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Review article

INFLUENCE OF DIFFERENT LEVELS OF NUTRIENTS, IRRIGATION REGIME AND AGRONOMIC PRACTICES ON POTATO (*SOLANUM TUBEROSUM*) CULTIVATION – AN OVERVIEW

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ABSTRACT

Potato (*Solanum tuberosum* L.) belongs to Solanaceae family and it is a major economically important non-grain food crop, prevailing all across the world. Basic nutrients such as carbohydrates, dietary fibre, vitamins and minerals are available in potato tuber. Soil physico-chemical properties including soil moisture and nutrient status, soil biological properties and various soil management and agronomic practices including irrigation and nutrient management play a significant role to exert effects on the yield attributing characters, marketable and total tuber yield and tuber quality as well. This article reviews the latest research on irrigation and nutrient management practices to enhance tuber yield and quality, adopted so far.
Keywords: Potato, Growth indices, Irrigation requirement, Nitrogen (N); Phosphorus (P), Potassium (K), Agronomic practices.

Introduction

Potato (*Solanum tuberosum* L.), belonging to Solanaceae family, is considered as a major economically important non-grain food crop of the world's population (Rykaczewska, 2013) and ranks fourth after wheat, rice, and corn in terms of human consumption. It is rich in carbohydrates, amino acids, vitamins, and minerals (Sriom *et al*., 2017). Many factors, including cultivar, weather conditions, planting date, plant nutrition irrigation etc. influence potato production either positively or negatively, Supplying of essential nutrient elements to potato crop is considered important for its growth and development and ultimately to obtain a good yield (Westennann, 2005; Kahsay, 2019). However, judicious use of nutrient supplements through external sources are necessary to maintain potato yield qualitatively and quantitatively without any soil degradation. In this review, an attempt has been made to highlight effects of various parameters including nutrient application (N, P and K), irrigation requirement, their interaction effects and various agronomic techniques on yield and yield attributing characters of potato.

