World Journal of Applied Chemistry
2025, Vol. 10, No. 2, pp. 25-41
https://doi.org/10.11648/j.wjac.20251002.11

SciencePG
Science Publishing Group

Research Article

Response of Potato (*Solanum tuberosum* L.) to NPSB Fertilizer Rate and Inter Row Spacing at Buno Bedele Zone

Alemayehu Abdeta*, Tolasa Tamiru

Oromia Agricultural Research Institute, Bedele Agricultural Research Center, Bedele, Ethiopia

Abstract

Potato is one of the most important tuber crops grown in Ethiopia as it plays a crucial role in Ethiopian agriculture, contributing to food security and livelihoods of majority of farmers. However, Ethiopia's Potato production and productivity lag behind other countries due to various constraints faced by the farmers of the country, notably among them improper application rate of NPSB fertilizer and inter row spacing for potato production. Thus, study was conducted to determine the effect of NPSB fertilizer rates and inter row spacing on tuber yield and yield components of potato during 2022-2023 cropping season. The experiment consisted of four levels of NPSB (50,100,150 and 200 kg ha^{-1}) fertilizer and three (65, 75 and 85cm) inter row spacing with control treatment. The experiment was laid out in 4x3 factorial plus control arrangements in randomized complete block design with three replications. The analysis of variance showed that the main effect of NPSB application rates and inter row spacing were significantly affected all studied parameters. However, interaction effect showed non-significant. Hence, application of 200 kg ha $^{-1}$ NPSB resulted maximum marketable tuber yield (51.36t ha^{-1} while lower yield was obtained from control treatment. Furthermore, the highest marketable tuber yield (45.16 t ha $^{-1}$ were obtained from the inter-row spacing of 85cm whereas the lowest result for these parameters were recorded at 65 cm. Conversely, the highest value of agronomic efficiency 152.4 kg kg^{-1} was obtained at lowest NPSB rate 50 kg ha $^{-1}$ while lowest agronomic efficiency 142.65kg kg^{-1}was obtained from highest NPSB 200 kg ha $^{-1}$. The result of correlation analysis showed that there is positive and significant correlation among tuber yield and yield components, such Marketable tuber yield was strolgly correlated with tuber number (r=0.49**), total tuber yield (r=0.99***), Average tuber weight (r=0.92***), large tuber size (r=0.92***), Medium tuber size (r= 0.46**) and small tuber size (r=0.46**). *Besides,* the partial budget analysis revealed that the highest net benefit obtained (1231355 birr ha^{-1}) with acceptable marginal rate of return (3823.92%) and (2120240 birr ha^{-1}) with acceptable marginal rate of return (11444.83%) from NPSB kg ha^{-1} and 85cm inter row spacing respectively. Therefore, the production of potato with 150 kg ha $^{-1}$NPSB fertilizer rate and 85cm inter row spacing is most productive and economically profitable and can be recommended for the study area for further scaling up.

Keywords

Potato, NPSB, Inter Row Spacing

*Corresponding author: abdeta.alex35@gmail.com (Alemayehu Abdeta)

Received: 7 January 2025; **Accepted:** 17 April 2025; **Published:** 14 May 2025

1. Introduction

Potato (*Solanum tuberosum* L.) is originated in the highlands of South America [1]. It is fourth and third most important food crop in the world in terms of production and in terms of consumption respectively [2]. It is one of the important tuber crops grown worldwide, fourth and third most important food crop in the world in terms of production and in terms of consumption respectively [3]. Report of IPC [4]. showed that about billion people eat potato in worldwide particularly; developing countries. Moreover, potato is also suited to smallholder farmers in developing countries for the labor requirement [5]. It is a staple food consumed by almost two-thirds of the world's population, and in 2020, 359.07 million tons were produced worldwide [6-8].

Ethiopia is endowed with suitable climatic conditions for potato production. Around 70% of cultivated farming land in Ethiopia is suitable for potato production [9]. Still, the national average potato yield in Ethiopia is 16.69 t ha^{-1} [10], which is lower than world average yield up to 20 t ha^{-1} [2]. Besides, the yield of potato in Ethiopia is lower than that of most potato producing countries in Africa like South Africa and Egypt, which produce 34 and 24.8 t ha^{-1}, respectively [11].

Despite its great significance in the farming system of the country, Potato production is constrained by many confounding circumstances that include low soil fertility, periodic moisture stress, diseases-insect pests, lack information about a variety, unavailability of improved varieties, and limited or improper application of fertilizers and irrigation [12]. However, among these inappropriate agronomic practices like fertilizer application rates and inter spacing are the main constraints of potato production in the country [13, 12].

In case of spacing, plant spacing plays a crucial role in potato cultivation. Besides, as plant density increases, there is a patent decrease in plant size and yield per plant. This effect is due to increased inter-plant competition for water, light and nutrients [14]. The blanket recommended plant spacing for all potato varieties in Ethiopia is 75 cm by 30 cm between rows and plants, respectively [15]. On the other hand, farmers in Ethiopia are using different spacing below or above the national recommendation [16].

Conversely, on the other hand, soil nutrient status is also the most important parameter that limits the yielding potentials of various crops including potato. Under such conditions, the application of multi-nutrient blended fertilizers is believed to enhance the productivity and nutrient use efficiency of crops [17]. Ethio-SIS [18] reported deficiencies seven nutrients such as nitrogen (86%), phosphorus (99%), sulfur (92%), boron (65%), zinc (53%), potassium (7%) and copper in Ethiopian soils. Subsequently, to overcome this problem, the application of multi-nutrient-based balanced fertilizers containing N, P, K, S, B, and Zn in blended form would be essential to increase crop production and productivity. Thus, Ethiopian government has been encouraging the use of balanced nutrient-based blend fertilizers since 2013. To supply nutrients such as sulfur and boron, the earlier used DAP was replaced by NPSB.

In the past farmers use DAP and Urea as blanket recommendation. Shunka al et [19] indicated that blanket application might have led to the depletion essential elements and consequently not satisfy the nutrient requirements of crops including potato. Accordingly, blended fertilizers, such as NPSB (18.9% N, 37.7% P_2O5, 6.95% S, and 0.1% B) are currently being used by the farmers in the study area based on the recommendation drawn from soil fertility map of the areas [20]. Nevertheless, the rate of blended fertilizer (NPSB) was not determined. Thus, farmers use inappropriate rates of fertilizer (NPSB) due to lack information on the application rates. Therefor, it needed to determine optimum rates of blended fertilizers (NPSB).

In the study area, information for potato production fertilizer rate and inter row plant spacing is limited for optimum tuber yield. Hence, determining optimum NPSB fertilizer and inter row spacing for potato production is very important to come up with relevant recommendations that can optimize potato tuber yield. Thus, the objective of thess experiment was to determine effects of blended (NPSB) fertilizer rates and inter row spacing on yield and yield components of Potato that economically viable in the study area.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted on two and one farmer's field during the 2022-2023 cropping highland agro-ecosystems of Gechi and Chora district, Oromia Regional National State, southwestern Ethiopia. Gechi district is located 475 km southwest of Addis Ababa and bordered on the south by Didessa, on the east by the Jimma Zone, on the north by Bedele, and on the east by the Didessa River which separates it from the Jimma Zone. The experimental site receives an average annual rainfall of 1850mm with maximum and minimum temperatures of 18℃ and 21℃, respectively [17]. There are two distinct seasons: the rainy season starting in late March and ending in October and the dry season occurring from November to early March. Chora is located 519 km away from the capital city of the country and 36 km away from Bedele Town of Buno Bedele Zone. It is generally characterized by warm climate with a mean annual maximum temperature of 25.5℃ and a mean annual minimum temperature of 12.5℃. The annual rainfall ranges from 1440 mm. The soil of the area is characterized as an old soil called Niti soils.

2.2. Exprimental Material

The experiment was conducted using Belete as test crop.

This variety was released by Holeta agricultural research center in 2009. The variety was selected based on its adaptation and better performance in the area. Blended NPSB (18.9% N, 37.7% P_2O_5, 6.95% S and 0.1% B) was used as the source of fertilizers.

2.3. Treatment and Experimental Design

The experiment were consisting of three inter row spacing (65, 75 and 85cm) and four levels of NPSB fertilizer rates (50, 100, 150 and 200 kg ha $^{-1}$) with one control. 100 kg ha^{-1} of urea was used in each plot except control plot as a constant rate based on blanket recommendation. The treatments were laid in randomized complete block design with three replication. Each experimental unit had 4.55m length and 3m width with a total net area of 13.65m^2 each experimental unit length is divided into 7, 6 and 5 rows at 65cm, 75cm and 85cm intervals, respectively.

Table 1. Treatments combination for effect of NPSB and Inter row spacing for Potato crop.

