

Research Article

Response of Potato (*Solanum tuberosum* L.) to NPS Fertilizer Rates and Inter-Row Spacing in Kechi District, South Western Ethiopia

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Fertilizer requirement and spacing vary across locations due to differences in soil types, nutrient and moisture availability, economic factors, and other environmental conditions. Therefore, a field experiment was carried out to investigate the effect of different rates of NPS fertilizers and inter-row spacing on growth, yield, yield components, and economic performance of potato in Kechi research farm, Dawro zone of south-western Ethiopia. The experiment was arranged in factorial combination of six NPS (19N–38P2O5–7S) fertilizer rates (0 kg/ha, 50 kg/ha, 100 kg/ha, 150 kg/ha, 200 kg/ha, and 250 kg/ha) and five inter-row spacings (45, 55, 65, 75, and 85 cm) which were laid out in RCBD with three replications using the Gudene variety. Growth, yield component, and yield data were collected and analyzed. In addition, a partial budget analysis was performed. The results showed that the main effect of NPS fertilizer and inter-row spacing had significantly ($P < 0.05$) affected plant height, tuber number, tuber yield, and tuber size and average tuber weight. Maximum marketable tuber number per plant (11.627), total tuber number per plant (13.020), average tuber weight per plant (83.493 g), the proportion of large-sized tuber number per plant (41.893%), marketable tuber yield (48.056 t/ha), and total tuber yield (51.145 t/ha) were obtained from 200 kg/ha of NPS fertilizer which was statistically at par with 150 kg/ha and 250 kg/ha NPS, while the lowest result for those parameters was recorded from unfertilized plots. Results regarding inter-row spacing revealed that the highest marketable tuber number per plant (11.744), total tuber number per plant (13.144), and average tuber weight per plant (85.559 g) were recorded at 75 cm, while the lowest result for these parameters was recorded at 45 cm. Moreover, the highest marketable tuber yield (45.084 t/ha) and total tuber yield (48.462 t/ha) were obtained from the inter-row spacing of 65 cm which was statistically at par with 55 cm inter-row spacing, while the lowest result for these parameters was recorded at 85 cm. The partial budget analysis further revealed that 200 kg/ha NPS fertilizer gave the maximum net benefit. However, 150 kg/ha NPS resulted in the highest marginal rate of return (4303.91%). Thus, 150 kg/ha NPS fertilizer and inter-row spacing of 55 cm or 65 cm are suggested for attaining higher potato yield.

1. Introduction

Potato (*Solanum tuberosum* L.) is the world's most important root and tuber crop after rice, wheat, and maize and has historically contributed to food and nutrition security in the world [1, 2]. Potato tubers are not only rich in carbohydrates but also a mineral resource for consumption; also, the food needs of half a billion people in the world [1, 2]. The annual production of the world and Africa

in the year of 2018 was about 368.2 and 26 million tons, respectively [3].

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world after rice and wheat in terms of human consumption. More than a billion people eat potato worldwide, and global total production exceeds 300 million metric tons. There are more than 4,000 varieties of native potato and also over 180 wild species, mostly found in the Andes [4]. In central highlands of Ethiopia, an

adaptation trial of potato was conducted to identify potato varieties that are better for adaptation, yield, and other agronomic traits and disease tolerance. The national average potato yield in Ethiopia is 13.9 t ha^{-1} [5], which is lower than world average yield up to 20 t ha^{-1} [6]. Annual potato production in Ethiopia has increased from 349,000 tons in 1993 to around 743, 153 tons in 2018 [3] and can potentially be grown on about 70% of arable land in the country.

Potato producers in Ethiopia use poor agronomic practices which include inadequate land preparation, sub-optimal plant population, and fertilizer application [7, 8]. Among agronomic practices, spacing deserves special attention. Optimum spacing varies with soil fertility status, soil moisture, the nature of the crop, and degree of weed infestation [9, 10]. Blanket spacing recommended in Ethiopia for ware potato production was 75 cm between rows and 30 cm between plants. Yet, research evidence from different parts of the country indicated an inter-row spacing of 50 cm and 60 cm in Eastern Ethiopia [11] and 65 cm in North Ethiopia [12]. The variation in plant spacing at different locations according to the scholars was associated with soil type, soil fertility status, plant architecture or growth habit, soil moisture, rainfall, nutrient availability, and other environmental conditions. This recalls the need to develop site-specific recommendations.

Apart from spacing, soil nutrient status is also the most important parameter that limits the yielding potentials of various crops including potato. It was evident that sources of plant nutrients for Ethiopian agriculture over the past five decades have been limited to urea (46N) and diammonium phosphate (DAP) fertilizers ($18\text{N}-46\text{P}_2\text{O}_5$) which contain only nitrogen (N) and phosphorus (P). It was supplied based on the blanket approach without taking site-specific variability into consideration. These might have led to the depletion of other important essential elements [13] and consequently not satisfy the nutrient requirements of crops including potato. Soil fertility survey made over 150 districts in Ethiopia indicated that soil lacks about seven nutrients (N, P, potassium (K), sulfur (S), copper (Cu), zinc (Zn), and boron (B)) [14]. Shiferaw [15] also reported that Ethiopian soils lack most of the macro- and micronutrients that are required to sustain optimal growth and development of crops. Reference [16] in soils of Southern Ethiopian also reported the limitation of N, P, K, S, B, and Cu. To fill such gaps, the Ministry of Agriculture of Ethiopia introduced a new compound fertilizer NPS (19% N, 38% P_2O_5 , and 7% S) instead of DAP.

