield pulp for paper industry and they may also provide raw material to the chemical industry [11].

Potato could be one of the most important crops to be introduced in the area where the population experiences recurrent malnutrition due to heavy dependence on cereal crops and poor crop productivity [61]. Potato is regarded as a high-potential food-security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops like maize [20]. It has been stated by John [25] that at least six major potato roles can be assigned to the potato tuber: as a hunger-relieving crop; as food, either fresh, processed or as animal food; as a propagule, from which to produce the next crop; as a feed stock in industry for starch and alcohol; as an item of commerce; and as a resource of biodiversity. He also detailed that potatoes are grown and eaten in more countries than any other crop; they are grown in all the continents except Antarctica. He also stated regarding the global economy; they are the fourth most important crop in total production and the fourth largest contributor to human caloric consumption, after the three cereals, rice, wheat and maize.

Different scholars found out that the optimal response to nitrogen (N) fertilizer application differs by cultivar [28, 27] and soil type. Fertilizer application works best provided that a soil test has been done [50]. Newly released potato cultivars require additional revision to develop best management recommendations for N fertilization of potato and for optimization of tuber yield and quality [47].

Nitrogen is the mineral nutrient most commonly deficient in agricultural soils. As a result, in developed countries, farmers apply relatively high rates of N fertilizers. Soil-plant system inefficiencies prevent complete utilization of the N, leaving residual N in the soil, which is a waste of natural resources and cause for environmental concern [21]. Correlated to this, application of fertilisers beyond its optimum often shows inefficient for production so creates risks of nitrate and phosphorus pollution on groundwater [22, 59]. Worldwide, crops do not directly utilize about half of the applied N and the overall N use efficiency has declined with increasing N fertilizer use [6]. On the other hand, in developing countries such as Ethiopia, Kenya, and Uganda, the amounts of fertilizers applied to the potato crop are very low. For instance, in a study conducted by [15], the amounts of FYM, N, and phosphorus applied to potato crop were estimated to be only 4 t ha^{-1}, 43 kg N ha^{-1}, and 101 kg P ha^{-1} in Kenya, 3 t ha^{-1}, 30.6 kg N ha^{-1}, and 33.4 kg P ha^{-1} in Ethiopia, and 2.2 t ha^{-1}, 37.6 kg N ha^{-1}, and 46.9 kg P ha^{-1} in Uganda, respectively.

Fertilizer requirement varies across locations due to numerous reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety [61]. Regarding variety, according to Atkinson et al. [2], newer potato cultivars are becoming more widely grown because of improved characteristics such as earliness, yield, quality and storability; increased resistance to insects, pathogens and other environmental stresses.

2. Potato and Nitrogen (N) Fertilizer

To have a realistic knowledge about potato, like other crops, it is essential to assess different literatures that are dealing with this crop because a research by itself is a way of revising previous studies to have a look at the gaps or limitations that have been observed. It also helps to grasp the methods followed by different investigators.

2.1. Nutrients Uptake and Partitioning

Uptake of nutrients by crop plants in adequate amount and proportion is very important for producing higher yields. Similarly, distribution of absorbed or accumulated nutrients in shoot and grain (higher N in grain) is associated with yield improvement [8]. Nutrient uptake in crop plants is mainly measured by tissue analysis. Nutrient distribution in grain compared to total uptake in the plant is known as nutrient harvest index. It should not be confused with grain harvest index, which is the ratio of grain weight to grain plus straw weight [9].

Nitrogen uptake efficiency reflects the efficiency of the crop in obtaining N from the soil [35]. Nitrogen use efficiency (NUE) in crop plants is defined in several ways in the literature [8]. In simple terms, efficiency is ratio of output (economic yield) to input (fertilizers) for a process or complex system [9]. Agronomic efficiency may be defined as the nutrients accumulated in the above-ground part of the plant or the nutrients recovered within the entire soil-crop-root system [46].

