

Research Article

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Influence of integrated soil fertilization on the productivity and economic return of garlic (*Allium sativum* L.) and soil fertility in northwest Ethiopian highlands

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Abstract: Garlic (*Allium sativum* L.) is one of the main economical spices produced by poor smallholder farmers in the highlands of Ethiopia for both marketing and consumption. However, its productivity in the area has ever been declining mainly due to soil fertility depletion. Hence, an experiment was conducted under irrigation for two years in 2017 and 2018 in one of northwest Ethiopian highlands known as *Lay Gayint* to assess the productivity response of garlic to NPS inorganic fertilizers and cattle manure applications. Factorial combinations of four levels of N-P₂O₅-S inorganic fertilizers (0-0-0; 70-21-9; 112-37-16; and 159-58-25 kg ha⁻¹) and four levels of fresh cattle manure (0, 5, 10, and 15 t ha⁻¹) were laid out in randomized complete block design with three replications. Unlike that of NPS inorganic fertilizers application and its interaction with cattle manure, physicochemical properties of the experimental soil were highly significantly improved with cattle manure application. Most growth and bulb yield parameters of garlic were significantly influenced by combined applications of NPS inorganic fertilizers and cattle manure, and their responses were more pronounced with the progress of the cropping seasons. Combined applications of 112-37-16 kg ha⁻¹ N-P₂O₅-S inorganic fertilizers with 15 and 10 t ha⁻¹ cattle manure gave the highest bulb yields (18.03–22.05 t ha⁻¹), net benefits (Ethiopian Birr 509,456–626,814 per hectare), and marginal rate of returns (1,492.35–2,005.15%) in both study years of 2017 and 2018. Hence,

combined applications of 112-37-16 kg ha⁻¹ N-P₂O₅-S inorganic fertilizers with 10–15 t ha⁻¹ cattle manure are recommendable for garlic growing farmers in northwest Ethiopian highlands.

Keywords: bulb yield, fertility depletion, inorganic fertilizers, net benefit, nutrient imbalance, organic fertilizers

1 Introduction

Garlic (*Allium sativum* L.) belongs to the onion family Alliaceae and it is a widely consumed vegetable crop, spice, and versatile medicinal plant in the world [1,2]. Garlic is used as a seasoning or condiment in many foods [3] owing to its pungent flavor [4]. It gives a good taste and flavor to foods and helps to make foods more palatable and digestible [5]. It is also used widely as a traditional dietary supplement for protecting and curing many human diseases including atherosclerosis, cancer, diabetic, heart attack, and hypertension [1,6,7]. Garlic does therefore have big demand both in local and international markets.

Although it grows under a wide range of climatic conditions, garlic in Ethiopia grows best at higher elevations ranging from 1,800 to 2,800 m above sea level where cool weather prevails [4,5]. Garlic is hence one of the most important economic crops of poor smallholder farmers of Ethiopian highlands [8]. Most Ethiopian highland farmers produce garlic partly for their home consumption and largely for marketing as a source of their income [5]. Despite Ethiopian highlands being of great potentials for garlic production, actual garlic productivity in Ethiopian highlands is low [3] and it has still been declining seriously owing mainly to soil degradation and fertility depletion [5]. On the other hand, garlic requires relatively high amount of nutrients for normal growth and development [9], and its soils should

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therefore be fertile, rich in organic matter, well-drained and capable of holding adequate moisture [5], while garlic does have unbranched shallow root system with low nutrient extraction capacity [4].

Low productivity of garlic in Ethiopian highlands is further associated to the traditional exploitative farming practices employed by smallholder farmers [10,11]. Several workers also reported that most crop soils in Ethiopian highlands have seriously been degraded and their productivity becomes very low mainly due to exploitative farming with complete removal of crop residues and abandoning of crop rotation and organic matter application [12–15]. Since time immemorial before the start of using chemical fertilizers, farm yard manure applications and sound crop rotation practices were the only means of replenishing soil fertility of cultivated crop fields in Ethiopian highlands [16]. Using chemical fertilizers for enhancing crop productivity in the country has, however, been over-popularized for more than four decades, and thus, farmers have been misled with chemical fertilizers and abandoned to use crop rotation and organic matter [14,15]. Using inorganic fertilizers for crop production would not indeed be considered as malpractice, but rather their exclusive usage for long time without complementary application of organic matter into the crop soils is the main shortcoming of using inorganic fertilizers by Ethiopian farmers [12,17].

Apart from abandoning the application of farm yard manure, most smallholder farmers in northwest Ethiopian highlands use even inorganic chemical fertilizers largely for major cereal crops [16], but not much for secondary crops including garlic [18]. Even those limited number of farmers, who used commercial inorganic fertilizers for garlic production, applied them at the lower rates much below their blanket recommendation rates [4,10]. Unlike to inorganic fertilizers, organic fertilizers contain all essential plant nutrients and improve physical, chemical, and biological properties of the soil, although their available nutrients concentration per unit weight and time is very low compared to that of inorganic fertilizers [17]. There are hence complementarities between inorganic and organic fertilizers to supply balanced nutrients to crop plants and to maintain and improve the soil health [19,20]. Apart from very limited awareness of farmers about balanced soil fertility management, there is, however, no well-consolidated information about site-specific optimum recommendations of using inorganic and organic soil fertilizers for garlic production in the highlands of the country [18]. There is, hence, a need for systematic investigations towards determining site-specific recommendation rates of commonly available inorganic (NPS) and organic

(cattle manure) fertilizers for optimal garlic production in Ethiopian highlands. Thus, the main objective of this study was assessing the potential of integrated applications of NPS inorganic fertilizers and cattle manure for enhancing the productivity and economic benefit of garlic and soil fertility in northwest Ethiopian highlands.

2 Materials and methods

2.1 Experimental site

A field experiment was conducted in two dry seasons of 2017 and 2018 with irrigation in the rural village of 013 at *Taria* irrigation site in one of northwest Ethiopian highlands known as *Lay Gayint*. The experimental site is geographically located at 11°44'N latitude and 38°28' E longitude. The altitude of the site is 3,108 m above sea level. The mean annual rainfall of the site is 1,120.62 mm with spring shower rainfall from March to May and main summer rainfall from June to September. The rainfall of the area reaches peak in July and declines consistently from September to November. The dry season extends from December to February with occasional light shower rainfall. The average minimum and maximum temperatures of the site are 7.99 and 18.08°C, respectively. The night temperature of the site becomes low below 7°C from mid-October to December and night chilling occurs often in this season. Planting of garlic was hence done at the beginning of January. Fifteen years' (2004–2018) mean monthly and minimum and maximum temperatures of the study site are presented in Figure 1.

2.2 Planting material

A local garlic cultivar “*Gayint Necho*” commonly grown in the area was used for the experiment. Its bulbs were purchased from the local market and properly dried, stored, and prepared for planting after the experimental plot had been prepared. At planting time, well-cured cloves were separated from the bulbs and only medium-sized cloves were selected and used for planting.

