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Review

A REVIEW ON THE EFFECTS OF IRRIGATION AND NITROGEN FERTILIZATION REGIMES ON POTATO YIELD

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ABSTRACT

Water and nitrogen are the most important factors affecting yield and quality in potato management. Proper irrigation and nitrogen fertilizer management ensures water conservation and reduces nutrient loss. Nitrogen (N) is the most commonly deficient mineral nutrient in agricultural soils to increase potato production. Therefore, the split application of nitrogen fertilizers is important to prevent losses through leaching, evaporation, denitrification, weeding, erosion by running water, and precipitation. Determining the appropriate amounts of nitrogen and irrigation water to improve the efficiency of water and nitrogen use can minimize N losses, minimize costs and increase production profits. Potato is very sensitive to water stress due to its shallow root system and requirement to consume a plenty of water in all growing season. Therefore, regular irrigation of potato is important for obtaining the best tuber yield. This review has been made to identify and analyze in current research on N management practices and irrigation regimes to improve and maintain potato tuber yield. Variability of results from research studies show that determined precise results are not transferred from one place to another because potato varieties and cultivation conditions are not the same. In addition, it was determined that the responses of potato varieties to different nitrogen amounts varied from region to region. According to different irrigation regimes, it has been seen that the best result increasing yield in potato is obtained from applications when the plant is irrigated the most and field capacity is fully saturated. In addition, although the most appropriate nitrogen and irrigation interaction differ from region to region and depending on the variety, it has been determined that the most irrigation is applied and the nitrogen is obtained from application roughly 200 kg/ha.

Keywords: Nitrogen rate, Irrigation regimes, Tuber yield, Solanum tuberosum

1. INTRODUCTION

Potato (Solanum tuberosum L.) is one of the most important plants serving as a food source. It is a good strategy to prevent food insecurity, particularly in disaster conditions [1]. Potato (Solanum tuberosum L.) is the fourth most important food crop and is believed to contribute significantly to maintaining future global food security. The crop has high water needs and is particularly susceptible to drought stress during the tuber growth stage. The low drought tolerance is mainly attributed to the shallow and sparse root system and irrigation is demanded to reach acceptable tuber yield and quality [2, 3]. There are critical growth periods when irrigation is necessary for optimum yield and quality in potato. Nitrogen (N) is the most effective nutrient for growth, development, productivity and tuber quality. Although there is often conflicting information in the sources regarding irrigation and N management of this crop, it is generally confirmed that production and quality are greatly affected by N dose and irrigation amount and that these requirements are related to crop technique [4]. In modern production, the aim is to maximize crop production and optimization of both N and water use to minimize the risk of N leakage into groundwater. Water deficit can result in smaller tuber size and lower yields. Potato yield is greatly affected by the timing and process of water stress at different growth periods. Potato crops are influenced by lack of humidity at all periods of growth, but during tuber initiation and bulking this has a serious impact on yield [5]. Potatoes are susceptible to water deficiency and low water stress leads to decrease in leaf number and size, photosynthesis, which affects tuber number/plant, size and yield. Nitrogen is an important element influencing crop yield and also considerably affects crop yield in water deficient conditions. Hence, researching the source-sink interrelation and its impact on yield under different water and nitrogen conditions aid to maximize crop yield and optimize water and nitrogen use efficiency [6]. Nitrogen deficiency in potato is indicated by a decrease in growth and tuber yield in point of tuber number and size [7]. Soil water is known to affect nutrient transport to the root surface in water flow generated by transpiration and high water uptake by plant roots significantly increases root N uptake by mass flow [8]. Additionally, the water and nitrogen combined effect on the potato yield was also examined in some studies, but these studies have explored to achieve the highest efficiency levels [4, 5, 9].

