BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

GRADUATE PROGRAM

EFFECTS OF NPS FERTILIZER RATE AND IRRIGATION FREQUENCY DTEREMINATION METHOD ON THE GROWTH AND TUBER YIELD OF POTATO (*Solanum tuberosum L.)* IN KOGA IRRIGATION SCHEME, WEST GOJJAM, NORTH WESTERN ETHIOPIA

MSc. Thesis

By

Minwyelet Jemberie

May 2017
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Minwyelet Jemberie

Submitted In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture

Major Advisor: Melkamu Alemayehu (PhD)

Co-Advisor: Yigizaw Dessalegn (PhD)

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THESIS APPROVAL SHEET

As members of the board of examiners of the Master of Sciences (MSc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Minwyelet Jemberie** Entitled **"Effects of NPS Fertilizer Rate and Irrigation Frequency Determination Method on the Growth and Tuber Yield of Potato (*Solanum tuberosum L.)* In Koga Irrigation Scheme, West Gojjam, North Western Ethiopia"** We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc.) in **Horticulture**.

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DECLARATION

This is to certify that, this thesis entitled **"Effects of NPS Fertilizer Rate and Irrigation Frequency Determination Method on the Growth and tuber Yield of Potato (*Solanum tuberosum L.)* In Koga Irrigation Scheme, West Gojjam, North Western Ethiopia"** submitted in partial fulfillment of the requirements for the award of the degree of Master of Sciences (M.Sc.) in **"Horticulture"** to the graduate program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr**. Minwyelet Jemberie** (**ID No. BDU0702196UR**) is an authentic work carried out by him under our guidance. This thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate to the best of our knowledge.

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DEDICATION

I dedicate this thesis to my mother Yalemwork Berie, my wife Hiwot Yilhal, my brother Getasil Tesfahun and my daughter Leamlak Minwyelet for their affection and consistent care in the success of my life.

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ABSTRACT

Potato is one of the most widely grown vegetable crops in Koga Irrigation Scheme. Conventional irrigation frequency determination method and blanket recommendation of fertilizers dominate the potato cropping system in the area. Thus, a field experiment was conducted with the objective to investigate the effects of NPS fertilizer rate and irrigation frequency determination method on the growth, yield and yield parameters of potato. The treatments consisted of six levels of NPS fertilizer (0, 90.8, 136.2, 181.6, 227.4, 272 kg ha^{-1}) combined with two irrigation frequency determination methods (WFD and CWR) which were laid out in RCBD with three replications. NPS fertilizers and irrigation frequency determination methods in their main effects had significantly influenced almost all the tested parameters of potato. In addition their interaction effect influenced days to flowering and maturity, stem number per hill, leaf area index, plant height and average tuber weight of potato significantly. Significantly maximum marketable tuber yields of potato were obtained when potato plants were irrigated based on the WFD method as well as when the potato plants were supplied with 272 kg ha^{-1} NPS fertilizer. Moreover, irrigation of potato based on WFD produced the highest crop-water productivity (7.14 kg m^{-3}) than irrigation based on CWR (6.55 kg m^{-3}). Based on the partial budget analysis, 272 kg ha^{-1} NPS fertilizer with WFD method of irrigation frequency determination gave the maximum net benefit (107,588.00birr ha^{-1}). However, application of 227.4 kg ha^{-1} NPS fertilizer irrigated with WFD method gave the highest marginal rate of return (1813.36%) which can be recommended for economical and agronomical feasible production of potato in Koga Irrigation Scheme. But the results are limited to one season and location, multi-seasonal and location studies are further recommended.

Key Words: *Crop-Water-Requirement (CWR), Plant height, Wetting Front Detector (WFD)*

ABBREVIATIONS AND ACRONMYS

ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
ATP	Adenosine Triphosphate
CEC	Cation Exchange Capacity
CV	Coefficient of Variation
CWR	Crop Water Requirement
DAP	Diammonium Phosphate
DNA	Deoxyribonuclic Acid
EARO	Ethiopian Agricultural Research Organization
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
Ha	Hectare
Kg	Kilogram
LIVES	Livestock and Irrigation Value Chains For Ethiopian Small holders
LSD	Least Significant Difference
M.a.s.l	Meter above sea level
NPS	Nitrogen, Phosphorus and Sulfur
OC	Organic Carbon
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
T/ha	Tons/hectares
WFD	Wetting Front Detector

Table of Contents

LIST OF TABLE

LIST OF FIGURE

LIST OF APPENDIX TABLE

Chapter 1: INTRODUCUTION

1.1. Background and Justification

Potato (*Solanum tuberosum* L.) is the most widely consumed vegetable in the world. It produces more dry matter, protein and calories per unit area and time than the major cereal crops. For this reason, potato is recognized as inexpensive and nutritive food security crop. The production of potatoes increases from year to year. It is produced by various countries in the world. The current world production is near to 365.4 million tons with the productivity of about 18.9 t/ha. With 87.3 million tons annual production, China is the leading country in the world (FAO, 2012). Africa`s annual potato production is currently about 29.3 million tones which is much lower than the quantity produced by China.

Potato is one of the important crops grown in mid- and high- altitude areas of Ethiopia. It was introduced to Ethiopia in 1858 by the German botanist Shimper (Berga Lemaga *et al.* 1992). Since then, it serves as food and cash crop for small scale farmers. Among root and tuber crops produced in Ethiopia, potato ranks first in volume produced and in quantity consumed followed by Cassava, Sweet potato and Yam (CSA, 2016). In Ethiopia, about 70% of the agricultural land is suitable for potato production (Tsegaw Tekalign 2006).

Amhara Region is the major potato growing area in Ethiopia followed by Oromia and Southern Nations Nationalities and Peoples State (SNNPRS). The Region contributes about 40% of the national potato production where South Gonder, North Gonder, East Gojam, West Gojam and Awi are major potato producing zones. Although the country has suitable environmental and edaphic conditions and a number of improved potato varieties being released, the productivity of potato at national (7.97t/ha) and regional (8.53/ha) level is very low (CSA, 2015/16) compared with the world average of 18.9t/ha (FAO, 2012).

Major constraints of potato production in Amhra regions are diseases and insect pests, soil nutrient depletion, moisture stress, lack of tuber seeds of improved varieties, inappropriate postharvest handling practices, lack of improved storage and market access (Yazie Chanie *et al*. 2009).

The results of variety trials conducted over several locations on different crop species clearly indicated that nutrients in the soil are significant parameter controlling crop yield including potato. It is also important to note that fertilizer response vary with soil fertility status and crop species (Tamirie Hailu 1989). In this regard, various studies have been conducted on

fertilizer requirements of potato in various parts of the country. According to Bereke Tsehai (1988), an application of 150 kg N and 66 kg P_2O_5 per hectare under rain-fed conditions resulted tuber yield advantage of 32% over the unfertilized control. An experiment conducted at Alemaya on clay soil indicated that application of 87kg N and 46 kg P_2O_5 per hectare was needed for optimum potato production (Getu Beyene 1998). On the other hand an application of 110kg N and 90 kg P_2O_5 per hectare was also recommended for potato production on black soil of Holetta (IAR, 2000). Applications of 138 kg N and 20 kg P per hectare were required for optimum productivity of potato on vertisols at Debre Berhan (Zelealem Ayichew 2009). Application of 150 kg ha^{-1} DAP and 350 kg ha^{-1} urea is also recommended for the production of potato at Koga Irrigation Scheme (Anteneh Abawa *et al.*, 2012).

Chemical fertilizer sources in Ethiopian agriculture have been limited to urea and Diammonium Phosphate (DAP) over the past five decades. These types of fertilizers deliver only nitrogen and phosphorus which may not satisfy the nutrient requirements of the crops including potato in the agricultural soils. According to Hailu Shiferaw (2014) Ethiopian soil lacks most of the macro and micronutrients that are required to sustain optimal growth and development of crops. This is exacerbated especially by Ethiopian fertilizer rates that are below international and regional standards (USAID, 2013). Consequently, the yield and productivity of crops in Ethiopia including potato are much lower than other countries. To solve these problems the Ministry of Agriculture (MoA) currently popularize the implementation of soil test based fertilizer application system through the use of soil fertility information (MoA, 2013) and thus introduced a new fertilizer (NPS) which contains Nitrogen, Phosphorous and Sulfur in the country's farming system to increase productivity of crops. However its rate of application for the production of most of the crops including potato is not yet known.

The other important factor for crop production is soil moisture. The ever increasing world population which needs an increase in crop yield necessitates therefore a rapid expansion of irrigated agriculture throughout the world. Furthermore as the population increases, the need of ground and surface water for domestic consumption, agriculture and industrial sectors increases which deplete the fresh water resources. Such conditions the pressure of water resource utilization which will be serious concern for future (FAO, 2008).

Water is essential for plant production in much larger quantities than the soil nutrients (Wang 2006). According to the authors water is essential and an inevitable for opening of the stomata to ensure gaseous exchange during photosynthesis. Water is required to absorb and translocate soil nutrients and assimilates in various parts of the plant. Plants transpire water, which they usually have to take up from the soil. Furthermore, it influences the availability of oxygen, the activities of fauna and flora, leaching of nutrients and agrochemicals in to the subsoil, and swelling and shrinking of certain clay soils.

Soil water affects a balance between processes that add water to the soil, such as infiltration of rainfall, and processes through which water is lost from the soil, such as plant water use transpiration, evaporation, run off and drainage (Russell, 1973). Moreover, water around the crop roots determines crop growth and influences the availability and movement of fertilizers and other agricultural chemicals. Accurate measurement of soil water content is therefore important to maximize yield and quality of the crop, and hence to optimize the water use efficiency. This is especially important in the water scarce arid and semi-arid regions of the world.

Knowing how much and when to apply water are the prime prerequisites for effective water management. On the other hand the amount of water required for crop production dependents on the type of crops and their growth stage, the environment in which they grows (e.g. wet and humid or dry and arid), the depth of the water table, soil health (e.g. soil fertility level, presence of salinity and surface crusts) and management options such as fertilizer application and the target yield. It is particularly important to maintain the optimal soil water content during the water-sensitive growth stages, as any damages during these stages cannot be compensated at the other stages. Saving in water resource can be made mainly through proper timing and depth of irrigation. Therefore, measurements of soil water content is essential to establish water management strategies that will enable farmers to schedule irrigation according to soil water holding capacities, plant water use and prevailing weather conditions.