Trt	Rates NPSB (Kg/ha)	NPSB fertilizer composition (kg/ha)				Inter row spacing	Combination
		N	P_2O_5	S	B		
1	0	0	0	0	0	75	control
2	50	9.45	18.85	3.48	0.05	65	50*65
3	50	9.45	18.85	3.48	0.05	75	50*75
4	50	9.45	18.85	3.48	0.05	85	50*85
5	100	18.9	37.7	6.95	0.1	65	100*65
6	100	18.9	37.7	6.95	0.1	75	100*75
7	100	18.9	37.7	6.95	0.1	85	100*85
8	150	28.35	56.55	10.43	0.15	65	150*65
9	150	28.35	56.55	10.43	0.15	75	150*75
10	150	28.35	56.55	10.43	0.15	85	150*85
11	200	37.8	75.5	13.9	0.2	65	200*65
12	200	37.8	75.5	13.9	0.2	75	200*75
13	200	37.8	75.5	13.9	0.2	85	200*85

NPSB=Nitrogen, Phosphorus, Sulfur and Boron

2.4. Data Collection

Days to emergence was the number of days from planting to 50% emergence was used as days to emergence for statistical analysis. Days to 50% flowering was recorded by counting the number of days from planting to when 50% of plants in each plot flowered. Days to Physiological maturity was recorded when the haulms (vines) of 90% of the plant population per plot turned yellowish or showed senescence. Plant height was measured from the ground surface to the tip of the main stem at physiological maturity from five randomly selected plants from the middle rows. Average stems number was number of stems raised from the ground from randomly selected five plants was counted when 50% of the plants in each plot attained flowering stage and mean number of only stems that had directly grown from the mother tuber and acted as an independent plant above the soil were considered as stems [21]. Stems branching from other stems above the soil were not considered as main stems. Tuber number was total number of tubers harvested from five randomly selected plants grown in the net plot area was counted and mean tuber number per plant/hill was computed and used for further analysis purpose [22].

Marketable tuber yield was tubers which was free of diseases, insect pest damages and above 25g in weight were considered as marketable tubers as indicated by Lung'aho et al (2007). The weight of such tubers harvested from the net plot area was measured using scaled balance and expressed as ton per hectare. Unmarketable tuber yield was tubers which was diseased and insect pest attacked and less than 25g, misshaped and decayed are considered as unmarketable tuber as indicated by Lung'aho et al [21]. Average tuber weight was recorded by dividing total fresh weight of tubers by the total number of fresh tubers per plot

[23, 24]. Tuber size category was tubers which were large (>75g), medium (25-75g) and small (<25g). Total tuber yield was was recorded by sum of weights of marketable and unmarketable. Agronomic Efficiency is described as the economic production obtained per unit of Fertilizer applied and was calculated as: $AE = \frac{YF-YO}{F}$ (Kg kg^{-1}) Where, YF is the grain yield of a fertilized plot (kg ha^{-1}), Y0 is the grain yield of the control plot (kg ha^{-1}), and F is the amount of NPSB or applied (kg ha^{-1}).

2.5. Soil Sampling and Analysis

A pre-planting soil samples were also collected at a depth of 0-20 cm following the standard method and analyzed for some selected physico-chemical properties of the soil at Bedele Research Center following the standard manual. Accordingly, determination of soil particle size distribution was carried out using the hydrometer method [25]. Soil pH was measured using digital pH meter in 1:2.5 soils to water ratio. Cation exchange capacity of the soil was determined following the modified Kjeldahl procedure [26] and reported as CEC of the soil. Percent base saturation was calculated from the sum of exchangeable basis as a percent of the CEC of the soil. Organic carbon was determined following wet digestion methods as described by Walkley and Black [27] whereas kjeldahl procedure was used for the determination of total N as described by Jackson [28]. The available P was measured by Bray II method [29].

2.6. Data Analysis

All the measured parameters were subjected *were first checked for all assumptions of ANOVA. Then the data were subjected to Analysis of Variance (ANOVA) and simple correlation analysis was performed using SAS PROC CORR [30] by SAS version 9.2). The data collected were statistically analyzed using the Analysis of Variance (ANOVA) procedures [31] Means were separated using the LSD test to signify the treatment differences at a 5% level of probability [32].*

2.7. Partial Budget Analysis

The economic analysis was done to investigate the economic feasibility of the treatments. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers expected from the same treatment. The average open market price (Birr kg ha^{-1}) for potato and the official prices of blended and urea fertilizers was used for analysis. Labor costs was involved for application of blended NPSB fertilizer rates was recorded and used for analysis. The net returns (benefits) and other economic analysis was based on the formula developed by CIMMYT methodology [33].

3. Results and Discussion

3.1. Soil Physic-chemical Before Planting

The laboratory result indicated that soil texture of the study area is dominated by clay and the textural class of soil of experimental site is clay (Table 2). The soil pH of experimental site 5.21, which is strongly acidic according to Tekelign [34]. The organic carbon content of the soil is 4.58% which is medium according to the rating of Landon [35]. The medium organic carbon content of the soil might be due to the intensive cultivation and continuous removal of crop residues. Organic carbon in soils influences physical, chemical and biological properties of the soils such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in the soils. Therefore, restoring the soils with organic fertilizers is important for enhancing crop yields as well as soil health. Total nitrogen (0.34%) was medium according to the rating of EthioSS [20] who classified soil nitrogen content very high (>0.5), high (0.25-0.50), medium (0.15-0.25), low (0.05-0.15). The available soil phosphorus (0.88 mg kg^{-1}) of the experimental site was very low according to rating of [29]. The very low available phosphorus might be due to the high phosphorus sorption and due to high P fixing capacity of the soil in the study area. CEC of study area was 23.51 cmol (+) kg-1 which classified as medium [35]. Medium CEC of the soil might be due to moderate organic matter content and high soil acidity.

Table 2. *Selected soil physico-chemical properties before planting of experimental sites during 2022-2023.*

Soil Characteristics	Gechi district		Chora district			
	2022	2023	2022	2023		
Textural class	Clay	Clay	Clay	Clay	Value	[36]
pH	5.21	5.16	5.45	5.24	Strongly Acidic	[34]
OC	4.55	3.73	5.07	4.58	Medium	[34]
Total N (%)	0.39	0.29	0.44	0.34	Medium	[20]
Av P	0.76	0.61	0.71	0.88	very low	[29]

Soil Characteristics	Gechi district		Chora district			
	2022	2023	2022	2023		
CEC	22.33	18.67	24.63	23.51	Medium	[35]

OC=Organic Carbon, Total N (%)= Total Nitrogen, Av P= Available phosphorus, CEC=Cation exchange Capacity

3.2. Analysis of Variance (ANOVA)

The results of a combined analysis of variance showed that the main effect of different levels of applied NPSB and inter row spacing fertilizer rates significantly ($P < 0.01$) affected all parameters (Table 3 and Table 4). On the other hand, the interaction effects of the NPSB application and inter row spacing showed non significant variation in all parameters (Tables 3 and 4).

Table 3. Mean squares of ANOVA for phenological, and growth of potato as influenced by NPSB rates and inter-row spacing.

Sours of variation	DF	DE	DF	DM	PH	SN	NT
Rep	2	2.01NS	23.11NS	50.19NS	23.04NS	10.61NS	66.33NS
NPSB	3	1.34*	42.22*	88.32*	105.44*	69.61*	435.06**
IRS	2	0.92*	12.14*	6.03*	40.02*	4.57*	28.58**
NPSB*IRS	6	0.11NS	5.44NS	9.88NS	19.55NS	0.26NS	1.62NS
Error	130	0.31	9.45	7.07	52.29	1.68	10.48

Key: DF= Degree freedom IRS, DE=Days to Emargency, DM=Days to Maturity, PH = Plant Height, SN=Stem Number, TN = Tuber Number, *= significant, ** = Highly Significant and NS=Non-significant

Table 4. Mean squares of ANOVA for yield and yield components of Potato as influenced by NPSB rates and inter-row spacing.

SV	DF	MY	UMY	TY	AVTY	LTS	MTS	STS
Rep	2	626.07NS	11.93NS	712.95NS	2.24NS	0.56NS	80.26NS	16.34NS
NPSB	3	24357.94**	224.48**	29088.21***	3736.42**	931.11**	526.41**	108.46**
IRS	2	3701.25**	32.39**	4404.45**	516.15**	129.04**	34.59**	6.95**
NPSB*IRS	6	53.99NS	9.66**	542.80NS	26.08NS	6.52NS	1.96NS	0.41NS
Error	130	321.71	20.73	339.25	49.13	12.28	12.69	2.63

Key: SV= Source of variation, DF= Degree freedom IRS= Inter-row spacing, TN= Number of tuber, MY=Marketable tuber yield, UMY=Un Marketable tuber yield, TY=Tuber yield, AVTW=Average tuber weight, LTS=Large tuber size, MTS=Miduem tuber size, *= significant, **=Highly Significant =NS-Non significant

3.3. Effect of NPSB Fertilizer Rates and Inter Row Spacing on Phenological Parameter

3.3.1. Days to 50% Emergence (Days)

Days to 50% emergence was significantly ($p < 0.05$) affected by the main effect of NPSB and inter row spacing. However, non-significant results attributed to interaction effect between different NPSB rates and Inter row spacing with regard to days to emergence (Table 3). Thus, late germination (14.37days) was obtained from the 200 kg ha^{-1} NPSB plot and early germination mean (10.23days) was observed from plot received control plot (Table 3). Days to 50% emergence was delayed by about 4 days in 200kg ha^{-1} application as compared to control plot. This might be due to the role of increased NPSB fertilizer that enthused growth and prolonged vegetative phase. On othe rhand, 100 and 150 kg ha $^{-1}$ of NPSB, fertilizer rates, showed statistically par and significantly different from control plots. Interestingly, Kinde and Asfaw [37] reported similar findings reported that increased application of blended fertilizer delayed the time to attain 50% emergence by 6.0 days. Contrarily to this result Muluneh (2018) reported that increasing the application of blended NPSB fertilizer from 0 to 350 kg ha $^{-1}$ did not show significant differences on the time emergence of potato plants.