Though, site-specific information regarding NPS fertilizer is scanty, emerging evidence indicated varied rates of NPS fertilizer. For instance, Melkamu and Minwyelet [17] from Northwestern Ethiopia reported the amount ranged from 136.20 kg/ha to 283.75 kg/ha NPS which was attributed to soil nutrient status, variety, and location. Reference [18] recommend $55.5:89.7:16.52 \text{ kg/ha}$ N: P_2O_5 :S fertilizer rate application for optimum production of potato at Dessie Zuria District, Ethiopia. Thus, generating site-specific NPS rate is suggested.

Despite the fact that many farmers in Ethiopia have been growing potato, limited information with respect to the

intrarow spacing, NPS fertilizer rate and their interaction effects on potato crop is documented. Thus, the present study examined the hypothesis that potato crop responded to the varied rate of NPS fertilizers and inter-row spacing. Therefore, the objectives of the study were to investigate the effect of different rate of NPS fertilizers and inter-row spacing on growth, yield, yield components, and economic performance of potato and to determine appropriate inter-row spacing and NPS fertilizers rate for economic yield production.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted on a research farm of Kechi (Dawro zone), south-western Ethiopia (Figure 1). The Kechi farm lies between $7^{\circ}5'37.98''\text{N}$ to $7^{\circ}1'4.11''\text{N}$ latitude and $36^{\circ}57'5.45''\text{E}$ to $37^{\circ}0'26.56''\text{E}$ longitude with an average altitude of 2090 m.a.s.l. The farm has diverse topographies covering an area of 131.26 ha and with mean monthly temperature ranging from 14°C to 24°C . The annual rainfall of the area varies from 1443 to 2535 mm (Figure 2). The soil type of the area is Luvisols. The soil textural class where the field experiment conducted was silty clayey loam.

2.2. Sample Preparation and Soil Analysis. Soil sample was collected at a depth of 0–20 cm with 10 subsamples to make a composited soil sample. It was processed (air-dried, ground, and passed through 2 and 0.5 mm sieves) and analyzed for selected chemical and physical properties following the standard procedure. Particle size distribution analysis for textural class determination was conducted by the Bouyoucos hydrometer method with Marshall's triangular coordinate system [20, 21]. Soil pH was measured using a glass electrode pH meter with a ratio of 1:2.5 soil to water [21]. The soil organic carbon (OC) content was determined by the wet oxidation method (Walkley and Black, 1934) and the total nitrogen (TN) content by the Kjeldahl Method [22]; available P, K, and S were determined using the Mehlich 3 method [23]. The soil physical and chemical properties of the experimental field are presented in Table 1.

2.3. Experimental Material, Treatments, and Experimental Design. Potato variety "Gudanie (CIP-386423.13)" was used as a test crop. Gudane was released by Holetta Agricultural Research Center in 2006. It has specific adaptation from 1600 to 2800 m.a.s.l., with a rainfall range of 1000–1500 mm. NPS (19N–38 P_2O_5 –7S) and urea (46%N) fertilizers were used as a source of N, P, and S nutrients.

The experiment had two factors, namely, NPS rates and inter-row spacing. The treatments consisted of six levels of NPS (kg/ha) (0, 50, 100, 150, 200, and 250) and five inter-row spacings (cm) (45, 55, 65, 75, and 85). The experiment was laid out in randomized complete block design (RCBD) in a factorial arrangement with three replications. The gross plot size was $4.55 \text{ m} \times 3.6 \text{ m}$ (16.38 m^2) accommodating 10, 8, 7, 6, and 5 rows for 45, 55, 65, 75, and 85 cm inter-rows,