Furthermore, soil water status and mineral nutrition of plants are interrelated. Optimal soil fertility will enhance crop water uptake and thus ensures maximum use of water for crop growth and development including potato. As potato is relatively sensitive to soil water deficits, the total available soil water should not be depleted by more than 30 - 50 %. Depletion of the total available soil water by more than 50% during the growing period of potato resulted reduced yield (FAO, 2013).

In Koga irrigation scheme farmers are growing different vegetables including potato using traditional furrow irrigation method. They irrigate their crops at interval of eight or more days. Such furrow irrigation method has however a problem of under and over irrigation which may lead to leaching of agrochemicals, lowering of the groundwater table, destruction of soil structure, higher cost of production, high incidence of diseases and insect pests and conflict of interest over water access (Wang, *et al*, 2006). In this regard, Badr *et al*, (2012) observed reduction of yield and quality as well as high incidence of diseases and insect pests in potato by over, and under irrigation.

To address these challenges, the Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) project through the International Water Management Institute (IWMI) has introduced an irrigation scheduling device known as a 'Wetting Front Detector (WFD)' which can be buried at 20 and 40cm depth for soil moisture test. WFD is simple and affordable irrigation-scheduling tool that monitors the physical movement of water down to the soil profile (Stirzak 2004; Stirzaker 2003). The device is being used in countries like South Africa to improve water management in irrigation schemes (Annandale *et al*., 2005).

WFD was also used in Ethiopia at Deberzet Agricultural Research Centre to compare traditional and scientific irrigation scheduling practices for furrow irrigated potatoes. According to Geremew Eticha (2008), traditional irrigation practices employed by farmers were not able to supply the required amount of water necessary to ensure optimum yield of potato. Thus, they emphasized the need for introduction of better and more efficient way of determining soil water content and thus accordingly adjust the irrigation schedule. They also reported that WFD helped the farmers to judge how much water the plants including potato need throughout their growing period. This study was therefore initiated with the major objective to investigate the growth and yield response of potato at different rates of NPS fertilizer and irrigation determination method based on crop water requirement using WFD in Koga irrigation scheme.

1.2. Objectives of the Study

The general objective of the present study was to assess the effects of NPS fertilizer rates and Irrigation frequencies determination method on the tuber yield and quality of potato at Koga Irrigation Scheme. The specific objectives were indeed:

- To determine the optimum NPS fertilizer rate for optimum tuber yield of potato production at Koga irrigation Scheme.
- To determine appropriate irrigation frequency determination methods for potato production at Koga Irrigation Scheme.
- To assess the interaction effects of irrigation frequency determination method and NPS fertilizer rates on growth, yield and quality of potato at Koga Irrigation Scheme**.**

Chapter 2: LITRETUER REVIEW

2.1 Origin and Distribution of Potato

The potato origin of (*Solanum tuberosum L.*) is in South America, most likely from the central Andes in Peru. It was domesticated and has been grown by indigenous farming communities for over 4,000 years. Potato was introduced into Europe in the sixteenth century and subsequently distributed throughout the world (Berga Lemaga *et al.*, 1995). Its genetic diversity in terms of landraces and wild species that occurs in Bolivia, Colombia, Ecuador, Peru, and Venezuela, potato cultivation is distributed between 40°N and 20°S latitudes. It grows well in temperate regions, especially in North America, Belarus, Poland, Russia, France, Germany, United Kingdom and other countries. In the tropics including Ethiopia, potato is introduced by the German scientist Shimper in 1858 (Berga Lemaga *et al.*, 1992). Its cultivation does better especially in higher elevations.

2.2 Ecology of Potato

2.2.1 Climatic requirements

Potato is normally a temperate crop and it requires cool climate. But it is also adapted to wide range of climatic conditions. It grows well in temperatures range 15-25^{0}C**.** High day temperatures of 20-25^{0}C are good for vegetative growth while temperatures between 15-20^{0}C are suitable for tuber formation. Tuber formation stops totally when the temperature exceeds above 30^{0}C (FAO, 2006).

Soil temperature is also important for grow and development of potato. Optimum soil temperatures for normal tuber growth are 15 to 18°C. Cool conditions at planting lead to slow emergence of seed tubers which may extend the growing period of potato plant. Early varieties bred for temperate climates require a day length of 15 to 17 hours while the late varieties produce good yields under both long and short day conditions. For tropical climates, varieties which tolerate short days condition are required (FAO, 2013).

2.2.2 Soil requirements

Potato can be grown on any soils which are rich in organic matter. For better yield, the soils should be well drained and aerated. Potatoes grown in light or porous soil require relatively higher amount of fertilizer. Loam or sandy loam soils are most suitable for proper tuber development. Potato is moderately sensitive to soil salinity. The yield of potato decreased

with increasing soil salinity (FAO, 2013). Potato prefers slightly acidic soils with the pH values of 5.2-6.4. Potato cannot tolerate alkaline soil.

It is grown on ridge or flat seed bed depending on the moisture condition available. For rain fed production in dry conditions, flat planting tends to give higher yields due to soil water conservation measures. Under irrigation condition potato is mainly grown on ridges.

2.3 Effects of NPS Fertilizer on Yield and Yield Components of Potato

One of the contributing factors to low potato yields in most parts of the world is low soil fertility. This is attributed by continuous cultivation without adequate replenishment of the mined nutrients (Naz *et. al*., 2011). Nutrients like N, P, K, S, Ca, Mg, Fe and Zn influence the yield and quality of potato tuber. Especially nitrogen phosphourous and potatium are absorbed in large quanity during the growing period of potato (White *et al*., 2007).

As potato is relatively a shallow rooted crop, it is a high input intensive crop which requires an efficient crop management practice to ensure adequate nutrient uptake and to attain optimum crop growth and yield (Sandhu *et al.*, 2014). Potato is a short-cycle crop, requiring sufficient macro- and micro-nutrients and irrigation at all stage of development for optimum yield. Among the macronutrients, nitrogen (N) generally represents the greatest limitation in potato production (Hendrickson and Douglass, 1993). Nitrogen plays an important role in the balance between vegetative and reproductive growth of potato (Alva, 2004). Thus nitrogen fertilizer is considered as one of the most important factors that limits the yield of potato (Tran *et al*., 1991).

Applications of N fertilizer can increase the yield and yield components of potato (Zelalem Ayichew *et. al*, 2009). The increase in average tuber weight of tubers in response to the increased supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthesis which may have induced formation of bigger tubers thereby resulting in higher yields (Patricia and Bansal, 1999). According to Zelalem Ayichew, (2009), application of 207 kg N/ha increased plant height, the above ground biomass by 224.5%, underground biomass by 108%, marketable tuber yield by 175%, total tuber yield by 119%, marketable tuber number by 95.6%, and total tuber number by 34% and average tuber weight by 82% over the control. Similar results were also observed where application of nitrogen fertilizers increased the yield and yield components of potato

(Kandil *et al*., 2011; Naz *et al.*, 2011; Shiferaw Boke, 2014; Wassie Hailu, 2009; Wassie Hailu; Shiferaw Boke, 2011).

On the other hand application of excess nitrogen fertilizer may influence various growth and yield parameters of potato. According to Sebastiani *et al*. (2007) for instance excessive nitrogen fertilization reduced starch, dry matter, and sugar contents in potato tubers. Furthermore, excess nitrogen during production reduces the storability of potato tubers. The fact that nitrogen promotes growth of potato vines and by the time of harvesting, tubers may not have been able to mature completely and reach maximal dry matter content. Similar results are reported by Zelalem Ayichew *et al*. (2009) that increasing soil nitrogen content led to decrease in dry matter content of potato tubers. Sebastiani *et al*. (2007) indicated that excess N rates significantly reduced tuber dry matter content due to vigorous growth of the plants which produced more above ground vegetative parts competing for photosynthesis necessary for tuber development. Zaag (1992) found that small applications of nitrogen increased the dry matter content of the tubers, whereas large applications tend to the opposite effect. Considering this result, there seems to be some difficulty in managing the nitrogen fertilization to maximize simultaneously the dry matter content and production (Rodrigues *et al*., 1998).

Phosphorous is the other important nutrient in the fertilization of potato soil. Phosphorus plays significant role in physiological and biochemical reactions such as photosynthesis, conversion of sugar into starch (Taheri *et al*., 2011). The increase in tuber dry matter content in response to increasing the rate of P application signify that phosphorus is an important nutrient for enhancing production of photo-assimilate and starch storage in tubers. This suggestion is consistent with that of Kumar *et al*., (2013) who stated that P increases photosynthesis, and indicated that translocation of photosynthesis from source to sink has occurred up to maturity as a result of increased nutrient absorption (Biruk Masrie 2014).

Phosphorus plays an important role in plant nutrition, particularly it helps to increase early crop growth (Jenkins, *et al*., 1999). Potato respond differently depending upon soil phosphorous contents coupled with soil pH (Sanderson *et. al*., 2003). Potato yield, number of tubers and size of tubers are greatly affected by phosphorus fertilization. Tuber set is also increased with application of phosphorus (Freeman *et al*., 1998). Moreover phosphor application significantly increased plant height, marketable tuber yield and marketable tuber number (Zelalem Ayichew *et al.,* 2009).

Plants require a variety of elements for growth and development of which N, P, and K are the most important because they are required in large quantities. Sulfur is fourth major nutrient after NPK, required by plants. Sulfur plays an essential role in chlorophyll formation and therefore helps to give plants their green color. Sulfur is known to take part in many reactions in all living cells (Sharma 2015). Thus it is the key component of balanced nutrition required for the production of potato where intensive cropping and use of high grade fertilizers resulted in depletion of soil sulfur. Therefore deficiency of N, P, K, and S elements is manifested in the detrimental effects on the growth and development of the plants (Tisdale Sentayhu *et al*., 1995).

Various researchers reported the beneficial effects of the application of sulfur containing fertilizers on growth, yield and yield parameters as well as quality of potato (Chettri *et al.*, 2002 and Choudhary *et al*., 2013). The increase in growth and yield of potato with application of sulfur can be explained with the increased metabolic activities, photosynthesis, assimilation, and bulking rate as indicated by Sharma (2015). On the other hand the decrease in tuber dry matter, starch and essential amino acids particular cystine and leucine were observed with sulfur deficiency (Eppendorfer and Eggum, 1994). Sulfur deficiency may also result poor utilization of nitrogen, phosphorus, potash and a significant reduction of catalase activities at all age of plants (Nasereen *et al.*, 2003).

