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Original Paper

Quantification of vermicompost with nitrogen equivalence ratio on soil chemical properties and onion (Allium cepa L.) production in North Western Amhara Region Ethiopia

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***Abstract*— The experiment was conducted to determine the effects of vermicompost with equivalent nitrogen ratios on soil chemical properties and onion production in Northwestern Ethiopia. The experiment comprised six treatment levels: Control, Recommended Nitrogen, 75% Recommended Nitrogen + 25% Vermicompost, 50% Recommended Nitrogen + 50% Vermicompost, 25% Recommended Nitrogen + 75% Vermicompost, and 100% Vermicompost. These were arranged in a Randomized Complete Block Design (RCBD) with three replications. Data were analyzed using Analysis of Variance (ANOVA) via SAS software. The results showed that vermicompost combined with nitrogen affected the yield components of onions. However, soil properties, except for Total Nitrogen (TN) and Organic Carbon (OC), were not significantly affected by the treatments. The application of 50% vermicompost with 50% nitrogen resulted in the highest bulb yield (23.6 t/ha) compared to the control. Therefore, for a quick improvement in yield, applying 50% vermicompost with 50% nitrogen can be preferable in the study area and areas with similar agro-ecological conditions to achieve the highest net benefit.**

Keywords*— vermicompost, nitrogen, soil properties, onion, fertilizer

I. INTRODUCTION

Onion (Allium cepa L.) is one of the most important commercial vegetable crops and significantly contributes to the human diet, economic earnings, and medical capabilities [1]. Onions are primarily valued for their distinct flavor and their ability to enhance the flavor of food [2]. The most commonly cultivated onion varieties in Ethiopia include Han, Robaf, Lambada, Mata Hari, Rio Bravo, and Sirius [3]. Onion production in Ethiopia covers 31,673.21 hectares, with a total yield of 293,887.585 tons and an average productivity of 9.3 tons/ha [4]. In comparison to the global average of 19.7 tons/ha [5], this yield is relatively low. This phenomenon is particularly pronounced in the Amhara region compared to other regions. Low yields are mainly attributed to factors such as the choice of variety, low soil fertility, pests and diseases, price fluctuations, and inadequate storage facilities [6].

Furthermore, a lack of fertile soil and the application of integrated nutrient management (the combination of organic and inorganic fertilizers) are relevant issues in many areas [1]. Vermicompost is one of the organic fertilizers obtained as a byproduct of organic matter breakdown through the activity of earthworms and microorganisms [7]. Earthworm fragments help increase microbial activity and accelerate breakdown rates in a non-thermophilic process [8]. Vermicompost not only provides organic matter and nutrients but also improves the soil's microbial population and enhances its physical, biological, and chemical properties, which in turn increases crop productivity [9]. Various research findings have confirmed the impact of organic fertilizers as stimulants for onion plant growth and yield [10], as well as their role in enhancing bulb quality and storability [11].

In Ethiopia, the utilization of vermicompost is receiving high emphasis due to its ease of production, availability of inputs and labor, improved nutrient composition, and lower cost compared to inorganic fertilizers [12]. Furthermore, nitrogen availability in vermicompost is critical for balancing vegetative and reproductive growth in onions. Several studies have demonstrated that supplementing onion bulbs with nitrogen fertilizer can improve dry matter and protein content [13]. Moreover, the concentration of available nitrogen in most organic fertilizers, including vermicompost, is usually higher compared to other nutrients. On the other hand, continuous application of chemical fertilizers can lead to soil quality degradation, such as increased soil acidity, loss of organic matter, and depletion of nutrients not included in the fertilizer formulation [14]."

Similarly, organic fertilizers are used in large quantities, and their nutrients are released slowly. This makes them less effective in influencing soil characteristics and crop productivity over a short period of time [15]. Thus, integrated nutrient management is critical for the long-term maintenance and management of soil fertility and crop productivity. Based on this, the use of a judicious and effective combination of organic and inorganic fertilizers is crucial. This is not only for increasing the production and quality of onions but also for maintaining soil health sustainably. Particularly in our region, the application of a balanced combination of organic and inorganic fertilizers for soil and crop improvement has not been well studied or investigated. Therefore, this study was conducted to investigate the integrated effect of nitrogen and vermicompost equivalency ratio on soil chemical properties, yield, and yield components of onion at the Koga irrigation scheme.