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2. EFFECT OF NITROGEN FERTILIZATION ON POTATO

Although potatoes are widely grown and adapted to very different climatic conditions, it has need for a stable fertilization, without which the yield and quality of tubers is clearly affected. Potato is intensely fertilized because they have a high nutritional demands. Fertilizer practice relate to soil type, soil fertility, irrigation facilities. Likewise, nutrient uptake by the potato crops depends on the climatic condition, soil type and fertility status and crop management practice [10]. N is one of the most vital macronutrients for growth and biomass development. Plants can benefit N in several forms. Their significant sources are ammonium ($NH4^+$) and nitrate ($NO3^-$) [11]. N shows an important role in plant growth as it is a component of chlorophyll, amino acids, proteins, nucleic acids, coenzymes and membrane components [12]. Therefore, N supply means bigger tubers for plant. Evaporation, leaching, denitrification, erosion and sedimentation can be prevented by applying nitrogen in a split form. Thus, nitrogen efficiency is increased.

By applying the right source of N fertilizer at the right rate, time and place, N can be managed effectively. The period when the potato plant needs nitrogen the most is the tuber bulking period. About 58-70% of the total N is taken at this stage of development [7]. Nitrogen fertilizers are the most commonly used mineral fertilizers on potato farming lands. Nitrogen fertilizers have positive effects on both growth and plant development when they are in the most appropriate form and amount. However, when nitrogen fertilizer is applied excessively, resistance to diseases and pests decreases, and storage resistance also decreases. In case of insufficient application of nitrogen during tuber formation period, it causes drying of tuber and old leaves and tuber development decreases significantly. Nitrogen fertilization is necessary due to the limited root system of the potato and the low nitrogen utilization efficiency. However, irrigation management should be done appropriate together with nitrogen. Otherwise, nitrogen can be leached away, especially with over-irrigated surface irrigation methods [13]. Potato plant generally requirements more nitrogen fertilizer than other plants to reach high yields. The save of nitrogen fertilizer applied in the developing plant is less than 50% on average [14].

The management of nitrogen fertilization is extremely important both economically and environmentally. Nitrogen deficiency decreases plant growth and also reduces tuber size and yield [15]. However, excess nitrogen can lead to reduced tuber quality, delayed maturation and nitrate leaching. [16]. In addition, the effectiveness of nitrogen fertilization and optimum nitrogen utilization can alter among farming and over the years [15]. This diversity is based on variation in both crop nitrogen demand and soil nitrogen content. As a result, the development of tools to more accurately predict individual field nitrogen needs in potato production will improve tuber yield and quality. In this way, it can be used as a strategy to minimize nitrogen loss and damage to the environment. Plant nutrition is a biological process essential for plant health and efficiency. Fertilizers are the primary method of nutrient management. However, taking into consideration that soil is the main source of nutrients for plants, fertilizers are method to make up for certain deficiencies in the soil. In this case, it is necessary to obtain information about the lack of elements in the soil [17]. Nitrogen, one of these fertilizers, has a direct effect on potato growth and yield [18].

Potato, like other cultivated plants, need adequate and balanced nutrients for good growth and yield. Compared to other plants, the potato is most demanding on nitrogen and potassium. In terms of nutrient consumption, approximately one ton of potatoes tuber removes 4 kg of nitrogen from the soil [19]. Deficient nitrogen content incurs a negative effect on vegetative growth and tuber formation. As a result, a vital decrease in tuber yield occurs. For this reason, nitrogen should be given as much as the plant needs for optimum efficiency. Therefore, the important point is that the nitrogen requirement of the plant changes according to the growth periods. For example, in potato, it changes with the varieties, the period when the plant needs the most macronutrients is the tuber bulking stage, and this period alter between 42 and 70 days after planting [20]. On the other hand, soil, climate and biotic factors are also important factors affecting the nutrient requirement. Nitrogen optimization is very important to increase yield and reduce nutrient loss in potatoes. Ensuring this depends on the correct selection of the nitrogen source, dose and application time, as well as the variety, soil moisture level and soil structure [21, 22, 23, 24].