Regarding to inter row spacing, the minimum and maximum days to 50% emergence has ranged from 10.67 days to 13.55 days by widening the inter row spacing from 65 cm to 85 (Table 5). In this experiment, earlier plant emergence was obtained in closer inter-row spacing (65cm) and the delayed time to attain days to 50% emergence was obtained at wider intra-row spacing (85 cm). Days to 50% Emergence was delayed about 3 days in wider inter row spacing 85cm as compred to closest inter row spacing 65cm). This days might be due to lesser competition for resource like water, light and nutrients and poor nutrient use efficiency of the crop because of the wider spacing. This result was in line with the findings of Tadesse and Mulugeta [38] who reported that increasing intra-row spacing resulted in delayed time required to reach 50% emergence.

3.3.2. Days to 50% Flowering

The mean result of days to 50% flowering of potato showed that significant ($P<0.05$) differences Main effect NPSB rates and inter row spacing but not by interaction effect of the two. Accordingly, the earliest days to 50% flowering (64.67 days) was recorded from the control plot; while the longest days required attaining 50% flowering (71.12 days) was recorded from the plot received 200 kg ha $^{-1}$ NPSB. 50% flowering delayed by 7 days at 200kg ha^{-1} NPSB fertilizer as compred to control plot. This might be attributed to the positive effect of NPSB that stimulated growth and prolonged vegetative phase; thus, delaying the reproductive phase of plants [39]. N nutrient in NPSB has high influence in delaying the flowering of potato by prolonging its vegetative growth [40]. Optimum rates application of fertilizer might led to a general increment of most metabolic processes; however extremely increase in N fertilizer rate can delay the time to flowering [41]. The present result is in line with that of Getaneh and Laekemariam [42] who reported that application of NPS fertilizer showed significant effect on prolonging of time of flowering. Other researchers also reported that increasing fertilizer rates, including NPS prolonged days to flowering and maturity of potato and other vegetable crops in different agro-ecologies [43]. In case of inter row spacing, varying inter-row spacing showed significant influence ($P<0.05$) on days to 50% flowering of potato. Minimum and maximum days to 50% flowering ranged from 62.67days to 67.67 days (Table 3). The delayed flowering of the crop at wider inter row spacing might be due to the space which allows less competition for sun light, water and nutrient and this enabled the crop to maintain physiological activity for a long period, thereby continuing photosynthesis. Mamiru and Geletu [44] had reported significant differences in days to 50% flowering for potato crop and they reported that, the wider the plant spacing, the delayed to attain 50% flowering.

3.3.3. Days to 90% Maturity

Days to 90% maturity was significantly ($p < 0.05$) affected by the main or sole effects of NPSB rates and inter spacing but their interaction documented insignificant effect (Table 3). Thus, the mean days to 90% maturity has ranged from (110.33–115.67) days due to the application of different rates of blended fertilizers. Maximum mean days to 90% maturity were recorded from application of 200 kg NPSB blended fertilizer ha $^{-1}$ was delayed by 5 days whereas the earliest day was attained from control treatment. This delaying might be due the role of NPSB fertilizer in extending the vegetative growth of the crop that led to delayed days to mature. P nutrient in NPSB attributed this to sustained physiological activities of the plants excessive accumulation of photosynthetic assimilates that lead to continued photosynthesis and growth of the plants [45, 38]. The present study was supported by the findings of Muluneh [46] who reported extending maturity of potato was observed with the increased rate of NPSB fertilizers. Again, this finding was agree with finding of researchers also reported that increasing fertilizer rates, including NPSB prolonged days to maturity of potato and other vegetable crops in different agro-ecologies [12]. Bewuketu [47] also reported that application of blended NPSZnB fertilizer delayed days to attain physiological maturity. Increasing rates of NPSB fertilizer may promote the vegetative phase of potato plants that may in turn prolong flowering and maturity of the potato plant. This might be attributed from the increased N uptake from the applied NPSB fertilizer that contributes to have excessive haulm development and in turn prolonged days required to attaining 90% maturity. In the same manner, Mean maximum of (114.53 days) to 90% maturity of potato were recorded at wider intra-row spacing (85 cm) and minimum of (111.70 days) were recorded from 65cm inter-row spacing. The result indicated that wider plant spacing allowed lesser competition for sun light, water and nutrient which enhanced potato plant to maintain physiological activity for a long period. This result was supported with the findings of [48]; [49] who reported that decreasing inter-row spacing resulted in shortening the time required to reach 90% maturity.

Table 5. Main effects of NPSB fertilizer rate and inter-row spacing on Days to 50% Emergence, days to 50% flowering and days to 90% maturity.

Treatment	Day to Emergance	Days to Flowering	Days to Maturity
NPSB (kg ha-1)	(Day)	(Days)	(Days)
0	10.23d	64.67d	110.33d
50	12.55c	66.11c	112.67c
100	13.67b	66.67c	112.87c
150	14.19b	68.37b	114.11b
200	15.64a	71.12a	115.67a
Lsd (0.05)	1.13	1.87	1.09
Inter row spacing (cm)			
65	10.67c	62.67c	111.70c
75	12.13b	64.12b	113.67b
85	13.55a	67.67a	114.53a
Lsd (0.05)	1.03	1.67	0.67
CV (%)	3.21	5.11	5.29

LSD (0.05)=least significant differences and CV (%)= coefficient of variation and **=Highly significant

3.4. Effect of Different NPSB Application Rates and Inter Row Spacing on Growth Parameters

3.4.1. Plant Height (cm)

The main or individual effects of NPSB rate and inter row spacing significantly ($p < 0.001$) influenced plant height. However, their interaction did not show a significant impact on plant height (Table 2). Increased application of NPSB fertilizer from 0 to 200 kg NPSB ha-1 had increased the plant height from (78.27cm) to (87.33 cm) and that the highest plant height (87.33) was recorded when 200 kg NPSB ha $^{-1}$ and the lowest plant height (78.27 cm) which was recorded under control plot (Table 3). There is significant and linear increase in plant height in response to increasing the rate of NPSB blended fertilizer application and this may be attributed to the critical role phosphorus, Nitrogen and Sulfur and B which plays in enhancing cell division, growth, and stem elongation to meet the demand for the increased plant height [44].

Moreover, the widening tinter -row spacing from 65 cm to 85cm had significantly influenced the plant height at which it was increased from (80.57 cm) to (83.55cm) respectively. The highest plant height (83.55 cm) was recorded from closer inter-row spacing (65cm) and the shorter plant height (80.57 cm) was attained from the wider intra-row spacing of 85 cm. The taller plant growth in the narrower might be attributed due to the stiff competition for sun light in closer intra-row spacing. Generally, closer spacing stimulated plants to grow taller with sufficient NPSB fertilizer in the soil in order to meet the light demand of the crop. The significant increase in plant height observed by plants treated at higher rates of NPSB fertilizer also could be due to the fact that P is required in large quantities in shoot and root tips where metabolism is high and cell division is rapid. Similarly, sulfur promotes the formation of chlorophyll, higher photosynthetic activity, vigorous vegetative growth, and taller plants [50]. Therefore, the combined effects of N, P, and S in NPS fertilizer increased the plant height of potato plants. This result has supported by the finding of [16]; [42] that the highest plant height was recorded from closer or narrower inter row spacing.

3.4.2. Number of Main Stem

The NPSB fertilizer rate and inter row spacing had significant ($P<0.05$) main stem per hill. However, the interaction effect of the two factors was not significant on main stem number (Table 2). Increasing the rate of NPSB fertilizer increased main stem number per hill linearly. Application 0 to 200 kg NPSB ha^{-1} fertilizer rates resulted in significantly higher main stem number. Increasing the rate of the fertilizer application from 0 to 200 kg NPSB ha^{-1} increased the of main stems number per hill (Table 3). The highest main stem number (10.01 $hill^{-1}$) were obtained from the application of 200 kg ha^{-1} NPSB fertilizer while the shortest main stem number (5.19 $hill^{-1}$) was recorded at the control plot. The significantly tallest plants and highest number of main stems were observed towards the application of higher rates of NPSB fertilizer that might be ascribed to the increased availability of nitrogen in the soil for uptake by plant roots, which might have sufficiently enhanced vegetative growth through increasing cell division and elongation. In line with this result; according to Muluneh (2018) reported that, the highest number of stem (6.48) was recorded on at rates of 350 kg ha^{-1} NPB. Moreover, other researchers reported that stem number per hill was significantly affected by the application of phosphorus fertilizer and intra-row spacing [51-53].

Table 6. Main effects of NPSB fertilizer rate and inter-row spacing on Plant height and Main stem number.