Moreover, sulfur has direct effect on soil properties as it may reduce soil pH which may improve the availability of micro elements such as Fe, Zn, Mn & Cu (Prakash *et al*., 1997; Singh *et al.*, 1995; Tantawy *et al.*, 2009).

The rate of application of fertilizers for improved growth, yield and yield components of potato depends among others on the specific conditions of the area such as climatic conditions, the fertility status of the soil and others. Acordingly, Bereke Tsehai (1988) obtained tuber yield advantages of 32% over the unfertilized control by the application of 150 kg/ha of N under rain fed conditions. An experiment conducted at Alemaya on clay soil indicated that application of 87 kg/ha of N was needed for optimum potato production (Getu Beyene 1998). Application of 110 kg/ha of N and 90 kg/ha P2O5 was recommended for potato production on the black soil of Holetta (IAR, 2000).

2.4 Effect of Irrigation on Yield and Yield Parameters of Potato

Potatoes are shallow rooted vegetables and more sensitive to soil moisture stress than other deeper rooted crops. Thus sufficient amount of water is required to ensure high yield in potatoes. Moisture stress, depending on the crop growth stage, can reduce potato tuber yields, produce misshapen tubers, and/or adversely affect the processing quality of the tubers. For example, transient moisture stress during stolon formation or tuber initiation can reduce tuber set while moisture stress at tuber bulking stage can reduce tuber size (Abubaker *et al*., 2014). Since potato is relatively sensitive crop under conditions of limited water supply, it should be preferably directed towards maximizing yield per ha rather than spreading the limited water over the larger area. Savings in water can be made mainly through timing and depth of irrigation application. Compared to many other crop plants, potatoes close their stomata at relatively small soil moisture deficits. Thus, soil moisture stress influences various physiological activities that affect the tuber yield and quality (Pereira *et al.,* 2007).

Potato yield is reduced both by over- and under-irrigation. The reduction in yield with high water quantity is due to poor aeration in the soil. Wet soil is conducive to pathogens that may cause tuber rotting and decay of seed tubers that cause an erratic emergence. Moreover, excessive irrigation can also erode hills, thus exposing shallow tuber set to greening or sunscald. Furthermore excessive moisture may cause infection of potato by early and late blight pathogens (Rowe and Secor, 1993).

On the other hand moisture stresses, that occur before the onset of tuber initiation and thereafter effectively reduce the number and weight of tubers (Mackerron and Jefferies, 1986). Water deficiency causes reduction of yield by reducing the growth of crop canopy and biomass as potato crop has low tolerance for water stress (Badr *et al.,* 2012).

Soil moisture management is a key production activity of potato to obtain profitable yield. Therefore timing and method of application of irrigation water are important in the production of potato as it affects the growth and yield of potato. Moreover they affect the quality of potato tubers. Tuber quality parameters such as tuber grade, specific gravity, heat necrosis, susceptibility to bruise, hollow heart, translucent-end, jelly end rot, and darkness of fried strips and chips are influenced by moisture stress. Tuber grade as determined by shape, smoothness, and freedom from visible defects such as growth cracks, dumbbells, and knobs, is highly sensitive to irrigation management deficiencies (Pereira *et al*., 2007).

Over-irrigated potatoes during vegetative growth and tuber initiation have a greater potential for developing brown center and hollow heart, and are generally more susceptible to early blight problem. Excess soil water can also lead to tuber quality and storage problems (Bradley A. *et. al.,* 2005). Furthermore, use of effective water application method may go a long way in addressing the global water crisis in future, thereby reducing wastage of water (Ala, 2012).

Potato yield is also greatly influenced by timing and duration of water stress during the different growth stages of potato. Tuber initiation and bulking stages are the most sensitive to water stress as compared to the vegetative stage. Scheduling water application is thus very important since excessive irrigation reduces yield, as well as inadequate irrigation causes water stress and reduces production (Wang et. *al*., 2006). Therefore, optimal irrigation scheduling requires accurate estimates of crop evapo-transpiration (ETc) (Doorenbos and Pruit, 1977). However, determination of ETc during the initial stage without full ground cover requires considering soil evaporation and crop transpiration separately (Ritchie, 1972).

Soil moisture required to obtain maximum yield of potato is about 50% of available water in the soil, although it may vary between 25-75% which can be explained by climatic, plant and soil characteristics. In this regard, Waddell *et al*. (1999) observed reduction of total as well as as marketable yield of potato by 11% when irrigation was given at 60% depletion of soil water compared to 30% depletion. Moreover they observed saving of irrigation water close to by 20% at 30% depletion compared to irrigation at 60% soil moisture.

The crop water requirements of potato depends among other the climatic conditions and the stage of development of the potato plant. Generally the crop water requirements (ETm) of about 500 -700 mm are required for about 120-150 days for higher yield of potato. The relationship between maximum evapo-transpiration (ETm) and reference evapo-transpiration (ETo) is given by the crop coefficient (kc) which differ with the growth stages of potato, i.e. at initial stage 0.4-0.5 (20-30 days), developmental stage 0.7-0.8 (30 - 40 days), mid-.season stage 1.05-1.2 (30 - 60 days), late-season stage 0.85-0.95 (20-35 days), and at maturity 0.7-0.75 (FAO, 2013).

2.5 Interaction Effects of Irrigation and Fertilizer on Yield and Yield Components of Potato

Water requirement of potato is especially dependant on growth stage of the plant that intern determines the nutrient requirement of the plant (Wright and Stark 1990; Shock *et al*. 1993). As water transport nutrients within the plant, water stress affects the nutrient use efficiency of plants including potato. In this regard, Meyer and Marcum (1998) observed the interaction effects of nitrogen fertilizer use efficiency and application of irrigation water. Irrigation water and application of nitrogen fertilizers were also important inputs that influenced the yield as well as the quality of potato tubers that intern influenced the net return as indicated in the findings of various researchers (Alva, 2008). Water stress, even for a short period, often has a severe impact on potato tuber yield and quality as it affects the nutrient use efficiency the plants. Inadequate water availability results in loss of yield, grade, internal quality, and inefficient use of other production inputs (Alva, 2008).

Chapter 3: MATERIALS AND METHODS

3.1: Description of the Study Area

The study was conducted at Koga Irrigation Scheme in Northwestern Ethiopia particularly at Adet Agricultural Research Center irrigation research site during the irrigation season of 2015/2016. Koga Irrigation Scheme is found about 35 km far to southwest of the Amhara Regional State capital city, Bahir Dar (Figure 3.1). Koga Irrigation Scheme is located at 11^{O} 10′N to 11^{O} 25′N latitude and 37^{O} 02′E to 37^{O} 17′E longitude with an elevation of 1960 m.a.s.l.

According to Bahir Dar Meteorology Station report (unpublished), the area received an annual mean rain fall of 1395.23 mm for the last 10 years (2005-2015). The mean maximum and minimum temperatures of the area are 27^{O}C and 12.8^{O}C, respectively (Appendix Table 2).The area received about 0.33mm of total rain fall during the experimental period (January to April 2016) while the mean minimum and maximum temperatures were 9.36 ^{O}C and 30.36 ^{O}C, respectively (Appendix Table 2). The average mean minimum temperature during the experimental period was about (9.36 ^{O}C) ranging from 6.70-11.80 ^{O}C less than the last ten years average (10.85 ^{O}C) whereas the mean maximum temperature was about 30.36 ^{O}C which was higher than the corresponding period of the last ten years average (29.18 ^{O}C) (Appendix Table 2).

Major crops grown in Koga irrigation command area include: - maize, finger millet, bread wheat and tef during the main cropping season and bread wheat, potato, onion and cabbage during the irrigation season.

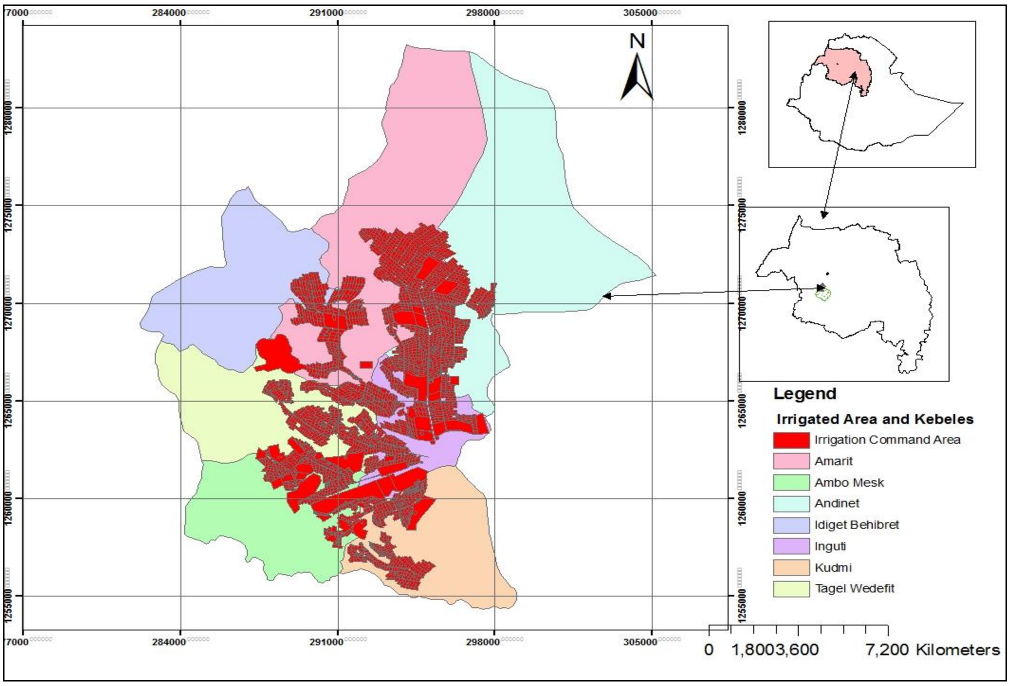

Figure 3.1. Geographical location of the study area

3.2: Description of Experimental Materials

Plastic hose, geo-membrane, WFD (wetting front detector) and TDR (Time domain refractometer) were used in the study which were necessary to irrigate the experimental field and to measure irrigation water and soil moisture. Belete variety of potato which was developed and released by Holetta Agricultural Research Centre was used for the study. According to MoARD (2008), the variety is high yielder, relatively diseases tolerant and adapted to a wide range of altitudes. Healthy seed tubers of Belete variety produced in Adet agricultural research center were used for this study. The newly introduced NPS fertilizer with 19% nitrogen, 38% P_2O_5 and 7% sulfur was used in the study. NPS fertilizer rates were calculated based on the recommendations of DAP and urea at the rate of 150kg ha^{-1} and 350 kg ha^{-1}, respectively, for potato production at Koga Irrigation Scheme.