Irrigation

Irrigation is indispensable to a growing crop to avoid physiological water stress, so that depleted soil moisture becomes replenished at a given growing period. Leaf area development and eventually the photosynthetic activity of the crop and dry matter production and allocation suffered significantly under drought and high temperature (Geremew *et al*., 2007). However, it is also important to consider the fact that watering should be done at the proper time and at a proper amount to maximize crop yield. Potato plants also respond to water in the same manner. Soil moisture regulation in potato field is playing a vital and a significant role in tuber production because potato needs good soil aeration also and it has been found that temporary soil dryness may cause quantitative and qualitative yield reduction. Although its various growth stages such as stages of stolon formation, tuber formation and tuber development are considered as critical to moisture stress (Begum *et al*. 2018), early growth stages of stolonization and tuberization are found as most sensitive stages to moisture stress in respect of tuber numbers and total tuber yields. It was observed that inadequate water supply at these two stages caused tuber yield decrease significantly as compared to bulking and tuber enlargement stages (Hassan *et al*., 2002). Furrow irrigation is very common for potato cultivation. However, sprinkler irrigation has been popularized in hills, in the areas showing undulating topography, in the areas possessing scanty water supply and/or in the areas where furrow irrigation is not possible to use. With trickle and sprinkler irrigation system water utilization is economically regulated and it is possible to save water up to 30 - 50% as compared to surface irrigation (Jamal *et al*., 2001). Recently, drip irrigation system, that offers an opportunity to supply water at different depths of the soil layer, has been popularized in potato cultivation because of more applicability to increase WUE. As potato is very much sensitive to water stress, it has been observed potato tuber yield responds linearly to the amount of water applied (Badr *et al*., 2012). However, excess and deficit water had adverse effects on potato yield (lynch and Tai, 1979; Beukema and van der Zaag, 1990; Abubaker *et al*., 2014). The highest yield (19.9 tons/ha) was obtained from 600 mm irrigation (Abubaker *et al*., 2014). Applying irrigation at below or above of 600 mm caused a decline in marketable potato yield, leading to an increased pest infestation and increased numbers of under-sized potato tubers. However, it is essential to obtain a thorough knowledge on the relationship of irrigation and fertilization and their combined effect to exert influence over crop growth and seasonal crop evapotranspiration (ETc), so that irrigation management is improved to obtain maximum water productivity (WP). WP refers the ratio between crop yield and crop water consumption (Pereira *et al*., 2012). It has been observed that the deficit irrigation strategy led to a decreased tuber yield due to a reduced tuber number and its weight (El-Mokh *et al*., 2015). They also suggested that in arid areas, it could be possible to increase the tuber yield by increasing applied nitrogen level (300 kg/ha) under full [water replacements of cumulated crop evapotranspiration (ETc) at levels of 100%] and deficit irrigation [water replacements of ETc at levels of 60%) strategies. However, increased nitrogen level beyond 200 kg/ha might exhibit adverse effect on the yield under severe deficit regime (water replacements of ETc at levels of 30%). Interestingly, although higher water productivity (WP) was observed with 300 kg/ha level of nitrogen under irrigation at 100% and 60% level, but 30% irrigation regime with 200 kg/ha N level also exhibited highest WP. Thus, it is evident that interaction between water and nitrogen should be a major concern to manipulate potato yield. In a separate experiment, Ierna and Mauromicale (2018) reported improved above ground biomass and tuber yield under integrated management practices with irrigation based on 100% of Etc + high rate of N-P-K (300-100-450 kg/ha) fertilization, but not WP. Fertilization was found to increase WP, specially during irrigating fields at plant emergence, where both low (N-P-K, 50-25-75 kg/ha) and medium (N-P-K, 100-50-150 kg/ha) fertilization led to maximization of WP along with an acceptable tuber yield (3.7 t/ha dry weight). For early potato crops, proper irrigation and fertilization at vegetative growth and tuber bulking stages are usually common practices to maximize yield both quantitatively and qualitatively due to the fact of sensitiveness to water stresses (Ierna and Mauromicale, 2012). Earliness of the tuber yield is also influenced by the adequate supply of water from tuber initiation to near maturity stage (Ierna and Mauromicale, 2018) and by proper fertilization at proper growth stages, otherwise a considerable amount of nutrients are lost by leaching (Foti *et al*., 1995). It has been observed that fertilization may lead to more evapotranspiration and eventually, cause a decreased WP. This necessitates the need of a comprehensive approach so that irrigation water and fertilizers can be efficient utilized to enhance tuber yield because proper combination of irrigation and fertilization practices might promote the photosynthetic production efficiency of leaves that would enhance the dry matter accumulation and in turn, crop growth rate (Camargo *et al*., 2015; Ierna and Mauromicale, 2018). Farrag *et al*. (2016) reported that total and marketable tuber yield were improved with an increasing irrigation requirement (50, 75 and 100% of IR) with drip irrigation practice. They studied the effect of combination of different irrigation levels and soil mulching with black polyethylene (PE-B), transparent polyethylene (PE-T) and rice straw (RS) and found a maximum positive interaction effect on the tuber yield and yield attributing characters when black polyethylene (PE-B) mulch combined with 100% IR was used. However, the use of 75% IR along with PE-B mulch showed maximum water use efficiency (WUE). All in all, PE-B mulch followed by RS exhibited highest WUE and both of them were superior to the PE-T and bare soil. Mulching provides positive effects on the yield parameter because it acts as a physical barrier to restrict soil water loss by evaporation, to control weed growth and to maintain soil temperature and soil fertility and to prevent soil erosion (Azad *et al*., 2015; Sun *et al*., 2015b). Different types and colors of polyethylene mulch regulates the soil temperature in a varied manner as they can change the levels of light radiation reaching the soil due to their exhibition of optical properties (Kasirajan and Ngouajio, 2012). Soil mulching reduced IR and evapotranspiration and thus, increased WUE by 4.5 times (Kumari, 2012). Sun et el. (2015a) suggested to use PRD (partial root-zone drying) irrigation as a promising practice for enhancement of water use efficiency and P uptake and use efficiency for potato production where water scarcity may prevail. Kumar *et al*. (2007b) reported highest tuber yield and its quality as well under the irrigation regime of 1.20 Ep (open pan evaporation). However, they found highest WUE at 0.80 Ep. Water availability to crop regulates the tuber size also. Inadequate irrigation water supply (<1.20 Ep) led to a decrease in preferable grade of tuber size (> 28 mm). Specific gravity and starch percentage in tuber increased with increase in irrigation. They suggested potato cultivation with irrigation at 1.20 Ep for higher yield and better quality and irrigation regime at 0.80 Ep as most appropriate for scheduling irrigation.