2.3 Treatments and design

Factorial combinations of four levels of N–P₂O₅–S inorganic fertilizers (0–0–0; 70–21–9; 112–37–16; and

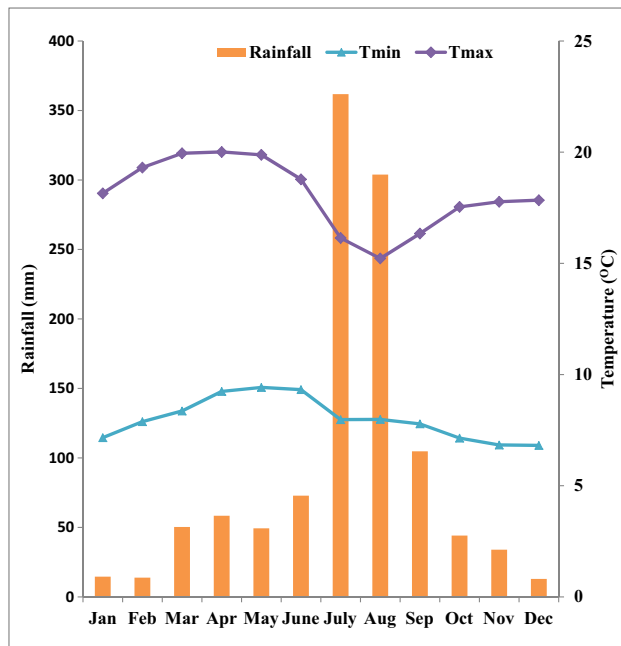


Figure 1: Fifteen years' (2004–2018) mean rainfall and minimum and maximum temperatures of the study site (T_{\min} = minimum temperature, T_{\max} = maximum temperature).

159–58–25 kg ha⁻¹) and four levels of fresh cattle manure (0, 5, 10, and 15 t ha⁻¹) were laid out in randomized complete block design with three replications. Blended NPS fertilizer (19% N, 38% P₂O₅, and 7% S) and urea (46% N) were used as sources of nitrogen (N), phosphate (P), and sulfur (S) inorganic fertilizers. Without considering the application of organic fertilizers, 112–37–16 kg ha⁻¹ has been used as the blanket recommendation rate of N–P₂O₅–S for garlic and onion in the country.

The experimental plot was plowed four times with oxen-driven local plowing implement (*Maresha*) and divided further into replications and plots with labor. As per the treatments, fresh cattle manure collected from the surrounding was thoroughly mixed up and uniformly surface-broadcasted on the experimental plots and incorporated in 20 cm soil depth with forked spade before two weeks of planting. The gross size of each experimental plot was 2.10 m by 2.10 m (4.41 m²) with the net plot area of 1.50 m by 1.90 m (2.85 m²). Paths between adjacent plots and replications were 0.6 and 1.0 m wide, respectively. On the first of January 2017 and 2018, well-cured seed clones were planted in rows at the recommended spacing of 30 cm between rows and 10 cm between plants at the depth of 3–4 cm and covered with soil. The whole amount of blended NPS was applied as per the treatments during the planting time, while urea as supplement of blended NPS fertilizer was applied in

three splits. The first one-third of the urea required for a plot/treatment was applied after two weeks of garlic emergence, while the second one-third and the third one-third were applied after six and eight weeks of garlic emergence, respectively. All other agronomic practices were applied as per their recommendations used for garlic production in the country. To see the residual effect of fertilizers on the succeeding fertilizer application treatments, as well as on the growth performance of garlic in the second experimental year, the experimental plots after harvesting of garlic in the first experimental year were tilled and kept idle during the main rainy season of 2017. Besides, growing garlic during the main rainy season on nearly flat irrigated field has not been practiced, since the rainfall during the main rainy season is excessive enough on flat land to drain well and the soil becomes wet to favor the severe infestation of garlic damping-off disease.

2.4 Soil analysis

Soil sampling and analysis were carried out two times, initially before starting the experiment in 2017 and finally after the completion of the experiment in 2018. Initially, before starting the experiment in 2017, seven soil samples were collected randomly in crisscross fashion of the whole plot at a plow depth of 0–20 cm using an augur and composited by taking equal amount of soil from collected samples. Finally, after the completion of the experiment in 2018, soil sampling and compositing were rather done at each experimental plot basis following the same procedures used for samples collected initially before starting the experiment. In both cases, composited soil samples were air-dried and crushed with motorized grinder and sieved with a 2 mm diameter screen sieve for further laboratory analysis.

Prepared composite soil samples ready for laboratory were analyzed further in Bahir Dar Soil Laboratory for determination of soil texture, pH, cation exchange capacity (CEC), and contents of organic carbon (OC), total nitrogen (TN), available phosphorous (AP), and available sulfate (ASO₄). Particle size distribution (soil texture) was determined by hydrometer method [21,22], while soil pH was measured using a digital pH meter in a 1:2.5 soil-water suspension [23]. OC was determined by wet digestion Walkley and Black method [24]. Determination of TN was carried out through micro-Kjeldahl digestion method [25]. AP was determined calorimetrically using Olsen's method [26], while ASO₄ was determined turbidimetrically using

a spectrophotometer method [27]. CEC was determined using titration method [28].

For soil bulk density (BD) determination, three independent undisturbed core soil samples were taken randomly on the whole experimental plot initially before starting the experiment in 2017 and on each experimental plot finally after the completion of the experiment in 2018. Core soil samples were further oven-dried at 105°C for 24 h and their BD was measured using the soil core method [29]. Soil analysis results of samples taken initially before starting the experiment were used both for characterization of the experimental soil and as baseline for comparison of the final soil analysis results of samples taken after two-year applications of NPS inorganic fertilizers and cattle manure to garlic plots. Lab analysis results of pH, BD, CEC, OC, TN, AP, and ASO_4 status of the experimental soil before starting the experiment were rated according to Panda [23], Blake and Hartge [29], Landon [30], Charman and Roper [31], Havlin et al. [32], Tadesse et al. [33], and Buchholz [34], respectively, while texture of the soil was classified according to Brady and Weil [35]. Percentile change/improvement of each soil variable (property) after two-year applications of NPS inorganic fertilizers and cattle manure was computed as:

$$\Delta P (\%) = \frac{(fP - iP)}{iP} \times 100, \quad (1)$$

where, $\Delta P (\%)$ is a change or improvement of a soil property (P) in percentile, while fP and iP are the final and initial values of a soil property, respectively.

2.5 Manure analysis

Before incorporating into the soil, collected cattle manure was thoroughly mixed up separately and five kg composite sample was taken for further laboratory analysis. Composite sample of cattle manure was prepared by taking randomly and mixing up of several samples from the mass. Composited sample of cattle manure was further oven-dried at 65°C until attaining constant weight. Its dry matter content was estimated as the ratio of sample weights after and before oven drying and expressed in percentile. Oven-dried sample was then crushed and sieved for further analysis of its carbon, nitrogen, phosphorous, and sulfur contents in Bahir Dar Soil laboratory. OC and nitrogen contents of cattle manure were determined by Degtjareff method [36] and micro-Kjeldahl digestion method [37], respectively. Phosphorous and sulfur contents of cattle manure were determined by mass spectrophotometric method [38].