2.1. Effect of Different Nitrogen Sources On Tuber Yield

In plant production, nitrogen is taken by the plant in the form of nitrate ($NO3$) and ammonium ($NH4$). Different studies have been conducted to determine whether different nitrogen sources have an effect on tuber yield in potato production. Muthoni and Kabira (2011) conducted a two-year study on different nitrogen sources. Nine different nitrogen forms (DAP, DAP+ Farmyard manure, NPK, NPK+ Farmyard manure, Farmyard manure, Farmyard manure + CAN, TSP+CAN, NPK+TSP, DAP) and two different potato varieties (Tigoni and Asante) were used. As a result, they reported that different nitrogen sources have a significant effect on yield and the highest yield was obtained from DAP+ Farmyard Manure application in the first year and NPK application in the second year [25]. Likewise, Gathungu et al. (2000) reported that different nitrogen sources significantly affect tuber yield and that the highest yield was obtained from CAN (Calcium ammonium nitrate) and ASN (Ammonium sulphate nitrate) applications [26]. On the other hand, contrary to these studies, Cambouris et al. (2016) found that the amount of nitrogen application significantly affects the yield. However, they found that the nitrogen source did not affect it [23]. Zebart et al., (2012), similarly, showed that nitrogen source did not affect tuber yield in their study [27].

2.2. Effect of Nitrogen Application Time On Tuber Yield

Even if the main purpose in production is to maximize yield, many factors such as application time, input cost and availability of resources come into play in fertilization. There are many factors that can affect the rate at which photosynthesis products are created and consumed at different growth stages. Nitrogen, in particular, is one of the most important nutrients affecting the production and distribution of assimilates. The application time of nitrogen fertilizer can significantly affect the yield and quality of potato tubers [28, 29]. Since nitrogen is a fertilizer that is constantly needed for plant growth and development, it is not appropriate to give nitrogen at once. For this, field trials for specific conditions and potato varieties can solve the best nitrogen management [30, 31]. Sun et al., (2012) examined the effect of four different application times on yield in potato in their study. At the end of the study, the highest tuber yield was obtained from T1 (150 kg/ha at planting) and T3 (150 kg/ha at planting + 50 kg/ha one week before tuber growth period) [32]. Öztürk et al., (2007), on the other hand, determined that the application time significantly affects the large (more than 5.0 cm in diameter), small (less than 3.5 cm in diameter) and total tuber yield, except for the middle tuber (diameter 3.5-5.0 cm) [33].

2.3. Effect of Different Nitrogen Rates On Tuber Yield

Nitrogen fertilization is the most costly and significantly affecting tuber yield in potato production [34]. Thus, due to the environmental impact and high fertilizer prices, it is necessary to keep nitrogen application in certain varieties between limited values [35, 36, 37]. In some countries, the recommended amount of nitrogen fertilization for potato production varies between 70 and 330 kg/ha. However, it has been reported that the optimum nitrogen rate is between 147 and 207 kg/ha, depending on the variety and nitrogen cost [35]. In the study by Akpınar et al., (2019), in which different nitrogen doses were applied, it was shown that the 20 kg/da nitrogen dose was the most economically and application higher than 20 kg/da did not have any effect on the yield [24]. Ahmed et al., (2017), on the other hand, reported that the highest tuber yield was obtained from nitrogen doses given in four different periods (5 days, 20 days, 35 days and 50 days after planting) [38]. In addition, according to the results of their research, Ghiyal and Bhatia (2018) determined that the highest total tuber yield was 120 kg/ha nitrogen dose [39]. However, Workineh et al., (2017) suggested that 69 kg/ha nitrogen fertilization rate provides the most economical and best tuber yield and that this dose should be used for production in ecologies under the same conditions [40]. When other studies are examined, it is seen that the most appropriate nitrogen dose for potatoes is between about 200 kg/ha (Figure 1). However, these studies were carried out at the regional. Therefore, it should be noted that the amount of nitrogen fertilization in potato production varies from region to region. In addition, the most appropriate dose should be determined by the researchers and recommendations should be given to the farmers in the region according to dose.