Nitrogen (N)

N, accounting for nearly 1–4 per cent of the plant's dry matter, is the major guiding force behind plant production. Plants take up N from the soil in the form of nitrate (NO_3^-) or ammonium (NH_4^+). Being the basic constituent of proteins, it participates in all major plant growth and yield forming processes. Several experiments confirmed that adequate supply of nitrogen enhances root growth, uptake of other nutrients and overall development of the crop plants (Brady and Weil, 2008; Bell, 2016). N application exhibits a positive impact on the chlorophyll concentration that increases the photosynthetic rates and eventually dry matter accumulation, leaf area index (LAI), plant height and other yield attributing characters (Abou-Hussein *et al*., 2003); Najm *et al*. (2010). Various studies have shown that yield and yield attributing characters of potato tuber are greatly influenced by N-application (Fayera, 2017). Overall tuber yields were observed to be improved by applying nitrogen at a rate of 110 kg/ha; however, beyond of which there was no statistically significant improvement in tuber yields (Alemayehu *et al*., 2015). Highest marketable tuber yield, in a separate experiment, was obtained with nitrogen application doses of 110 kg/ha and 165 kg/ha with a statistically nonsignificant effects within themselves (Birtukan, 2016). However, reports also showed that potato yield remained unaffected when N was applied @90, 110, 130 kg/ ha in pot experiment while irrigation regimes and variety significantly influenced yield and yield components of potato plants (Tolessa *et al*., 2016). Usually N is applied in organic and inorganic forms. Najm *et al*., (2010) reported that nitrogenous fertilizer (150 kg/ha), cattle manure (20t/ha) and their interaction exerted a highly significant effect on tuber yield (max. 36.8 t/ha). T It has been observed that shoot weight, LAI, plant height and in turn total tuber yield are increased by mineral N fertilization up to a certain limit (Vos, 1997; Zvomuya *et al*., 2002; Kumar *et al*., 2007a; Zelalem *et al*., 2009), while excessive vegetative growth may occur due to excessive N application which might result in delaying maturity and in turn, reduction in the tuber yield and also deterioration of the tuber quality (Kumar *et al*., 2007a; Najm *et al*., 2010). Apart from this, overdose of inorganic N fertilizers leads to pollution such as eutrophication, soil structure deterioration, land degradation etc.

Phosphorus (P)

Phosphorus (P) is a critical component of productive potato development, as many soils lack adequate P to maximize crop growth. P nutrition stimulates various plant physiological activities such as photosynthesis, root growth particularly the development of roots and rootlets, N-fixing capacity of legumes, plant disease resistance, flower formation, seed production, uniform and earlier crop maturity (Brady and Weil, 2008). P affects plant metabolism through its function in the energy transfer, respiration, and photosynthesis of cellular resources. It serves as one of the important components in the structural part of nucleic acids, coenzymes, phosphoproteins, phospholipids, phytin etc. (Kahsay, 2019). Hence, plant needs a sufficient supply of P from the earliest stages of growth to maturity. There are several reports showing boosting of tuber yield by P application (Desalegn *et al*., 2016; Firew *et al*., 2016; Girma *et al*., 2017). Maximum tuber yield was recorded P application at a rate of 135 kg/ha exerted maximum tuber yield output that was found to be 98% more as compared to control treatment (Birtukan, 2016). Potato plants exhibit a strong P requirement for optimal growth and production (Balemi, 2009); hence significant yield losses are evident when grown on deficient P soils. Reduction in the development or growth rate of plant biomass under P-deficient conditions can be due either to a small amount of photosynthetically active radiation (PAR) consumed (Colomb *et al*., 2000) or to a less effective transfer of intercepted radiation (Plenet *et al*., 2000). It is established that light interception by crop influences biomass accumulation with varying supplies of P (Rodriguez *et al*., 1998; Plenet *et al*., 2000). At low P level, total leaf area is reduced due to reduced leaf number as well as reduced leaf size, that exerts adverse impact on the light interception and, thus, plant development. It has been established that P-efficient genotypes, which possess more leaf area, also play a major role to cause high biomass accumulation and more dry matter yield to the leaf due to more light harvesting, influencing the total tuber yield significantly. Balemi (2009) reported CGN 17903 as the most efficient genotype as compared to other genotype such as CIP CGN 18233 due to the same reason.

