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Effect of Irrigation Interval and NP Fertilizer Rates on Agronomic Performance of Potato (*Solanum tuberosum* L.) at Boloso, Southern Ethiopia

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Abstract

Even though potato is the most important food security and cash crop, its productivity is constrained by improper irrigation water and fertilizer application. Hence, the study was conducted to evaluate the effect of irrigation interval and NP fertilizer rates on yield and yield components of potato at Boloso Sore, Southern Ethiopia. The treatments consisted of three levels of irrigation interval (every 5, 7 and 9 days) and five rates of NP fertilizer (0:0; 55.5:44.7; 111:89.4; 166.5:134 and 222:178.7 kg ha^{-1}). The treatments were laid out in split plot design with three replications. Data were collected on growth, yield and yield related parameters of the crop. Results of the study revealed that main and interaction effects of the treatments significantly influenced most of the studied parameters. Statistically, the lowest (14.55 t ha^{-1}) and the highest (43.26 tha^{-1}) marketable tuber yield were recorded due to combined effects of every 9 days irrigation interval with application of 0:0 kg NP ha^{-1} and every 5 days irrigation with application of NP at the rate of 222: 178.7 kg ha^{-1}, respectively. Regarding economic analysis, the maximum net benefit (372,441.55 $ETBha^{-1}$) and acceptable marginal rate of return (2558) were achieved from application of irrigation water in every 5 days and NP fertilizer at the rate of 222: 178.7 kg ha^{-1}. Therefore, this treatment combination can be considered by potato producers in order to harvest maximum marketable tuber yield and best economic return in situations similar to this experiment.

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Keywords

Jalene, Marketable tuber yield, Unmarketable tuber yield

Introduction

Potato (*Solanum tuberosum* L.) is originated in the highlands of tropical and subtropical regions of South America (MOA, 2011). It is the most widely consumed vegetable in the world playing a major role in national food security and nutrition, poverty reduction and income generation, and provides employment in the production, processing and marketing sub-sectors (Lung'aho *et al.*, 2007).

Despite its importance in improving food security and cash income of smallholder growers in Ethiopia (Tufa *et al*., 2015), potato one of the most important irrigated (Kassu *et al*., 2017) but very low yielding crops around 3.7 t ha^{-1} in Ethiopia (CSA, 2015) compared with world average yield of 16.8 t ha^{-1} (FAOSTAT, 2008).This could be due to poor management of irrigation water (Bezabih and Mengistu, 2011) and low fertility of soil in East Africa (Muriithi and Irungu, 2004). The interval between irrigations depends mainly on soil types and the crop growth stages while crop nutrient requirement is

governed nature of soil, variety, and weather conditions. No information is available on recommendation of irrigation interval and fertilizer rate for the crop in the study area. Hence, this study was aimed at evaluation of response of potato to irrigation interval and NP fertilizer rates.

Materials and Methods

Description of the study area

A field experiment was conducted at farmer's field at Tedisa Kebele/Wolaita Zone, Southern Ethiopia during dry season from December 2018 toApril2019. The area is located at 300km South of Addis Ababa and 2km from Areka town found at 37°40'52" E longitude and 7°3'25"N latitude (Dereje *et al*., 2015) at altitude of 1830 meters above sea level. The area experiences a bimodal type of rainfall and receives an annual rainfall of 1520 mm in bi-modal pattern which extends from March to September and the mean annual maximum and minimum temperatures are 24^0Cand 12^0Crespectively (Simon, 2016).