2.6 Crop data collection

Data of plant height (cm), leaf length (cm), number of leaves per plant, neck diameter (cm), days to maturity, bulb diameter (cm), number of cloves per plant, bulb weight (g), and marketable and total bulb yields ($t\ ha^{-1}$) of garlic were collected from net plot areas of the experimental plots following their standard methods and procedures as described by Yayeh et al. [4]. Data on days to maturity and bulb yields were collected at plot basis, while data on all other parameters were collected at plant basis by taking 10 randomly selected plants in the net area of each plot. Bulb yields obtained from the net plot areas were further converted to hectare basis.

2.7 Data analysis

2.7.1 Soil and crop data analysis

Soil data collected after the completion of the experiments, as well as crop data, were further subjected to analysis of variance (ANOVA) using general linear model procedures of SAS version 9.4 [39]. Homogeneity test between crop results of two experimental years was also carried out using Bartlett test method, and all test results were found significant ($P < 0.05$) and thus, combined analysis of the results over years was not possible as described by Gomez and Gomez [40]. Whenever the ANOVA result showed significant difference between treatments for a variable, further mean separation was done using Honestly Significance Difference (HSD) method.

2.7.2 Economic analysis

Cost-benefit of NPS inorganic fertilizers and cattle manure applications on garlic production was analyzed following the procedures described by CIMMYT [41]. Garlic clove seeds, blended NPS fertilizer, urea, cattle manure, and labor were the main inputs of the study and their costs were estimated at the local market prices of Ethiopian Birr 33, 17 and 11 per kg, 365 per ton, and 80 per man-day, respectively. Marketable bulb yield was adjusted by reduction of 10% to reflect the actual productivity of farmers as described by CIMMYT [41]. Gross return on hectare basis was estimated as average adjusted marketable tuber yield ($t\ ha^{-1}$) multiplied by farm gate price of Ethiopian Birr 33,000 per ton, while net return was estimated by subtracting the total variable cost from the gross return.

Marginal rate of return (MRR) was estimated as the percentile ratio of the net return and variable cost differences of the fertilizer treatments and the control without any fertilizer. Mathematically, MRR was calculated as follows:

$$\text{MRR (\%)} = \left(\frac{(\text{NRt} - \text{NRc})}{(\text{TVCt} - \text{TVCc})} \right) * 100, \quad (2)$$

where, NRt and NRc were the net returns of the treatments and the control, respectively; TVCt and TVCc were total variable costs of the treatments and the control, respectively.

3 Results

3.1 Initial soil status

Initial soil status was used for characterizing the experimental soil and as baseline for soil improvement assessment after two-year NPS inorganic fertilizers and cattle manure applications. Lab analysis results of a composite soil sample taken before starting the experiment are presented in Table 1. Texture of the experimental soil was found to be clay loam, while the pH was acidic. BD of the soil was high with compact category. Contents of OC, TN, and ASO_4 of the soil were low, while content of AP was very low. CEC of the soil was indeed moderate.

3.2 Manure quality

Quality of manure used for soil fertilization is judged by its dry matter and nutrient contents, as well as by its

Table 1: Physicochemical properties of the experimental soil before starting the experiment

Soil properties	Value	Rating category
Bulk density (g cm^{-3})	1.38	Compact
pH (1:2.5 soil to H_2O)	5.16	Acidic
CEC (cmol(+) kg^{-1})	15.42	Moderate
Organic carbon (%)	0.91	Low
Total N (%)	0.13	Low
Available P (ppm)	6.75	Very low
Available SO_4 (ppm)	4.37	Low
Particle distribution		
Sand (%)	36.0	
Silt (%)	30.1	
Clay (%)	33.9	
Textural class	Clay loam	

carbon to nitrogen ratio. Average results of two years of dry matter and macronutrient contents of cattle manure used for the experiment are presented in Table 2. Its average carbon to nitrogen ratio was low.

3.3 Soil properties after treatments

Application of cattle manure to garlic plots for two years in 2017 and 2018 attributed to improve the physicochemical properties of the experimental soil significantly ($P < 0.05$) and the results are presented in Tables 3 and 4. However, NPS inorganic fertilizers and their interaction with cattle manure application did not significantly ($P \geq 0.05$) influence the physicochemical properties of the experimental soil in northwest Ethiopian highlands (Tables 3 and 4). Except soil BD, all other soil properties were significantly increased positively with the increase of cattle manure application rates (Tables 3 and 4). However, soil BD was significantly decreased with the increase of cattle manure application rates (Tables 3 and 4). The highest improvements of physicochemical soil properties were recorded at the rate of 15 t ha^{-1} cattle manure application. Compared to their initial status before the experiment, application of 15 t ha^{-1} cattle manure for two consecutive years attributed to improve BD, pH, CEC, and contents of OC, TN, AP, and ASO_4 of the experimental soil by -25.36 , 17.64 , 72.37 , 146.15 , 200.00 , 122.52 , and 128.15 percent, respectively (Table 4).

3.4 Garlic productivity

Phenological, vegetative growth, and bulb yield-related variables of garlic were significantly influenced by applications of NPS inorganic fertilizers and cattle manure in both experimental years of 2017 and 2018 in northwest

Table 2: Average dry matter and macronutrient contents of cattle manure applied to the experimental plots in 2017 and 2018

Dry matter (%)	Macronutrients				C:N ratio
	C (%)	N (%)	P (%)	S (%)	
12.56	26.24	2.48	0.67	0.35	10.58

C, carbon; N, nitrogen; P, phosphorous; S, sulfur; samples of cattle manure applied in each year were taken for dry matter and macronutrient analysis.