Potassium

Potassium (K) is known for its active participation in various plant metabolic processes such as photosynthesis, enzymatic processes, synthesis of protein, carbohydrates and fats, transportation of photosynthates and in so many cellular processes. It promotes rigidness and erectness in the plants and also increases plant's resistance to pest and disease attack (Thompson, 2010). K is a major osmotically active cation of plant cell (Marschner, 1995; Mehdi *et al*., 2007), used for maintaining osmotic potential that regulates ionic balances, plant stomata, root permeability and water uptake (Mehdi *et al*., 2007; Bhattarai and Swarnima, 2016). Thus, K application in potato cropped soil may promote water stress tolerance to the crop and eventually may increase tuber yield in dry conditions (Abdrabbo *et al*., 2019). It has been found that K reduces senescence and physiological disorders and promotes increasing tuber shelf life (Bhattarai and Swarnima, 2016). Well-drained, light and loose soil with high organic matter content is always preferred by potato crops. For this reason, K is lost easily from such soil. High leaching loss and its low replenishment lead to K deficiency in intensively potato cultivated areas. Thus, utmost care is needed during K fertilization for maximization of quality and tuber yield. It has been evidenced that tuber yield is reduced with decreasing K reserves in soil (Gunadi, 2009) and insufficient K resulted in smaller-sized tubers (Westennann, 2005). K showed no impact on the total number of tubers (Trehan *et al*., 2001), although K application has been observed to improve the tuber size as K enhances carbohydrate content (Al-Moshileh and Errebi, 2004). Potato plant is recognized as an indicator crop for K availability due to its more K requirement (Al-Moshileh, and Errebi, 2004). But K is not given so much importance as it is paid to N and P in most of potato cultivated areas, which invites tuber yield reduction both from quantitative and qualitative aspects (Pervez *et al*., 2017). An increase in K application rate from 140 to 280 kg K_2O/ha was found to boost total tuber yield (Abdrabbo *et al*., 2019). However, they found a minimization of vegetative growth and productivity under a very high dose (420 kg K_2O/ha) of K application. This positive and negative effect of K on tuber yield might be due to the more or lower N and P uptake by the plants, that led to influence the vegetative growth and thus crop yield, respectively. Application of K up to 280 Kg K_2O/ha resulted in more K uptake by the plants, while more application rate of K up to 420 kg K_2O/ha reduced N and K uptake, generating a negative impact on the vegetative growth and tuber yield (Abdrabbo *et al* 2010). It was revealed that transformation of starch to sugar in the tuber occurred at lower application rate of K, while at higher dose it activates starch synthesis (Marschner, 1995). Vitamin C content was found to be increased with increasing potassium fertilizer dose. However, application of K at higher dose caused a decrease in vitamin C content in the tuber (Bhattarai and Swarnima, 2016).