Various indices are commonly used in agronomic research to assess the efficiency of applied N, mainly for purposes that emphasize crop response to N. Quantifying the status of N use efficiency in agriculture is a difficult task because (i) definitions used in research papers and interpretations of different N use efficiency indices vary and (ii) reliable data needed to compute N use efficiency indices are often not available, particularly at national, regional and global scales [6].

Nitrogen was initially concentrated in the stems and leaves, particularly if applied during tuber growth. Over 80% of the assimilated N was found in the tubers at the start of plant maturation. These facts indicate that a significant improvement in N fertilizer efficiency would result from split N fertilizer applications made according to crop growth needs [57].

2.2. Nutrient Management in Potato

Great opportunities exist to increase potato yield and quality by improving nutrient management. Potato demands high level of soil nutrients due to relative poorly developed and shallow root system in relation to yield [41]. Effective management of nutrients is critical for potato production, as tuber yield and tuber quality are directly impacted by quantity and timing of nutrient applications. A study by Love and Stark [32] stated that every potato variety exhibits unique characteristics and consequently present specific management challenges. These varietal differences can impact every aspect of production, from seed production to storage condition.

A number of factors that negatively affect efficiency can be mentioned. Split application of N is important in order to avoid loses through leaching, volatilization, denitrification, utilization by weeds, erosion by running-off water and sedimentation [50]. The other factor that can minimize the problem of soil as well as nutrient loss, as stated by the result of Shadrack Nyawade et al. [49], is that incorporating (e.g. by intercropping) suitable indeterminate legume cover crops in potato cropping systems minimizes soil and nutrient losses due to erosion.

Nitrogen management for the improvement of N efficiency is a high priority in potato cropping systems; typically, N is the most limiting nutrient in crop production and is higher in concentration than all other mineral nutrients in most plants [21]. Applying the right source of N fertilizer at the right rate, time, and place is critical to proper N management; and for the best results, apply N only when needed, calibrate application equipment to ensure proper placement, and adjust source, rate and timing to meet N needs and avoid seed or seedling injury [26]. Nitrogen supply is managed according to market classes (table stock, French fries, and potato chips), which require different quality parameters [4]. It is possible to improve crop yields and consequently N use efficiency through adopting soil and crop management practices. These practices include the liming of acid soils; appropriate source, rate, and timing of N application; supply of adequate soil moisture; crop rotation; conservation or minimum tillage; use of cover crops and animal manures; use of N-efficient crop species or genotypes within species; and control of diseases, insects, and weeds [9]. Noura Ziadi et al. [40] revealed in their study that the method of using controlled-release N fertilizers, such as polymer-coated urea (PCU), could reduce N losses and increase N use efficiency (NUE) by matching the release of N with potato N uptake.

The organic nutrient management is based on crop rotations, solid and liquid animal manures, green manures and compost [12]. The release of N from most of these fertilizers is slow and highly dependent on soil moisture and soil temperature affecting mineralization processes [55]. The finding of Moore et al. [38] also pointed out that two of the biggest challenges for organic potato growers are: 1) providing N for optimal yield and quality and, 2) selecting varieties that are both high yielding and have adequate quality when grown under an organic system, thus makes difficult N management in organic production systems.

2.3. The Role of N in Potato

In potato production, N is applied more frequently and in greater amounts than any other nutrients [5]. This indicates that N is an essential nutrient for crop growth, and the demand for N in the potato crop is relatively high. Moller et al. [37] stated that in organic potato growing N availability is one of the most important yield-limiting factors. Due to its vitality, the right amount, optimum amount, of N should be applied in order to utilize the maximum possible potential of a given genotype within that particular location.

According to Tisdale and Nelson [53], N is an integral part of the chlorophyll molecule besides its role in the formation of proteins. The report of FAO [10] affirmed that N makes up to 1 to 4 percent of dry weight of the plant; it is taken up from the soil in the form of nitrate (NO_3^-) or ammonium (NH_4^+) and combines with compounds of the carbohydrate metabolism in the plant to form amino-acids and protein.