Table 3: Main and interaction effects of NPS inorganic fertilizers and cattle manure application on physicochemical properties of the experimental soil

Main factor		Soil properties						
		BD	pH	CEC	OC	TN	AP	ASO ₄
Cattle manure (t ha ⁻¹)								
	0	1.40 ^a	5.14 ^c	15.54 ^d	0.95 ^d	0.14 ^d	6.87 ^d	4.30 ^d
	5	1.25 ^{ab}	5.46 ^{bc}	19.12 ^c	1.37 ^c	0.22 ^c	9.29 ^c	6.19 ^c
	10	1.16 ^{bc}	5.82 ^{ab}	23.03 ^b	1.81 ^b	0.31 ^b	12.71 ^b	8.11 ^b
	15	1.03 ^c	6.07 ^a	26.58 ^a	2.24 ^a	0.39 ^a	15.02 ^a	9.97 ^a
Sig. difference		*	*	**	**	*	**	**
N-P ₂ O ₅ -S (kg ha ⁻¹)								
	0-0-0	1.23	5.65	21.09	1.62	0.29	11.00	7.17
	70-21-9	1.20	5.62	21.05	1.58	0.25	10.96	7.13
	112-37-16	1.22	5.64	21.08	1.60	0.28	10.99	7.15
	159-58-25	1.19	5.59	21.06	1.57	0.24	10.95	7.12
Sig. difference		ns	ns	ns	ns	ns	ns	ns
Treatment combination								
NPS (kg ha ⁻¹)	CM (t ha ⁻¹)							
0-0-0	0	1.42	5.17	15.56	0.97	0.16	6.90	4.33
	5	1.26	5.47	19.13	1.39	0.24	9.31	6.21
	10	1.19	5.83	23.06	1.83	0.33	12.74	8.14
	15	1.05	6.08	26.59	2.27	0.42	15.05	9.99
70-21-9	0	1.39	5.13	15.53	0.93	0.13	6.86	4.29
	5	1.24	5.45	19.11	1.36	0.21	9.27	6.19
	10	1.15	5.81	22.99	1.80	0.29	12.70	8.10
	15	1.02	6.05	26.56	2.23	0.37	15.01	9.95
112-37-16	0	1.41	5.15	15.57	0.96	0.15	6.88	4.31
	5	1.27	5.48	19.14	1.38	0.23	9.30	6.20
	10	1.16	5.80	23.02	1.82	0.34	12.72	8.12
	15	1.04	6.07	26.60	2.25	0.41	15.04	9.98
159-58-25	0	1.38	5.11	15.50	0.94	0.12	6.84	4.27
	5	1.23	5.44	19.10	1.35	0.20	9.28	6.16
	10	1.14	5.84	23.05	1.79	0.28	12.68	8.08
	15	1.01	6.08	26.57	2.21	0.36	14.98	9.96
Sig. difference		ns	ns	ns	ns	ns	ns	ns
CV (%)		1.34	2.06	8.22	1.48	0.77	7.43	6.89

CM, cattle manure; BD, bulk density (g cm⁻³); pH (1:2.5 soil to H₂O), potential of hydrogen in water suspension; CEC, cation exchange capacity (cmol(+) kg⁻¹); OC, organic carbon (%); TN, total nitrogen (%); AP, available phosphorous (ppm); ASO₄, available sulfate (ppm); **highly significant at $P < 0.01$; *significant at $P < 0.05$; ns, not significant at $P \geq 0.05$; CV (%), coefficient of variation; means in a column followed with the same letter are not significantly different at $P \geq 0.05$.

Ethiopian highlands (Tables 5 and 6). Except in the treatment combinations with the control of manure application (0 t ha⁻¹), the influence of the treatments on all considered variables of garlic increased with the progress of the experiment from 2017 to 2018 (Tables 5 and 6). In spite of the progress of the experiment from the first to the second cropping years, the treatment combinations with the control of manure application resulted in decreasing of garlic growth and yield parameters.

Days to maturity, plant height, number of leaves per plant, leaf length, and neck diameter of garlic were significantly ($P < 0.05$) increased with the increase of NPS inorganic fertilizers and cattle manure application rates

(Table 5). Plant height and leaf length of garlic were even influenced by the treatment combinations significantly ($P < 0.01$) in the second experimental year. Maturity of garlic delayed from 126.67 days in the control treatment combination of NPS (0-0-0 kg ha⁻¹) and cattle manure (0 t ha⁻¹) to 137.33 days in the combination of the highest rates of both NPS (159-58-25 kg ha⁻¹) and cattle manure (15 t ha⁻¹) application in the second experimental year of 2018 (Table 5). Similarly, the lowest plant height (57.52 cm), number of leaves per plant (6.33), leaf length (54.96 cm), and neck diameter (0.42 cm) of garlic were recorded in the control combination without NPS inorganic fertilizers and cattle manure application, while

Table 4: Percentile changes of physicochemical properties of the experimental soil after two-year applications of NPS inorganic fertilizers and cattle manure to garlic plots

Main factor		Percentile changes (%) of soil properties					
		Δ BD	Δ pH	Δ CEC	Δ OC	Δ TN	Δ ASO ₄
Cattle manure (t ha ⁻¹)							
0		1.45 ^a	-0.39 ^c	0.78 ^d	4.40 ^d	7.69 ^d	1.78 ^d
5		-9.42 ^{ab}	5.81 ^{bc}	23.99 ^c	50.55 ^c	69.23 ^c	37.63 ^c
10		-15.94 ^{bc}	12.79 ^{ab}	49.35 ^b	98.90 ^b	138.46 ^b	88.30 ^b
15		-25.36 ^c	17.64 ^a	72.37 ^a	146.15 ^a	200.00 ^a	122.52 ^a
Sig. difference		*	*	**	**	*	**
SE \pm		3.56	2.92	3.73	7.45	15.17	5.54
N-P ₂ O ₅ -S (kg ha ⁻¹)							
0-0-0		-10.87	9.50	36.77	78.02	123.08	62.96
70-21-9		-13.04	8.91	36.51	73.63	92.31	62.37
112-37-16		-11.59	9.30	36.71	75.82	115.38	62.81
159-58-25		-13.77	8.33	36.58	72.53	84.62	62.22
Sig. difference		ns	ns	ns	ns	ns	ns
SE \pm		3.56	2.92	3.73	7.45	15.17	5.54
Treatment combination							
NPS (kg ha ⁻¹)	CM (t ha ⁻¹)						
0-0-0	0	2.90	0.19	0.91	6.59	23.08	2.22
	5	-8.70	6.01	24.06	52.75	84.62	37.93
	10	-13.77	12.98	49.55	101.10	153.85	88.74
	15	-23.91	17.83	72.44	149.45	223.08	122.96
70-21-9	0	0.72	-0.58	0.71	2.20	0.00	1.63
	5	-10.14	5.62	23.93	49.45	61.54	37.33
	10	-16.67	12.60	49.09	97.80	123.08	88.15
	15	-26.09	17.25	72.24	145.05	184.62	122.37
112-37-16	0	2.17	-0.19	0.97	5.49	15.38	1.93
	5	-7.97	6.20	24.12	51.65	76.92	37.78
	10	-15.94	12.40	49.29	100.00	161.54	88.44
	15	-24.64	17.64	72.50	147.25	215.38	122.81
159-58-25	0	0.00	-0.97	0.52	3.30	-7.69	1.33
	5	-10.87	5.43	23.87	48.35	53.85	37.48
	10	-17.39	13.18	49.48	96.70	115.38	87.85
	15	-26.81	17.83	72.31	142.86	176.92	121.93
Sig. difference		ns	ns	ns	ns	ns	ns
SE \pm		7.12	5.84	7.46	14.90	30.34	11.08

CM, cattle manure; Δ , change from the initial status; BD, bulk density (g cm⁻³); pH (1:2.5 soil to H₂O), potential of hydrogen in water suspension; CEC, cation exchange capacity (cmol(+) kg⁻¹); OC, organic carbon (%); TN, total nitrogen (%); AP, available phosphorous (ppm); ASO₄, available sulfate (ppm); **highly significant at $P < 0.01$; *significant at $P < 0.05$; ns, not significant at $P \geq 0.05$; SE, standard error; means in a column followed with the same letter are not significantly different at $P \geq 0.05$.

the highest plant height (72.13 cm), number of leaves per plant (11.33), leaf length (67.26 cm), and neck diameter (1.07 cm) of garlic were recorded in the combination of the highest rates of 159–58–25 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure.