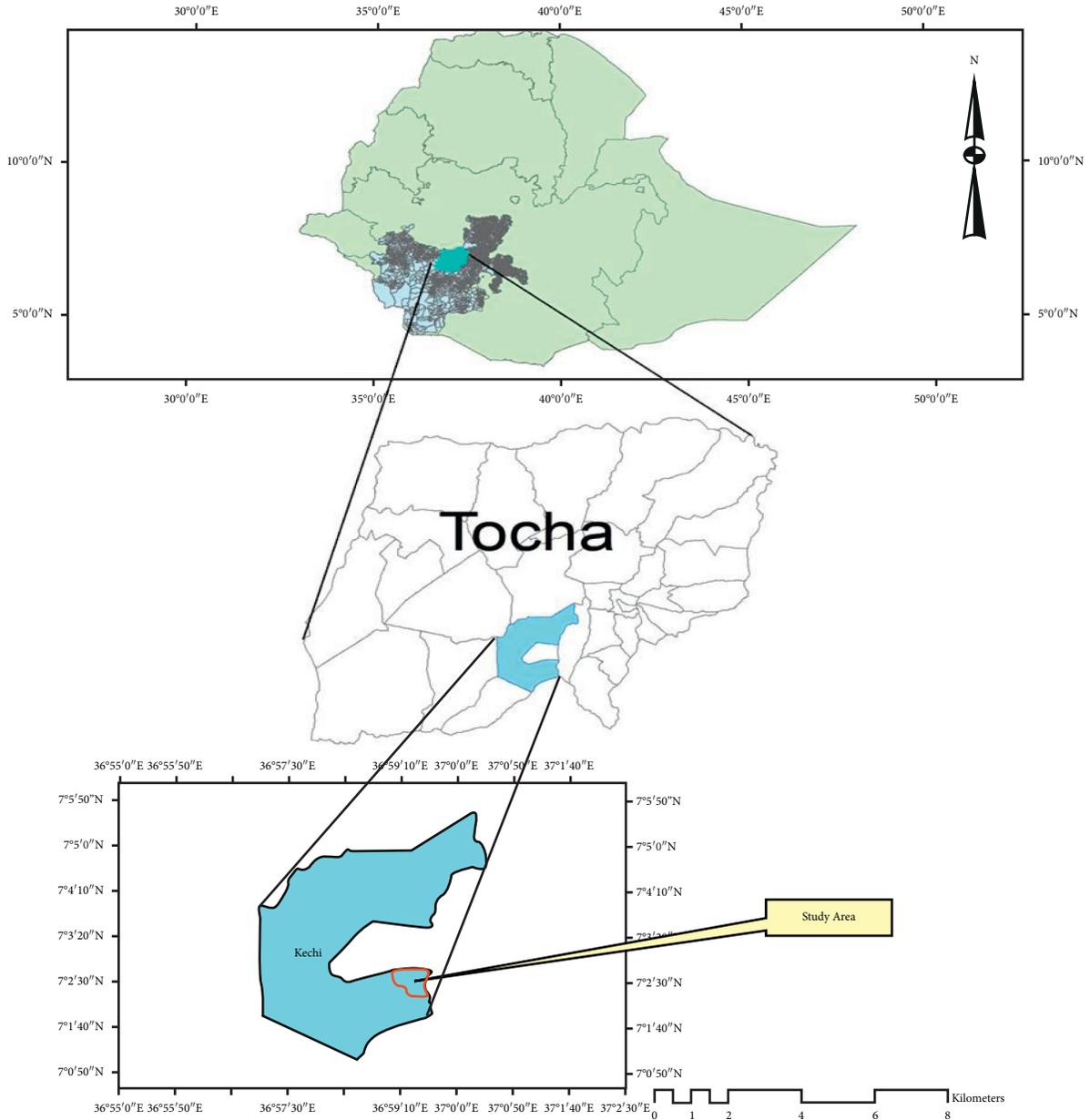


FIGURE 1: Map of the study area.

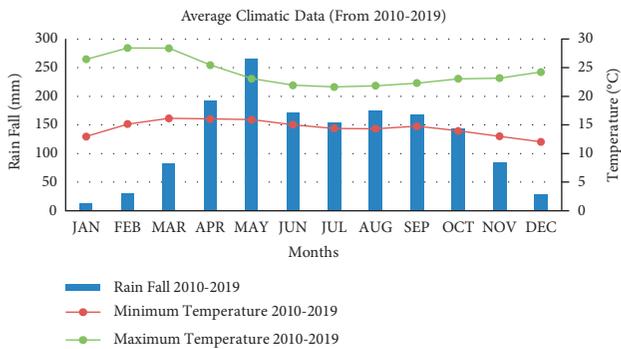


FIGURE 2: Climatic data of Kechi (source: [19]).

respectively. The blocks were separated by 1.5 m wide space, and each plot was separated by 1 m space.

2.4. Field Management. The experimental field was ploughed four times prior sowing. Medium-sized and well-sprouted tubers were planted at the sides of ridges at 30 cm intrarow spacing and the respective inter-row spacing. Based on the treatments, the total quantity of NPS fertilizer was applied at the time of planting. Nitrogen fertilizer was applied in the form of urea in two splits 25 and 50 days after planting for each treatment. Other cultural practices such as weeding, hoeing, and plant protection methods were done uniformly for all experimental plots as recommended by EIAR [26].

TABLE 1: Major soil characteristics of the experimental site.

Soil characteristics	Values	Rating	Reference
<i>Particle size</i>			
Sand (%)	20	—	
Silt (%)	44	—	
Clay (%)	36	—	
Textural class		Silt clay loam	
Soil pH	5.6	Moderately acidic (5.6–6.5)	[24]
Organic carbon (%)	2.79	Low (2–4%)	[25]
Total, N (%)	0.28	Medium (0.21–0.5%)	[25]
Available P (mg/kg)	19.12	Low (15–30)	[24]
Available K (mg/kg)	365.51	Optimum (190–600)	[24]
Available S (mg/kg)	4.82	Very low (<10)	[24]

2.5. Data Collection and Analysis. Growth- and yield-related parameters were collected from the net plot area of each plot to avoid border effects using the standard procedures described as follows. Growth parameter considered was plant height; crop phenology parameters include days to reach 50% flowering and 90% maturity, while yield parameters recorded include number of marketable, unmarketable, and total tubers, tuber size distribution, average tuber weight, and marketable, unmarketable, and total tuber yields.