3.3: Experimental Treatments and Design

The treatments consisted of 6 levels of NPS (0, 90.8, 136.2, 181.6, 227.4 and 272 kg ha^{-1}) and two irrigation frequency determination methods (WFD and CWR), total treatment combinations of 12 (Table 3.1). The experiment was laid down in Randomized Complete Blok Design (RCBD) in a factorial arrangement with three replications (Table 3.2). The size of a plot was 3 m x 6 m which accommodated a total of 80 plants in four rows. The distances

between blocks, plots, rows and plants were 2m, 2m, 0.75 and 0.30m, respectively. Harvesting was done from the two central rows of $9m^2$net plot area.

All management activities except fertilizer and water applications were applied uniformly in all plots of the experiment as indicated by EIAR (2007).

Table 3.3.Treatment combinations

NPS fertilizer rate (kg ha^{-1})	NPS fertilizer rate x Irrigation method	
0 kg	O kg ha^{-1} + WFD (T1)	0 kg ha^{-1} + CWR (T2)
90.8	90.8 kg ha^{-1} + WFD (T3)	90.8 kg ha^{-1} + CWR (T4)
136.2	136.2 kg ha^{-1} + WFD (T5)	136.2 kg ha^{-1} + CWR (T6)
181.6	181.6 kg ha^{-1} + WFD (T7)	181.6 kg ha^{-1} + CWR (T8)
227.4	227.4 kg ha^{-1} + WFD (T9)	227.4 kg ha^{-1} + CWR (T10)
272	272.0 kg ha^{-1} + WFD (T12)	272.0 kg ha^{-1} + CWR (T12)

Table 3.4.Field layout of the experiment

Block I		Block II		Block III	
Plot 1.1	T- 06	Plot 2.1	T-01	Plot 3.1	T -01
Plot 1.2	T- 09	Plot 2.2	T -11	Plot 3.2	T-07
Plot 1.3	T- 01	Plot 2.3	T- 03	Plot 3.3	T-06
Plot 1.4	T-12	Plot 2.4	T- 07	Plot 3.4	T- 08
Plot 1.5	T- 04	Plot 2.5	T -12	Plot 3.5	T- 05
Plot 1.6	T-07	Plot 2.6	T- 10	Plot 3.6	T- 10
Plot 1.7	T- 08	Plot 2.7	T- 09	Plot 3.7	T-04
Plot 1.8	T- 11	Plot 2.8	T -08	Plot 3.8	T -09
Plot 1.9	T- 02	Plot 2.9	T -06	Plot 3.9	T -11
Plot 1.10	T- 10	Plot 2.10	T -05	Plot 3.10	T- 03
Plot 1.11	T- 03	Plot 2.11	T- 02	Plot 3.11	T-12
Plot 1.12	T- 05	Plot 2.12	T -04	Plot 3.12	T-02

3.4: Application of Irrigation Water

Frequency of irrigation and amount to be applied was determined using CWR and WFD methods by furrow irrigation system. In CWR method water was applied at 10 days interval with the recommended amount of 476.4mm water for the total growth stage of potato. To prevent percolation of irrigation water geo-membrane was lined in the furrows while plastic hose with ¾ inch diameter was used to bring water in to the irrigation furrows.

WFD is a special shaped funnel, filter and a float mechanism. The funnel is buried in the soil within the root zone of the plants or crops. Wetting front detectors are usually used in pair, one being buried about one third (20cm) of the depth in the active root zone and the second at about two third (40cm) of the rooting depth. If the shallow depth detector is not pop-up it is likely that the crop is being under irrigated. If the deep detectors pop-up it indicates that the crop is over irrigated. When you see the yellow and red indicators pop-up, irrigation was stopped.

3.5 Water Productivity Determination

Irrigation water productivity is generally defined as crop yield per water used to produce the yield (Howell, 1997). Thus it was calculated as fresh weight (kg) obtained per volume of irrigation water applied (m^{-3}). The formula as indicated:-

$$\text{Water Productivity} = \frac{Yield(kg)}{water\ applied\ (\text{m3})}$$

3.6: Management of Experimental Plants

The land was ploughed two times according to the local practice using oxen before planting. During last ploughing ridges and ditches were prepared, leveled and compacted. Geo-membrane was lined in the ditches to prevent water percolation and sprouted tuber seeds of Belete variety were planted at the spacing of 0.75 m between rows and 0.3m between plants in the rows as recommended by IAR (2007). Based on the treatments the whole NPS fertilizer rates were applied in rows at the time of planting. The recommended rates of urea (161N kg ha^{-1}) were applied to all plots uniformly in two equal splits. While the first application was applied 25 days after planting the second half was applied 50 days after planting. Until emergence of sprouts, about 15 days, all plots were watered uniformly. Then after, irrigation of the experimental plots was done based on the treatment methods (WFD and CWR). Other Management activities such as weeding, cultivation and disease and insect pest control was done as required for each plots uniformly as described by IAR (2007).

3.7: Sampling of Experimental Soil

To know some of soil physicochemical properties of the experiment site, soil samples at the depth of 0-30 cm were collected randomly from the entire experimental field of 20 spots in a zigzag pattern before sowing. A soil composite was made and some properties of the experimental soil were analyzed in Amhara Design and Supervision Works Enterprise soil

laboratory. According to the analysis results, the soil of the experimental site is clay loam, in its textural classification with high exchangeable Al^{3+} content and is moderately acidic with a pH value of 5.83. The organic matter content of the experimental soil is 2.35%. The soil has also 5.25 ppm available phosphorous and 0.12% total nitrogen contents (Table 3.3). Based on the results of analysis, the soil of the study area is generally suitable for the production of potato.

Table 3.3: Soil physical and chemical properties of the study area before planting

pH (H2O) 1:2.5	EC (mS/cm)	CEC	Total N (%)	Organic (%)	Available P (mg/Kg)	Texture			
						Clay (%)	Silt (%)	Sand (%)	Soil Class
5.34	0.04	46.00	0.12	2.35	5.25	31	25	44	Clay loam

3.8: Data Collection and statistical Analysis

Growth, yield and yield components of potato were collected from the net plot area of $9m^2$ to exclude border effects based on the standard procedures described below.

3.8.1 Phenological parameter

Days to flowering: It was determined by counting the number of days elapsed from days to planting to the time when 50% of the plants in each plot started to flower through visual observation and the mean count days were used for further analysis.

Days to maturity: It was determined by counting the number of elapsed days from days to planting to the days when more than 90% of the plants in a plot attained physiological maturity, i.e. when 90% of the haulm of the plants dried.

3.8.2 Growth parameters

Plant height (cm): The plant heights of ten randomly selected plants from the net plot area at physiological maturity were measured from the ground level to the tip of the main stem using rulers and the mean values used for further analysis.

Leaf area index *(LAI):* Leaf area index (LAI) was calculated using the formula described by Yoshida (1981) as cited by Tilahun *et al.*, (2013) as indicated below. The sample leaves (5 plants per plot) were taken at the vegetative stage, at the beginning of tuberization.

$$\text{LAI (cm)} = \frac{\text{Sum of the leaf area of all leaves (cm)}}{\text{Ground area (cm)}}$$

Number of main stems (count/hill): the number of stems from five randomly selected hills was counted at 45 days after planting and means value was computed and used for further analysis.

3.8.3. Yield and yield component

Tuber weight (g/tuber):- The mean tuber weight in gram was computed by weighting 10 randomly selected tubers harvested from each net plot and the values were used for further analysis.

Tuber yield per hill (kg/hill): the tuber yield of ten randomly selected hills/plants in each net plot area was weighted and the mean values was computed and used for further analysis.

Unmarketable tuber yield (t/ha): Tubers which were damaged, diseased and insect pest attacked, undersized (<30mm), misshaped, decayed were considered as unmarketable. The weight of such tubers obtained from each net plot area was measured in kilogram using scaled balance and expressed as ton per hectare.

Marketable tuber yield(t/ha)*:* - Tubers which were free of mechanical, disease and insect pest damages and medium to large in size will be considered as marketable. The weight of such tuber obtained from the net plots was measured in kilogram using scaled balance and expressed as ton per hectare.

Total tuber yields (t/ha): the total tuber yield was obtained by adding marketable and unmarketable tuber yields.

Specific gravity of tuber: It was determined by weighing the weight of water displaced when 5 kg potato tuber was immersed in constant weight of water following the formula indicated below by Tesfaye Abebe (2013).

$$\text{SG} = \frac{\text{Weight of tubers in air (5kg)}}{\text{(Weight of tubers in air (5kg) - (weight in water)}}$$

Tuber dry matter (%): The dry matter of tubers was determined by weighing the dry matter of five randomly selected tubers after drying them in oven at110^{O}C for 72 hours and expressed in percentage using the formula below by Tesfaye Abebe (2012).

$$DM = \frac{\text{Weight of oven dry}}{\text{weight of fresh tuber}} X\ 100$$

All collected data were subjected to Analysis of Variance (ANOVA) using Statistical Analysis System version 9.0 (SAS Institute, 2002). Whenever treatment effects were significant, mean separation was conducted using Duncan Multiple Range Test (DMRT) at 1 or 5% probability level as indicated by Gomez and Gomez (1984). Correlation analysis among selected parameters was done using Pearson simple correlation coefficient.

3.9: Economic Analysis

To determine the economic feasibility of the treatments economic analysis in the form of net benefit analysis and marginal rate of return was done according to the procedures developed by CIMMYT (1988). The cost of urea and the labor required for the placement of the fertilizers and application of water was used as variable cost of the experiment. Moreover, the market prices of fertilizer and marketable tuber yield of potato and cost of labor were taken from market assessment during the experimental period.