Nutrient interactions

Nutrient use efficiency (NUE) is greatly influenced by the plant nutrients interactions that may lead to antagonistic or synergistic effect (Rietra *et al*., 2017). Thus, in order to obtaining sufficient NUE and adequate crop yield, proper fertilizer designing and optimization of fertilization are required. However, this is dependent on the nutrient interactions. Therefore, a vivid knowledge on nutrient interactions is needed. Interactions obtained from the application of nitrogen and phosphorus fertilizers exhibited promising impact on yield attributing characters and marketable tuber yield of potato (Zelalem *et al*.; 2009; Zewide *et al*., 2012). Interactions between mineral elements in the soil and also in the plant might influence the nutrient concentration in tubers. However, this not attributed to yield-dilution phenomenon. From experiments it has been established that an increase in yield, obtained by various fertilizer application does not exhibit a large change in nutrient concentrations in potato (White *et al*. 2009).

Agronomic practices

Potato plants, possessing sparse and shallow root system, are considered very sensitive to moisture stress because tuber yield was found to be influenced both quantitatively and qualitatively under moisture stress, especially during initiation and growth phases of tubers (Bao-Zhong *et al*., 2003; Al-Aubiady, 2005)). Out of many methods to maintain the proper moisture regime in soil for potato cultivation, drip irrigation was found as one of the best methods to obtain reasonable positive effect on yield attributing characters and tuber yield (Wang *et al*., 2006; Neelam and Raiput, 2007; Al-Janaby, 2012) because of the adequate availability of water in the rhizosphere and reduced evaporation, leading to more nutrient availability to the plants and stimulating the microbial dynamics in the soil for improved nutrient transformation from their plant unavailable to available forms. It was found that the quantity of irrigation water for potato cultivation could be decreased considerably by using drip irrigation in place of furrow irrigation by putting the irrigation pipes at the top and with this method soil fertility and productivity was increased by minimization of the leaching loss of the nutrient elements and production costs (Kahlel, 2015). In a separate experiment, potato cultivation under drip irrigated beds with mulching at IW/PAN-E ratio of 0.5 was found to be good practice for efficient water saving and higher productivity (Kahlon and Khera, 2015).

Several practices were reported to counteract the adverse effects of elevated soil temperatures on potato growth by increasing leaf area coverage. Intercropping is one of such practices, adopted for its multiple benefits to accrue stabilized potato production in tropical lowlands where high temperature is a limiting factor (Nyawade *et al*. 2018; Gitari *et al*. 2019), Intercropping of potato with legumes, lima bean (*Phaseolus lunatas* L.) and dolichos (*Lablab purpureous* L.), was found to increase 26–57% LAI and to reduce the soil (0–30 cm) temperatures by up to 7.3 °C as compared to sole potato stands (Nyawade *et al*., 2019). Such intercropping practice increased soil water contents (SWC), radiation use efficiency (RUE) and crop water productivity (CWP) by up to 38%, 56–78% and 45–67%, respectively and resulted in subsequent conversion into crop biomass.

Conclusion

The weather conditions, optimum moisture availability, various soil physico-chemical and biological properties and various soil management and agronomic practices influence the yield attributing characters and marketable and total tuber yield of potato significantly. Optimum irrigation treatment along with supplementation of N, P and K in optimum quantity and their interaction effect provide a steady boost to tuber yield. It is observed that a regular and adequate water supply is required at different growth stages to accrue higher potato tuber yield with a good quality. Fertilizer use efficiency may be adversely affected under conventional methods of irrigation due to leaching loss of nutrients. For this reason, a holistic and comprehensive approach is needed to apply fertilizers and water at an appropriate time and in a proper time in association with other suitable agronomic practices, so that maximum water and nutrient use efficiency are achieved in order to fetch maximum potato tuber yield.

It is established that timing and frequency of irrigation applied is critical to the NUE and WUE and in turn, to the yield attributing characters, tuber yield, tuber quality and disease resistance of the plants. Thus, it is imperative to pay special attention to its irrigation management system including irrigation scheduling under the backdrop of the fact that farmers are not well aware of these technicalities. Farmers should be provided all possible technical know how on proper irrigation and nutrient management system to obtain higher tuber production with better quality.

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