Treatments, experimental design and procedures

Treatments

The experimental treatments consisted of five combined rates of nitrogen (N) and phosphorus (P)rates in form of P_2O_5 (0:0, 55.5:44.7, 111:89.4, 166.5:134, 222:178.7kgha^{-1}) and three levels of irrigation interval (5, 7 and 9 days) which were arranged in split plot design with three replications. Main plots received irrigation interval while subplots received fertilizer rates. The subplot contained four rows with an area of 9 m^2 (3m x 3m) 10 plants per row. Jalene variety was used as test crop. Land was prepared following traditional famers' practice using oxen plough. Healthy, medium size and well sprouted potato tubers were planted at a spacing of 75cm between rows and 30cm between plants. The entire rate of phosphorus and half the rate of nitrogen was applied at the time of planting and the remaining half of nitrogen was applied 45 days after planting. Urea (46% N) and triple super phosphate (TSP) (46% P_2O_5) fertilizers were used as sources of nitrogen and phosphorus. The irrigation requirement was computed the equation of CROPWAT version 8.0 software and water was applied in furrows by 3 inch Parshall flume at 5cm head. Recommended amount of irrigation water was applied for initial, development, mid-season and late growth stages of the crop using climatic data obtained from Areka agricultural research center which is located approximately 2km south of the trial site. All other agronomic practices were performed as per the recommendation of potato crop except the treatments.

Data collection

Data were collected on days to 50% flowering, days to maturity, plant height (cm), average tuber weight (g), unmarketable tuber number per plant, marketable tuber number per plant, total tuber number per plant, unmarketable tuber yield (t ha^{-1}), marketable tuber yield (t ha^{-1}) and total tuber yield (t ha^{-1}).

Data analysis

All the collected data were subjected to analysis of variance (ANOVA) using SAS version 9.0 statistical software (SAS, 2004).When ANOVA results show significant variation, means were compared using Least Significance Difference (LSD) at 5% level of significance.

Economic analysis

To determine the economic feasibility of the treatments, gross benefit of the treatments was calculated using the adjusted yield (10%) and economic analysis in the form of net benefit analysis and marginal rate of return was done after removal of dominated treatments according to the procedures developed by CIMMYT (1988).

Results and Discussions

Treatment effect on crop phenology, plant height and average tuber weight

Days to 50% flowering, days to physiological maturity, plant height and average tuber weight were significantly differed due to treatment interaction (Table 2). The shortest significant days to 50% flowering (59) and physiological maturity (95.33) were obtained due to combined effect of every 9 days irrigation with application of NP at 0:0 kg NP ha^{-1}(Tables 4 and 5). On the other hand, the longest significant days to 50% flowering (81.33) and days to maturity (115) were resulted from combined application of irrigation at every 5 days and 222:178.7 kg NP ha^{-1}.This result agrees with the finding of Ierna and Mauromicale (2006) who reported increased supply of water in combination with medium or high fertilization rate favored an overall improvement in plant vigor in terms of development of leaves and stems resulting in delayed maturity.

These results are in line with the reports of Yosef (2016) who reported prolonged days to 50% flowering and maturity of different with increase in rates of NP fertilizer. Days to maturity was positively and highly significantly correlated with days to 50% flowering (Table 5).

Increasing irrigation interval above 5 days significantly reduced plant height for each level of fertilizer (Table 2). In contrary, increasing rates of NP were associated with significant increase in plant height for each level of irrigation interval. Accordingly, the shortest (46.67cm) and tallest (79.66cm) plants were found from combined effects of irrigation at every 9 days interval with application of NP at 0:0kg ha^{-1} and irrigation at every 5 days interval with application of NP at 222:178.7 kg ha^{-1}, respectively. The observed maximum value of plant height with due to combination of the shortest irrigation interval and the highest rate of fertilizer might be related to better availability of water and nutrients under this treatment combination as reported by Ierna and Mauromicale (2006).Plant height also showed strong positive and highly significant linear relationship with days to 50% flowering (r = 0.96) and days to maturity (r = 0.94) (Table 5).

All levels of fertilizer showed significantly bigger potato tuber weight at 5 days irrigation interval while increase in irrigation interval above 5 days was resulted in significant reduction in tuber weight for every level of fertilizer (Table 2). The highest potato tuber weight (81g) was recorded at 5 days irrigation interval with 222:178.7 kg NP ha^{-1} rate of fertilizer.