Treatment	Plant heihght	Number of Main stem
NPSB (kg ha-1)		
0	78.27b	5.19d
50	78.67b	6.65d
100	80.11b	7.474c
150	84.67a	8.87b

Treatment	Plant heihght	Number of Main stem
200	87.33a	10.01a
Lsd (0.05)	4.08	0.68
Inter row spacing (cm)		
65	83.55a	4.54c
75	81.22b	6.87b
85	80.57b	10.21a
Lsd (0.05)	1.22	3.3
CV (%)	8.67	14.47

LSD (0.05)=least significant differences and CV (%)= coefficient of variation and **=Highly significant

3.5. Effect of Different NPSB Application Rates and Inter Row Spacing on Yield and Yield Components of Potato

3.5.1. Tuber Number Hill^{-1}

Analysis of variance indicated that both the main effects of NPSB fertilizer rate and inter-row spacing had highly significant ($P < 0.01$) effect on tuber number per hill. However, there was no significant interaction effect. The highest total tuber number (26.88) was found from application of 200 kg ha $^{-1}$ while the lowest tuber number (12.78) was recorded from control plot. Increasing NPSB application from 0 to 200 kg ha^{-1} increased total tuber number. Increase of total tuber number per hill with an increase in NPSB rate could be due to the fact that N can activate the vegetative growth for more photo-assimilate production, while P enhanced the development of roots for nutrient uptake. Correspondingly, Tadesse and Mulugeta [38] have found that increasing the rate of phosphorus fertilizer significantly increased average tuber number per hill of potato. In agreement with the present finding, the authors of Getaneh and Laekemariam [42] reported a significant tuber number increment in response to NPS fertilizer application. P Nutrient in NPSB could have promoted the growth and photosynthesis rate of the plants and tuber formation. Again in agreement with the result of inter-row spacing, Getaneh and Laekemariam [42] reported that planting potato at the wider spacing resulted in the production of higher numbers of marketable tubers hill^{-1} than the narrower spacing. In line with this results, Burtukan [54] reported that increasing rates of both N and P from zero to the maximum increased marketable tuber number per hill by 94.6% over the control and the highest unmarketable tuber number (8.63) per hill was obtained from the control plot and the lowest unmarketable tuber number (3.9) was recorded for 110 kg N with 45 kg P ha-1. Similarly, Bruk [55] also reported that increasing the rate of NPSB application from 0 to 200 kg ha-1 linearly and significantly increased marketable tuber number from 13.47 to 22.68 but unmarketable tubers number per hill was decreased from 5.475 to 4.083.

Moreover, a significant difference in total tuber number was observed due to inter row spacing. The highest total tuber number (23.16) was obtained from wider inter row (85cm) spacing fertilizer rate which is statistically the same with 75cm inter row spacing. On the other hand, the lowest total tuber number (21.63) was recorded from 65cm inter row spacing (Table 7). Total tuber number per hill in response to planting the seed tubers at wider and/or intermediate spacing may be attributed low competition between plants for growth factors such as moisture, nutrients, and light and the optimal utilization of the growth factors for photosynthesis and assimilation of carbohydrates to tubers. Similar finding was reported Taye [56] planting potato at the wider spacing resulted in the production of higher numbers of marketable tubers/hill than the narrower spacing. In agreement with this result, Masarirambi et al [14] reported that the highest plant density having a lower number of marketable tubers per plant and the highest number of tubers was found at wider plant space. Similarly, Zamil et al [57] also reported the widest spacing gave the high tuber number of marketable tuber per hill which was significantly different from the closest spacing. In agreement with this result this result, Tesfa [58] also reported that narrow plant spacing resulted in the production of large number of under sized unmarketable tubers as compared to the wider plant spacing.

3.5.2. Marketable Tuber Yield (t ha^{-1})

Analysis of variance indicated that both the main effects of NPSB fertilizer rate and inter-row spacing had highly significant ($P < 0.01$) effect on marketable tuber number and unmarketable tuber number. However, there was no significant interaction effect. The highest marketable tuber yield (51.68 t ha^{-1}) were obtained from the application of 200 kg ha-1 of NPSB fertilizer rate. While the lowest marketable tuber number (22.83 t ha-1) was recorded from the control plot (Table 6). Increasing NPB application from 0 to 200 kg ha $^{-1}$increased marketable. The increase on marketable tuber yield an increase in NPSB rate could be due to the fact that N can trigger the vegetative growth for more photo-assimilate production, while P enhanced the development of roots for nutrient uptake. The improvement in yield attributes with the application of S could be ascribed to its pivotal role in regulating physiological and metabolic system in plant.

Moreover, Marketable tuber yield tuber was significantly affected by inter-row spacing rate. The highest marketable tuber yield (45.16 t ha -1) was recorded from 85cm inter row spacing while the lowest marketable tuber yield (39.65) was recorded from 65 cm interrow spacing. Marketable tuber yield was statistically the same for 75 cm and 85 cm inter-row spacing. The production of higher marketable tuber yield in response to planting the seed tubers at wider and/or intermediate spacing may be attributed low competition between plants for growth factors such as moisture, nutrients, and light and the optimal utilization of the growth factors for photosynthesis and assimilation of carbohydrates to tubers. This result agrees with the results reported by Girma et al [59] who reported that the highest marketable tuber yield were obtained from application highest fertilizer rate (115 kg ha-1 P_2O_5) and wider plan spacing (85cm). Similarly Fayera et al [60] also reported that the highest marketable tuber yield (3.73 kg/plot) and the lowest unmarketable tuber yield (0.97 kg/plot) were obtained from combination of 150 kgha-1 N and 30 cm intra row spacing however the lowest marketable tuber yield was obtained from combination of 10cm intra row spacing and without fertilizer. In agreement with the present result Frezgi [61] reported that plants at closest spacing produced significantly higher yield of small tubers as the consequence of higher competition between plants that reduced the marketable tubers yield and increased marketable tubers yield. The present result is also agreed with the findings of many authors Desalegn et al [62] 2; [63] that they reported increased application of inorganic fertilizer and plant grown in the closer spacing has revealed the higher increment in the marketable yield of a crop.

3.5.3. Un Marketable Tuber Yield (t ha^{-1})

The result showed tha main effect of inter-row spacing and NPSB fertilizer rates was highly significantly affect unmarketable ($p < 0.01$). However, their interaction was found nonsignificant. The highest unmarketable tuber yield (6.56 t ha) was recorded at narrow inter-row spacing (65 cm) and the lowest (6.03 t ha) was recorded at wider inter-row spacing (85 cm) which is statistically at par with 75 cm. The Unmarketable tuber yield decreased with increasing inter-row spacing. This could be due to the presence of intense inter-plant competition at closer spacing and the consequent result of much small sized tubers contribute to the higher unmarketable yield. Production of high number of unmarketable tubers at narrower spacing may be due to the fact that narrower planting may result in the production of large numbers of stems per unit area, which may lead to stiff competition among plants and tubers for growth factors, rendering the tubers small-sized and underdeveloped. However, wider spacing may result in the production of smaller number of stems per unit area, thereby reducing the competition of growth factors among plants and tubers and leading to the production of large-sized tubers. The present result indicates that weight of unmarketable tubers per plant decreases with increasing inter-row spacing and vice-versa. This might be due to the fact that at wider spacing the individual plants face less competition and resulted in big sized tubers which are marketable. On the other hand, at closer spacing severe competition between plants resulted small sized tubers which may increase the proportion of unmarketable yield. The results of other researchers also confirmed the present result whereby closest intra row spacing recorded higher yield of small sized tubers as the consequence of higher competition between plants [58, 51]. This result is in agreement with the findings of [64] who stated that the intra-row spacing has a marked effect on unmarketable tuber yield, and the highest unmarketable yield recorded from the closer spacing due to higher inter-plant competition, associated with the small sized tubers. The result of this current investigation is in agreement with the work of Frezgi [61] also indicated that closer seed tuber spacing resulted in a significantly higher yield of small-sized tubers as the consequence of higher competition between plants.

3.5.4. Total Tuber Yield (t ha^{-1})

Total tuber yield was highly significant ($p < 0.01$) affected by NPSB fertilizer rates and inter-row spacing. However, their interaction was found no significant. The highest total tuber yield (58.57 t ha -1) was obtained from 200 kg ha -1 while the lowest total tuber yield (24.33 t ha-1) were obtained from non-treated plots (Table 6). The difference in total tuber yield between the application rate of NPSB exhibited a significant increment on total tuber yield of potato plant. P nutrient from NPSB might enhance the development of roots particularly lateral and fibrous rootlets which in turn contributed to nutrient absorption, photosynthesis, and general physiological processes.

Maximum total tuber yield was obtained at wider inter row spacing. The highest total tuber yield (51.72 t ha^{-1}) was obtained (85 cm) inter-row spacing whereas the lowest total tuber yield (45.70 t ha^{-1}) recorded at the inter-row spacing (65 cm). Similar to this finding, Birahanu and Woldegiorgis reported that wider spacing of 75 cm × 30 cm was appropriate for high yield of potato. Furthermore, Girma et al [59] indicated that the total tuber yields of plants cultivated at the spacing of 85 cm between rows and 30 cm between plants exceeded the total tuber yield of plants. In agreement with the present result, Minwyelet et al [65] also reported that 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 (17.32t ha-1). The present result also agreed with that of results reported by Zabihi et al [57] that increasing planting density of potato resulted in higher tuber yields due to more tubers being harvested per unit area of land. Similarly, Fayera et al [60] also reported that the highest total yield of tubers (10377.78 kg/ha) obtained from application of high nitrogen rate (150 kgN ha-1) and at the closest spacing 10 cm intra row spacing. This result is in agreement with the finding of Muhammad et al [66]; Amasis [67] and Bikila et al [68] who reported that tuber yield per hectare was reduced due to the shortage of mineral nutrients and insufficient number of plants grown per hectare in wider intra-row spacing as compared to the plants grown at closer intra row spacing. For the current study, 20 cm intra row spacing was the most efficient for land utilization when combined with 250 kg NPS ha-1application.