2.5.1. Days to Flowering and Maturity (Days). Days to flowering in each plot was recorded by counting the number of days elapsed from the time of planting up to the time when 50% of the plants in the plot flowered. Similarly, the maturity date was recorded by counting the number of days elapsed from the time of planting up to the time when the haulm of 90% of the plants in the plot dried.

2.5.2. Plant Height (cm). It was collected by measuring the plant heights from the soil surface to the tip of the main stem of ten randomly selected plants using a ruler at physiological maturity of the crop, and the mean values in centimeter were computed for further analysis.

2.5.3. Tuber Yield ($t\ ha^{-1}$). Tubers free from mechanical, disease, and insect pest damages and medium to large in size were considered as marketable. On the other hand, damaged and small-sized tubers were considered as unmarketable as described by [27]. The weights of such tubers obtained from the net plot area of each plot were measured in kilogram using a scaled balance and expressed in $t\ ha^{-1}$ and considered as marketable yield as well as unmarketable tuber yield. Finally, the total tuber yield in $t\ ha^{-1}$ was obtained from the sum of marketable and unmarketable yields.

2.5.4. Tuber Number per Hill. This was recorded as the actual number of tubers collected from randomly selected 10 plants in net plot area at the time of harvesting and calculated as an average tuber number.

Tuber weight ($kg\ tuber^{-1}$) was recorded from randomly selected 10 plants of net plot area and determined by dividing the total fresh tuber yield to their respective total tuber number.

The collected data were subjected to analysis of variance using SAS statistical software [28]. The difference between treatments means were compared using least significant difference (LSD) at 5% level of significance. Moreover to determine the economic feasibility of the treatments, partial budget analysis was done according to the procedures developed by CIMMYT (1988).

3. Result and Discussion

3.1. Crop Phenology and Growth Parameters. Neither the main effects of inter-row spacing nor the interaction of NPS fertilizer rate and inter-row spacing significantly affected the number of days to 50% flowering and days to 90% maturity. However, phenological parameters were highly significantly ($P < 0.01$) affected by the NPS fertilizer rate. The maximum period required to reach days to 50% flowering (60 days) and days to 90% maturity (104.87 days) was recorded from the application of 250 kg/ha NPS which were statistically similar with the application of 200 kg/ha NPS. The shortest duration to 50% flowering (55.33 days) and 90% maturity (96.47 days) was recorded from unfertilized plots (Table 2).

Increasing rates of NPS 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 NPS fertilizer that contributes to have excessive haulm development and in turn prolonged days required to attaining 50% flowering and 90% maturity. The present result is in line with that of [17, 29] who reported that application of N, P, and S fertilizer showed significant effect on prolonging of time of maturity. Bewuketu [30] also reported that application of blended NPSZnB fertilizer delayed days to attain physiological maturity. 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 [31, 32]. Alemayehu et al. [33] and Biruk [34] also indicated that increasing N and P fertilization levels significantly delayed days required to reaching flowering and maturity in potatoes.

Plant height of potato was highly significantly ($P < 0.01$) influenced by NPS fertilizer rates and inter-row spacing but not affected by the interaction. Application of NPS fertilizer at the rate of 250 kg/ha and 200 kg/ha showed the highest

TABLE 2: Main effects of inter-row spacing and NPS fertilizer rate on days to 50% flowering, days to 90% maturity and plant height.

Treatments	50% flowering	90% maturity	Plant height (cm)
<i>Inter-row spacing (cm)</i>			
45	58.11	99.94	83.056 ^{ab}
55	58.00	99.94	83.500 ^a
65	58.00	99.89	82.667 ^b
75	57.94	99.00	81.611 ^c
85 significance	57.89 NS	100.22 NS	81.500 ^{c**}
LSD (0.05)	NS	NS	0.6249
<i>NPS fertilizer rate (kg/ha)</i>			
0	55.33 ^c	96.47 ^c	76.533 ^c
50	55.47 ^c	97.07 ^d	78.267 ^d
100	56.87 ^b	98.67 ^c	80.800 ^c
150	60.00 ^a	98.87 ^b	85.400 ^b
200	60.27 ^a	103.80 ^a	87.067 ^a
250 significance	60.00 ^{a**}	104.87 ^{a**}	86.733 ^{a**}
LSD (0.05)	0.54	0.567	0.6845
CV (%)	1.28	0.78	1.10

** = significant at 1% significance levels; NS= nonsignificant. LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation; means in column followed by the same letters are not significantly different at 5% level of significance.

plant height of potato (86.73 cm and 87.07 cm), respectively, while the shortest plant height (76.53 cm) was observed on plants without NPS fertilizer (Table 3). Moreover, the inter-row spacing of 55 cm gave significantly taller plants (83.5 cm) than wider inter-row spacing of 75 cm and 85 cm (Table 3). Plant height consistently decreased as inter-row spacing increased from 55 cm to 75 cm.

Comparatively low solar interception by the crop canopy and competition for light at narrower inter-row spacing might have resulted in longer internodes and increased plant height. The significant increase in plant height observed by plants treated at higher rates of NPS 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 [35]. In conformity, Gezahegn [36] reported that plant height increased in response to increased rate of N and P fertilizers, which could be related to the role of N in promoting vegetative growth and that of phosphate in favoring leaf expansion and stem elongation. It is also in line with the findings of other researchers where they found an increased height in the potato plant with the application of S-containing fertilizers [17, 18, 37]. Therefore, the combined effects of N, P, and S in NPS fertilizer increased the plant height of potato plants.