Proper N fertilization is critical for optimizing potato yield and quality. According to Jatav et al. [23], application of N exerted significant influence on all the growth parameters that is showing positive increment. Similar result was obtained by Kołodziejczyk [30]; each application of N doses caused a marked increase in potato-plant productivity as compared to a smaller dose. Insufficient available N leads to reduced growth and light interception [36], early crop senescence [28] and reduced yields [56]. Excessive available N can result in delayed tuber set [28], reduced yields [31] and reduced tuber dry matter content [36]. Excessive N also increases the potential for environmental problems associated with nitrate leaching or runoff [57].

2.4. Response of Potato to N Supply

The response of the potato plant to the available N supply is an important determinant for accurate N fertilizer recommendations. Knowledge of the residual soil NO_3-N concentrations, the rate and amount of N mineralized from the soil organic N sources and the actual N fertilizer efficiencies must also be known for this practice to be successful [56]. Several factors limiting crop yields have been proposed by many researchers. According to Downs and Hellmers [7] and Tisdale *et al*. [53] factors limiting crop yield (both in quantity and quality) can be categorized into four major headings such as soil, genetic, climatic and management practices. Related to this, as shown by Gastelo *et al*. [13], higher potential yield in potato can in part be achieved by adjusting the genetic response of the variety to the length of the photoperiod. Similarly, the yield response to mineral nutrient application in potato, as in other crops, was found to be determined by soil, plant, management and climatic factors [3]. Maintaining adequate level of soil fertility has been recognized as one of management practices that affect growth, development and yield of plants [53]. Potato plants have been reported to have high requirement for mineral nutrition [18]. Depending on conditions, a normal potato crop has been found to remove 90 to 190 kg N ha^{-1} and 30 to 50 kg P_2O_5 ha^{-1} [52].

2.5. Effects of N on Yield Related Parameters of Potato

2.5.1. Stem Number

The stem is generally considered to be the central structure of the potato plant [25]. He explained further potato plants grown from true seed have one main stem; but when propagated from ‘seed’ tubers the potato normally produces a number of stems (categorised either as main stems or secondary/lateral stems); main stems originate from the tuber eye and because the eye may contain several buds, more than one stem may emerge.

According to Getu [14], a significant difference in mean stem number of potato due to the N application was observed. On the other hand, the findings [1, 16] showed that the increase in stem number was as a result of either planting larger tuber size or the use of more tuber number per unit area. Similarly, investigators ([34, 33, 39]) have reported the absence of close relationships between mineral nutrition and the number of stems per plant; the yield difference due to N treatment was not attributed to its effect on stem density as the number of stems was not significantly influenced by N nutrition.

2.5.2. Tuber Size, Shape and Number

Gray and Hughes [16] said that the size and shape of potato tubers are largely the varietal characteristics, and it has been demonstrated that “long” is dominant to “round” shape. In some varieties of potato, shape is influenced by the cultural and environmental conditions. On the other hand, Gray and Hughes [16] reported that high levels of applied N and irrigation but, low level of potassium increases the length of the potato tubers relative to their width. Similarly, Blumenthal *et al*. [4] revealed that N supply to potatoes primarily influences tuber size, dry matter, and sugar contents.

Contradicting results have also been reported by different investigators regarding the effect of mineral nutrition on the number of tubers set per plant. For instance, Sharma and Arora [51] stated that there was no significant difference in the total number of tubers per square meter of land area as a result of N, P and K fertilizer application. However, [34] reported the presence of significant difference in tuber numbers due to N fertilization. Similarly, Lynch and Rowberry [60] stated that N fertilizer is reported to affect yield by its effect on the number of tubers produced per plant, the average weight of tubers, the establishment and leaf area duration. They also noted that yield increment due to N fertilizers was positive up to a certain level beyond which yield reduction was observed.