On the contrary, the smallest average tuber weight (41.67g) was recorded from 9 days irrigation interval and application of 0:0 kg NP ha^{-1}. The improvement in average tuber weight under shorter irrigation interval and higher rate of fertilizer treatments could be associated with better availability of moisture and nutrients which can lead to luxuriant growth, more foliage and leaf area and higher supply of photosynthesis thereby production of bigger tubers (Zelalem *et al.,* 2009). Average tuber weight showed strong positive and highly significant linear relationship with days to 50% flowering (r = 0.97), days to maturity (r = 0.89) and plant height (r =0.94) (Table 5) signifying improvement in average tuber weight is linearly related with improvement in these parameters with reduction and increment in irrigation interval and NP fertilizer rates, respectively.

Unmarketable, marketable and total tuber number per plant

All categories of tuber number per plant were significantly varied due to interaction effect of irrigation interval and fertilizer treatments (Table 3).

Interaction effect of every 5 days and 9 days irrigation interval showed significantly minimum and statistically similar unmarketable tuber number per plant (Table 3). On the other hand, combination of all irrigation interval levels with lower rates of fertilizer produced statistically maximum number of unmarketable tubers per plant.

Combined effect of every 9 days irrigation interval with application of NP fertilizer at 0:0 kg ha^{-1} produced the minimum significant marketable tuber number per plant (4.65) followed by the value of tuber number obtained from interaction effect of every 7 days irrigation interval with application of the same fertilizer rate (Table 3). Conversely, combination of every 5 days and 9 days irrigation interval with the maximum level of fertilizer (222; 178.7 kg NP ha^{-1}) produced statistically higher and similar tuber number per plant compared with the remaining treatment combinations.

Irrigating potato in every 7 and 9 days with application of 0:0 kg NP ha^{-1} fertilizer application produced the minimum significant total tuber number per plant (8.64/ 8.23) (Table 3) whereas combination of all levels of irrigation interval with the maximum rate of fertilizer (222; 178.7 kg NP ha^{-1}) produced statistically similar and higher number of tubers per plant compared with the effect of the rest treatment combinations.

The observed increment in marketable and total number of tubers per plant for each irrigation interval with increase in fertilizer levels might to be related to better availability of nutrients which would lead to better root and shoot growths for efficient utilization of other growth resources resulting in production of larger number and large sized tubers. This can further be supported by strong positive and highly significant linear relationship of total tuber number with marketable tuber number ($r= 0.98^{**}$) and average tuber weight (0.96^{**}) (Table 5).

Tuber yields (t ha^{-1})

All categories of tuber yields were also significantly responded to interaction effect of irrigation interval and fertilizer treatments (Table 4).

Combined effect of every 5 days irrigation interval and the highest rate of fertilizer (222:178.7 NP kg ha^{-1}) produced significantly minimum unmarketable tuber yield (0.44t ha^{-1}) followed by values obtained due to interaction effect of the same irrigation interval treatment and application of 166.5:134 NP kg ha^{-1} (Table 4). On the other hand, combined effect of all levels of irrigation interval with application of control fertilizer treatments (0:0 NP kg ha^{-1}) produced significantly higher unmarketable tuber yield over the remaining treatment combinations.

The minimum significant marketable tuber yield (14.55t ha^{-1}) was recorded form interaction effect of every 9 days irrigation and application of 0:0 NP kg ha^{-1}. Lower and statistically similar marketable tuber yields were observed due to interaction of every 5 days and 7 days irrigation interval with the same fertilizer treatment (0:0 kg NP ha^{-1}) compared with the remaining treatment combinations. Conversely, irrigating potato every 5 days with application of 222:178.7 NP kg ha^{-1} showed the highest significant marketable tuber yield (43.26t ha^{-1}) followed by value (36.17 t ha^{-1}) obtained from interaction of every 7 days irrigation with application of the same fertilizer rates (222:178.7 NP kg ha^{-1}) .