3.5.5. Average Tuber Weight (g)

Analysis of variance indicated that both the main effects of NPSB fertilizer rate and inter-row spacing had highly significant (P < 0.01) effect on average tuber weight. The highest average tuber weight (100.84 g) was obtained from the application of 200 NPSB fertilizers. On the other hand, the lowest average tuber weight (69.66 g) was recorded from the control plot (Table 4). Average tuber weight increment with increasing fertilizer rate. This result is also in agreement with Tadesse and Mulugeta [38] who reported the highest average tuber weight from the effect of wider spacing. Nigusie [69] also reported significant response of average tuber weight production of potato with an increased level of N and P nutrients. Again Solomon et al [70] reported application of 9.87 NPS doubled the size of average tuber weight as compared with unfertilized plant. Similar to the result of this study, Israel et al [13]; Zelalem et al [22] and Husna and Kisetu [71] who reported that the heavier average tuber weight were obtained from the increased application of NP fertilizer.

Furthermore, a significant difference in average tuber weight was observed due to NPS fertilizer application. The highest tuber Average tuber weight (93.32g) of potato was recorded at 85 cm inter-row spacing and the lowest tuber weight (86.88 g) was recorded at 65 cm inter-row spacing. Average tuber weight was statistically similar for inter-row spacing of 675 cm and 85 cm (Table 4). The production of tubers with maximum tuber weight recorded with intermediate and wider spacing might be due to the production of optimum number of stems with lesser competition for resource between plants as compared to closer plant spacing. This is implies that an increase in density probably causes an increase in competition between and within plants and hence leads to decrease in availability of nutrients to each plant and, consequently, results in decline of mean tuber weight. In line to this study, Arega [16] reported that maximum average tuber weight was recorded for plants planted at intermediate and wider plant spacing, and the lowest result was obtained at closer plant spacing. This result is also in agreement with Bikila et al [68] who reported the highest average tuber weight from the effect of wider intra row spacing.

3.6. Disease Incidence

Potato late blight was the major disease observed on potato during the experimental period. Accordingly, all treatments showed moderately susceptible (30ms) (Table 4) reactions to the disease.

Table 7. Combined mean tuber yield related parameters of potato in 2022-2023 cropping season at Gechi and Chora districts.

Treatment	NT(No)	MY (t/ha)	UMY (t/ha)	TY (t/ha)	ATW (g/tuber)	Disease (Blight)
NPSB rates (kg/ha)						
Control	12.78e	22.83e	7.22a	24.33e	69.66e	30Mr
50	17.90d	32.45d	6.39b	37.74d	77.13d	30Mr
100	21.44c	40.10c	6.25b	46.26c	88.65c	30Mr
150	24.22b	46.67b	5.28c	53.06b	95.19b	30Mr
200	26.88a	51.36a	1.5d	58.57a	100.84a	30Mr
LSD (0.05)	1.51	2.64	0.21	2.72	3.26	
CV (%)	14.47	13.31	7.24	11.91	7.75	
P-Value	**	**	**	**	**	
Inter row Spacing						
65	21.63b	39.65b	6.56a	45.70c	86.88b	30Mr
75	22.33ab	43.06a	6.25b	49.31b	91.16a	30Mr
85	23.16a	45.16a	6.03c	51.72a	93.32a	30Mr
LSD (0.05)	1.31	2.29	0.18	2.35	2.83	
CV (%)	14.44	13.31	7.24	11.91	7.75	
P-Value	**	**	**	**	**	

NT=Number of tuber, MY=Marketable tuber yield, UMY=Un Marketable tuber yield, TY=Tuber yield, AVTW=Average tuber weight, Mr=Moderately resistant LSD (0.05)= Least significant differences and CV (%)= coefficient of variation,** =Highly significant

3.7. Effect of Different NPSB Application Rates and Inter Row Spacing on Tuber Category

3.7.1. Large Tuber Size /Plant (g hill^{-1}) (>75g)

The analysis of variance revealed that main effect of NPSB fertilizer rates and inter row spacing were higly significantly (p<0.01) influenced on large tuber sized (>75g) but interaction effect showed non significant. The NPSB fertilizer rate increased from 0kg to 200 kg ha^{-1}, the number of large-sized tuber increased consistently. The highest proportion of large size tubers (40.65%) were produced from the application of 200 kg NPSB ha^{-1} and the lowest proportions of large-sized tubers (28.75%) were produced from control plot. The results showed wider plant spacing the yield of large tuber size was increased. This might be due to wider plant spacing had slight competition between plants for nutrients and growth factors than closer plant spacing which lead to produce high yield of large tuber sizes. This result is in agreement with Desta [72] who reported that the proportion of large size tuber was increased with the increasing application of blended fertilizers 100 kg NPSB per ha1) and 200 kg ha-1 NPSB with adjusted N increased yield of large size tuber by 138 and 148%, respectively, as compared to the control. The maximum proportion of large size tubers (36.44%) were produced from plants grown in 85cm inter row spacing and the lowest proportions of large-sized tubers (30.55%) were produced from plants grown at 65 cm (Table 7). The increased proportion of large-sized tubers at wider intra-row spacing might be due to wider plant spacing had slight competition between plants for nutrients and growth factors than closer plant spacing which lead to produce high yield of large tuber and medium tuber sizes. Similarly Lung'aho et al [21] also described that narrower spacing resulted in the production of many stems with in many small-sized tubers whereas wider spacing results in the production of a fewer stems per unit area resulting in the production of fewer large-sized tubers.

3.7.2. Medium Tuber Size (g hill^{-1}) (25-75g)

The analysis of variance revealed that main effect of NPSB fertilizer rates and inter row spacing were higly significantly (p<0.01) influenced on large tuber sized (25-75g). However interaction effect showed non significant. Thus, the highest proportion of medium size tubers (30.55%) were produced from the application of 200 kg NPSB ha^{-1} which is statically par with 50,100,150 kg NPSB ha^{-1} fertilizers rate and the lowest proportions of medium size tubers (25.80%) were produced from control plot (Table 6). This is might be due to application of NPSB that conterbut for tuber formation. Plants grown at 65cm plant spacing produced significantly maximum yield of medium tuber sizes than wider plant spacing (85cm) (Table 7). Closer plant spacing had high yield of medium tuber sizes than wider plant spacing. Accordingly, the highest medium tuber size 28.37 % was recorded under closer spacing (65cm). While lowest medium size (23.77%) was recorded from wider inter row spacing (85cm). This result might be due to higher number of plants per unit area produced at closer plant spacing than plants at wider spacing which lead to produced high yield of medium tuber size. This result agreed with the inding of Dagne et al [73] reported maximum yield of medium size tubers was recorded for closer spacing (60 × 20 cm) whereas the lowest yield of medium size tuber was observed with wider (75 × 30 cm) plant spacing.

3.7.3. Small Tuber Size /Plant (g/hill) (<25g)

The analysis of variance revealed that main effect of NPSB fertilizer rates and inter row spacing were higly significantly (p<0.01) influenced on small tuber sized (<25g). The increased NPSB fertilizer rate from 0 to 200 kg ha^{-1} decreased the proportion of small in the range between 20.33 to 16.77 %. The highest proportion of small size tubers (20.33%) was produced from control treatment and the lowest proportions of small size tubers (16.77%) was produced from application of 200 kg NPSB ha^{-1} which was statically at par with 100 kg NPSB ha^{-1} and 150 kg NPSB ha^{-1}. As general, the present result showed that increasing the rate of NPSB fertilizer application decreases the proportion of very small size tubers. This could be due to the interaction of nutrients in blended fertilizer and high number of plants produced per unit area at closer plant spacing that results strong competition between plants for nutrients and growth factors and leads to the production of high yield of small tuber size [51].

Similarly, the highest proportion of small (12.44%) was produced from plants grown at 65 cm inter row spacing and the lowest proportions of small (8.12%) was produced from plots plants grown at 85 cm which is statically par with 75cm inter row spacing (Table 7). The decrease in number of small-sized tubers at increasing inter-row spacing might be due to high interspecific competition at high plant density. Increase in density may increase the competition between and within the plants and hence lead to decrease in the availability of nutrients for each plant. The result agree with the finfing of Getaneh and Laekemariam [42] who reported that increase in plant density decreases mean tuber size probably because of plant nutrient elements reduction increases in interspecies competition and large number of tubers produced by high number of stems. Moreover, Nebiya [74] reported that increased P application from 0 to 138 P2O5 kg ha-1 decreased the very small sized tuber % of potato from 6 to 2.27%. Similarly, Biruk [55] also reported that increased NPSB fertilizer rate application from 0 to 200 kg ha-1 decreased the small sized tuber % of potato from 39.73 to 30.27 %. More interestingly, in agreement with the present result Birhanu et al [75] also reported that increasing plant density significantly increased the percentage of small-sized tubers. In similar to the current study, decreased plant population density revealed increased small sized tubers per hill was reported by different scholars [52].