Although their lowest records were observed in the control combination of 0–0–0 kg ha⁻¹ NPS and 0 t ha⁻¹ cattle manure application, the highest bulb-related parameters of garlic including bulb diameter (4.94 cm), number of cloves per bulb (9.67), bulb weight (62.29 g), marketable bulb yield (22.03 t ha⁻¹), and total bulb yield

(22.05 t ha⁻¹) were recorded from the combination of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure application in the second year of the experiment (Table 6). In the first year of the experiment (2017), the interaction effect of 112–37–16 kg ha⁻¹ NPS with 10 and 15 t ha⁻¹ cattle manure on total bulb yield of garlic was comparable. In the second year of the experiment, however, total bulb yield of garlic was significantly increased with the combination of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure over that of the combination of 112–37–16 kg ha⁻¹ NPS and 10 t ha⁻¹ cattle manure application (Table 6).

Table 5: Effect of NPS inorganic fertilizers and cattle manure application on phenological and vegetative growth parameters of garlic in 2017 and 2018 in northwest Ethiopian highlands

Treatment combinations		Days to maturity		PH (cm)		NLP		LL (cm)		ND (cm)	
NPS (kg ha ⁻¹)	CM (t ha ⁻¹)	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
0–0–0	0	128.33 ⁱ	126.67 ⁱ	59.41 ⁱ	57.52 ^j	7.67 ^j	6.33 ^j	55.52 ⁱ	54.96 ⁱ	0.46 ^h	0.42 ^f
	5	129.00 ^h	130.33 ^g	63.22 ^{fg}	65.04 ^{fg}	8.33 ^h	8.67 ^f	58.26 ^h	60.13 ^g	0.67 ^g	0.73 ^d
	10	130.00 ^g	133.00 ^{de}	65.82 ^{cde}	67.25 ^{de}	8.67 ^g	9.33 ^e	60.10 ^g	63.41 ^{ef}	0.86 ^e	0.90 ^c
	15	130.67 ^f	134.33 ^d	67.25 ^{bc}	69.36 ^{bc}	9.33 ^e	9.67 ^d	62.84 ^{def}	64.52 ^{cde}	0.92 ^{bc}	0.95 ^{bc}
70–21–9	0	129.67 ^g	129.00 ^h	61.56 ^h	60.83 ⁱ	8.00 ⁱ	7.33 ⁱ	58.61 ^h	57.93 ^h	0.66 ^g	0.61 ^e
	5	130.00 ^g	131.67 ^f	64.67 ^{def}	65.19 ^{fg}	8.67 ^g	9.33 ^e	60.13 ^g	63.28 ^f	0.71 ^f	0.78 ^d
	10	130.67 ^f	134.00 ^d	65.14 ^{def}	66.07 ^{ef}	9.00 ^f	9.67 ^d	61.70 ^f	64.05 ^{ef}	0.87 ^{de}	0.93 ^{bc}
	15	133.33 ^b	135.33 ^c	65.90 ^{cde}	66.45 ^{def}	9.67 ^d	10.33 ^c	63.55 ^{bcd}	65.64 ^{bc}	0.95 ^b	0.98 ^b
112–37–16	0	130.67 ^f	130.33 ^g	62.34 ^g	61.58 ^{hi}	8.33 ^h	7.67 ^h	59.26 ^{gh}	58.57 ^h	0.67 ^g	0.64 ^e
	5	131.33 ^e	132.67 ^e	65.20 ^{de}	66.93 ^{ef}	9.33 ^e	9.67 ^d	62.34 ^{ef}	64.28 ^{def}	0.92 ^{bc}	0.97 ^b
	10	132.67 ^c	135.67 ^c	66.50 ^{bcd}	68.22 ^{bcd}	10.00 ^c	10.33 ^c	63.46 ^{bcd}	65.76 ^b	1.01 ^a	1.03 ^{ab}
	15	133.33 ^b	136.33 ^b	68.12 ^{ab}	70.06 ^b	10.33 ^b	10.67 ^b	64.20 ^{abc}	66.30 ^{ab}	1.04 ^a	1.05 ^a
159–58–25	0	132.00 ^d	131.67 ^f	64.12 ^{efg}	63.24 ^{gh}	8.67 ^g	8.00 ^g	59.86 ^g	59.15 ^{gh}	0.69 ^{fg}	0.66 ^e
	5	133.33 ^b	135.33 ^c	66.81 ^b	67.58 ^{cde}	9.67 ^d	10.33 ^c	63.09 ^{cde}	65.31 ^{bcd}	0.89 ^{cde}	0.98 ^b
	10	134.67 ^a	136.67 ^b	68.24 ^{ab}	70.05 ^b	10.33 ^b	10.67 ^b	64.40 ^{ab}	66.44 ^{ab}	1.03 ^a	1.04 ^a
	15	134.67 ^a	137.33 ^a	69.30 ^a	72.13 ^a	10.67 ^a	11.33 ^a	65.03 ^a	67.26 ^a	1.05 ^a	1.07 ^a
P-value		*	*	*	**	*	*	*	**	*	*
SE±		0.16	0.17	0.62	0.65	0.08	0.10	0.38	0.39	0.013	0.015
CV%		0.85	0.89	7.37	6.81	6.07	7.46	4.33	4.29	10.78	12.08

N, nitrogen; P, phosphorous; S, sulfur; CM, cattle manure; PH, plant height; NLP, number of leaves per plant; LL, leaf length; ND, neck diameter; *significant at $P < 0.05$; **highly significant at $P < 0.01$; P-value, probability value; SE, standard error; CV, coefficient of variation; means in a column followed with the same letter are not significantly different at $P \geq 0.05$.

Unlike to that of 2017, both marketable and total bulb yields of garlic in 2018 were comparable in the combinations of 112–37–16 and 159–58–25 kg ha⁻¹ NPS with 10 and 15 t ha⁻¹ cattle manure, respectively.

Vegetative growth parameters of garlic were increased with the increase of NPS inorganic fertilizers and cattle manure application rates up to their highest combination rates of 159–58–25 kg ha⁻¹ and 15 t ha⁻¹, respectively. Unlike that of vegetative growth parameters, bulb yield-related parameters of garlic were increased up to the combined application rates of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure and declined at the highest interaction rates of NPS 159–58–25 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure. Compared to the control without any fertilizer application, combined application of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure increased the bulb productivity of garlic by 328.37 and 432.61% in 2017 and 2018, respectively. Applications of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure separately without combination of one to another increased the bulb productivity of garlic by 73.91–93.26% and 119.53–209.66%, respectively, which were very inferior over that of their combined application.