II. Materials and Method

A. Description of the study area

The experiment was carried out over two consecutive growing seasons (2020 and 2021) on a farmer's field in the North West Amhara Region of Ethiopia, at the Koga Irrigation Scheme in Mecha District. This is one of the irrigation schemes designed by the Ethiopian government to increase the yield and productivity of horticultural crops in North Western Ethiopia. The irrigation network covers around 7,000 ha and is primarily used for cultivating horticultural crops such as onions, tomatoes, peppers, cabbage, and carrots. Additionally, cereal crops such as wheat and maize are also grown during both the irrigation and rainy seasons. The land within the irrigation scheme has a steady slope and is classified as Nitisol. It is located at a latitude of 11°23′ and a longitude of 37°05′ E to 37°06′ E (Figure 1), with an average elevation of approximately 1,972 meters above sea level. The region receives an annual mean rainfall of 1,395.23 mm, and the mean maximum and minimum temperatures are 27°C and 12.8°C, respectively.

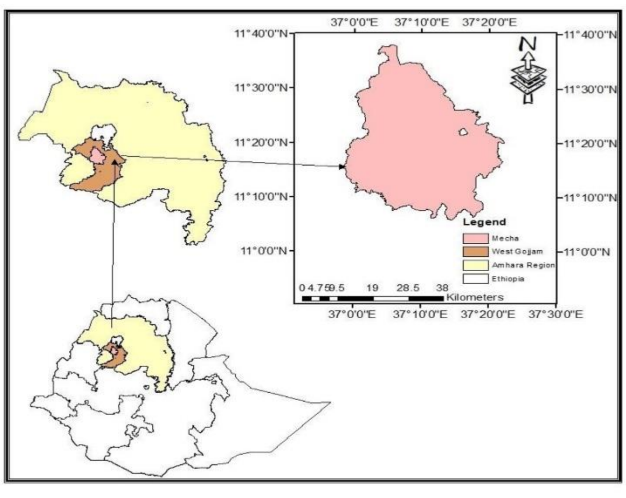

Fig. 1. Geographical location of the Study Area

B. Experimental design and procedure

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. It included six treatments: control (without nitrogen), recommended nitrogen (137 kg N ha^{-1}), 75% recommended N (103 kg N ha^{-1}) + 25% vermicompost (2.65 t ha^{-1}), 50% vermicompost (5.3 t ha^{-1}) + 50% recommended N (68.5 kg N ha^{-1}), 25% recommended N (34.3 kg N ha^{-1}) + 75% vermicompost (7.95 t ha^{-1}), and 100% vermicompost (10.6 t ha^{-1}). The equivalence ratio of vermicompost rates was adjusted based on the recommended nitrogen rate for onion. Urea and TSP were used as sources of synthetic N and P_2O_5 during the transplanting period. The onion variety Red Bombay was used as the test crop. The total area of each plot was 3.85 m x 3 m (11.55 m^2), with 1.5 m space between plots and blocks, and 0.4 m furrow width. Plants and rows were spaced at 0.05 m and 0.15 m, respectively. Vermicompost was incorporated into the ridges during the transplanting period. TSP (P_2O_5) was applied as a basal fertilizer to all plots at transplanting time, while inorganic N was applied in two splits: half at transplanting and the remaining half 30 days after transplanting.

C. Data collection, preparation and analysis

1) Vermicompost analysis

Following laboratory procedures, a representative composite sample of vermicompost was taken from the entire collected vermicompost from well-prepared pits for analysis of pH, total nitrogen (TN%), cation exchange capacity (CEC), organic carbon (OC%), available phosphorus (avP), and carbon-nitrogen ratio (C:N ratio) [16] (Table I).

Table I. Chemical Analysis Of Vermicompost Before Planting

Chemical analysis of vermicompost	Values
pH	7.61
TN%	1.3
CEC (cmol kg^{-1})	65.71
OC%	18.16
avP (mgkg^{-1})	477.63
C: N	14

OC%=organic carbon percent, TN%=total nitrogen percent, C: N=carbon to nitrogen ratio, CEC = cation exchange capacity, avP=available phosphorus, and pH= Power of hydrogen concentration.