3.2. Yield and Yield Components of Potato

3.2.1. Average Tuber Weight and Tuber Number per Hill. Analysis of variance indicated that both the main effects of NPS 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. Total tuber number and average tuber weight were significantly affected by inter-row spacing and NPS fertilizer rate, respectively. Significantly lower number of marketable tuber (7.65) and total tuber number (10.061) were found from 45 cm inter-row spacing, while the highest marketable tuber number (11.744) and total tuber number (13.144) were recorded from 75 cm inter-row spacing. Both marketable tuber number and total tuber number were statistically the same for 75 cm and 85 cm inter-row spacing.

The production of higher marketable and 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. In agreement with the result of inter-row spacing, [38, 39] reported that planting potato at the wider spacing resulted in the production of higher numbers of marketable tubers/hill than the narrower spacing.

Furthermore, a significant difference in total tuber number was observed due to NPS fertilizer application. The highest marketable tuber number (11.627) and total tuber number (13.020) were obtained from the application of 200 kg/ha of NPS fertilizer rate which is statistically the same with 250 kg/ha and 150 kg/ha of NPS rate. On the other hand, the lowest marketable tuber number (7.680) and total tuber number (10.140) was recorded from the control treatment (Table 4). Increasing NPS application from 0 to 200 kg/ha increased both marketable and total tuber number, but the increment was significant up to the rate of 150 kg NPS above which statistically nonsignificant increment was observed.

The increase on marketable and total tuber number per hill with an increase in NPS 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. Sulfur enhances cell multiplication, elongation, and expansion; chlorophyll synthesis results in higher dry matter accumulation and consequently higher yield attributes [40].

In agreement with the present finding, the authors of [41] and [29] have reported a significant marketable and total tuber number increment in response to N and P fertilizer application. According to [35], sulfur resulted significant influence on yield parameters and yield of potato. They reported that the highest number of tuber per plant was recorded at 45 kg/ha sulfur, which was significantly superior over control and 15 kg/ha sulfur. Similarly, Singh et al. [42] reported that application of 180 kg N along with 50 kg S increased the number of tuber by 43%. According to Solomon et al [43]. increasing NPS rate from 0-0-0 to 110-19.74-50.8 kg/ha of N-S-P₂O₅ increased the number of marketable tuber by 127%.

Unmarketable tuber number per hill decreased with increasing inter-row spacing. The highest unmarketable

TABLE 3: Main effects of inter-row spacing and NPS fertilizer rate on marketable tuber number/hill, unmarketable tuber number/hill, total tuber number/hill, and average tuber weight/tuber.

Treatments	MTN	UTN	TTN	AWT(g)
<i>Inter-row spacing (cm)</i>				
45	7.650 ^d	2.411 ^a	10.061 ^c	72.342 ^b
55	8.789 ^{cd}	2.489 ^a	11.278 ^{bc}	72.663 ^b
65	9.711 ^{bc}	1.539 ^b	11.250 ^{bc}	82.061 ^a
75	11.744 ^a	1.400 ^b	13.144 ^a	85.559 ^a
85 significance level	11.378 ^{ab**}	1.567 ^{b**}	12.944 ^{ab**}	83.456 ^{a**}
LSD (0.05)	1.8498	0.5328	1.7347	8.1357
<i>NPS fertilizer rate (kg/ha)</i>				
0	7.680 ^d	2.460 ^a	10.140 ^b	72.288 ^b
50	8.893 ^{cd}	2.234 ^a	11.127 ^{ab}	73.399 ^b
100	9.073 ^{bcd}	2.333 ^a	11.307 ^{ab}	77.597 ^{ab}
150	10.853 ^{abc}	1.593 ^b	12.447 ^a	83.215 ^a
200	11.627 ^a	1.393 ^b	13.020 ^a	83.493 ^a
250 significance	11.00 ^{ab**}	1.373 ^{b**}	12.373 ^{a*}	85.304 ^{a*}
LSD (0.05)	2.0264	0.5836	1.9003	8.9122
CV (%)	28.13	32.45	22.15	15.39

UMTN = number of unmarketable tubers; MTN = number of marketable tubers; TTN = number of total tubers. AWT = average weight of tuber; * = significant at 5% significance levels; ** = significant at 1% significance levels; LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation; means in column followed by the same letters are not significantly different at 5% level of significance.

TABLE 4: Main effects of inter-row spacing and NPS fertilizer rate on stand count percent, marketable tuber yield/ha, unmarketable tuber yield/ha, and total tuber yield/ha.