2.5.3. Average Tuber Weight

Average tuber weight has been reported to be the third most important yield component contributing to the total tuber yield [33, 39]. Environmental factors that favour cell division and cell expansion such as mineral nutrition, optimum water supply, etc were reported to enhance tuber size [44]. Sharma and Arora [51] indicated that the increase in the weight of tubers with the supply of fertilizer could be due to more luxurious growth, more foliage and leaf area and higher supply of photosynthate that helped in producing bigger tubers resulting in higher yields. Nitrogen and potassium application were also reported to extend the canopy life there by prolonging the duration of tuber bulking [18, 42]. Variation in seed tuber size can result in significant variation in tuber yield [25]. He explained more, there is a complicated relationship between seed tuber size and seed tuber weight; furthermore, it can vary between cultivars due to variation in tuber shape, and can vary between years and even between batches grown at different locations in the same year.

The result of a study conducted by Morena *et al*. [39] showed that variations in tuber yield due to N treatments were related to the tuber weight increment. Sharma and Arora [51] from their investigation on the effect of mineral nutrition on size categories of the potato tuber showed that increase in the yield of tubers with applied N and K was associated with increase in the number of tubers in the medium and large grades at the expense of small tubers. This was attributed to the increase in the weight of individual tubers.

2.6. Effects of N on Potato Tuber Quality Traits

Two key quality features affected by N are specific gravity (dry matter content) and reducing sugar (glucose) content. The influence of N levels on tuber quality was also stated by these scholars; accordingly, *deficient N*: very small tubers, high sugar levels, low dry matter, over-mature tubers, disease susceptible; *adequate N*: optimal-sized tubers, low sugar levels, high dry matter, mature tubers, disease resistant; *excess N*: slightly small tubers, high sugar levels, medium dry matter, immature tubers, disease and bruise susceptible. They also discovered, Phosphorus fertilizer application will help to improve quality (e.g. skin maturity and dry matter content) of tubers at harvest when excessive N fertility levels [4].

High, uniform specific gravity in potato tubers is important to the grower and processor [29]. Higher specific gravity contributes to higher recovery rate and better quality of the processed product [54]. Kleinkopf *et al*. [28] reported that the specific gravity of tubers decreased with increasing rates of N fertilizer. Similarly, [58] said that tuber specific gravity decreases if more N is available than needed for growth particularly if available during late tuber bulking. The reason that specific gravity decline with increasing N rate is due to prolonged vegetative growth and delay in maturity [48]. On the other hand, some studies [45, 24] noted that there was no significant difference in specific gravity of tubers due to N treatment.

The application of mineral nutrients has been found to affect the size (size categories) of potato tubers by affecting the plant establishment, number of tubers produced, growth rate of tubers and duration of bulking [19, 28, 51]). Nitrogen and potassium application were been frequently reported to increase the proportion of medium and large sized tubers [43, 51]. Sharma and Arora [51] reported decreased number of small (less than 25 g), and increased number of medium (25-75 g) and large (above 75 g) grade tubers with an increase in the level of N from 0 to 250 kg ha^{-1}.

3. Conclusion

Worldwide, Potato plays a great role such as, among others, utilization as food, in ethanol production, yield pulp for paper industry and may also provide raw material to the chemical industry. It could be one of the most important crops to be introduced in the area where the population experiences recurrent malnutrition. Also it is considered as a high-potential food-security crop for the reason of its ability providing a high yield of high-quality product per unit input with a shorter crop cycle (mostly less than 4 months).

Potato demands high level of soil nutrients due to relative poorly developed and shallow root system in relation to yield. Factors that limit crop yield (both in quantity and quality) can be categorized into four major headings such as soil, genetic, climatic and management practices. Effective management of nutrients is critical for potato production, as tuber yield and quality are directly impacted by quantity and timing of nutrient applications.

Fertilizer requirement varies across locations due to numerous reasons such as difference in soil types, nutrient availability of the soil, economic factors of the area, moisture supply and variety. Nitrogen management for the improvement of N efficiency is a high priority in potato cropping systems; typically, N is the most limiting nutrient in crop production and is higher in concentration than all other mineral nutrients in most plants. In potato production, N is applied more frequently and in greater amounts than any other nutrients. This indicates that N is an essential nutrient for crop growth, and the demand for N in the potato crop is relatively high. Hence, there exists great opportunities to increase potato yield and quality by improving nutrient management.

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