D. Soil sampling and analysis before transplanting

Before transplanting, representative soil samples were collected using a random sampling method from a depth of 0-20 cm across sites in the field with an auger. All samples were then combined to create one composite sample. The composite sample was crushed using a mortar and sieved to measure soil texture, cation exchange capacity (CEC), pH, and available phosphorus (P). A 0.5 mm sieve was used to determine organic carbon (OC) and total nitrogen (N) following the laboratory procedure outlined in [16] (Table II).

Table II. Soil Physico-Chemical Properties Before Transplanting

Soil physico-chemical properties	Values
Texture	Clay
pH	5.11
TN%	0.185
CEC (cmol kg^{-1})	31.32
OC%	2.48
avP (mgkg$^{-1)}$	20.60
C: N	13.41

OC%=organic carbon percent, TN%=total nitrogen percent, C: N=carbon to nitrogen ratio, CEC=cation exchange capacity, avP=available phosphorus, and pH= Power of hydrogen concentration.

E. Soil sampling and analysis after transplanting

After transplantation, soil samples were randomly collected from a depth of 0-20 cm at 10 spots across the experimental units based on treatments. The particle size distribution was determined using the hydrometer method (procedures) developed by [16], and the percentages of sand, silt, and clay were estimated and classified using the FAO textural triangle. The major chemical properties of the soil, such as OC, pH, CEC, total N, and available P, were determined according to the laboratory manual compiled by [16].

TABLE III. INTEGRATION EFFECT OF VERMICOMPOST AND NITROGEN FERTILIZER ON SELECTED SOIL PROPERTIES

Treatment	soil chemical properties across sites					
			Y1S1			
	pH	TN %	CEC ($cmolkg^{-1}$)	OC%	avP (ppm)	C: N
Control (0,0)	5.08	0.15c	26.75	2.17	24.39	14.45
RN (100%) (137N $kgha^{-1}$)	5.17	0.20ab	27.61	2.30	24.37	11.60
75%RN (103N kg ha^{-1}) +25% VC (2.65tha^{-1})	5.12	0.21a	28.05	2.23	24.69	10.73
50%RN (69N$kgha^{-1}$) +50% VC (5.3tha^{-1})	5.09	0.17bc	27.45	2.08	27.32	11.96
25%RN (34N$kgha^{-1}$) +75% VC (7.95tha^{-1})	5.12	0.19ab	27.68	2.02	26.92	10.82
100% VC (10.6tha^{-1})	5.08	0.19ab	27.82	2.19	27.82	11.31
LSD	NS	0.03	NS	NS	NS	NS
CV%	2.29	7.95	11.70	7.36	18.05	12.40
			Y1S2			
	pH	TN%	CEC ($cmolkg^{-1)}$	OC%	avP (ppm)	C: N
Control (0,0)	4.95	0.17	27.52	2.17	29.21	12.51
RN (100%) (137N $kgha^{-1}$)	4.79	0.20	28.29	2.15	30.91	10.49
75%RN (103N kg ha^{-1}) +25% VC (2.65tha^{-1})	4.85	0.17	26.71	2.04	28.14	11.92
50%RN (69N$kgha^{-1}$) +50% VC (5.3tha^{-1})	4.99	0.19	29.99	1.94	31.55	10.54
25%RN (34N$kgha^{-1}$) +75% VC (7.95tha^{-1})	4.94	0.21	28.91	2.08	32.34	10.22
100% VC (10.6tha^{-1})	4.89	0.20	29.38	1.98	33.02	9.91
LSD	NS	NS	NS	NS	NS	NS
CV%	2.12	9.56	6.57	11.41	10.75	11.35
			Y2S1			
	pH	TN%	CEC ($cmolkg^{-1)}$	OC%	avP (ppm)	C: N
Control (0,0)	5.08	0.21	29.07	2.26bcd	39.52	10.66
RN (100%) (137N $kgha^{-1}$)	5.01	0.21	29.63	2.40abc	41.12	11.70
75%RN (103N kg ha^{-1}) +25% VC (2.65tha^{-1})	5.13	0.21	27.45	2.21cd	41.76	10.46
50%RN (69N$kgha^{-1}$) +50% VC (5.3tha^{-1})	5.11	0.22	26.31	2.53a	42.36	11.62
25%RN (34N$kgha^{-1}$) +75% VC (7.95tha^{-1})	5.19	0.20	25.75	2.43ab	40.14	12.10
100% VC (10.6tha^{-1})	5.17	0.23	25.51	2.15d	41.08	9.48
LSD	NS	NS	NS	0.21	NS	NS
CV%	4.53	8.20	10.13	5.01	11.46	10.73