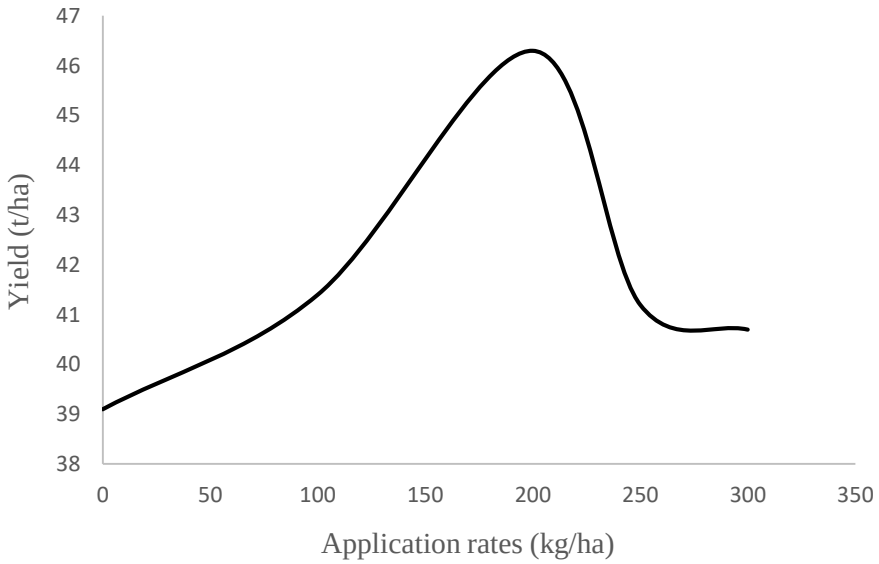

Figure 1. Effect of application amount on potato yield [4, 24, 35, 34, 41, 42, 43, 44, 45, 46]

3. EFFECT OF IRRIGATION REGIMES ON POTATO

During the potato production season, the plant growing period differs according to varieties. Moreover, the plant water consumption (Evapotranspiration, ET) of potato, which is 100-150 days on average, is between 500-700 mm depending on climate conditions [47]. Since potato are great sensitive to moisture deficit in the soil, the available water in the soil should not decrease below 65% in order to obtain the highest yield [48]. For an efficient potato production, irrigation should be done before 35% of the total available moisture is consumed and effective root depth should be taken as 0.4 m in irrigation. [49]. The duration when potatoes need water the most is the period from the beginning of tuber formation to 15 days before harvest. At this stage, if irrigation is not applied regularly, it can cause secondary growth. Irrigation increases the average tuber weight but does not always increase the number of tubers per plant. [50]. Therefore, it is necessary to correctly determine the time and number of irrigations of potato. Three base irrigation methods are used in potato, namely surface (furrow) irrigation, sprinkler irrigation and drip irrigation. Although each method has advantages and disadvantages, which method will be used differs according to the region, purpose and condition of the water source. Despite this difference, the commonly used method in the regions where potato cultivation is done is sprinkler irrigation. Recently, drip irrigation method has started to be used and become widespread. [51].

Different irrigation strategies have been developed for crops due to the decrease in agricultural water resources with the increasing water demand and the effects of ongoing climate change. Two of these are water-saving irrigation techniques such as partial root zone drying (PRD) and deficit irrigation (DI). Gültekin and Ertek (2018) applied five different irrigation levels (I100, I85, I70, I55 and I40) in a two-year study in which they investigated the effect of water deficit practices on tuber development and quality. In the first year, the amount of irrigation water was between 243 mm and 311.9 mm, evapotranspiration was between 337. 1 and 385.9, in the second year the amount of irrigation water was between 166.7 and 223.2, and evapotranspiration was between 204 and 255.7. Yields ranged from 30.85 to 47.13 t/ha in the first year and between 28.77 and 44.45 t/ha in the second year. At the end of the study, they reported that as the irrigation levels decreased, the number of tubers per plant, tuber weight, tuber diameter and length and marketable tuber ratio decreased, and the highest yield values and water use efficiency were obtained from I100 and I85 irrigation levels. [52].

