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Review Article

Plant Spacing and Nitrogen Fertilizer Effect on Potato (Solanum Tuberosum) Growth, Yield and Quality: Review

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Abstract: Potato is regarded as ahigh-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. 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. Intra-row spacing had great influence on economically important characteristics such as total yield, processing grade yield, tuber size distribution and tuber quality. As plant density increases, there is a marked decrease in plant size and yield plant^{-1}. This effect is due to increased inter-plant competition for water, light and nutrients. Proper N fertilization is critical for optimizing potato yield and quality. application of N exerted significant influence on all the growth parameters that is showing positive increment. Nitrogen supply plays a paramount part in the balance between vegetative and its reproductive for potato. nitrogen fertilization influences the potato tuber yield and quality. Low nitrogen usually causes low dry matter and sugar levels, while excessive nitrogen promotes vine growth and delays tuber initiation. Nitrogen management is critical for building leaf area to harvest sunlight for photosynthesis to maximize yield. Therefore, effective management of nutrients and proper use of plant spacing is critical for potato production, as tuber yield and quality.

Keywords: Inter-plant competition, Intra row spacing, Nutrient, Photosynthesis, Tuber quality, Tuber yield.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most widely grown tuber crops in the world and contributes immensely to human nutrition and food security (Karim *et al.*, 2010). Potato is one of most important commercial crops worldwide. With a total cropping area of about 20 million hectares globally, the potato is the fourth most important staple crop after rice, wheat, and maize (de Haan and Rodriguez, 2016). Potato is one of mankind's most valuable food crops and mainstay in the diets of people in many parts of the world (Struik and Wiersema, 1999). It is a vital source of nutrients for human populations and is taken almost daily by over a billion people fresh or refined (FAOSTAT, 2017). To feed the ever-increasing human population, potato yield must be increased. However, it should be kept in mind that soil, variety, environmental factors, and agronomic practices including plant spacing and nutrient management influence potato yield and quality.

Among all factors plant spacing and nitrogen fertilizer are the major factors which greatly affects potato yield and quality (Westermann 2005). Lamessa and Zewdu (2016) also indicated that population density and fertilizer application were major factors that affect production and productivity of potato.

Intra-row spacing means inter and intra arrangement of plant distance plays a vital role in the production of tuber crops. Sub-optimal planting geometry, wider rows and plant spacing lead to low population which in turn fail to compensate the yield obtained in optimum plant stand while narrower row and plant spacing increase the inter-and intra-plant competition leading to poor growth and development and dry matter accumulation resulting in poor yield (Pandey *et al.*, 2015). As plant density increases, there is a marked decrease in plant size and yield plant^{-1}. This effect is due to increased inter-plant competition for water, light and nutrients (Masarirambi *et al.*, 2012). Alam *et al.* (2016) reported that intra-row spacing had great influence on economically important characteristics such as total yield, processing grade yield, tuber size distribution and tuber quality. Crop spacing significantly influenced growth, yield contributing characters, tuber size distribution and yield of potato. It is therefore, essential to understand how individual plants interact with each other and the environment and to possibly come up with the ideal crop density levels to optimize yields.