NB: VC= vermicompost, RN = recommended nitrogen, Y1S1 = year one site one, Y1S2 = year one site two and Y2S1= year two site one

A glass electrode pH meter was used to measure soil pH in water at a 1:2.5 ratio. The soil organic carbon (OC) concentration was evaluated using the Walkley and Black wet digestion method, which involves digesting the OC in soil samples with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid solution. The Olsen extraction method was used to determine available phosphorus (avP). The total nitrogen content of the soil samples was determined using the Kjeldahl method. Cation exchange capacity (CEC) was determined by extracting soil samples with ammonium acetate (1N NH_4OAc) and repeatedly rinsing them with 96% ethanol to remove excess ammonium ions from the soil solution. The ammonium ions adsorbed in the soil were displaced by percolating sodium chloride into the NH_4^+-saturated soil, and the ammonium released during distillation was titrated using 0.1N NaOH (sodium hydroxide).

F. *Crop data collection*

Plant Height: Determined by selecting five randomly chosen plants from ground level to the highest apex and averaging the measurements for a single value.

Leaf Number: Determined by randomly counting all leaves from the five center rows at maturity and calculating the mean value.

Leaf Length: Determined at maturity by randomly selecting five plants from each row and averaging the measurements for a single reading.

Bulb Diameter: Measured using a caliper on three plants' bulbs from the center rows at harvest and then averaged for a single reading.

Marketable Bulb Yield and Unmarketable Bulb Yield: Marketable bulbs were judged based on visual inspection, where infected, damaged, shriveled, and bulbs smaller than 20mm were considered unmarketable and other bulbs were classified as marketable.

Total Bulb Yield: Calculated by summing both marketable and unmarketable bulbs from the net middle plot area (six ridges, 3.3m x 3m or 9.9m²).

G. *Economic Analysis*

Economic analysis was conducted to make a sound decision among the factors used in onion production. The partial budget and marginal rate of return (MRR) were used to assess changes in farming methods that affected a sector of the farm rather than the full farm practice. These tools also served as a planning method for estimating profit changes within a farm [17]. This was estimated by deducting 10% of the yield and multiplying by the local field price (20 Ethiopian Birr per kilogram of onion). Dominance analysis was conducted by identifying treatments in ascending cost order that had a net benefit less than or equal to those of treatments with lower costs, which were then considered dominated [17].

H. Statistical Analysis

All data were subjected to variance analysis using the GLM procedure in SAS software, version 9.4 (SAS Institute, 2002). A Least Significant Difference (LSD) test at a probability level of 0.05 was used to separate treatment means where significant differences existed [18].

III. Results And Discussion

A. Effect of vermicompost with nitrogen on soil chemical properties after harvest

(Table III) shows the results of soil chemical characteristics after harvest across experimental sites. Except for soil nitrogen at Y1S1 (Year One Site One) and organic carbon at Y2S1 (Year Two Site One), the treatment of vermicompost with nitrogen equivalent ratio rates did not affect the other soil characteristics (Table III). The non-significant effects of the applied treatments on these parameters could be attributed to the slow release of nutrients from vermicompost into the soil solution, combined with the short cropping season of onion cultivation.