Irrigation can have a direct impact on yield and yield components. Dry matter content in tuber increases with 60% and 100% full irrigation but decreases at 120% of full irrigation. [53]. According to Dervish et al. (2006) reported that restricted irrigation reduced tuber dry matter production and average weight of commercial tuber [54]. Likewise, Nagaz et al. (2007) stated that there is a decrease in tuber number and weight as a result of water scarcity during the formation and development of tubers [55]. In addition, Carli et al. reported that both dry matter and starch content increased with water restriction [56]. According to Sahebi et al. (2012) Starch content greatly enhanced with water limitation compared to control. Contrary to these, Ballmer et al. (2012) reported that water restriction reduced the starch content of tubers [57]. Sahebi et al. (2012) stated that there was no significant change in starch content with irrigation [58]. These different results may have been caused by soil and climatic conditions, stress intensity and timing.

Potato is a very sensitive plant to water shortage in the soil. The highest efficiency is obtained when the usable water in the soil is in the range of 30-50%. If the moisture level in the soil drops below 50%, the yield may decrease. Potatoes are significantly affected by water deficiency during germination, tuber formation and tuber growth periods, while they are less sensitive to water during maturation and early vegetative periods. Potatoes need frequent irrigation for good growth and yield. Yield is significantly affected by storage quality, disease resistance and duration, rate, frequency of irrigation. Variable irrigation level has a significant impact on yield and yield components in potatoes. Hence, applying less water than necessary may cause a decrease in the yield value. If irrigation is applied fully in potatoes, the yield will be at the highest value. However, if the water applied in underground drip irrigation is 80% ETc, yield values similar to the full irrigation conditions applied in above-ground drip irrigation can be obtained. Therefore, it is seen that 20% of irrigation water can be saved in potatoes [59].

Research has shown that the yield and quality of potato tubers will be affected even by short-term water stress. The size of harm to tuber yield and quality will rely on the rigor, timing and lenght of water stress during the growing season. Water stress throughout the growing season has less effect on tuber yield and quality than similar reduction in crop water use over a shorter period of time. To determine the most profitable use of limited water resources, it is critical to understand how water stress affects tuber yield and quality at each growth stage. Special irrigation management according to the growth stages of the potato is given below.

3.1. Sprout Development (Planting to Emergence)

The soil must be moist for the seed tuber to emerge. However, the humidity level should not be excessive. The excess moisture in the soil during this period may result in the plant not being able to take in oxygen and therefore cause the tubers to decay. Irrigation should be done regularly and adequately. In conditions where the temperature is high, the soil temperature can be reduced by watering at short. Excessive irrigation or precipitation may cause irregular or no emergence during this period. Excess moisture will also reduce tuber respiration by placing the seed piece under metabolic stress [60, 61].

3.2. Vegetative Growth (Emergence to Tuber Initiation)

The vegetative growth phase begins with the sprouting of the seed piece and extends to stolon formation. Plant against water stress in this period, generally reduces the effect of water stress in later growth stages and improves tuber quality. Water stress during the this stage decrease leaf area, root expansion, and plant height, and delays canopy development. During this period, the plant does not grow much, but maintain its development rapidly. Therefore, the water consumption of the plant is almost half of a mature plant. Excessive amount of water may cause the formation of exposed roots during this period. Thus, the amount of water to be given should not be more than the plant demand. In case of water is limited, tuber formation occurs earlier, but the number of tuber decreases.

3.3. Tuber Initiation

It is described as the process in which the stolon leaves growing and the tip swells to twice the stolon diameter. It is particularly sensitive to water stress during tuber formation. In addition, water stress can reduce the specific gravity during this period [62]. Water stress can reduce the number of tubers per plant during this period. However, this is not the same for all cultivars. Regular watering has a positive effect on tuber formation. Therefore, the plant needs the most water during this period. If not enough water is given, plants can accelerate maturation. Tubers cannot reach the demand size and yield may decrease. In the drought condition, deformations may occur in the tubers. Hence, in case of insufficient water intake, tuber quality is adversely affected as well as yield.

3.3. Tuber Bulking

The tuber bulking stage continues with a steady increase in tuber size and weight unless restrictive condition. Root growth improves, but the rise in total plant dry matter is considerably depend on tuber growth. Water stress at this stage often affects the total tuber yield more than the quality. Low humidity reduces or stops tuber growth during and after the stress period. So it shortens tuber bulking period and can also led to internal and external tuber defects. Excessive irrigation can inhibit physiological activity and nutrient uptake and may also reduce tuber growth by increasing disease susceptibility[62].