Treatments	SCP	MTY (t/ha)	UTY (t/ha)	TTY (t/ha)
<i>Inter-row spacing (cm)</i>				
45	90.833	38.575 ^b	4.113 ^a	42.689 ^b
55	94.722	42.684 ^a	3.842 ^a	46.526 ^a
65	93.333	45.084 ^a	3.3767 ^b	48.462 ^a
75	93.611	37.492 ^b	3.242 ^b	40.734 ^b
85 significance level	94.722 NS	31.717 ^{**}	3.235 ^{b**}	34.952 ^{c**}
LSD (0.05)	NS	3.7003	0.2897	3.7182
<i>NPS fertilizer rate (kg/ha)</i>				
0	92.000	26.442 ^c	4.767 ^a	31.209 ^c
50	91.667	30.025 ^c	3.693 ^b	33.719 ^c
100	94.667	36.908 ^b	3.332 ^c	40.239 ^b
150	95.00	46.303 ^a	3.289 ^c	49.594 ^a
200	95.667	48.056 ^a	3.089 ^c	51.145 ^a
250 significance	91.667 NS	46.929 ^{a**}	3.201 ^{**}	50.131 ^{a**}
LSD (0.05)	NS	4.0535	0.3174	4.0731
CV (%)	7.16	14.94	12.19	13.70

SCP = stand count percent; UMTY = yield of unmarketable tuber; MTY = yield of marketable tuber; TTY = total tuber yield; ** = significant at 1% significance levels; LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation; means in column followed by the same letters are not significantly different at 5% level of significance.

tuber number (2.411) was recorded at narrow inter-row spacing (45 cm) and the lowest (1.567) was recorded at wider inter-row spacing (85 cm) which is statistically at par with 65 cm and 75 cm. 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. This suggestion is in accordance with that of [44] who described that narrower spacing resulted in the production of many stems with 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. According to Girma et al. [38, 39], planting potato at the narrower spacing resulted in the production of higher numbers of unmarketable tubers than the wider spacing.

The maximum number of unmarketable tuber (2.46) was recorded from unfertilized treatment which was statistically at par with the application of 50 kg/ha and 100 kg/ha NPS

fertilizer, whereas the minimum number of unmarketable tuber number was recorded from 200 kg/ha NPS fertilizer rate. Moreover, the authors of [29] and [42] reported that application of N-, P-, and S-containing fertilizers increased production of marketable tubers and decreased unmarketable tubers.

The highest tuber weight (85.56 g) of potato was recorded at 75 cm inter-row spacing and the lowest tuber weight (72.34 g) was recorded at 45 cm inter-row spacing. Average tuber weight was statistically similar for inter-row spacing of 65 cm, 75 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 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 [38] 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.

Furthermore, a significant difference in average tuber weight was observed due to NPS fertilizer application. The highest average tuber weight (83.49 g) was obtained from the application of 200 NPS fertilizer. However, this result was statistically similar with the application of 150 kg/ha and 250 kg/ha NPS fertilizer. On the other hand, the lowest average tuber weight (72.29 g) was recorded from the control treatment (Table 4). Average tuber weight increment with increasing fertilizer rate up to optimal was also reported by different authors. Nigusie [45] reported significant response of average tuber weight production of potato with an increased level of N and P nutrients. Application of NPS fertilizer produced the biggest tuber of potato than the control treatment [17]. According to Solomon et al., [43] application of 9.87 kg/ha S₂ with 55–25.4 kg/ha N₂/P₂O₅ doubled the size of average tuber weight as compared with unfertilized plant.

3.2.2. Tuber Yield. Marketable, unmarketable, and total tuber yield among inter-row spacing and NPS fertilizer rates were highly significant ($p < 0.01$). However, their interaction was found nonsignificant. Maximum marketable and total tuber yield was obtained at medium or intermediate inter-row spacing than wider plant spacing. The highest marketable tuber yield (45.084 t/ha) and total tuber yield (48.462 t/ha) was obtained from intermediate or medium (65 cm) inter-row spacing, whereas the lowest marketable yield (31.717 t/ha) and total tuber yield (34.952 t/ha) were recorded at the wider inter-row spacing (85 cm). Both marketable and total tuber yield was statistically similar for inter-row spacing of 65 cm and 55 cm (Table 5).

The increase in total tuber yield at intermediate inter-row spacing might be attributed to efficient use of available soil nutrients and other growth factors and enables to produce more tubers at the higher plant population per

TABLE 5: Main effects of inter-row spacing and NPS fertilizer rate on tuber size distribution.

Treatments	VSSST (%)	SST (%)	MST (%)	LST (%)
<i>Inter-row spacing (cm)</i>				
45	12.632 ^a	21.393 ^a	42.294	23.681 ^c
55	10.692 ^a	17.796 ^{ab}	39.776	31.736 ^b
65	6.440 ^b	15.312 ^{bc}	43.436	34.868 ^{ab}
75	6.773 ^b	12.981 ^c	39.663	40.583 ^a
85 significance level	6.936 ^{b**}	13.546 ^{bc**}	42.339	37.179 ^{ab**}
LSD (0.05)	3.9867	4.5827	NS	7.0599
<i>NPS fertilizer rate (kg/ha)</i>				
0	17.421 ^a	21.102 ^a	37.396	24.081 ^d
50	13.427 ^a	20.927 ^a	40.000	25.646 ^c
100	8.089 ^b	16.717 ^{ab}	42.169	33.026 ^{bc}
150	6.844 ^b	14.087 ^b	40.506	38.563 ^{ab}
200	5.803 ^b	12.360 ^b	39.944	41.893 ^a
250 significance level	5.984 ^{b**}	12.041 ^{b**}	43.595	38.447 ^{ab**}
LSD (0.05)	4.3672	5.0201	NS	7.7337
CV (%)	38.49	35.42	21.54	31.48