Nitrogen management is the most crucial for potato production and it is the relative measures of leaf chlorophyll content which resulted in more photosynthate for the crop improvement through more dry mater production. The imbalance of N hampered the production of tuber of potato (Hailu *et al.*, 2017). Even under best management practices, approximately 30- 50% of applied nitrogen is lost through different agencies and, hence, the farmer is compelled to apply more than what the crop needs to compensate for losses through leaching, volatilization, and denitrification making the nutrient unavailable during the critical stages of crop growth (Ahmed *et al.*, 2017). Rate and time of application of nitrogen affect the crop growth period and invariably increases yield, tuber plant^{-1}, tuber size as well as tuber numbers. A significant improvement for N fertilizer used efficiency results from split N fertilizer applications according to potato growth needs (Datta *et al.*, 2015). Foliar sprays of urea provide a means of fertilizing the crop late on in the season and can increase tuber yield and qualities also (Ayyub *et al.*, 2006). Nitrogen is required to maintain higher dry matter production, tuber quality, bulking rate, and haulm growth. (Sandhu *et al.*, 2014). The demand for this nutrient increases rapidly after germination and falls when 75 per cent of the plant growth is completed. Any delay in making this nutrient available, particularly during early active phase of growth, results in a set back to the crop. Zewide *et al.*, (2012) found that N increased shoot dry weight to about 37%. This is due to the positive impact of N on photosynthetic rate, leaf expansion, total number of leaves, and dry matter production. However, excessive nitrogen lead to poor tuber quality, delayed crop maturity and excessive nitrate leaching, while nitrogen deficiency usually result in poor growth and low yield (Harris, 1992). Information on the optimum dose of nitrogen to be applied for potato crop under different agro-climatic condition is necessary for a judicious use of fertilizer and also to obtain higher yields. Generally, plant spacing and nitrogen fertilizer are the most limiting factors which greatly affects potato production. Therefore, the objective of this paper is to review the effect of plant spacing and nitrogen fertilizer rate on growth, yield and quality of potato

2. Effect of Plant Spacing and Nitrogen Fertilizer on Potato

2.1. Effect of Plant Spacing on Potato Yield and Quality

2.1.1. Effect of Plant Spacing on Growth of Potato

The tallest plant was observed at narrow spacing and shortest plant recorded when potato planted at wide spacing (Nxumalo *et al.*, 2020). This was probably because smaller intra row spacing increased plant population density which promoted plant competition for sunlight and consequently resulted in tall potato plant stalks compared to the other Irish potato plants with wider in-row spacing distances such as 45 cm and 60 cm (Mvumi *et al.*, 2018). The authors also reported that the competition for sunlight in plants such as potatoes resulted in taller than usual plants as a result of phototropism. In contrary, Zebenay (2015) reported that plants grown t wider spacing had the highest plant height than plants grown at narrow spacing. Bikila *et al.*, (2014) also agreed that the tallest plant height was observed when the inter row spacing and intra row spacing increase from 60x20 to 80x40 respectively. This may be due to better availability of nutrients, water and sun light since plants in wider spacing have less competition and grow more shoot; however, densely populated plants show intensive competition which leads to decrease in plant height. However, wider intra row spacing resulted in reduction in plant height and in closer inter row spacing the highest plant height was observed. This is due to the presence of higher competition for sunlight among plants grown at closer intra row spacing (Tesfaye *et al.*, 2013). Similar results obtain by Ashwani *et al.*, (2013) showed that planting at wider intra row spacing resulted in reduction in plant height. In general, the plant height of the potato crop increases when plants are planted in closer intra row spacing due to competition for sunlight. In other words, when plants are planted in wider intra row spacing the same result may be obtained due to the plant getting enough mineral, water and sunlight.

Nxumalo *et al*., (2020) indicated that the number of leaves was significantly influenced by the effect of intra-row spacing. Mangani *et al*., (2015) also found that there was high number of leaves at low plant density (wider intra row spacing) of Irish potato. The authors justified that the decrease in inter plant related competition for water, nutrient and light which is present at higher planting density. Moreover, Yenagi *et al*., (2004) reported that leaf area plant^{-1} in potato decreased with decreasing spacing in potato Sturz *et al*., (2007) reported that the stem number may be influenced by other factors such as physiological age of the seed tuber, pre-plant storage temperatures or green sprouting and variety. Abrha *et al*., (2013) reported that planting distance determines the number of shoots (hill) per unit area and each stem behaves as separate potato plant since each has its own root and stem system. In contrary, Zerga *et al*., (2017) reported that intra row spacing had no a significant difference on number of branches plant^{-1}, number of stem plant-1 and plant length.