Table 8. Combined mean tuber category of potato in 2022-2023 cropping season at Gechi and Chora districts.

Treatment	Tuber category		
NPSB (kg ha-1)	Large tuber size (>75g)	Miduem tuber size (25-75g)	small tuber size (<25g)
0	28.75d	25.80c	20.33a
50	35.80c	26.55c	18.17b
100	36.16b	27.33b	18.09b
150	36.56b	28.27b	17.44c
200	40.65a	30.55a	16.77c
Lsd (0.05)	1.37	2.01	0.89
Inter row spacing (cm)			
65	30.55c	28.37a	12.44a
75	34.17b	25.95b	9.67b
85	36.44a	23.77c	8.12b
Lsd (0.05)	2.07	1.77	1.29
CV (%)	7.75	14.89	14.51

LSD (0.05)=least significant differences and CV (%)= coefficient of variation and **=Highly significant

3.7.4. Agronomic Use Efficiency (kg kg^{-1})

Agronomic efficiency is the amount of harvestable grain yield per kg of applied nutrient. Agronomic efficiency (AE) was significantly affected by NPSB rates. The highest agronomic efficiency (152.4 kg kg^{-1}) was obtained at the application of 50 kg NPSB ha^{-1} followed by agronomic efficiency of 100 kg NPS ha^{-1} while the lowest value (142.65 kg kg^{-1}) was recorded for 200 kg NPSB ha^{-1} (Figure 1). The increase in agronomic efficiency at a lower rate of NPSB application and its decrease at higher rates might be due to the rate of increase in seed yield being lower than the rate of increase in NPSB supply. This result was supported by the results reported by Desta [72] that the lowest agronomic efficiency (32.53) was obtained from application of 200 kg ha^{-1}NPSB while the highest agronomic efficiency (78.11) was obtained from treatment that received 100% NPSB. This result is in line with Alemaayhu et al. [17] who indicated that matching appropriate essential macronutrients and micronutrients with crop nutrient uptake could optimize nutrient use efficiency and crop yield. Fageria et al also reported that an efficient plant is one that produces higher economic yield with optimum quantity of applied or absorbed nutrient.

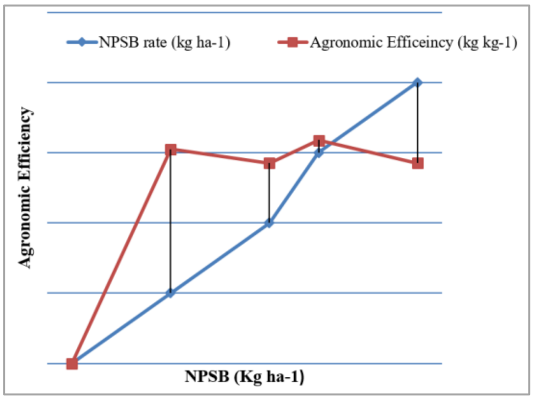

Figure 1. Effect of NPSB Agronomic Efficiency.

3.8. Correlation Analysis among Growth and Yield Parameters

The correlation analysis was performed to determine correlation coefficient between growth and yield parameters as affected by NPSB fertilizer rate and inter-row spacing. Thus, the result indicated that plant height was positively correlated with number of stem (r=0.26*), number of tuber (r=0.23*), Medium tuber size (r=0.21*) and small tuber size (r=0.21*). likewise, number of main stem highly significantly strong correlated with number of tuber (r=0.99***), Marketable yield (r=0.48**), total tuber number (r=0.48**) large tuber size (r=0.39**), medium tuber size (r=0.97**) and small tuber size (r= 0.98**). Moreover, Number of tubr per hill was strongly correlated with number of main stem (r=0.99***), Marketable yield (r=0.48**), unmarketable yield (r=0.35**), total tuber yied (r=0.48**), Average tuber weight (r=0.39**), large tuber size (r=0.39**), medium tuber size (0.99**) and small tuber size (r=0.98**). Similarly, Marketable tuber yield was strolgly correlated with tuber number (r=0.49**), total tuber yield (r=0.99***), Average tuber weight (r=0.92***), large tuber size (r=0.92***), Medium tuber size (r= 0.46**) and small tuber size (r=0.46**) (Table 9).

Table 9. Correlation on growth, yield and tuber yield traits in Gechi and Chora district during the 2022-2023 cropping season.

	PH	NMS	NT	MY	UMY	TTY	AVTW	LTS	MTS	STS
PH	1									
NMS	0.26*	1								

	PH	NMS	NT	MY	UMY	TTY	AVTW	LTS	MTS	STS
NT	0.23*	0.99***	1							
MY	0.09ns	0.48**	0.49**	1						
UMY	0.06ns	0.35**	0.35**	0.72**	1					
TTY	0.08ns	0.48**	0.48**	0.99***	0.76***	1				
AVTW	0.08ns	0.39**	0.39**	0.92***	0.74***	0.93***	1			
LTS	0.08ns	0.39**	0.39**	0.92***	0.74***	0.93***	0.99***	1		
MTS	0.21*	0.97***	0.98***	0.48**	0.35**	0.48**	0.39**	0.39**	1	
STS	0.21*	0.98***	0.98***	0.46**	0.35**	0.48**	0.39**	0.39**	0.98**	1

PH = Plant height; NMS = Number of main stem; NT= Number of tuber; MT= Marketable tuber; UMT= Unmarketable tuber; TTY= Total tuber Tuber yield; AVTW = Average tuber weight; LTS=Large tuber size; MTS=Medium tuber size; STZ=Small tuber size, *** Very highly significant, ** =highly significant and ns=non significant

3.9. Partial Budget Analysis

The partial budget analysis revealed that the maximum net benefit of Birr 1231355 ha^{-1} with marginal rate of returns (MRR) of 3823.92% was estimated for plants that received 150 kg ha^{-1} blended NPSB fertilizer. The lowest net benefit of Birr 604995ha-1 was obtained from plants that did not receive blended NPSB fertilizer and iter row spaced at 65 cm612730 intra-row spacing (Table 10). Furthermore, compared to other inter row spacing the highest net benefit (2120240-birr ha^{-1}) with an acceptable marginal rate of return (11444.83%) was obtained when 85cm inter row spacing was used (Table 10). While the lowest net benefit of Birr 12730 ha^{-1} was obtained from inter row spaced at 65 (Table 10).

Table 10. Result of economic analysis for response of Potato tuber yield to NPSB fertilizer rates and Inter row spacing.

NPSB rate (kg ha^{-1})	AGY	GFB	TVC	NB	MRR%
0	20547	616410	11415	604995	0
50	27405	822150	17025	805125	3567.38
100	33390	1001700	22150	979550	3403.41
150	42003	1260090	28735	1231355	3823.92
200	46224	1386720	32880	1353840	2955.01
Inter Row spacing (cm)					
65cm	27585	1655100	42370	1612730	0
75cm	33354	2001240	46950	1954290	7457.64
85cm	36144	2168640	48400	2120240	11444.83

Note: AdTY = Adjusted tuber yield kg ha-1, GB = Gross Benefit, TVC = Total Variable Cost, NB= Net Benefit and MRR= Marginal Rate of Return

4. Conclusion

Potato is one of the important tuber crops of the world including Ethiopia, contributing to nutrition, livelihoods, cultural heritage, and food security across the country. Its continued cultivation and development are essential for sustaining rural economies and ensuring the well-being of Ethiopian communities. However, despite holding a significant agricultural importance in Ethiopia, potato cultivation faces certain challenges in enhancing its production and productivity. Among such challenges, limited information regarding how different food barley varieties respond to various nutrient management practices, inadequate availability of improved barley varieties and iimproper or insufficient application rates of fertilizers, particularly nitrogen, which is essential for optimal barley production are most notable. The evidence about optimum spacing and Fertilizer application rates for potato production deserves growers' attention as it is influenced by soil fertility status, crop variety, soil moisture status, and their interaction. Thus, agronomic and economic responses of potato under varying inter-row spacing and NPSB fertilizer rates were studied Buno Bedele zone. The result revealed that growth and yield parameters were significantly affected only by main effects of NPSB rates and inter-row spacing only but not by interaction effect. Hence, application of 200 kg NPSB kg ha^{-1} resulted maximum marketable tuber yield (51.36t ha^{-1}) and total tuber yield (58.57 t ha^{-1}) while lower yield were obtained from control treatment. Furthermore, the highest marketable tuber yield (45.16 t ha^{-1}) and total tuber yield (51.72t ha^{-1}) were obtained from the inter-row spacing of 85cm whereas the lowest result for these parameters were recorded at 65 cm. Application of NPSB fertilizer on potato exceed non-application both in yields and net benefits. Remarkably, the lowest NPSB rate (50 kg ha^{-1}) demonstrated the highest agronomic nitrogen use efficiency. The partial budget analysis revealed that the highest net benefit obtained (1231355 birr ha^{-1}) with acceptable marginal rate of return (3823.92%) and (2120240 birr ha^{-1}) with acceptable marginal rate of return (11444.83%) from NPSB kg ha^{-1} and 85cm inter row spacing respectively. This economic analysis underscores the importance of selecting appropriate varieties and optimizing nitrogen fertilization strategies to enhance barley yield and profitability in agricultural production systems. Therefore, the production of potato with 150 kg ha^{-1}NPSB fertilizer rate and 85cm inter row spacing is most productive and economically viable and can be recommended for the study area for further demonstration.