Chapter 4: RESULTS AND DISCUSSION

4.1 Growth, Yield and Yield Components of Potato as influenced by NPS Fertilizer rates and Irrigation Frequency Determination Methods in Koga Irrigation Scheme

4.1.1 Growth parameters

Plant height

The analysis of variance revealed that the plant height of potato was highly significantly ($P < 0.01$) influenced by NPS fertilizer rates and irrigation methods as main effects and by their interaction effect (Appendix Table 5). The highest plant heights of potato were observed when the application of water was determined based on WFD (65.2cm). Moreover the application of NPS fertilizer at the rate of 227.4 kg ha^{-1} showed the highest plant height of potato (65.2cm) while the shortest plant height was observed on plants without NPS fertilizer (40.3cm) as indicated in (Table 4.1).

In the interaction effect, the highest potato plant height (65.2cm) was observed with the application of 227.4 kg ha^{-1} NPS fertilizer and irrigation based on WFD. In the case of CWR however the longest potato plants (64.8 cm) were observed with the application of 272 kg ha^{-1} NPS fertilizer (Table 4.2). Plants irrigated based on CWR and without NPS fertilizer were shorter (40.3 cm) than those plants without NPS fertilizer but irrigated based on WFD (42.7 cm).

The use of wetting front detector (WFD) for determination of frequency of irrigation water may improve the nutrient use efficiency of potato plants which intern increase the plant height as indicated in this study. This is because potato plants irrigated based on WFD required 227.4 kg ha^{-1} NPS fertilizer while those irrigated based on CWR required 272 kg ha^{-1} NPS fertilizer to attain the same plant height. The results of the present study area generally in line with the findings of various researchers where they found an increased potato plant height with the application of sulfur containing fertilizers (Tisdale Sentayehu (1995); Chettri, (2002); Choudhary (2013); Sharma (2015)). Similarly, increasing of plant heights with the application of NPS fertilizers were also observed in other vegetables including garlic and onion (Muluneh Negatu 2015).

Stem number

Number of stem per hill was highly significantly ($P < 0.01$) influenced by NPS fertilizer rates and determination of irrigation frequency in their main as well as in their interaction effects (Appendix Table 5). The highest stem number of potato per hill (10.37) was observed when irrigation frequency was determined with WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg ha^{-1} produced the highest stem number per hill (10.37) while the least number of potato stem (5.17) was observed without NPS fertilizer (Table 4.1).

The interaction of 272 kg ha $^{-1}$ NPS fertilizer and irrigation frequency determined based on WFD produced the highest number of potato stem per hill (10.37) while the interaction of 272 kg ha $^{-1}$ NPS fertilizer and irrigation frequency based on CWR produced the second highest number of stem (9.3) which is statistically similar with potato stem number (9.03) produced with the interaction effect of irrigation frequency based on WFD method and application of 227.4 kg ha $^{-1}$ NPS fertilizer (Table 4.2).

The results of the present study clearly indicated that the increase in NPS fertilizer rates increases the stem number of potato in both irrigation frequency determination methods. However, the increase in stem number in WFD method especially at higher level of NPS rate was more compared to CWR method. This could be due to the improved nutrient use efficiency of potato plants in WFD based irrigation frequency determination. According to Shaaban and Kisetu (2014), the number of potato stem per hill increased with increasing fertilizer rates, especially that of nitrogen fertilizer which is in line to the results of the present study.

Leaf area index

The leaf area index of potato plants was affected by NPS fertilizer rates and irrigation water determination methods in their main effects as well as in their interaction effect. While the main effects of both treatments influenced highly significantly ($P < 0.01$), the leaf area index of potato plants was significantly ($P < 0.05$) influenced by the interaction effect of the treatments (Appendix Table 5). The highest leaf area index (6.37) of potato plants was observed when irrigation frequency was determined with WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg ha^{-1} produced the highest leaf area index (6.37) of potato plants while the lowest leaf area index (5.17) was observed without NPS fertilizer (Table 4.1).

In the interaction effect, the highest leaf area index (6.37) was observed when potato plants were supplied with 272 kg ha $^{-1}$ NPS fertilizer and irrigated based on WFD method. The application of NPS fertilizer at the rate of 272 kg ha $^{-1}$ and irrigation based on CWR method produced the second highest leaf area index (5.94) of potato which is statistically similar with leaf area index (5.81) obtained with the interaction effect of irrigation frequency based on WFD method and application of 227.4 kg ha $^{-1}$ NPS fertilizer (Table 4.2). The least leaf area index (3.09) of potato plants was observed with the interaction effect of CWR method and non-application of NPS fertilizer (control treatment).

The results of the present study clearly indicated an increase of leaf area index with increased NPS fertilizer rates in both irrigation frequency determination methods. However, the increase in leaf area in WFD method was more expressed than in CWR method which is probably associated with the improved nutrient use efficiency of plants which intern promoted the growth and development of potato plants. The increase in leaf area of potato plants was also observed with an increase in fertilizer rates and proper irrigation scheduling programs as indicated by the findings of various researchers which is generally in line with the findings of the present study Bradley (2005); Geremew Eticha (2008); Shfiferaw Boke (2014).

Table 4.1: Main effects of NPS fertilizer rate and irrigation frequency determination method on growth parameters of potato in Koga Irrigation Scheme

Treatment	Growth parameters				
	PH (cm)	SN (count/hill)	LAI	DTF (day)	DTM (day)
Method of irrigation frequency determination					
WFD	55.24^{a}	7.93^{a}	5.15^{a}	76.28^{a}	108^{a}
CWR	51.26^{b}	7.38^{b}	4.80^{b}	74.50^{b}	107^{b}
Sig. Deference	**	**	**	**	**
NPS fertilizer rate (kg ha^{-1})					
0	41.52^{e}	5.47^{f}	3.26^{f}	67.2^{e}	103^{e}
90.8	47.55^{d}	6.57^{e}	4.30^{e}	71.2^{d}	106^{d}
136.2	52.05^{c}	7.5^{d}	5.00^{d}	75.2^{c}	107^{c}
181.6	53.85^{b}	7.9^{c}	5.44^{c}	77.7^{b}	109^{b}
227.4	62.03^{a}	8.7^{b}	5.73^{b}	78.3^{b}	109^{b}
272.0	62.50^{a}	9.8^{a}	6.16^{a}	82.8^{a}	111^{a}
Mean	53.25	7.65	4.98	75.39	107.67
SE±	0.17	0.04	1.2	0.69	0.28
CV (%)	0.77	2.64	3.10	1.11	0.49
Sig. Deference	**	**	**	**	**

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur DTF= Days to flower, DTM= Days to maturity, PH= Plant height, LAI= Leaf Area Index, SN= Steam number, SE= standard error; CV= coefficient of variation; * Significant at ($P \leq 0.05$), ** highly significant at ($P \leq 0.01$). Means sharing the same letter in column do not differ significantly.

Days to flowering

Days to flowering of potato plants was affected by NPS fertilizer rates and irrigation water determination methods in their main effects as well as in their interaction effect. While the main effects of both treatments influenced highly significantly ($P < 0.01$). Days to flowering of potato plants was significantly ($P < 0.05$) influenced by the interaction effect of the treatments (Appendix Table 4). The maximum days to flower (76.3 days) of potato plants

was observed when irrigation frequency was determined with WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg ha^{-1} prolonged days to flower (82.8 days) while the lowest days to flower (67.2 days) were observed without NPS fertilizer (Table 4.1).

In the interaction effect, the lowest days to flower (66.7 days) was observed when potato plants were irrigated based on WFD and supplied without NPS fertilizer. The highest day to flower (84.3 days) was observed the application of NPS fertilizer at the rate of 272 kg ha^{-1} and irrigation based on CWR method (Table 4.2).

The results of the present study clearly indicated an increase in number of flowering days with increased NPS fertilizer rates in both irrigation frequency determination methods. However, the increasing in days to flowering in WFD method was more expressed than in CWR method which is prolonged days to flower where the application of 272 kg ha^{-1} NPS prolonged the days to flowering by seventeen days compared to the control.

The increase in fertilizer rate application prolonged days to flowering in the findings of various researchers which is generally in line with the findings of the present where excess application of NP fertilizer rates delayed days to flowering (Anita (2005); Bradley (2005); Geremew Eticha (2008)).

Days to maturity

Days to maturity of potato plant was affected by NPS fertilizer rates and irrigation water determination methods in their main effects as well as in their interaction effect influenced highly significantly ($P < 0.01$) as indicated in Appendix Table 4. The highest days to maturity (108 days) of potato plants was observed when irrigation frequency was determined with WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg ha^{-1} increased days to flowering (111 days) while the lowest days to flowering (103 days) were observed on plants without NPS fertilizer (Table 4.2).

In the interaction effect, the lowest days to maturity (102 days) was observed when potato plants were not supplied with NPS fertilizer and but irrigated based on WFD method. The highest day to maturity (112 days) was observed when potato plants were supplied with the 272 kg ha^{-1} NPS fertilizer and irrigation based on CWR method (Table 4.2).

The results of the present study clearly indicated an increase NPS fertilizer rates in both irrigation frequency determination methods prolonged days to maturity. However, the

increase in days to maturity in CWR method was more expressed than in WFD method which prolonged the days to maturity. Non-application of NPS fertilizer and WFD irrigation method hastened days to maturity by six days compared to higher application of NPS fertilizer and CWR irrigation method. In general, the maturity of potato crop was hastened under lower NPS rates and irrigated based on WFD irrigation method than the highest NPS rates and irrigated based on CWR irrigation method where the application of 272 kg ha^{-1} NPS fertilizer delayed the days to maturity by six days compared to the control (Table 4:2). These results were in line with the findings of Zelealem Ayichew (2009), Bradley (2005) and Geremew Eticha (2008) where excess NP fertilizer rates delayed the days to maturity of potato.