TABLE IV. Response Of Onion Growth Parameters For Vermicompost And Inorganic Fertilizer Application At Koga Irrigation Scheme

Treatment	Growth parameters		
	Leaf Number	Leaf Length (cm)	Plant height(cm)
Control (0,0)	8.9	27.8	32.8b
RN (100%) (137N $kgha^{-1}$)	8.9	29.5	35.2ab
75%RN (103N $kgha^{-1}$) +25% VC (2.65$tha^{-1)}$	8.9	30.9	36.5a
50%RN (69N $kgha^{-1}$) +50% VC (5.3tha^{-1})	8.7	31.1	37.3a
25%RN (34N $kgha^{-1}$) +75% VC (7.95tha^{-1})	8.5	29.2	35.0ab
100% VC (10.6tha^{-1})	8.7	29.6	35.0ab
LSD (0.05)	NS		2.8
CV%	7.9	8.2	8.4

NB: VC= vermicompost, RN= recommended nitrogen

The applied vermicompost and nitrogen rates, however, had a significant ($P < 0.05$) effect on nitrogen at Y1S1 and organic carbon at site Y2S1 (Table III). When compared to the control, the application of (75% N + 25% VC) and (50% N + 50% VC) resulted in the maximum nitrogen and organic carbon content (Table III). The increase in soil organic carbon in treated plots could be linked to the improvement of soil organic matter as a result of vermicompost application. These findings were consistent with those of [19], who found that applying dry bio-slurry (14 t ha^{-1}) with blended fertilizer improved soil OC content after harvest, scoring the highest value compared to the control. Similarly, [20] found that soil OC concentration responded significantly to the application of 15 t ha^{-1} FYM immediately after rice harvest, with the highest carbon value (8.7%) compared to the control.

TABLE V. Response Of Onion Yield Parameters For Vermicompost With Inorganic Nitrogen Application At Koga Irrigation Scheme

Treatment	Onion yield parameters	
	Bulb Diameter (mm)	Bulb Yield (tha^{-1})
Control (0,0)	45.5c	15.6c
RN (100%) (137N $kgha^{-1}$)	50.1ab	23.2a
75%RN (103N $kgha^{-1}$) +25% VC (2.65$tha^{-1)}$	49.2b	19.3b
50%RN (69N $kgha^{-1}$) +50% VC (5.3tha^{-1})	51.8a	23.6a
25%RN (34N $kgha^{-1}$) +75% VC (7.95tha^{-1})	49.5ab	18.6b
100% VC (10.6tha^{-1})	50.4ab	17.3bc
LSD (0.05)	2.3	2.7
CV%	4.9	14.4

NB: VC= vermicompost, RN =recommended N

The combined effect of vermicompost and nitrogen on total nitrogen may be due to the mineral N entering the soil solution via both vermicompost and urea fertilizer sources, which enhances nutrient availability in the soil root system. These results agree with those of [21], who discovered that the combination of vermicompost with inorganic nitrogen (25% VC + 25% N) on onions increased soil total nitrogen and other nutrient content after onion harvest, compared to the control.

B. Integrated effect of vermicompost and nitrogen fertilizers on onion growth parameters

Vermicompost and inorganic nitrogen combined considerably improved onion plant height ($P<0.05$) (Table IV). When compared to the control (untreated plots), applying 50% VC (vermicompost) (5.3 t ha^{-1}) with 50% N (69 kg N) resulted in the highest onion plant height value (Table IV). Plant height may increase in response to the application of vermicompost (VC) with nitrogen (N) fertilizer due to an improvement in soil chemical properties. This is caused by the mineralization of vermicompost and the release of nitrogen (N) from urea fertilizer into the soil solution, making it easier for the plant to absorb for growth and development. Furthermore, vermicompost may have a positive impact on water absorption and holding capacity, which aids in nutrient utilization by the plant root system.

Moreover, the use of vermicompost may provide balanced micro- and macronutrients as well as increased availability of plant nutrients, which would support the metabolic activity of microorganisms and improve plant growth.

These findings agree with [22], who discovered that onion plants treated with farmyard manure (13.5 t ha^{-1}) and NPS (245.1 kg ha^{-1}) were taller than untreated plants. This is also consistent with the findings of [23], who found that the application of 50% vermicompost with 50% inorganic fertilizer resulted in the highest plant height of onions, while the lowest value was obtained from the control treatment. Another study conducted by [24] also revealed that the treatment receiving 20:50 NP kg ha^{-1} with Rhizobium inoculation had the maximum mung bean plant height (78.08 cm), whereas the control treatment had the lowest value of 68 cm.

TABLE VI. Partial Budget And Marginal Analysis Of Onion As Affected By The Application Of Vermicompost With Nitrogen.