4. COMBINED EFFECT OF NITROGEN APPLICATION AND IRRIGATION REGIMES ON POTATO

Irrigation and fertilization are very important for increasing production in agricultural lands. Irrigation and fertilization are major inputs that increase the efficiency of each other and ensure the requested quality and amount of product. Water rescue by shortage irrigation shows different climatic and crop limitation. A sensitive crop such as potato is especially difficult to control. Because it demonstrated negative reaction to deficit irrigation [63]. Developing nitrogen management just will not be effective in reducing nitrogen leaching in sandy soils. Nitrogen can move below the root zone through irrigation and rainfall. Chemicals that cannot be taken up by the plant or held by the soil move downwards with the water. Rainfall and irrigation are critical in determining the rate at which the chemical moves down the soil profile. Therefore, measured irrigation management is important to minimize leaching of chemicals and nutrients. Hence, wetting depth should be done according to the root depth in each irrigation. In this way, it will also facilitate nitrogen uptake by roots and thereby minimize potential leakage loses below the root zone [64]. Excessive application of mobile nutrients such as nitrogen can cause leaching below the root zone with overwatering. However, it can reduce the yield in case of limited irrigation. So, N fertilizer needs to be optimized according to water availability. Although the information on irrigation and nitrogen management of potatoes is often contradictory in the literature, it is generally accepted that yield and quality are highly affected by N dose and irrigation, and they are related to cultivation technique. In potato production, nitrogen and water management is required to ensure steady growth, high dry matter content and marketable tuber [4]. Water stress has many undesirable effects on nutrient uptake, growth and yield of plants. Nutrients such as nitrogen are effective against water stress, and proper use of nitrogen can prevent a significant reduction in yield under water stress conditions. Da Silva et al., (2018) investigated the effects of irrigation method and application time on tuber yield and nitrogen use efficiency in potato. In the study, a total of 168 kg/ha of ammonium nitrate was divided equally into three applications as 56 kg/ha. According to the results obtained, it was determined that the irrigation method did not have a significant effect on tuber yield and nitrogen use efficiency. Average tuber yield was 32.1 t/ha and average nitrogen utilization efficiency was 41%. It was determined that the nitrogen utilization efficiency was highest at the beginning of the tuber (62%), followed by the emergence (44%) and the lowest (18%) at planting. Researchers stated that the nitrogen applied in the emergence and tuber formation increases the nitrogen use efficiency and tuber yield, but even if there is more loss than nitrogen, some nitrogen is required during planting [65]. In addition, in the study by Elmetwalli et al., the effects of water deficit and nitrogen deficiency on tuber yield were investigated. According to the research results the highest yield was obtained with 1.25 ETc irrigation regime and 200 kg

N/ha application. In addition, potato productivity can be maximized if the appropriate irrigation system, optimum water regime and nitrogen fertilization rate are determined. [43].

5. CONCLUSION

In this review, the effects of irrigation and nitrogen management on potato yield were explored by evaluating previous studies. In general, potato yields are highest at all stages of its development when available soil moisture does not fall below 60% between irrigations. Water stress during tuber initiation and bulking reduces yield by increasing tuber malformations. In this case, it is seen that the most sensitive period to stress is the tuber bulking period. In case of low or excess nitrogen in the vegetative and tuber initiation stages of development can reduce the overall yield of potato. However, high nitrogen availability throughout the entire growing season often delays tuber maturity. This effect on yield and development varies with time and amount of both nitrogen and water availability, region and variety. Different experiments around the world show that the application of the nutrient is positively related to obtaining higher potato yields. Experiments confirmed that adequate nitrogen and irrigation application increase potato production. Therefore, applying adequate N and irrigation is an option to maximize potato production and yield. The final nitrogen ratio, irrigation regime, and nitrogen and water utilization efficiency are interrelated. For sustainable production, collecting these parameters with the yield and yield component of the potato provides sufficient benefit.

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