2.1.2. Effect of Plant Spacing on Yield of Potato

Nxumalo *et al*., (2020) reported that intra row spacing had no significant difference for the number of tubers per plant. Lamessa and Zewdu (2016) also found that the average number tubers per plant were not significantly affected by effect of spacing and fertilizer application. According to Yenegi *et al*., (2004), reduction in potato tuber number in densely populated area might be due to increased number of plants per unit area. This increase in number of plants per unit area exerted competition among plants for nutrients and light that caused a reduction in number tubers. Intra-row spacing showed significant difference in tuber weight per plant, the highest tuber weight was produced at the 45 and 60 cm spacing and the lowest recorded at the 15 cm spacing (Nxumalo *et al*., 2020). Tohin (2010) also found that tuber weight in potatoes decreased with decreasing plant spacing. The author also reported that the larger tubers in wider spacing were probably due to less competition among the plants for space, light, water and nutrients which facilitated faster growth and development of tubers thereby increasing tuber size in wider spacing as compared to closer spacing. Number of tubers per plant was not significantly different from each other in all the intra row spacing. Moreover, Lamessa and Zewdu (2016) observed that the average number of tubers per plant was not significant due to the main effect of spacing and fertilizer application on potato. Gulluoglu and Arioglu (2009) reported that the greater the spacing the higher the number of potato tubers formed per plant. Significant differences were recorded due to effect of intra-row spacing on yield of Mondial potato tubers (Nxumalo *et al*., 2020). Lamessa and Zewdu (2016) indicated that population density and fertilizer application were major factors that affect production and productivity of potato but still they found that statistically there were no significant differences due to spacing on yield which is contradicting with the findings of this study. The authors further reported that higher plant density due to narrow spacing compensate for the reductions in plant yield.

2.1.3. Effect of Plant Spacing on Potato Quality

Nxumalo *et al*., (2020) found that there was increased dry matter content with decreasing plant population that means dry matter content increased as the spacing became wider. Getachew *et al*., (2013) also agreed that high plant population is associated with low dry matter content in potatoes. Because at low plant spacing, there was high competition for light and other important resources which eventually led to a few resources being channeled to each sink. Mangani *et al*., (2015) reported that the low dry matter content at the widest plant spacing was due the high photosynthetic rate thus relatively high vegetative growth at the expense of the tubers, thus the dry matter partitioning to the tubers was less. Getachew *et al*., (2013) found high plant population to be associated with low dry matter content. When potato planted at low plant spacing, there was a high competition for light and other important resources. This then led to a few resources being channeled to each sink. Low dry matter content at the widest plant spacing was due to the high photosynthetic rate thus a relatively high vegetative growth at the expense of the tubers. Dry matter partitioning to the tubers was less. Many other studies showed increased dry matter with decreasing plant population (Vander Zaag *et al*., 1990; Tamiru, 2004). Different studies showed that increasing plant spacing resulted in an increase in specific gravity (Vander Zaaag *et al*., 1990; Zebarth *et al*., 2006). Getachew *et al*., (2013) also found that potato planted at wider spacing gave the highest specific gravity than the narrow spacing used as a result of having less intra-plant competition associated with reduced plant population. Fonseka *et al*., (1996) also observed a fall in specific gravity as the plant spacing was increased from 30 to 35 cm. White and Sanderson (1983) also showed that wider spacing (38 and 56 cm) increased specific gravity. In contrary, Rykbost and Maxwell (1993) reported that plant population not to have an effect on the specific gravity of all the varieties they studied.