VST=very small-sized tuber number (%); SST=small-sized tuber number (%); MST=medium-sized tuber number (%); LST=large-sized tuber number (%); ** = significant at 1% significance levels; LSD (0.05)=least Significant Difference at 5% level; CV = coefficient of variation; means in column followed by the same letters are not significantly different at 5% level of significance.

hectare in plants grown at optimum plant spacing than closer and wider plant spacing. Increased plant population increased yield due to more tubers being harvested per unit area of land [46]. This result was in agreement with the findings of Harnet et al. [12] who reported that the highest marketable and total tuber yield was recorded at 65 cm inter-row spacing and the lowest was recorded at 80 cm inter-row spacing. The authors of [11] and [47] also reported that closer and intermediate spacing of 50 cm × 25 cm and 60 cm × 25 cm produced higher marketable and total tuber yield, whereas wider spacing of 80 cm × 30 cm and 75 cm × 30 cm led to the production of lower marketable tuber yields. Furthermore, Zabihi et al. [48] reported that plant density in potato affects some of the important plant traits such as total yield, tuber size distribution, and tuber quality. Increase in plant density led to decrease in mean tuber weight, but number of tubers and yield per unit area were increased.

On the contrary to this finding, Birahanu and Woldegiorgis reported that wider spacing of 75 cm × 30 cm was appropriate for high yield of potato. In addition, the authors of [39] indicated that the marketable tuber yields of plants cultivated at the spacing of 85 cm between rows and 30 cm between plants exceeded the total tuber yield and marketable tuber yields of plants grown at the spacing of 65 cm between rows and 30 cm between plants. Generally, these contradictions from the present study result indicated that optimum spacing may vary with variety, soil, climate, and other environmental factors for the same crop.

Application of NPS fertilizer at the rate of 200 kg/ha produced the highest marketable tuber yield (48.056 t/ha)

and total tuber yield (51.145 t/ha), while the lowest marketable tuber yield (26.442 t/ha) and total tuber yield (31.209 t/ha) were obtained from non-NPS-treated plots (Table 4). The yield increment due to NPS fertilizer application was significant up to 150 kg/ha above which non-significant increment was observed. The difference in marketable and total tuber yield between the application rate of 150 kg/ha, 200 kg/ha, and 250 kg/ha NPS fertilizer was nonsignificant (Table 5).

Different scholars indicated that application of P [29, 49–51]; S [52, 53]; NP [38, 54]; and NS [42] exhibited a significant increment on marketable and total tuber yield of potato plant. In addition, an increase of potato tuber yields with increasing levels of NPS in different areas of Ethiopia was reported by [15, 17, 18, 32, 55, 56]. Reference [38] showed that the increased level of N and P fertilizer from 0 to 110 N₂ with 90 kg/ha P₂O₅ increased the marketable yield by 131% and addition of 20 kg S/ha over NP raised the marketable yield by 153%.

P nutrient from NPS might enhance the development of roots particularly lateral and fibrous rootlets which in turn contributed to nutrient absorption, photosynthesis, and general physiological processes. Potato tuber yield is also known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers, and the time at which the maximum yield is obtained [50, 51]. They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. References [29, 49] also reported that increasing P application increased total tuber yield.

The increase in tuber yield with increasing sulfur levels may be due to its role in synthesis of sulfur-containing amino acids, proteins, energy transformation, and activation of enzymes which in turn enhances carbohydrate metabolism and photosynthetic activity of plant with increased chlorophyll synthesis [57] and partitioning of the photosynthates in the shoot and tubers [58]. Application of sulfur-containing fertilizers like NPS improves availability of plant nutrients such as P, Fe, Mn, and Zn, by amending the soil pH that may in turn increase yields of vegetable crops including potato [59]. According to [53], application of S fertilizer resulted significant differences on yield and raising the level 0 to 45 kg/ha increased total tuber yield per plant by 32.55%. Reference [52] reported S fertilizer contributed to a significant increment of potato tuber yield through enlarging tuber weight.

With an increase of inter-row spacing, nonmarketable tuber yield decreased where the highest unmarketable tuber yield (4.113 t/ha) was recorded at 45 cm, whereas the lowest (3.235 t/ha) was recorded from 85 cm. This might be due to the fact that closer spaced plants may have high competition for growth factors due to high plant number per unit area than wider plant spacing which led to produce high number of undersized tubers and unmarketable tuber yield. Similarly, the authors of [38, 39] found that plants grown at closer spacing produced high unmarketable tuber yield than plants grown at wider plant spacing.

With respect to NPS fertilizer rate, unmarketable tuber yield decreased with increase in NPS fertilizer rate, where the

lowest unmarketable tuber yield (3.089 t/ha) was recorded at 200 kg/ha NPS fertilizer rate and the highest unmarketable tuber yield (4.767 t/ha) was recorded at the control treatment (Table 4). In line with this result, Minwuyelet [17] reported that potato plants without NPS fertilizer produced the highest unmarketable tuber yield of 2.4 t/ha while those supplied with the highest NPS fertilizer rate produced the lowest unmarketable tuber yield of 0.50 t/ha.