The lowest significant total tuber yield (19.88t ha^{-1}) was observed due to interaction of every 9 days irrigation and application of NP at the rate of 0:0 kg ha^{-1} (Table 4). Combination of every 5days and 7 days irrigation intervals with the same rate of fertilizer also produced significantly lower total tuber yield compared with the interaction of the remaining treatment combinations. On the other hand, the maximum significant total tuber yield (43.7t ha^{-1}) was obtained from interaction of every 5 days irrigation interval with application of 222:178.7 kg NP ha^{-1}. Combined effect of every 7 days irrigation interval with application of 166.5:134kg NP ha^{-1} and 222:178.7kg NP ha^{-1} also showed significantly higher total tuber yields compared with the effects of the rest treatment combinations.

The highest marketable and total tuber yields were recorded from the interaction of frequent irrigation and the maximum rate NP fertilizer which might be related to increased supply of water and nutrients resulting in luxuriant growth, more foliage and leaf area and higher supply of photosynthates leading to formation of bigger tubers thereby resulting in higher yields (Patricia and Bansal, 1999). Marketable and total tuber yields showed strong positive and highly significant linear association with all measured parameters except with unmarketable tuber number and unmarketable tuber yield (Table 5).

Table.1 Physico-chemical properties of the soil (0-20cm)

Physical properties							
Particle size				Bulk density (g/ cm^3)	Field capacity (%)	Permanent wilting point (%)	Total available moisture (%)
Clay (%)	Silt (%)	Sand (%)	Textural class				
15	22	63	Sandy loam	0.98	40	17.5	22.5

Chemical properties			
Parameter	Value	rating	Reference
pH	6.3	Slightly acidic	EthioSIS (2014)
Organic carbon (%)	1.44	Medium	Tekalign(1991)
Available phosphorus (ppm)	1.04	Very low	Olsen *et al.*(1954)
Total Nitrogen (%)	0.12	Medium	Halvin*et al.* (1999)
CEC (cmol kg^{-1})	17.4	Medium	Landon (1991)
EC (dS/cm)	0.83	Salt free	EthioSIS (2014)

Table.2 Effect of treatment interaction on crop phenology, plant height and average tuber weight

Treatments Irrigation interval/ NP (kg ha^{-1})	Days 50% flowering	Days to Maturity	Plant height (cm)	Average tuber weight (g)
Every 5 days /0:0	65.67^{f}	99.33^{gh}	60.33^{g}	57.17^{j}
Every 5 days /55.5:44.7	70.67^{e}	102.00^{ef}	64.33^{f}	63.00^{h}
Every 5 days /111:89.4	74.67^{d}	106.33^{c}	69.00^{e}	68.67^{f}
Every 5 days /166.5:134	78.00^{c}	110.00^{b}	73.50^{c}	72.83^{d}
Every 5 days /222:178.7	81.33^{a}	115.00^{a}	79.66^{a}	81.00^{a}
Every 7 days /0:0	61.33^{h}	97.67^{h}	55.00^{i}	44.33^{m}
Every 7 days /55.5:44.7	66.67^{f}	100.67^{fg}	58.67^{h}	50.50^{k}
Every 7 days /111:89.4	70.67^{e}	102.67^{ef}	63.67^{f}	60.33^{i}
Every 7 days /166.5:134	75.00^{d}	105.00^{c}	70.00^{de}	70.50^{e}
Every 7 days /222:178.7	80.00^{ab}	109.67^{b}	75.50^{b}	76.50^{b}
Every 9 days /0:0	59.00^{i}	95.33^{i}	46.67^{k}	41.67^{n}
Every 9 days /55.5:44.7	64.00^{g}	98.67^{gh}	53.00^{j}	48.60^{l}
Every 9 days /111:89.4	69.00^{e}	100.66^{fg}	58.67^{h}	65.67^{g}
Every 9 days /166.5:134	73.67^{d}	103.00^{de}	64.33^{f}	69.00^{f}
Every 9 days /222:178.7	78.66^{bc}	106.66^{c}	70.50^{d}	74.00^{c}
LSD $_{(0.05)}$	1.61	2.04	1.18	1.15
CV (%)	1.35	1.18	1.1	1.09