2.2. Effect of Nitrogen on Growth, Yield and Quality of Potato

2.2.1. Effect of Nitrogen Fertilizer on Growth of Potato

Nitrogen triggers vegetative growth development. As a result, N fertilizer is crucial in canopy growth, especially in terms of shoot dry matter (Najm *et al*., 2012). The higher nitrogen content can be attributed to increased root proliferation due to nitrogen's effect on cellular activities and the translocation of some growth-stimulating compounds to roots, resulting in improved tuber growth and nutrient absorption (Sharma and Sood, 2002). According to Sandhu *et al*., (2014) plant height of potato increased as a result of increasing the application of nitrogen fertilizer rate. Firew *et al*., (2016) also observed the highest plant height with the application of maximum nitrogen rate. Similarly, Alemayehu *et al*., (2015) states that the tallest plant height of potato recorded with the highest nitrogen fertilizer rate. Moreover, Fayera, (2017) said that the utility of nitrogen fertilizer has an impact on plant top additionally discovered that increasing the N-fertilizer application at a rate from 0 to a hundred and fifty kg ha^{-1} will increase by way of 38.58 cm over control treatment. Similarly, Zelalem *et al*., (2009) demonstrated that nitrogen at a rate of 207 kg ha^{-1} will increase plant height with the aid of 24 cm. This is due to the truth that extended awareness of nitrogen fertilizer can increases the nitrogen uptake. This increment has a positive effect on the chlorophyll concentration the photosynthetic rates the leaf expansion the complete quantity of go away and the dry matter accumulation.

2.2.2. Effect of Nitrogen Fertilizer on Potato Yield

Zewide *et al*., (2012) performed experiments on N application at various levels and reported that increasing nitrogen application rates resulted in an increase in tuber yield from 23.75 to 38 tons/ha. At a dosage of 165 kg/ha, the maximum yield was achieved. Increased nitrogen application increased the total tuber number per hill from about 10-12, which might be attributed to the potato plant's increased vegetative growth. This result confirmed other researcher's findings (Reddy and Rao, 1968; Hanley *et al*., 1965; Herlihy and Carroll, 1969). Increasing in tuber number was observed in response to N could be attributed to an increase in stolon number through its effect on gibberellins biosynthesis in the potato plant (Alemayehu *et al*., 2015). Nitrogen is one of the main element which has direct part in vital roles in chlorophyll synthesis and growth processes especially the vegetative growth parameters of plants. In agreement with the present finding, a significant increment in tuber number in response to nitrogen application was reported by Jafari-Jood *et al*., (2013). With an increase in added nitrogen, the number of marketable tubers increased, but the number of small tubers decreased. This finding was consistent with Hanley *et al*., (1965), who reported from their 3-years study that N application increased the number of tubers per hill. Several experiments have shown that nitrogen application significantly impacts potato tuber yield and yield attributing characters (Fayera, 2017). The author added that increasing rate of nitrogen amplify average tuber weight plant^{-1}, marketable tuber weight, unmarketable tuber weight, whole tuber yield plot^{-1}, yield, tuber number plant^{-1} and small tuber size. Moreover, Zamil *et al*., (2010) and Guler (2009) also reported that the maximum tuber yield was obtained when nitrogen dosage of 300 and 254 kg per hectare was applied respectively. When enough irrigation water was applied, a higher rate of N nutrition was needed to increase yields (Thompson *et al*., 2000; Rajasekaran, 2007). Haymanot *et al*., (2017) pointed out the findings of an experiment that the total N uptake and concentration in above ground part were raised by two and three folds, respectively with application of 230 kg N ha-1 that had increased N concentration in tuber by 57.17% and soils after harvest by 20.87% as compared to the control. Generally, the highest values of total dry matter, above ground biomass, total plant dry matter and medium size tubers were found at the 184 kg N ha^{-1} rate. Kumar *et al*., (2017) carried out an investigation to evaluate the nitrogen management in potato and to identify a carefully controlled nitrogen application rate and better synchronization between applied nitrogen and potato nitrogen uptake. The findings of investigation revealed that the performance of potato crop was significantly influenced by different split nitrogen doses. As a result, the maximum yield was recorded with highest fertilization of nitrogen.