Abbreviations

Ava P	Available Phosphorus
BeARC	Bedele Agricultural Research Center
NPSB	Nitrogen, Phosphorus, Sulfur and Boron (Blended fertilizer)
CEC	Cation Exchange Capacity
CIMMYT	International Centre for Wheat and Maize Improvement
ETB	Ethiopian Birr
EthioSIS	Ethiopian Soil Information System
Ph	Power of Hyddrogen
Total N	Total Nitrogen

Acknowledgments

The Authors would like to thank almighty God! Next we would like to thank Oromia Agricultural Research Institute for the provision of research budget. Also we would like to acknowledge BeARC for facilitating resource needed during the experimental period. Moreover, the contributions of individuals, who involved directly and indirectly in field follow up and data collection are well acknowledged.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Asfaw F (2016) Effect of integrated soil amendment practices on growth and seed tuber yield of potato (Solanum tuberosum L.) at Jimma Arjo, Western Ethiopia. Journal of Natural Sciences Research, 6(15), pp. 38-63.

[2] FAOSTAT (Food and Agriculture Organizations of the United Nations. Statistics Division (2022). https://www.fao.org/faostat/en/#data/QCL

[3] Hand Book Variety Registration., 2021. Crop Variety Registration for Plant Variety Release. Protection and Quality Control Directorate of Ethiopia, Variety Registration, Addis Ababa, Ethiopia.

[4] IPC (International Potato Center) (2020). Procedures for standard evaluation trials of advanced potato clones. An International Cooperators Guide. www.cipotato.org

[5] Devaux JP, Goffart P, Kromann J, Andrade V, Polar and Hareau G (2021). The potato of the future: opportunities and challenges in sustainable agri-food systems, Potato Res. 681–720, https://doi.org/10.1007/s11540-021-09501-4

[6] Degebasa AC (2019). Review of potato research and development in Ethiopia: Achievements and futur prospects. Journal of Biology, Agriculture and Healthcare, 9(19), 27–36. https://doi.org/10.7176/JBAH/9-19-04

[7] Campos H and Ortiz O (2019). The potato crop: Its agricultural, nutritional and social contribution to humank The potato crop: Its agricultural, nutritional and social contribution to humankind. Springer International Publishing. https://doi.org/10.1007/978-3-030-28683-5

[8] Dongyu Q (2022). Role and potential of potato in global food security. Food and Agriculture Organization of th United Nations.

[9] Yenenesh T, Conny JM, Almekinders RS and Paul CS (2017). Understanding farmers' potato production practices and use of improved varieties in Chencha, Ethiopia, Journal of Crop Improvement, 31: 5, 673-688.

[10] CSA (Central Statistical Agency Ethiopia). 2022. Report on area and production of major crops. Agricultural sample survey. Addis Ababa.

[11] Food and Agriculture Organization of the United Nations (FAO) (2023). Faostat. https://www.fao.org/faostat

[12] Alemayehu TG, Nigussie D, and Tamado T (2015). Response of potato (Solanum tuberosum L.) yield and yield components to nitrogen fertilizer and planting density at Haramaya, Eastern Ethiopia. Journal of Plant Sciences, 3(6): pp. 320-328.

[13] Israel Z, Ali M and Solomon T (2012). Effect of different rates of nitrogen and phosphorus fertilization on Yield and yield component of potato (SolanumtuberosumL.) at Mashan, Southwestern of Ethiopia. African Journal of Plant Science. 3(2): 016-024.

[14] Mulatu NT, Hagayo ST (2024) Factors Affecting Improved Potato Production In Central Ethiopia: Evidence From Duna District. Journal of International Trade, Logistics & Law. Dec 1; 10(2).

[15] Ministry of Agriculture and Natural Resources (MoANR) (2016). Crop Variety Release, Protection and Seed Quality Control Directorate, Issue number 19, Addis Ababa, Ethiopia.

[16] Arega A, Tekalign A, Solomon T and Tekile B (2018). Effect of inter and intra row spacing on tuber yield and yield components of potato (Solanum tuberosum L.) in guji zone, southern Ethiopia. J Adv plant sci, 1(1), p. 102.

[17] Alemayehu A, Solomon T, Gezahegn B (2023). Periodic Biological, Yield, Nutrient Up Take and Use Efficiency of Bread Wheat as Influenced by NPSB and Urea Fertilize Rates in Gechi District, Southwestern Ethiopia. World Journal of Applied Chemistry, 8(4), 80-92. https://doi.org/10.11648/j.wjac.20230804.13

[18] EthioSIS (Ethiopia Soil Information System) (2016). Soil Fertility and Fertilizer tentative recommendation Amhara Region. Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA), Addis Ababa, Ethiopia, 275pp.

[19] Shunka EK, Negash A, Chindi G, Wgiorigis T, Abebe A, Solomon M, Bedasa L, Said and Tesema (2021). Determining the rate of blended fertilizers and urea for potato production under rainfed condition in Jeldu, West Showa, and Ethiopia. Archives of Agriculture and Environmental Science, 6(1), 18-25.

[20] EthioSIS (Ethiopian Soil Information System) (2014). Soil analysis report. Agricultural Transformation Agency (Unpublished).

[21] Lung`aho C, Berga L, Nyongesa M, Gildemacher P, Kinyae P, and Demo P (2007). Commercial seed potato production in eastern and central Africa. Kenya Agricultural Research Institute.

[22] Zelalem A, Tekalign T and Nigussie D (2009). Response of potato (Solanumtuberosum L.) to different rates of N and P fertilization on Vertisol at Debre Berhan.

[23] Govinden N (2006). Potato tuber characteristics preferred by growers. Mauritius Sugar Industry Research Institute Food Crop Agronomy Department. Occasional Report No. 34: 10-18.

[24] Simeret B, Nigussie D, and Tekalign T (2013). Influence of Inorganic Nitrogen and Potassium Fertilizers on Seed tuber Yield and Size Distribution of Potato, Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination: Experiences, Challenges and Prospects. Gebremedhin Woldegiorgis, Steffen Schultz and Baye Berihun (Eds.). 12-14 March 2012, Bahir Dar, Ethiopia. PP 130-144.

[25] Dewis J and Freitas F (1984). Physical and chemical methods of soil and water analysis. FAO Soil Bulletin No. 10. FAO, Rome. 275 pp.

[26] Chapman HD (1965). Cation exchange capacity by ammonium saturation. pp. 891- 901. In: Black, CA. (Ed.) Methods of Soil Analysis. Agronomy part II, No. 9, American Society of Agronomy, Madison, Wisconsin, USA.

[27] Walkley A and Black IA (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29–37. https://doi.org/10.1097/00010694-193401000-00003

[28] Jackson ML (1958) Soil chemical analysis. pp. 183-204. Prentice Hall, Inc., Engle Wood Cliffs. New Jersey.

[29] Bray HR and Kurtz (1945). Determination of organic and available forms of phosphorus in soils. Soil Sci. 9: 39-46.

[30] SAS (Statistical Analysis System Institute) (2014). SAS Version 9.4 © 2002-2012. SAS Institute, Inc., Cary, North Carolina, USA.

[31] Gomez KA and Gomez AA (1984). Statistical Procedures for Agricultural Research, 2nd edition, John Wiley and Sons, New York, p. 680.

[32] Steel, R. G. D., Torrie, J. H. and D. A. Dicky. 1997. Principles and Procedures of Statistics, A Biometrical Approach. 3rd Edition, McGraw Hill, Inc. Book Co., New York, 352 358.

[33] CIMMYT (1988). from agronomic data to farmer recommendations: An economics training manual.

[34] Tekalign T (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

[35] Landon JR (Ed) (1991). Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York 474.

[36] Bouyoucos, GJ (1962). Hydrometer Method Improved for Making Particle Size Analyses of Soils. Agronomy Journal, 54(5): 464-465.

[37] Kinde L and Asfaw Z (2016). Effect of spacing and fertilizer dose on growth and yield of potato (Solanum tuberosum L) Gudenie variety at West Hararghe, Eastern Ethiopia. International Journal of Horticulture and Ornamental Plants Vol. 2(1), pp. 011-018.

[38] Tadesse and Mulugeta (2023). Effect of blended fertilizer rates and planting density on yield and yield components of Irish potato (Solanum tuberosum L.) at Gombora condition, Hadiya zone, Southern Ethiopia Diriba Sh, Tilaye B (2020). Effects of Different Rates of NPS, NPSB and NPSZn Blended Fertilizers on Growth and Yields of Potato (Solanum tuberosum L.). Discovery Agriculture.; 6(16): 184-92.

[39] Şanli A, Karadoğan T, Erbaş S and Tosun B (2015). The effects of plant density and eye number per seed piece on potato (Solanum tuberosum L.) tuber yield.

[40] Abrha H, Belew D and Woldegiorgis G (2013). Effects of Inter-and Intra-Row Spacing on Seed Tuber Yield and Yield Components of Potato in Ofla Woreda. Seed Potato Tuber Production and Dissemination.

[41] Getaneh L and Laekemariam F (2021) Response of Potato (Solanum tuberosum L.) to NPS Fertilizer Rates and Inter-Row Spacing in Kechi District, South Western Ethiopia. Applied and Environmental Soil Science, 2021(1), p. 5582066.