Values within a column followed by the same letter(s) are not significantly different at 5% level of probability; LSD =Least significance difference; CV =Coefficient of Variation; NP = Nitrogen and phosphorus fertilizers

Table.3 Interaction effect of treatments on yield parameters (per plant) of potato

Treatments			
Irrigation interval/ NP (kg ha^{-1})	UNMTNPP	MTNPP	TTNPP
Every 5 days /0:0	3.49^{ab}	5.83^{gh}	9.30^{g}
Every 5 days /55.5:44.7	3.34^{abc}	6.91^{f}	10.25^{f}
Every 5 days /111:89.4	3.28^{abc}	7.48^{d}	10.76^{e}
Every 5 days /166.5:134	2.76^{de}	8.54^{bc}	11.30^{bc}
Every 5 days /222:178.7	2.61^{e}	9.19^{a}	11.79^{a}
Every 7 days /0:0	3.45^{ab}	5.19^{i}	8.64^{h}
Every 7 days /55.5:44.7	3.47^{ab}	6.19^{g}	9.66^{g}
Every 7 days /111:89.4	3.15^{bc}	7.35^{def}	10.50^{ef}
Every 7 days /166.5:134	3.09^{cd}	8.13^{c}	11.22^{cd}
Every 7 days /222:178.7	3.16^{bc}	8.69^{b}	11.86^{a}
Every 9 days /0:0	3.58^{a}	4.65^{j}	8.23^{h}
Every 9 days /55.5:44.7	3.53^{a}	5.7^{h}	9.23^{g}
Every 9 days /111:89.4	3.52^{a}	6.99^{ef}	10.51^{ef}
Every 9 days /166.5:134	3.36^{abc}	7.44^{de}	10.80^{de}
Every 9 days /222:178.7	2.70^{e}	8.86^{ab}	11.69^{ab}
$LSD_{(0.05)}$	0.34	0.48	0.43
CV (%)	6.2	4.0	2.5

Values within a column followed by the same letter(s) are not significantly different at 5% level of probability; LSD =Least significance difference; CV =Coefficient of Variation; NP = Nitrogen and phosphorus fertilizers.

UNMTNPP= unmarketable tuber number per plant, MTNPP = marketable tuber number per plant, TTNPP = total tuber number per plant

Table.4 Interaction effect of treatments on yield parameters (t ha^{-1}) of potato

Treatments Irrigation interval/ NP (kg ha^{-1})	UNMTY	MTY	TTY
Every 5 days /0:0	5.07[b]	18.57[i]	23.62[h]
Every 5 days /55.5:44.7	4.18[d]	21.93[g]	26.11[f]
Every 5 days /111:89.4	3.04[f]	26.99[e]	30.04[d]
Every 5 days /166.5:134	1.29[j]	34.47[c]	35.75[c]
Every 5 days /222:178.7	0.44[k]	43.26[a]	43.70[a]
Every 7 days /0:0	5.17[ab]	16.75[i]	21.91[i]
Every 7 days /55.5:44.7	4.2[cd]	20.84[h]	25.04[g]
Every 7 days /111:89.4	3.27[e]	25.22[f]	28.49[e]
Every 7 days /166.5:134	2.09[h]	35.22[c]	37.31[b]
Every 7 days /222:178.7	1.82[i]	36.17[b]	37.98[b]
Every 9 days /0:0	5.33[a]	14.55[k]	19.88[j]
Every 9 days /55.5:44.7	4.39[c]	18.72[i]	23.10[h]
Every 9 days /111:89.4	3.34[e]	24.53[f]	27.87[e]
Every 9 days /166.5:134	2.44[g]	27.29[e]	29.73[d]
Every 9 days /222:178.7	2.43[g]	33.20[d]	35.64[c]
$LSD_{(0.05)}$	0.2	0.78	0.76
CV (%)	3.65	1.76	1.52

Values within a column followed by the same letter(s) are not significantly different at 5% level of probability; LSD =Least significance difference; CV =Coefficient of Variation; NP = Nitrogen and phosphorus fertilizers.