Table 4.2: Growth of potato plants as influenced by the interaction effects of NPS fertilizer rates and irrigation frequency determination methods in Koga Irrigation Scheme

Irrigation frequency determination method	NPS fertilizer rates (kg ha $^{-1}$)	DTF	DTM	PH	LAI	SN
WFD	0	66.67^{g}	102.0^{i}	42.73^{i}	3.44^{i}	5.77^{h}
	90.8	69.67^{f}	106.67^{f}	50.00^{g}	4.67^{g}	6.63^{g}
	136.2	74.00^{e}	107.00^{ef}	53.67^{e}	5.11^{f}	7.70^{e}
	181.6	77.33^{cd}	108.00^{d}	54.97^{d}	6.05^{d}	8.07^{cd}
	227.4	78.00^{c}	109.00^{c}	65.20^{a}	5.81^{b}	9.03^{b}
	272	81.33^{b}	111.00^{b}	60.20^{b}	6.37^{a}	10.37^{a}
CWR	0	74.50^{d}	104.0^{h}	40.30^{j}	3.09^{j}	5.17^{i}
	90.8	72.67^{e}	105.33^{g}	45.10^{h}	3.93^{h}	6.50^{g}
	136.2	76.33^{d}	107.67^{de}	50.43^{g}	4.81^{g}	7.20^{f}
	181.6	78.00^{c}	109.67^{c}	52.73^{f}	5.37^{e}	7.73^{de}
	227.4	78.67^{c}	109.67^{c}	58.87^{c}	5.65^{cd}	8.37^{c}
	272	84.33^{a}	112.00^{a}	64.80^{a}	5.94^{b}	9.30^{b}
Mean		75.39	107.67	53.25	5.02	7.65
SE±		0.69	0.28	0.17	1.2	0.04
CV (%)		1.11	0.49	0.77	3.10	2.64
Sig. difference		*	**	**	*	**

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur DTF= Days to flower, DTM= Days to maturity, PH= Plant height, LAI= Leaf Area Index, SN= Steam number, SE= standard error; CV= coefficient of variation; * Significant at ($P \leq 0.05$), ** highly significant at ($P \leq 0.01$). Means sharing the same superscript letter do not differ significantly.

4.1.2 Yield and yield components of potato

Average tuber weight

The analysis of variance revealed that NPS fertilizer rate and method of irrigation frequency determination in their main effects as well as in their interaction effect influenced the average tuber weight of potato. While the main effects of both treatments influenced highly significantly ($P < 0.01$), the tuber weight of potato was significantly ($P < 0.05$) influenced by the interaction effect of the treatments (Appendix Table 6). The highest bulb weight (77.5g) of potato was obtained when irrigation frequency was determined with WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg NPS ha^{-1} produced the biggest tuber of potato (85.3 g) while the smallest tuber weight (51.1g) was obtained from potato plants without NPS fertilizer (Table 4.3).

In the interaction effect, the biggest potato tuber weight (88.4g) was recorded at 272 kg ha^{-1} NPS fertilizer with irrigation frequency determination method of WFD. The smallest average tuber weight (42.5g) was recorded on potato plants without NPS fertilizer and irrigated based on CWR method. Moreover application of medium rates of NPS fertilizer rates and irrigation frequency determined based on WFD method produced potato tubers which were statistically similar with those potato tubers produced with high NPS fertilizer rates and irrigation frequency based on CWR method (Table 4.4). Generally, the increase in NPS fertilizer was more effective on tuber weight when potato plants were irrigated based on the WFD method than CWR method.

Based on the results of the present study the application of irrigation water based on the WFD method may save the rate of fertilizer application including NPS as the method probably improves the nutrient use efficiency of potato plants as indicated in this study. The developmental stages of plants including potato are very crucial for their responses towards the management activities including irrigation water and fertilizer applications as indicated by Geremew Ethica (2008) and Zelealem Ayichew (2009) who reported significant response of average tuber weight production of potato with increased level of NPK.

Tuber dry matter

The analysis of variance showed that tuber dry matter content of potato was very highly significantly ($P < 0.001$) influenced by NPS fertilizer rates in the main effect while irrigation frequency determination methods had non-significant effect on the dry matter content of

potato tubers. Similarly, the interaction effect of NPS fertilizer rates and irrigation frequency determination methods had non-significant effect on potato tuber dry matter content (Appendix Table 8).

Generally the tuber dry matters increased with increasing NPS fertilizer rates. However plants especially supplied with higher rates of NPS fertilizer produced tubers with similar higher dry matter content ranging from 18.21% to 20.09 %. On the other hand plants which were not supplied with NPS fertilizer produced tubers with the lowest dry matter content (14.12 %) as indicated in (Table 4.3). The increase in dry mater content with increased NPS fertilizer rates may be associated with improved growth and development of plants and thus increased assimilates in potato tubes which is generally in line with the findings of various researchers (Zelealem Ayichew (2009), Tesfaye Abebe (2012) and Sharma (2015)

Specific gravity

The analysis of variance showed that the specific gravity of potato was highly significantly (P < 0.01) influenced by the main effect of NPS fertilizer rates and irrigation frequency determination methods. The interaction effects of NPS feretilizer and determination of irrigation frequency method had no significant influence on the specific gravity of potato tubers (Appendix 8).

Potato plants irrigated based on WFD method produced tubers with relatively high specific gravity than those irrigated based on CWR method. While the higher rates of NPS fertilizer produced potato tubers with the highest specific gravity, tubers from non fertilized potato plants recorded the lowest specific gravity as indicated in Table 4.3 which can be probably associated with the increased stored assimilates in potato tubers with higher rates of NPS fertilizer. The results of this study are in agreement with the findings of Zelealem Ayichew (2009), Sharma (2011) and Tesfaye Abebe, (2013) who reported significant increase of specific gravity of potato tubers with the increased fertilizer rates.

Table 4. 3: Main effects of NPS fertilizer rate and method of determination of irrigation frequency on yield parameters of potato in Koga Irrigation Scheme

Main factors		ATW (g/tuber)	TDM (%)	SPG
Determination of irrigation frequency	WFD	77.5[a]	18.07	1.28[a]
	CWR	70.7[b]	17.12	1.26[b]
Sig. Difference		**	NS	**
NPS fertilizer rate				
	0	51.1[c]	14.43[c]	1.20[c]
	90.8	74.3[b]	16.89[b]	1.25[b]
	136.2	75.2[b]	16.44[b]	1.25[b]
	181.6	76.7[b]	18.21[ab]	1.26[b]
	227.4	81.9[ab]	20.09[a]	1.33[a]
	272.0	85.3[a]	19.58[a]	1.32[a]
Mean		74.2	17.60	1.27
SE±		9.81	10.87	0.01
CV (%)		8.51	9.02	1.32
Sig. Difference		**	**	**

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur; TDM=Tuber dry matter, ATW=Average tuber weight, SPG=specific gravity, SE= standard error; CV = coefficient of variation; * Significant at ($P \leq 0.05$), ** highly significant at ($P \leq 0.01$). Means sharing the same letter in column do not differ significantly

Table 4.4: Interaction effects of NPS fertilizer rates and irrigation frequency determination method on yield parameters of potato in Koga Irrigation Scheme.

Irrigation frequency determination method	NPS fertilizer rates (kg ha $^{-1}$)	ATW (g/tuber)	TDM (%)	SPG
WFD	0	59.73^{e}	14.79	1.22
	90.8	79.01^{acd}	17.72	1.25
	136.2	82.22^{ab}	16.44	1.26
	181.6	81.37^{ab}	19.18	1.27
	227.4	83.61^{ab}	20.56	1.35
	272	88.40^{a}	19.74	1.34
CWR	0	42.45^{f}	14.07	1.20
	90.8	69.54^{cde}	16.05	1.25
	136.2	68.11^{de}	16.44	1.23
	181.6	72.03^{bcd}	17.14	1.25
	227.4	80.21^{abc}	19.62	1.30
	272	82.24^{ab}	19.41	1.30
Mean		74.09	17.60	1.27
SE±		0.01	10.67	0.02
CV (%)		8.51	9.02	1.32
Sig. difference		**	NS	NS

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur TDM=Tuber dry matter, ATW=Average tuber weight, SPG=specific gravity, SE= standard error; CV = coefficient of variation; * Significant at ($P \leq 0.05$), ** highly significant at ($P \leq 0.01$). Means sharing the same letter in column do not differ significantly

Tuber yield per hill

Tuber yield per hill of potato was affected by NPS fertilizer rates and irrigation water determination methods in their main effects but not by their interaction effect. The main effects of both treatments influenced highly significantly ($P < 0.01$) the tuber yield of potato plants (Appendix table 6). The highest tuber yield per hill (0.99 kg) of potato plants was obtained when potato plants were irrigated based on irrigation frequency determination

method of WFD. On the other hand the application of NPS fertilizer at the rate of 272 kg ha^{-1} produced tuber yield per hill of 1.4 kg while the lowest tuber yield per hill (0.5 kg) was obtained from potato plants without NPS fertilizer (Table 4.5).

The results of the present study clearly indicated that an increase in NPS fertilizer rates increased the tuber yield per hill which are generally in agreement with the findings of Geremew Eticha, (2008) and Zelealem Ayichew, (2009), who reported significant increase in tuber yield per plant of potato with increased NPS fertilizer rates. Moreover, the increase in tuber yield per hill in WFD method may be associated with efficient nutrient utilization of potato plants.

Table 4.5: Main effects of NPS fertilizer rate and method of irrigation frequency determination on yield of potato in Koga Irrigation Scheme

Main factors		Tuber yield (kg/hill)	Marketable tuber yield (t ha^{-1})	Unmarketable tuber yield (t ha^{-1})	Total tuber yield (t ha^{-1})
Determination of irrigation frequency	WFD	0.99^{a}	33.90^{a}	1.2^{b}	35.09^{a}
	CWR	0.88^{b}	29.99^{b}	1.4^{a}	31.44^{b}
Sig. Difference		**	NS	**	**
NPS fertilizer rate	0	0.5^{e}	14.85^{f}	2.4^{a}	17.32^{f}
	90.8	0.8^{d}	27.32^{e}	1.1^{cd}	28.40^{e}
	136.2	0.9^{c}	30.67^{d}	1.7^{b}	32.38^{d}
	181.6	0.95^{c}	32.37^{c}	1.2^{c}	33.57^{c}
	227.4	1.2^{b}	39.47^{b}	0.9^{d}	40.40^{b}
	272.0	1.4^{a}	47.02^{a}	0.5^{e}	47.53^{a}
Mean		0.94	31.94	1.3	33.27
SE±		0.01	0.80	0.04	0.73
CV (%)		4.5	2.80	15.74	2.57
Sig. Difference		**	**	**	**

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur TYPP=Tuber yield per plant, MTY= Marketable tuber yield UNMTY=Unmarketable tuber yield, TTY=Total tuber yield, SE= standard error; CV= coefficient of variation; * Significant at ($P \leq 0.05$), ** highly significant at ($P \leq 0.01$). Means sharing the same letter in column are not significantly different

Marketable tuber yield

The analysis of variance revealed that the marketable tuber yield of potato was highly significantly ($P < 0.01$) influenced by NPS fertilizer rates and irrigation methods in their main effects but not significantly influenced in their interaction effect (Appendix Table 7). The highest marketable tuber yield of potato was obtained when the application of water was determined based on WFD (33.90 t ha^{-1}). Moreover the application of NPS fertilizer at the rate of 272 kg ha^{-1} produced the highest marketable tuber yield (47.02 t ha^{-1}) while the lowest marketable tuber yield (14.85 t ha^{-1}) was obtained on potato plants without NPS fertilizer as indicated in Table 4.5.