Treatments	Economic return variables				
	Actual yield tha^{-1}	10% Adjusted Bulb Yield tha^{-1}	Total variable Cost Birr ha^{-1}	Net Benefits Birr ha^{-1}	MRR%
Control (0,0	15.6	14.04	0	280800.0	0
100% VC (10.6tha^{-1})	17.3	15.57	3240	308160.0	844.4
25%RN (34N kg ha^{-1}) +75% VC(7.95tha^{-1})	18.6	16.74	3726.4	331073.6	D
50%RN (69N kg ha^{-1}) +50% VC (5.3tha^{-1})	23.6	21.24	4212.8	420587.2	18403.2
75%RN (103N kg ha^{-1}) +25% VC (2.65tha^{-1})	19.3	17.37	4699.2	342700.8	D
RN (100%) (137N kgha^{-1})	23.2	20.88	5185.6	412414.4	D

NB: VC = vermicompost, RN =recommended nitrogen, D = dominated

C. Integrated effect of vermicompost with nitrogen on onion yield parameters

Vermicompost and inorganic nitrogen fertilizers significantly impacted onion bulb width and yield (Table V; $p < 0.05$). As a result, compared to the control (untreated plots), the application of 50% VC (5.3 t ha^{-1}) and 50% inorganic nitrogen (69 N kg ha^{-1}) resulted in the highest bulb diameter and yield values (Table V). This could be due to the use of organic manures, which provide both macronutrients and micronutrients while enhancing photosynthetic processes, chlorophyll production, nitrogen metabolism, and auxin levels in plants, all of which contribute to improved bulb diameter. The increase in plant height, leaf count, and other yield-related parameters, such as the fresh weight of the entire plant bulb, could account for the larger overall bulb yield.

Furthermore, this effect could be due to the release of nitrogen from urea and vermicompost (VC) into the soil solution, which promotes greater plant growth and development. Additionally, the enhancement of the physico-chemical properties of the soil and the addition of macro- and micronutrients from the vermicompost may have contributed to the increase in yield and overall plant improvement. Comparable results were reported by [25], who found that applying 20 t ha^{-1} vermicompost before onion transplanting produced the highest onion bulb yield (19.8 t ha^{-1}) compared to the control. An additional study by [26] revealed that the addition of farmyard manure to experimental plots resulted in the highest onion bulb yield (12 t ha^{-1}) compared to untreated plots (control). According to [27], the maximum onion seed production (1462.5 kg ha^{-1}) was obtained by applying 75% of the prescribed fertilizer along with 2.5 t ha^{-1} vermicompost, which was 263% greater than the control (untreated) treatments.

D. Partial Budget Analysis

The current costs of vermicompost (0.2 Birr per kg), urea fertilizer (13.643 Birr per kg), the field price of onions (20 Birr per kg), and labor costs per man-day in the area (70 Birr) were used to calculate net benefits. The acceptability of treatments was evaluated using a 100% marginal rate of return. This economic study found that undominated treatments outperformed the control in terms of net benefit (Table VI). A 50% vermicompost with 50% recommended nitrogen and 100% vermicompost produced net benefits of 420,587.2 Birr and 308,160.0 Birr, respectively, with marginal rates of return of 18,403.2% and 844.4%. Farmers can gain an additional 18.4032 Birr and 8.444 Birr for every 1 Birr spent on 50% vermicompost with 50% recommended nitrogen and 100% vermicompost, respectively. Except for the dominated rates, all undominated treatment rates may be deemed acceptable by onion farmers in the research area. Thus, 50% vermicompost with 50% recommended nitrogen was the most cost-effective option for farmers, offering lower expenses and greater benefits. Because the second approach also shows a promising net benefit and an acceptable marginal rate of return, farmers can also use 100% vermicompost exclusively for onion production.

IV. Conclusions

The findings suggest that using vermicompost in conjunction with nitrogen fertilizers could boost yield, with the highest net benefits. The application of 50% vermicompost and 50% nitrogen provides a higher net benefit with an acceptable marginal return. Thus, local small-scale farmers should use this combination for onion cultivation in this irrigation scheme. In the future, similar research will be conducted across agroecological zones in permanent plots over multiple years to improve agricultural output and soil health.

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