3.5 Economic return

The highest net returns of Ethiopian Birr 518,409 and 626,814 per hectare were obtained in 2017 and 2018, respectively, from the combined application of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure (Table 7). In both experimental years of 2017 and 2018, however, the highest MRRs of 4,034.94 and 4,820.47% were recorded from the combination of 70–21–9 kg ha⁻¹ NPS and 10 t ha⁻¹ cattle manure application, although its net return was far behind from other several treatment combinations (Table 7). MRR of the treatment combination of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure, which gave the highest net returns in both experimental years, was the fifth in both experimental years.

4 Discussion

Compact BD and low chemical properties of the experimental soil before the treatments indicated the poorness of the soil health of the crop land of northwest Ethiopian

Table 6: Effect of NPS inorganic fertilizers and cattle manure application on bulb yield related parameters of garlic in 2017 and 2018 in northwest Ethiopian highlands

Treatment combinations		BD (cm)		NCB		BW (g)		MBY (t ha ⁻¹)		TBY (t ha ⁻¹)	
NPS (kg ha ⁻¹)	CM (t ha ⁻¹)	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
0–0–0	0	2.98 ^g	2.52 ^g	5.67 ^g	5.33 ⁱ	15.53 ^f	15.20 ^h	4.11 ^l	3.92 ^m	4.30 ^k	4.14 ^l
	5	4.12 ^e	4.40 ^e	6.33 ^f	7.00 ^f	23.07 ^e	26.15 ^{fg}	5.56 ^k	6.17 ^l	5.72 ^j	6.29 ^{jk}
	10	4.39 ^d	4.76 ^{abcd}	7.67 ^{de}	8.33 ^d	35.80 ^c	39.21 ^d	8.15 ^h	10.11 ^h	8.21 ^g	10.15 ^g
	15	4.71 ^{ab}	4.93 ^{ab}	8.33 ^{bc}	8.67 ^{cd}	38.86 ^c	44.32 ^c	9.40 ^g	12.79 ^g	9.44 ^f	12.82 ^f
70–21–9	0	3.54 ^f	3.35 ^f	6.67 ^f	6.00 ^{gh}	23.34 ^e	23.10 ^g	6.12 ^j	5.78 ^l	6.25 ⁱ	5.94 ^k
	5	4.41 ^d	4.57 ^{de}	7.33 ^e	7.67 ^e	27.13 ^d	28.54 ^f	7.59 ⁱ	7.97 ⁱ	7.67 ^h	8.03 ^h
	10	4.55 ^{bcd}	4.66 ^{cd}	8.33 ^{bc}	8.67 ^{cd}	52.97 ^{ab}	54.16 ^b	16.48 ^d	18.63 ^d	16.53 ^c	18.67 ^d
	15	4.68 ^{ab}	4.98 ^a	8.67 ^b	9.33 ^{ab}	53.04 ^{ab}	55.25 ^b	16.83 ^d	19.39 ^c	16.87 ^c	19.42 ^c
112–37–16	0	3.55 ^f	3.41 ^f	6.67 ^f	6.33 ^g	36.15 ^c	34.17 ^e	8.20 ^h	7.11 ^j	8.31 ^g	7.20 ⁱ
	5	4.61 ^{abc}	4.72 ^{bcd}	8.33 ^{bc}	8.67 ^{cd}	52.49 ^{ab}	53.96 ^b	13.97 ^e	16.28 ^f	14.06 ^d	16.34 ^e
	10	4.66 ^{ab}	4.81 ^{abc}	8.67 ^b	9.33 ^{ab}	55.45 ^a	61.33 ^a	17.99 ^b	21.06 ^b	18.03 ^a	21.10 ^b
	15	4.79 ^a	4.94 ^{ab}	9.33 ^a	9.67 ^a	55.67 ^a	62.29 ^a	18.38 ^a	22.03 ^a	18.42 ^a	22.05 ^a
159–58–25	0	3.44 ^f	3.23 ^f	6.33 ^f	5.67 ^h	26.40 ^d	25.03 ^g	7.27 ⁱ	6.73 ^k	7.44 ^h	6.97 ^{ij}
	5	4.38 ^d	4.56 ^{cde}	8.00 ^{cd}	8.33 ^d	50.58 ^b	54.72 ^b	12.03 ^f	16.89 ^e	12.17 ^e	17.00 ^e
	10	4.42 ^{cd}	4.75 ^{bcd}	8.67 ^b	9.00 ^{bc}	53.06 ^{ab}	55.65 ^b	16.96 ^{cd}	19.51 ^c	17.08 ^b	19.59 ^c
	15	4.55 ^{bcd}	4.84 ^{abc}	8.67 ^b	9.33 ^{ab}	53.15 ^a	61.54 ^a	17.19 ^c	21.15 ^b	17.30 ^b	21.20 ^b
P-value		**	**	*	*	**	**	**	**	**	**
SE±		0.06	0.06	0.14	0.16	1.10	1.14	0.11	0.13	0.12	0.24
CV%		9.8	11.17	12.55	13.93	18.68	18.19	6.55	6.69	7.34	12.29

N, nitrogen; P, phosphorous; S, sulfur; CM, cattle manure; BD, bulb diameter; NCB, number of cloves per bulb; BW, bulb weight; MBY, marketable bulb yield; TBY, total bulb yield; *significant at $P < 0.05$; **highly significant at $P < 0.01$; P-value, probability value; SE, standard error; CV, coefficient of variation; means in a column followed with the same letter are not significantly different at $P \geq 0.05$.

highlands. Several workers also reported similar results earlier in the cultivated land of northwest Ethiopian highlands [12–15]. These low physicochemical properties of the experimental soil would be the outcome of severe soil degradation and fertility depletion in the crop land of the study area, which might likely be associated further to the exploitative traditional farming with complete removal of crop residues and abandoning of crop rotation and organic matter application to the cultivated land of Ethiopian highlands [14,15]. The crop soil of the study area was thus necessitating proper amendments including organic fertilizer application. Cattle manure with low carbon to nitrogen ratio was hence used as organic fertilizer in the present study to see its effect on soil fertility and productivity in short duration of the experiment, while organic inputs with low carbon to nitrogen ratio could be degraded quickly [15].

Application of cattle manure for two consecutive years resulted in marked improvement of the physicochemical properties of the experimental soil. In agreement with the present results, several workers [19,20,42–44] also reported that applications of different organic inputs improved physical and chemical properties of crop soils significantly. Since organic fertilizers do have residual

effects, regular application of organic fertilizers to the crop soils enhances their improvement effects on soil properties and crop productivity as the progress of the cropping seasons [19,20]. This is because of that the residual effects of organic fertilizers applied in previous cropping seasons accumulated forward and combined with the direct effects of currently applied ones to have more improvement effects ever before [20,42]. Cumulative direct and residual effects of cattle manure applied in two experimental years of 2017 and 2018 attributed, hence, to improve the physicochemical properties of the experimental soil very markedly and their improvement effects increased highly significantly with the increase of manure application rates.