The use of wetting front detector (WFD) for determination of frequency of irrigation water may improve the nutrient use efficiency of potato plants which intern increase the marketable tuber yield as indicated in this study. Similar results were also obtained in crop-water productivity analysis (Appendix Table 3) where the crop water productivity of WFD (7.14 kg m^{-3}) was much higher than the crop-water productivity of CWR method (6.55 kg m^{-3}). The results of the present study are generally in agreement which the findings of Shock (2007), Alva (2008), Geremew Ethica, (2008) and Zelealem Ayichew, (2009) who reported an increase in marketable yields of potato through proper scheduling of irrigation water using WFD and application of NPS fertilizer.

Unmarketable tuber yield

As indicated in Appendix Table 7 unmarketable tuber yield of potato plants was affected by NPS fertilizer rates and irrigation water determination methods in their main effects as well as in their interaction effect highly significantly ($P < 0.01$).The highest unmarketable tuber yield (1.4 t ha^{-1}) of potato was obtained when irrigation frequency was determined with CWR. Potato plants without NPS fertilizer produced the highest unmarketable tuber yield of 2.4 t ha^{-1}.while those supplied with the highest NPS fertilizer rate produced the lowest unmarketable tuber yield of 0.50 t ha^{-1} (Table 4.5).

In the interaction effect, the highest unmarketable tuber yield (2.77 t ha^{-1}) was obtained when potato plants was not supplied with NPS fertilizer and irrigated based on CWR method. The least unmarketable tuber yield (0.33 t ha^{-1}) of potato plants was produced with the interaction effect of WFD method and 272 kg ha^{-1} NPS fertilizer.

The results of the present study clearly indicated an increase of unmarketable tuber yield with decreasing NPS fertilizer rates in both irrigation frequency determination methods. However, the increase in unmarketable tuber yield in CWR method was much more expressed than in WFD method which is probably associated with the improved nutrient use efficiency of plants which intern promoted the growth and development of potato plants. The increase in unmarketable tuber yields of potato plants was also observed with decreasing fertilizer rates and improper irrigation scheduling programs as indicated by the findings of various researchers which are generally in line with the findings of the present study of Zelealem Ayichew, (2009).

Total tuber yield

The analysis of variance revealed that total tuber yield of potato was highly significantly ($P< 0.01$) influenced by the main effects of NPS fertilizer rates and irrigation frequency determination methods. However the interaction effects of both factors had not influenced the total yield of potato (Appendix Table 7, Table 4.6). The highest total tuber yield of potato was obtained when the application of water was determined based on WFD (35.09 t ha^{-1}). Moreover the application of NPS fertilizer at the rate of 272 kg ha^{-1} produced the highest total tuber yield (47.53 t ha^{-1}) while potato plants without NPS fertilizer produced the lowest total tuber yield (17.32 t ha^{-1}) as indicated in (Table 4.5). Although non-significant different, potato plants irrigated based on WFD produced relatively high total tuber yield with increasing NPS fertilizer than those irrigated based on CWR (Table 4.6).

The increased total tuber yield in wetting front detector (WFD) method in the present study may be associated with improved nutrient use efficiency of potato plants which intern increase the total tuber yield which is generally in line with the findings of Shiferaw Boke, (2014) and Zelealem Ayichew, (2009) who reported significant response of total tuber yield of potato with increased level of NPS fertilizer and proper scheduling of irrigation.

Table 4.6: Interaction effects of NPS fertilizer rates and irrigation frequency determination method on yield parameters of potato in Koga Irrigation Scheme

Irrigation frequency determination method	NPS fertilizer rates (kg ha $^{-1}$)	TY (kg/hill)	MTY (t ha^{-1})	UNMTY (t ha^{-1})	TTY (t ha^{-1})
WFD	0	0.54	16.67	2.17^{b}	18.33
	90.8	0.87	29.33	0.83^{ef}	30.17
	136.2	0.96	32.87	1.53^{c}	34.4
	181.6	0.98	33.93	1.13^{de}	35.06
	227.4	1.22	42.03	0.80^{ef}	42.83
	272.0	1.41	48.56	0.33^{g}	49.27
CWR	0	0.46	13.03	2.77^{a}	15.80
	90.8	0.76	25.30	1.33^{cd}	26.63
	136.2	0.84	28.47	1.90^{b}	30.37
	181.6	0.91	30.80	1.27^{cd}	32.06
	227.4	1.08	36.90	1.07^{def}	37.96
	272.0	1.31	45.47	0.70^{f}	45.80
	272.0	1.31	45.47	0.70^{f}	45.80
Mean		0.94	31.94	1.32	33.27
SE±		0.01	0.80	0.04	0.73
CV (%)		4.48	2.81	15.74	2.57
Sig. difference		NS	NS	**	NS

Where, CWR = Crop water requirement; WFD= Wetting front detector; NPS= Nitrogen, phosphors and sulfur TY=Tuber yield per plant, MTY= Marketable tuber yield UNMTY=Unmarketable tuber yield, TTY=Total tuber yield, SE= standard error; CV= coefficient of variation; * Significant at (P≤0.05), ** highly significant at (P≤0.01). Means sharing the same letter in column are not different

4.2: Relationship between selected growth parameters and total bulb yield of potato as influenced by NPS fertilizer and method of irrigation frequency determination in Koga Irrigation Scheme

The analysis of correlation showed that plant height, days to maturity, leaf area, stem per hill, average tuber weight, dry matter content and marketable tuber yield was highly positively correlated($P < 0.001$) with yield of potato(Table 4.7).

The analysis of correlation also showed that specific gravity was highly negatively correlated ($P < 0.001$) with plant height, days to maturity, leaf area, stem per hill and average tuber weight (Table 4.7). Positively correlated parameter showed that the yield was increased they as yield related parameter increased while negatively correlated parameters showed that yield increased the parameters decreased as indicated by Zelealem Ayichew (2009).

Table 4.7. Relation between growth yield parameter of potato as affected by NPS fertilizer rate and irrigation method treatments at Koga 2015/16.

	PH	LA	SPH	ATW	DM	SPG	TYPH	MTY
PH	1							
LA	0.95**	1						
SPH	0.96**	0.95**	1					
ATW	0.76**	0.80**	0.75**	1				
DM	0.80**	0.76**	0.78**	0.78**	1			
SPG	-0.41**	-0.48**	-0.41**	-0.41**	-0.26^{NS}	1		
TYPH	0.96**	0.95**	0.97**	0.80**	0.77**	-0.47**	1	
MTY	0.96**	0.96**	0.97**	0.82**	0.78**	-0.47**	0.99**	1

Where, PH = plant height, LA= leaf area; SPH= stem per hill, ATW= average tuber weight; DM= dry matter content; SPG= specific gravity; TYPH= tuber yield per hill; MTY= marketable tuber yield; * Significant at ($P \leq 0.05$); ** highly significant at ($P \leq 0.01$).

4.3 Economic Analysis

4.3.1. Partial budget analysis

Partial budgeting is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. According to CIMMYT (1988) the partial budget analysis includes the total variable costs and net benefits of each treatment. The gross benefit of the treatments will be calculated using the adjusted yield and the field price of the crops while the net benefit will be calculated by subtracting variable costs from the gross benefit of each treatment. In the present study, the field price of potato and NPS fertilizer cost were taken as 3.00 Birr kg^{-1} and 15.50 Birr kg^{-1}, respectively. The average labor cost was also assumed to be 50 Birr per man-day. In this regard, labor cost required for application of water using WFD was generally lower compared to CWR although the number of days for the latest was lower than the former (Appendix Table 1). This is due to the fact that the time required in WFD were lower than in CWR that intern reduce the cost of water application in WFD. Moreover the total potato tuber yield was adjusted by 15%.

According to CIMMYT (1988) the highest net benefit of potato was obtained by the combination of 272 kg ha^{-1} NPS fertilizer and irrigation frequency based on WFD with the value of Birr 107,558.00 while the lowest net benefit was recorded at 0 kg ha^{-1} NPS fertilizer and irrigation based on CWR method (Table 4.8).

Table 4.8: Partial budget analysis of potato

Treatments Combinations (kg ha^{-1})	Average yield (t ha^{-1})	Adjusted yield (t ha^{-1})	Gross field benefit (Birr ha^{-1})	Cost of NPS (Birr ha^{-1})	Cost of labor to apply NPS (Birr ha^{-1})	Cost of labor to apply water (Birr ha^{-1})	Total costs that vary (Birr ha^{-1})	Net benefits (Birr ha^{-1})
0 NPS x WFD	16.67	14.17	42510	0	0	7406.41	7406.41	35103.60
0 NPS x CWR	13.03	11.08	33240	0	0	9876.54	9876.54	23363.50
90.8 NPS x CWR	25.30	21.51	64530	1407.40	2777.78	9876.54	14061.70	50468.30
90.8 NPS x WFD	29.33	24.93	74790	1407.40	2777.78	7406.41	11591.60	63198.40
136.2 NPS x WFD	32.87	27.93	83790	2111.10	3148.15	7406.41	12665.70	71124.30
136.2 NPS x CWR	28.47	24.20	72600	2111.10	3148.15	9876.54	15135.80	57464.20
181.6 NPS x WFD	33.93	28.84	86520	2814.80	3703.70	7406.41	13924.90	72595.10
181.6 NPS x CWR	30.80	26.18	78540	2814.80	3703.70	9876.54	16395.00	62145.00
227.4 NPS x CWR	36.90	31.37	94110	3524.70	4074.07	9876.54	17475.30	76634.70
227.4 NPS x WFD	42.03	35.73	107190	3524.70	4074.07	7406.41	15005.20	92184.80
272 NPS x CWR	45.47	38.65	115950	4216.00	4629.63	9876.54	18722.20	97227.80
272 NPS x WFD	48.57	41.28	123840	4216.00	4629.63	7406.41	16252.00	107588.00

NPS_0WFD=0 kg NPSha^{-1} and WFD irrigation method, NPS_0 CWR=0 kg NPSha^{-1} and crop water requirement method

4.3.2: Marginal rate of return

To calculate marginal rate of return, first the dominance analysis was carried out by listing the treatments in order of increasing the total variable costs. According to CIMMYT (1988) any treatments that have net benefits less or equal to the previous treatment was denominated and eliminated from further analysis (Table 4.10). Accordingly, the highest marginal return was recorded from potato plants which were supplied with 227.4kg ha^{-1} NPS fertilizer and irrigated based on WFD method of irrigation frequency determination with the value of 1813.36 followed by those plants supplied with 272 kg ha^{-1} NPS fertilizer and irrigated based on WFD method (Table 4.9).