UNMTY= unmarketable tuber yield, MTY = marketable tuber yield, TTY = total tuber yield

Table.5 Relation between measured parameters

	DF	DM	PH	UMTNPP	MTNPP	TTNPP	ATW	UMTY	MTY
DF									
DM	0.92**								
PH	0.96**	0.94**							
UMTNPP	-0.72**	-0.76**	-0.74**						
MTNPP	0.97**	0.90**	0.94**	-0.79**					
TTNPP	0.97**	0.86**	0.92**	-0.67**	0.98**				
ATW	0.97**	0.89**	0.94**	-0.67**	0.96**	0.96**			
UMTY	-0.93**	-0.92**	-0.91**	0.71**	-0.93**	-0.91**	-0.92**		
MTY	0.95**	0.94**	0.94**	-0.75**	0.95**	0.92**	0.93**	-0.97**	
TTY	0.94**	0.93**	0.94**	-0.76**	0.94**	0.92**	0.93**	-0.96**	0.99**

DF, DTM,PH, UMTNPP, MTNPP, TTNPP, ATW, MTY, MTY, TTY and ** highly denote Daysto50% flowering, Days to physiological maturity, plant height, UMTNPP=Unmarketable tuber number per plant, Marketable tuber number per plant, Total tuber number per plant, Average tuber weight, Unmarketable tuber yield, Marketable tuber yield, Total tuber yield and ** highly significant at P≤0.01 difference, respectively

Table.6 Marginal rate of return (MRR) of potato yield as influenced with irrigation interval and NP fertilizer at BolosoSore

Treatments Irrigation interval / NP (kgha^{-1})	Total variable cost (ETB ha^{-1})	Net benefits (ETB ha^{-1})	MRR (%)
Every 9 days/0:0 kg	5200	125,750	
Every 7 days /0:0 kg	6800	143,950	1137.5
Every 9 days /55.5:44.7kg	7324.95	161,155.05	3277
Every 7days/55.5:44.7	8924.95	178,635.05	1092.5
Every 9 days /111:89.4kg	9449.90	211,320.1	6226
Every 7 days /111:89.4	11,049.90	215,930.1	288
Every 9 days /166.5:134	11,173.50	234,436.50	14,973
Every 7 days /166.5:134	12,773.50	304,206.5	4361
Every 7 days /222:178.7	14,498.45	311,054.55	397
Every 5 days /222:178.7	16,898.45	372,441.55	2558

Selling price of potato at harvesting time =10 ETB kg^{-1}, labor cost =100ETB Man day, costs of N and P fertilizers were 13 and 13.5 ETB kg^{-1}, respectively.

Economic analysis

Results of economic analysis (Table 6) showed that the maximum net benefit estimated to372,441.55 ETB ha^{-1} was obtained from irrigating potato in every 5 days and application 222:178.7kg NP ha^{-1}. Combination of every 7 days irrigation with the same rate of fertilizer also gave higher value of net benefit (311,054.55 ETB ha^{-1}) over the remaining treatments.

All non-dominated treatments gave marginal rate of return above the minimum acceptable rate of return.The highest marginal rate of return (14,973%) was recorded from combination of every 9 days irrigation interval with application of NP at 166.5:134 kg ha^{-1} followed by marginal rate of return (6226%) obtained from combination of the same irrigation interval with application of 111:89.4 4kg NP ha^{-1}. Generally, combination of every 5 days irrigation with application of 222:178.7 kg NP ha^{-1}in this experiment revealed maximum net benefit (372,441.55ETB ha-1) with acceptable marginal rate of return ((2558%).

Based on the result of current study, it is concluded that producers can apply irrigation water in every 5 days and NP fertilizer at 222:178.7kg ha^{-1} to harvest the highest marketable tuber yield and reasonable economic benefit under situations similar to this study. However, maximum marketable tuber yield and acceptable economic return were achieved from application of the lowest irrigation treatment and the highest level of fertilizer treatment, further research is required considering irrigation interval below 5 days and fertilizer rate above 222:178.7kg NP ha^{-1} in order to produce comprehensive recommendation.

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