Unlike to organic fertilizers, however, inorganic fertilizers do have little or no residual effects directly on soil properties [20]. Indeed, they would indirectly have residual effects on soil properties through increasing the crop biomass, if crop residues could be left behind in the crop fields and incorporated into the soil. But, inorganic fertilizers applied to crop fields like the present garlic plots where no crop residues were left behind in the crop field might have little or no residual effects on soil properties and this might be the reason that NPS inorganic fertilizers and their interaction with cattle manure applications did

Table 7: Economic return of garlic production as influenced by NPS inorganic fertilizers and cattle manure application in 2017 and 2018 in northwest Ethiopian highlands

Treatment combinations		TVC (EB ha ⁻¹)	MBY (t ha ⁻¹)	AMBY (t ha ⁻¹)	GR (EB ha ⁻¹)	NR (EB ha ⁻¹)	MRR (%)	Rank
NPS (kg ha ⁻¹)	CM (t ha ⁻¹)							
In 2017								
0–0–0	0	13,712.00	4.11	3.70	122,067.00	108,355.00	—	—
	5	16,342.00	5.56	5.00	165,132.00	148,790.00	1,537.45	15
	10	18,972.00	8.15	7.34	242,055.00	223,083.00	2,181.14	11
	15	21,602.00	9.40	8.46	279,180.00	257,578.00	1,891.29	9
70–21–9	0	17,337.00	6.12	5.51	181,764.00	164,427.00	1,546.81	14
	5	19,967.00	7.59	6.83	225,423.00	205,456.00	1,552.37	12
	10	22,597.00	16.48	14.83	489,456.00	466,859.00	4,034.94	6
	15	25,227.00	16.83	15.15	499,851.00	474,624.00	3,180.80	5
112–37–16	0	19,587.00	8.20	7.38	243,540.00	223,953.00	1,967.63	10
	5	22,217.00	13.97	12.57	414,909.00	392,692.00	3,343.18	7
	10	24,847.00	17.99	16.19	534,303.00	509,456.00	3,602.16	2
	15	27,477.00	18.38	16.54	545,886.00	518,409.00	2,978.96	1
159–58–25	0	22,262.00	7.27	6.54	215,919.00	193,657.00	997.68	13
	5	24,892.00	12.03	10.83	357,291.00	332,399.00	2,003.97	8
	10	27,522.00	16.96	15.26	503,712.00	476,190.00	2,663.54	4
	15	30,152.00	17.19	15.47	510,543.00	480,391.00	2,262.99	3
In 2018								
0–0–0	0	13,712.00	3.91	3.52	116,127.00	102,415.00	—	—
	5	16,342.00	6.17	5.55	183,249.00	166,907.00	2,452.17	14
	10	18,972.00	10.11	9.10	300,267.00	281,295.00	3,400.76	10
	15	21,602.00	12.79	11.51	379,863.00	358,261.00	3,242.66	9
70–21–9	0	17,337.00	5.78	5.20	171,666.00	154,329.00	1,432.11	15
	5	19,967.00	7.97	7.17	236,709.00	216,742.00	1,827.77	11
	10	22,597.00	18.63	16.77	553,311.00	530,714.00	4,820.47	6
	15	25,227.00	19.39	17.45	575,883.00	550,656.00	3,892.67	5
112–37–16	0	19,587.00	7.11	6.40	211,167.00	191,580.00	1,517.70	12
	5	22,217.00	16.28	14.65	483,516.00	461,299.00	4,219.68	8
	10	24,847.00	21.06	18.95	625,482.00	600,635.00	4,474.36	2
	15	27,477.00	22.03	19.83	654,291.00	626,814.00	3,809.66	1
159–58–25	0	22,262.00	6.73	6.06	199,881.00	177,619.00	879.58	13
	5	24,892.00	16.89	15.20	501,633.00	476,741.00	3,348.18	7
	10	27,522.00	19.51	17.56	579,447.00	551,925.00	3,254.96	4
	15	30,152.00	21.15	19.04	628,155.00	598,003.00	3,014.53	3

N, nitrogen; P, phosphorous; S, sulfur; CM, cattle manure; TVC, total variable cost; EB, Ethiopian Birr; MBY, marketable bulb yield; AMBY, adjusted marketable bulb yield; GR, gross return; NR, net return; MRR, marginal rate of return.

Since their all MRRs were acceptable (more than 100%), the treatment combinations were ranked based on their net returns.

not show significant effect on physicochemical properties of the experimental soil.

BD is a good indicator for monitoring the physical property of soils, mainly soil structure [45], but with negative relationship. Unlike other soil properties, as rates of cattle manure application increased in two years, BD of the experimental soil decreased significantly, reflecting the improvement of soil structure and increased soil porosity. Accumulated soil organic matter as outcome of cumulative direct and residual effects of cattle manure application in two consecutive years might increase the aggregation and

stability of soil structure which would further play a great role in increasing soil porosity, root and soil microbes proliferation, aeration, water retention and movement, preventing surface sealing, minimizing soil erosion, and easing tillage practices [12,13,46]. Improvement of these physical properties of the soil might eventually contribute a lot to the enhancement of crop productivity.

Enriched soil organic matter as the result of cumulative direct and residual effects of regular cattle manure application at substantial rates would also account for the improvement of chemical properties of the experimental

soil. High soil organic matter owing to regular cattle manure application improved pH of the experimental soil through improving CEC and enriching cations of the soil. More than its direct effect on improving the soil pH, high soil organic matter might rather play a great role in binding toxic elements like copper (Cu), manganese (Mn), and aluminium (Al) in highly acidic soils, thereby enhancing soil biological activities, as well as crop diversity and productivity [17,47]. High soil organic matter in acidic soils is also important for reducing the fixation of nutrients like phosphorous primarily through binding the fixing materials, mainly Fe- and Al-oxides. Negassa et al. [47] earlier indicated that high soil organic matter checks soil pH and reduces Al toxicity and phosphorous fixation in strongly acidic soils.

Increased soil organic matter due to regular cattle manure application might directly attribute to improve CEC of experimental soils, while soil organic matter (humus) is part of negatively charged soil colloidal materials that are accountable for cation exchange. Through its mineralization, enriched soil organic matter would also be accountable for the enhancement of soil plant nutrients including nitrogen, phosphorous, and sulfur. Contrary to inorganic fertilizers that constitute one or few nutrients, organic fertilizers constitute almost all essential plant nutrients and they are considered as complete fertilizers. Since organic fertilizers release plant nutrients slowly and contain low nutrients per unit mass, organic fertilizers applied at low rates may not, however, supply the required amount of macronutrients like NPS per unit time for optimal growth and development of crop plants, and hence, they should be supplemented with inorganic fertilizers [17,42]. Productivity response of crops to inorganic fertilizers applied alone for long period without supplementing organic fertilizers like the present study area may be declining markedly, while the existing soil humus would severely be depleted and unable to supply the required amount of other essential nutrients for optimal growth and development of crop plants [42]. In areas where organic sources are limited, it is therefore necessary to complement organic fertilizers with inorganic fertilizers for optimal crop productivity.