Table 4.9: Dominance analysis for potato tuber yield as affected by NPS fertilizer (kg ha^{-1}) and method of irrigation frequency determination at Koga Irrigation Scheme

Treatment combinations	Total variable cost (Birr ha^{-1})	Net benefits (Birr ha^{-1})	Dominance analysis
0 NPS x WFD	7406.41	35103.60	
0 NPS x CWR	9876.54	23363.50	Dominated
90.8 NPS x WFD	11591.60	63198.40	
136.2 NPS x WFD	12665.66	71124.30	
181.6 NPS x WFD	13924.91	72595.10	
90.8 NPS x CWR	14061.72	50468.30	Dominated
227.4 NPS x WFD	15005.18	92184.80	
136.2 NPS x CWR	15135.79	57464.20	Dominated
272 NPS x WFD	16252.04	107588.00	
181.6 NPS x CWR	16395.04	62145.00	Dominated
227.4 NPS x CWR	17475.31	76634.70	Dominated
272 NPS x CWR	18722.17	97227.80	Dominated

Table 4.10: Marginal rate of return (MRR) of potato yield as influenced with NPS fertilizer and irrigation frequency determination method in Koga Irrigation Scheme

Treatment combinations	Total variable cost (Birr ha^{-1})	Net benefits (Birr ha^{-1})	MRR (%)	Rank
0 NPS x WFD	7406.41	35103.60	0.00	
90.8 NPS x WFD	11591.60	63198.40	671.29	C
136.2 NPS x WFD	12665.70	71124.30	737.91	D
181.6 NPS x WFD	13924.90	72595.10	116.80	E
227.4 NPS x WFD	15005.20	92184.80	1813.36	A
272 NPS x WFD	16252.00	107588.00	1235.42	B

Chapter 5: CONCLUSIONS AND RECOMMENDATION

5.1: Conclusions

A field experiment was conducted in Meacha Worda at Koga Research Site of Adet Agricultural Research Center, Amhara region, Ethiopia. The objectives of the experiment were to investigate the effects of irrigation frequency determination method and NPS fertilizer rates on the yield and yield components of potato and to identify the optimum irrigation frequency determination method and rate of NPS fertilizer for optimum productivity of potato in the study area. The results of the present study showed that NPS fertilizer rates and methods of irrigation frequency determination in their main effects influenced almost all the tested growth, yield and yield parameters of potato. In their interaction effect, potato parameters including 50% flowering, 90% maturity, plant heights, leaf area index and average tuber weights were significantly influenced. Moreover, significantly maximum marketable tuber yields of potato were obtained when potato plants were irrigated based on the WFD method and when the potato plants were supplied with 272 kg ha^{-1} NPS fertilizer with the values of 33.9 t ha^{-1} and 47.02 t ha^{-1}, respectively. Plants without NPS fertilizer were inferior in all the tested parameters of potato. Furthermore, application of irrigation water based on WFD produced the highest crop-water productivity (7.14 kg m^{-3}) than application of irrigation water based on CWR (6.55 kg $m^{-3)}$ which indicates the improved water use efficiency in WFD method. The highest total tuber yield of 41.28 t ha^{-1} was found when potato plants were supplied with 272 kg ha^{-1} NPS fertilizer and irrigated based on WFD method with the net benefit of 107,588.00 Birr ha^{-1}. However, the highest marginal rate of return (MRR) was recorded on potato plants supplied with 227.4 kg ha^{-1} NPS fertilizer and irrigated based on WFD irrigation determination method with the value of 1,813.36%.

5.2: Recommendation

Based on the results of the present study, it is recommended that NPS fertilizer at the rate of 227.4 kg ha^{-1} and irrigation frequency determination method based on WFD are economically and agronomical feasible for the production of potato in Koga Irrigation Scheme. However, as the results are limited to one season and location, further study should be done over more seasons and locations to establish the forceful recommendations so as to improve the production and productivity of potato in the study area.

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APPENDIX

Appendix Table 1: The date and amount of water applied (mm) per plot by two irrigation methods at different stage of the crop during the experiment.

CWR				WFD			
Crop stage	Days	Amount of water for 18m2	Crop time(110days)	Crop stage	Days	Amount of water	Crop time(110days)
Initial stage	Jan 16	40 mm	10	Initial stage	Jan 16	25 mm	10
	Jan 26	40	20		Jan 23	25 mm	17
	Total	80			Jan 30	25 mm	24
					Total	75 mm	
Development stage	Feb 5	50mm	30	Development stage	Feb 7	30 mm	31
	Feb 15	50	40		Feb 14	35 mm	38
	Feb 25	50	50		Feb 21	35 mm	45
	Total	150mm			Feb 28	30 mm	52
					Total	130 mm	
Mid stage	Mar 7	45mm	60	Mid stage	Mar 6	35 mm	59
	Mar17	45 mm	70		Mar 13	35 mm	66
	Mar27	37 mm	80		Mar 20	35 mm	73
	total	127			Mar 27	30 mm	80
End stage	Apr 6	42.6mm	90			135mm	
	Apr 16	38.4 mm	100				
	Apr 26	38.4mm	110	End stage	Apr 3	35mm	87
Total		119.4			Apr 10	25 mm	93
					Apr 17	25 mm	100
					Apr 24	15 mm	107
					Apr 30	18 mm	113
				Total		118mm	
All total		476.4mm		All Total		458mm	

Appendix Table 2: Average mean rain fall (mm), mean minimum and maximum temperature (^{0}C) at Koga during the experimentation period, 2015/2016

Elements	Months				
	Jan	Feb	March	April	Mean
Rain fall (mm)	0.00	0.00	0.00	0.30	0.30
Minimum temperature (^{0}C)	6.70	7.50	11.80	11.50	9.36
Maximum temperature(^{0}C)	27.40	28.60	32.60	32.90	30.36

***Source: National Meteorology Agency, Bahir Dar area Merawi Station*.**

Appendix Table 3: Water productivity

Irrigation method	Yield (kg ha^{-1})	Water requirement (m^3 ha^{-1})	Water productivity (kg m^{-3})	Efficiency (%)
CWR	30000	4764	6.55	-
WFD	34000	4580	7.14	8.26

Appendix Table 4: Mean square values of phenology parameter of potato as influenced by NPS rate and Irrigation method.

Source of Variation	Degrees of freedom	Days to Flowering	Days to Maturity
Replication	2	0.36^{NS}	1.5**
NPS rate	5	185.71**	52.20**
Irrigation method	1	28.44**	5.44**
NPS*Irrigation	5	1.91*	2.04**
Error	22	0.69	0.28

Where, ** = highly significant; * = significant; ns = Non-significant

Appendix Table 5: Mean square values of Growth related parameter of potato as influenced by NPS rate and Irrigation method.

Source of Variation	Degrees of freedom	Plant height	Leaf area	No of main stem per hill
Replication	2	0.65^{NS}	65.78^{NS}	0.08^{NS}
NPS rate	5	401.60**	6.7**	14.29**
Irrigation method	1	143.20**	5.5**	2.72**
NPS*Irrigation	5	3.95**	6.57*	0.15**
Error	22	0.17	0.20	0.04

Where, ** = highly significant; * = significant; ns = Non-significant

Appendix Table 6: Mean square values of Yield and Yield components of potato as influenced by NPS rate and Irrigation method.

Source of Variation	Degrees of freedom	Tuber yield per hill	Ava. Tuber weight
Replication	2	0.00^{NS}	60.22^{NS}
NPS rate	5	0.51**	869.48**
Irrigation method	1	0.10**	416.26**
NPS*Irrigation	5	0.00^{NS}	134.42 *
Error	22	0.00	39.81

Where, ** = highly significant; * = significant; ns = Non-significant

Appendix Table 7: Mean square values of Yield and Yield components of potato as influenced by NPS rate and Irrigation method.

Source of Variation	Degrees of freedom	Unmarketable Tuber yield	Marketable Tuber Yield (tone)	Total tuber yield(tone)
Replication	2	0.03^{NS}	5.54*	3.31^{ns}
NPS rate	5	2.80**	1095.94**	640.05^{**}
Irrigation method	1	0.56**	209.24**	120.27^{**}
NPS*Irrigation	5	0.18**	1.41^{ns}	0.74^{ns}
Error	22	0.04	1.23	0.72

Where, ** = highly significant; * = significant; ns = Non-significant

Appendix Table 8: Mean square values of Quality parameter of potato as influenced by NPS rate and Irrigation method.

Source of Variation	Degrees of freedom	Dry matter content (%)	Specific gravity
Replication	2	0.26^{NS}	0.00^{NS}
NPS rate	5	107.40**	0.01**
Irrigation method	1	32.49^{NS}	0.01**
NPS*Irrigation	5	3.70^{NS}	0.00^{NS}
Error	22	10.07	0.00

Where, ** = highly significant; * = significant; ns = Non-significant

BIOGRAPHICAL SKETCH

The author, Minwyelet Jembrie, was born on 15 October 1971 E.C in Yelemana Densa woreda, West Gojjam Zone of Amhra Regional State of Ethiopia. He attended elementary education (grade 1-8) at Adet Elementary School from 1977 - 1985. After completing elementary education, he was enrolled at Adet Secondary high School at Adet town, where he pursued and completed his Secondary Education from 1986– 1990 (grade 9-12). He then joined Extension program Bahir Dar University in January 1996 and graduated with Diploma in Biology. In 2001 additional graduate the degree of Bachelor of Art in Management and graduate the Degree of Bachelor of Sciences in Plant Science in July 2003. Upon graduation, he was employed by Adet Agricultural research center was assigned to work as Technical Assistance and Researcher of horticultural crops. After serving the Adet Agricultural research center for four years by Bachelor of Science in plant science, he joined the School of Graduate Studies of Bahir Dar University in October 2007 to pursue a study leading to the Degree of Master Science in Horticulture.