3.2.3. Tuber Size Distribution. Main effect of NPS fertilizer rate and inter-row spacing showed highly significant ($P < 0.01$) effect on tuber size distribution (very small-sized tuber, small-sized tubers, and large-sized tuber number) except for medium-sized tubers. However, their interaction effect was not significant (Table 6). Maximum number of very small-sized tuber (12.632%) and small-sized tuber (21.393%) was obtained from 45 cm, while the lowest numbers of very small-sized tubers (6.440%) and small-sized tuber number (12.981%) were recorded from 65 cm to 75 cm, respectively. However, there was no significant difference in both very small- and small-sized tuber numbers which was between 85, 75, and 65 cm inter-row spacing.

The probable reasons behind 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. As a result, there would be a decline in mean tuber weight [60]. This result was in agreement with the finding of Wiersema [61] who reported that, at higher stem density, the tuber produced will remain smaller than at lower stem densities. Reference [62] also 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. Reference [12] also reported a high proportion of very small-sized tubers produced from the narrow spacing than wider spacing. According to [11], the maximum yield of very small-sized tubers was recorded for high planting density, and low yield was recorded for low planting density.

With respect to the NPS fertilizer rate, the lowest numbers of very small-sized tuber (5.803%) and small-sized tuber number (12.041%) were obtained from the application of 200 kg/ha and 250 kg/ha of NPS fertilizer, respectively, whereas the highest numbers of very small-sized tubers (17.421%) and small-sized (21.102%) tubers were recorded at the control treatment. Increasing NPS fertilizer rate from 0 to 200 kg/ha showed linear and consistent decrement in very small- and small-sized tuber number though there was no significant difference between 250 kg/ha, 200 kg/ha, and 150 kg/ha (Table 6). The decrement in the proportion of small-sized tubers due to fertilizer rate increment was also reported by [49]. Main effect of the NPS fertilizer rate and inter-row spacing did not show significant difference on medium-sized tuber distribution. Though nonsignificant difference was observed, the highest percent of medium-sized tubers was recorded at an inter-row spacing of 65 cm.

TABLE 6: Partial budget analysis data for NPS fertilizer rate.

NPS rate (kg/ha)	AMTY (t/ha)	AMTY (t/ha)	GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	MRR
0	26.442	23.7978	118989	0	118989	
50	30.025	27.0225	135112.5	1460	133652.5	1004.35
100	35.908	33.2172	166086	2420	163666	3126.41
150	45.303	41.6727	208363.5	3380	204983.5	4303.91
200	48.056	43.2504	216252	4340	211912	721.72
250	46.929	42.2361	211180.5	5300	205880.5	

Note. AMTY = average marketable tuber yield; ATY = 10% adjusted tuber yield; GFB = gross field benefit; TVC = total variable cost; MRR = marginal rate of return; NB = net benefit,

The highest mean percent of large-sized tuber (40.583%) was obtained from 75 cm, but was not statistically different from 65 cm to 85 cm inter-row spacing (Table 6). Moreover, the lowest percent of large-sized tuber (23.681%) was recorded at the narrowest inter-row spacing of 45 cm. Furthermore, as NPS fertilizer rate increased from 0 kg/ha to 200 kg/ha, the number of large-sized tuber increased consistently, where the highest percent of small-sized tubers (41.893%) was recorded at 250 kg/ha NPS fertilizer rate, while the lowest proportion (24.081%) was obtained from the control treatment. NPS rates from 150–250 kg/ha had statistically the same effect on proportion of large-sized tubers.

3.3. Economic Analysis. According to [63], the partial budget analysis includes the total variable costs and net benefits of each treatment. In this study, the costs of fertilizer and cost for transporting and application varied, while other costs were constant for each treatment. Therefore, the fertilizer and labor-related costs, gross incomes, net benefit, and associated net return are presented in Table 6. Overall benefits of application of NPS fertilizer on potato exceed nonapplication both in yields and net benefits. Application of 200 and 250 kg/ha NPS fertilizer recorded the 1st and 2nd highest net benefits, while application of 150 kg/ha NPS fertilizer recorded the 3rd highest net benefit of potato. Overall, the highest marginal rate of return was obtained from the application of 150 kg/ha of the NPS fertilizer rate (Table 6).

4. Conclusion

Information regarding optimum spacing and nutrient 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 NPS fertilizer rates were investigated in Kechi research farm, Dawro zone of south-western Ethiopia. The result revealed that growth and yield parameters were significantly affected only by main effects of NPS rates and inter-row spacing. Application of 200 kg NPS/ha resulted maximum marketable tuber yield (48.056 t/ha) and total tuber yield (51.145 t/ha) in which it resulted about 82% and 64% advantage over unfertilized plot, respectively. Furthermore, the highest marketable tuber yield (45.084 t/ha) and total tuber yield (48.462 t/ha) were obtained from the inter-row spacing of

65 cm which was statistically at par with 55 cm, whereas the lowest result for these parameters were recorded at 85 cm. In terms of economic performance, 150 kg/ha NPS was found to show the highest marginal rate of return (4303.91%). Therefore, potato growing farmers are advised to apply 150 NPS kg/ha with an inter-row spacing of 55 cm or 65 cm. Further study considering other potential varieties, seasons, and locations are suggested.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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