Vigorous vegetative growth as the result of balanced fertility management is essential for good bulb formation and enhancing productivity of garlic [5]. But, excessive vegetative growth largely due to excessive nitrogen would negatively affect bulb formation and productivity of garlic [9,48]. Delay of garlic maturity with the increase of NPS inorganic fertilizers and cattle manure application rates would also be associated to high vegetative growth of garlic as the result of increasing the supply of plant nutrients including nitrogen, which plays a great role in enhancing vegetative growth of plants [4,10].

Response of garlic productivity to the application of NPS inorganic fertilizers alone was much lower than that of applying cattle manure alone and this low productivity response of garlic to the application of NPS inorganic fertilizers without cattle manure combination worsened with the progress of the cropping years from 2017 to 2018 which revealed not having residual effect of inorganic fertilizers on the improvement of garlic soil productivity and severe depletion of soil plant nutrients and their sources like humus in the crop soils of the study area as reported by several scholars [12–15,17,46]. On the contrary, however, garlic productivity response to the application of cattle manure alone was much higher than that of applying the NPS inorganic fertilizers alone and this productivity improvement with the application of cattle manure was more pronounced as the progress of the cropping years. In line with these results, Harendra et al. [49] noted that farmyard manure improves both crop productivity and the physical and chemical conditions of soils through supplying all essential plant nutrients and organic matter. Ram et al. [20] also indicated that regular application of organic fertilizers would have cumulative direct and residual effects on the improvement of both crop productivity and soil physicochemical properties, while inorganic fertilizers, on the contrary, would have neither any residual effect on the succeeding crop productivity nor any significant direct and residual effects on soil physicochemical properties.

High growth and yield responses of garlic to the combined applications of NPS inorganic fertilizers and cattle manure in the present study reflected also the severity of soil degradation and fertility depletion in the study area of northwest Ethiopian highlands. In Ethiopian mid highlands with the altitude of 1,850 to 2,000 m above sea level where soil degradation and fertility depletion is moderate, garlic growth and yield responses to inorganic and organic fertilizers [8–10] were not as high as that of the present study. In agreement with these results, Diriba [5] indicated that response of garlic to soil fertilizer applications is much dependent upon the fertility status of soils, as well as on kind and amount of fertilizers applied into the soil. According to Tamene et al. [17], productivity response of crops to the application of NP inorganic fertilizers into organic matter rich soils would be much higher than that of NP application into soils containing low organic matter, while soil organic matter serves as a pool source for all essential plant nutrients through mineralization and plays a major role in maintaining the balance of macro- and micronutrients' supply to the growing crop plants. On the contrary, crop productivity response to the application of organic fertilizers

into soils containing high organic matter would be much lower than that of organic fertilizers applied into soils containing low organic matter [13]. Accordingly, low organic matter content of the experimental soil would largely be accountable for low and high productivity responses of garlic to the applications of NPS inorganic fertilizers and cattle manure separately without one to the other combination, respectively.

In the present study area of northwest Ethiopian highlands where soil degradation and fertility depletion are severe [14,15], integrated application of NPS inorganic fertilizers and cattle manure enhanced the productivity of garlic much higher than their separated applications. Shalini et al. [50] also noted that complementary use of chemical fertilizers and organic manures has great importance to maintain and sustain a higher level of soil fertility and crop productivity. Harendra et al. [49] reported that apart from boosting bulb yield, application of organic fertilizers in complement with inorganic fertilizers enhanced nutrients' uptake by garlic markedly. Besides supplying essential plant nutrients, cattle manure application, unlike NPS inorganic fertilizers, improved the physico-chemical properties of the experimental soil very significantly which might in turn play a great role in enhancing the productivity of garlic. Since organic fertilizers release plant nutrients slowly and contain low nutrients per unit mass, organic fertilizers applied at low rates may not, however, supply the required amount of macronutrients per unit time like inorganic fertilizers for optimal growth and development of crop plants, and hence, they should be supplemented with inorganic fertilizers [42].

Net returns and MRRs of garlic with combined application of NPS inorganic fertilizers and cattle manure in the second experimental year of 2018 were markedly higher than that in the first year of 2017 which might be due to additive residual effect of cattle manure on the improvement of garlic productivity. On the contrary, net returns and MRRs of garlic with NPS inorganic fertilizers alone without cattle manure in 2018 were much lower than in 2017 as the result of declining productivity response of garlic to the continuous application of NPS inorganic fertilizers alone without supplementing cattle manure into the degraded soil containing low organic matter.

According to CIMMYT [41], any technologies with more than 100% MRR are acceptable by farmers. It also forwarded that technologies with highest net benefits are recommended for farmers as long as their MRRs are acceptable (more than 100%). In the present study, hence, all the treatment combinations beyond the control without NPS and cattle manure application were found acceptable, while their MRRs were more than 100%. Indeed, the

combined application of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure, which gave the highest net returns in both experimental years with acceptable high MRR, would first be recommended for garlic growing farmers in the present study area of northwest Ethiopian highlands. Following the combined application of 112–37–16 kg ha⁻¹ NPS and 15 t ha⁻¹ cattle manure, the combined application of 112–37–16 kg ha⁻¹ NPS and 10 t ha⁻¹ cattle manure could also be recommended for garlic growing farmers in the study area.

5 Conclusion

Results of the study clearly revealed that productivity of garlic responded positively to integrated applications of NPS inorganic chemical fertilizers and cattle manure. The positive response of garlic productivity to integrated applications of inorganic and organic fertilizers was more pronounced with the progress of the cropping seasons due to forward additive residual effect of organic fertilizers on the improvement of growth and productivity of garlic. The combined application of 112–37–16 kg ha⁻¹ NPS inorganic fertilizers with 15 and 10 t ha⁻¹ cattle manure gave the highest net returns and MRRs, and it is hence recommended for garlic growing farmers in the present study area of northwest Ethiopian highlands. Combined application of 159–58–25 kg ha⁻¹ NPS inorganic fertilizers with 10 and 15 t ha⁻¹ cattle manure caused declining of bulb yield-related parameters owing to excessive vegetative growth which might likely have been triggered by excessively high nitrogen supply. Neither NPS inorganic fertilizers application nor its interaction with cattle manure affected soil properties significantly, but cattle manure application, on the contrary, improved soil properties significantly. In the study area of northwest Ethiopian highlands, where fertility depletion and soil organic matter degradation are severe, as well as availability of organic inputs is not abundant enough, it is necessary to supplement the application of inorganic fertilizers with the available organic inputs regularly for sustainable improvement of crop soils and their productivity.

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