Xing *et al*., (2016) reported that application of N-fertilizer significantly increased tuber yield (by 76% maximum) and quality over the unfertilized treatments whereas differences between the two N fertilizer application rates were non-significant. Increasing nitrogen level up to110 kg N ha-1 lead to more tuber yield, highest stem number, plant length, total dry biomass, total tuber number, large-sized tuber yield (59.01%) and marketable tuber yield (Alemayehu *et al*., 2015). Similarly, Zelalem *et al*., (2009) and Guler (2009) have reported highly significant increases in total tuber yield in response to increased level of nitrogen application. The increase in average tuber weight of potato with the supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthesis, which helped in producing bigger tubers, hence resulting in higher yields (Belachew, 2016).

2.2.3. Effect of Nitrogen Fertilizer on Quality of Potato

Nitrogen is the building block of amino acids, affecting nutritional quality, sugar content, and dry matter directly (Blumenthal *et al*., 2008). Additionally, nitrogen fertilization influences the potato tuber size profile and impacts potato quality and processing ability (Smith and Talburt, 1987). Low nitrogen usually causes low dry matter and sugar levels (Iritani and Weller, 1980), while excessive nitrogen promotes vine growth and delays tuber initiation (Ayyildiz, 2021). Higher specific gravity contributes to higher recovery rate and better quality of the processed product (Tony, 2010). Kleinkopf *et al*., (1981) reported that the specific gravity of tubers decreased with increasing rates of nitrogen fertilizer. Similarly, Westermann *et al*., (1994) 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 (Sanderson *et al*., 1987). On the other hand, some studies (Roberts and Cheng, 1988; Joern and Vitosh, 1995) noted that there was no significant difference in specific gravity of tubers due to N treatment. Increases in nitrogen levels from 50 to 150 kg ha-1 resulted in a substantial rise in starch content. The highest starch content (64.6%) was reported when 150 kg N ha^{-1} was applied, and it was found to be superior to the other nitrogen levels. The rate of photosynthesis, the translocation of photosynthates from leaves to tubers, and eventual conversion to starch both influence the amount of starch accumulated (Kumar *et al*., 2008). Moreover, El-Hadidi *et al*., (2017) reported that there was a positive and significant difference among the different levels of nitrogen in respect to starch, specific gravity, and dry matter content. Specific gravity, starch and dry matter contents increased with N application rates. Specific gravity increased with increasing levels of nitrogen up to higher level. Specific gravity is one of the most widely used factors for estimating internal quality; there is a high correlation between tuber starch content, mealiness, total solids, and specific gravity, and processors use this measurement to determine suitability for processing (Laboski and Kelling, 2007). Increased N applications may cause reductions in specific gravity (Porter and Sisson, 1993; Zebarth *et al*., 2004).

3. CONCLUSION

Potato is one of the most widely grown tuber crops in the world and contributes immensely to human nutrition and food security in many countries, but productivity and yield are par below the demand of consumption. Major constraints in potato cultivation are inappropriate plant spacing and nutrient management. Population density and fertilizer application were major factors that affect production and productivity of potato. Potato plants grown at narrow spacing resulted in the tallest plants and the shortest plants were obtained at widest spacing. This was probably because smaller intra row spacing distance increased plant population density which promoted plant competition for sunlight and consequently resulted in tall potato plant stalks compared to the other Irish potato plants with wider in-row spacing distance. Application of nitrogen fertilizer usually boost potato yield, considering their application dose because higher or lower application rate may exert a negative impact on different growth parameters of potato and hence on overall potato tuber yield. It has been observed that although most of the farmers in the world recognize the application of chemical fertilizers in potato cultivation, they do not use them at their recommended doses due to limited credit supply, high fertilizer cost, lack of knowledge about the use of organic fertilizer etc. Therefore, using recommended plant spacing and nitrogen fertilizer rate at their specific areas are essential to improve potato yield and quality so as to ensure long-term food security.

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