[42] Mekashaw M, Alemayehu M, Shumye G, Haileslassie A (2020). Effects of blended NPS fertilizer rates on yield and yield components of potato (Solanum tuberosum L.) varieties at Dessie Zuria district, Northeast Ethiopia. Cogent Food & Agriculture. Jan 1; 6(1): 1779478.

[43] Mamiru TT and Geleto GM (2022). Effect of Blended Fertilizer Rates and Planting Density on Yield and Yield Components of Irish Potato (Solanum Tuberosum L.) at Gombora Condition, Hadiya Zone, Southern Ethiopia. Hadiya Zone, Southern Ethiopia (August 3, 2022).

[44] Ababiya A (2018). Integrated use of NPS blended fertilizer and cattle manure on growth, yield and quality of potato (Solanum tuberosum L.) under Dabo Ghibe Kebele, Seka Werada of Jimma Zone, Southwest Ethiopia (Doctoral dissertation, Jimma University).

[45] Muluneh S (2018). Effects of Blended NPSB Fertilizer Rates on Growth, Yield and Yield Related Traits of Potato (Solanum tuberosum L.) Varieties under Irrigation in Degem District, Central Highland of Ethiopia. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

[46] Bewuketu G and Bekele (2019), “Effect of blended NPSZnB fertilizer and cattle manure rates on growth, yield and quality of potato (Solanum Tuberosum L.) at Banja District, Awi Zone, North Western Ethiopia,” International Journal of Research Studies in Agricultural Sciences (IJRSAS), vol. 5, no. 5, pp. 27–36.

[47] Abrha H, Belew D and Woldegiorgis G (2014). Effect of inter and intra row spacing on seed tuber yield and yield components of potato (Solanum tuberosum L.) at Ofla Woreda, Northern Ethiopia. African Journal of Plant Science, 8(6), pp. 285-290.

[48] Tsega B, Asrat M and Alemayehu M (2022). The Spacing Effects on Potato Tuber Seed Yield in Farta District, Northwestern Ethiopia. Asian Journal Of Plant And Soil Sciences, Pp. 136-149.

[49] Sharma SP, Sandhu AS, Bhutani RD and Khurana SC (2014). Effects of planting date and fertilizer dose on plant growth attributes and nutrient up take of potato (Solanum tuberosum L.). Int. J. Agr. Sci. Hisar, India. 4(5): 196-202.

[50] Tesfaye G, Derbew B and Solomon T (2013). Combined effects of plant spacing and time of earthing up on tuber quality parameters of potato (Solanum tuberosum L.) at Degem District, North Showa zone of Oromia regional state. Asian Journal of Crop Science, 5(1): 24-32.

[51] kifle Z, Getu B and Mohammed K (2017). Effects of Intra-Row Spacing on Vegetative Growth Performance of Potato (Solanum tuberosum L) at Wolkite University, Ethiopia. International Journal of Photochemistry and Photobiology 2(4): 108-11.

[52] Mumia BI, Muthomi JW, Narla RD, Nyongesa M, Olubayo FM (2017). Effect of seed potato tuber storage methods on occurrence of potato diseases. International Journal of Research in Agricultural Sciences; 4(4).

[53] Bekele D, Abera G, Gobena A (2020). Effects of chemical fertilizer types and rates on tuber yield and quality of potato (Solanum tuberosum L.) at Assosa, Western Ethiopia. African Journal of Plant Science. Apr 30; 14(4): 155-64.

[54] Biruk N, Abdulahi J and Gedamu F (2018). Effects of Rates of Blendd NPSB and Nitrogen Fertilizers on Yield and Yield Components of Potato (Solanumtuberosum L.) in East Badawacho District, Southern Ethiopia (Msc Thesis, Haramaya University).

[55] Amare T, Bazie Z, Alemu E, Alemayehu B, Tenagne A, Kerebh B, Taye Y, Awoke A, Feyisa T and Kidanu S, 2022. Yield of potato (Solanum tuberosum L.) increased by more than two-folds through nitrogen and phosphorus fertilizers in the highlands of North-Western Ethiopia. Heliyon, 8(10).

[56] Zabihie M, Jamaati S, Khayatnezhad M and Gholamin R (2010). Quantitative and qualitative yield of potato tuber by used of nitrogen fertilizer and plant density. American-Eurasian Journal of Agricultural and Environmental Science, 9(3): 310-318.

[57] Tesfa B (2012). Influence of plant spacing on seed tuber production of potato (Solanum tuberosum L.) cultivars grown in Eastern Ethiopia. MSc. Thesis submitted to school of plant sciences, Haramaya University, Ethiopia.

[58] Girma T, Beyene S, Biazin B (2017). Effect of organic and inorganic fertilizer application on soil phosphorous balance and phosphorous uptake and use efficiency of potato in Arbegona District, Southern Ethiopia. Journal of Fertilizers & Pesticides. 2017; 8(03): 1-6.

[59] Fayera T, Gizaw Y and Megersa M (2015). Assessment on Working Donkey Welfare Issue in Wolaita Soddo Zuria District, Southern Ethiopia. Global Veterinaria, 14(6): 867-875.

[60] Frezgi A (2007). Effect of planting density and nitrogen application on yield and yield components of potato (Solanum tuberosum L.) at Enderta, Southern Tigray, and Ethiopia. MSc. Thesis Haramaya University, Haramaya.

[61] Desalegn R, Wakene T, Dawit M and TolessaT (2016). Effects of Nitrogen and Phosphorus Fertilizer Levels on Yield and Yield Components of Irish Potato (Solanum tuberosum) at Bule Hora District, Eastern Guji Zone, Ethiopia. International Journal of Agricultural Economics 1(3): pp: 71-77.

[62] Anil VS, Manjunatha MH, Yogeesh KJ, Karosiya A, Priyanka S (2024). Overwhelming late blight resistance in Solanum chacoense, Solanum sparsipilum and potato cultivar Kufri Girdhari: Hypersensitive response and a phenomenon of infected leaf shed, pivotal for resistance among the wild potato species. Scientia Horticulturae. Nov 1; 337: 113438.

[63] Tadele F, Derbew B and Solomon T (2013). Combined effect of plant spacing and time of earthing up on tuber quality parameters of potato (Solanum tuberosum L.) at Degeme district, North Shewa Zone of Oromiya regional state. “Aslan J. Crop Sci. 5(1) 24-32.

[64] Minwyelet J, Melkamu A and Yigizaw D (2017). 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, and North Western Ethiopia. MSc. Thesis. Bahir Dar University, Bahir Dar.

[65] Muhammad N, Hussain Z, Rahmdil and Ahmed N (2015). Effect of Different Doses of NPK Fertilizes on the Growth and Tuber Yield of Potato. Life Science International Journal, 9(1, 2, 3, 4), 3098-3105.

[66] Amasis M (2018). Integrated use of NPS blended fertilizer and cattle manure for growth, yield and quality of potato (Solanum tuberosum l.) under daboghibe, kebele, seka werada of jimma zone, southwest Ethiopia.

[67] Bikila A, Derbew B and Adugna D (2014). Yield and yield of potato (Solanum tuberosum L.) seed tuber as influenced by inter and intra-row spacing at Bako, Western Ethiopia. Journal of Biological Sciences. 3(5): pp. 11-19.

[68] Nigusie A (2016). “Effect of phosphorus and potassium fertilizer rates on yield and yield component of potato (Solanum tubersum L,) at K/awlaelo, tigray, tigray agricultural research institute, mekelle, Ethiopia,” Food Science and Quality Management, vol. 48, pp. 2016–2060.

[69] Solomon A, Bedasa M, Said I, Tesema L (2021). Determining the rate of blended fertilizers and urea for potato production under rainfed condition in Jeldu, West Showa, Ethiopia. Archives of Agriculture and Environmental Science.; 6(1): 18-25.

[70] Husna Sh and Kisetu E (2014). Response of Irish Potato to NPK Fertilizer Application and its Economic Return when Grown on an Ultisol of Morogoro, Tanzaina. Journal of Agricultural and crop science. Vol 2(9), pp. 188-196.

[71] Desta B (2018). Evaluation of blended and non-blended fertilizer types and rates on potato (Solanum tuberosum L.) yield and yield components at Assosa, Western Ethiopia. Msc. Thesis, Hawasa University, Hawasa.

[72] Dagne Z, Dechassa N, Mohammed W (2018) Influence of Plant Spacing and Seed Tuber Size on Yield and Quality of Potato (Solanum tuberosum L.) in Central Ethiopia. Adv Crop Sci Tech 6: 406. https://doi.org/10.4172/2329-8863.1000406

[73] Nebiya J (2016). Effect of depth and rate of phosphorus fertilizer application on yield and yield related traits of potato at Haramaya, eastern Ethiopia. MSc Thesis, Haramaya University, Haramaya.

[74] Ayalew B, Dessalegn T, Bidire E, Giziew A, Tilahun G (2021). Improved Potato Production Technology in Productive Safety Net Programme areas of Western Amhara Region. Innovations for Food and Livelihood Security. 2021: 35.

[75] Fageria NK, Baligar, VC and Li Y C (2008). The role of nutrient efficient plants in improving crop yields in the twenty first century. Journal of plant nutrition, 31(6), 1121-1157.