Ukrainian Journal of Ecology

Ukrainian Journal of Ecology, 2022, 12(11), 39-49, doi: 10.15421/2022_412

ORIGINAL ARTICLE

Growth, nodulation and yield of mung bean (*Vigna Radiata* L. (*Wilczek*) as affected by bio-chemical fertilizers integration at Southern Ethiopia

T. Tadewos[1*], T. Ayalew[2], T. Yoseph[2]

[1]Southern Agricultural Research Institute, Bonga Agricultural Research Center, Bonga, Ethiopia

[2]Hawassa University College of Agriculture, Hawassa University, Ethiopia

**Corresponding author E-mail: ttadewos5@gmail.com*

Received: *17 November, 2022; Manuscript No: UJE-22-80254;* ***Editor assigned:*** *19 November, 2022, PreQC No: P-80254;* ***Reviewed:*** *30 November, 2022, QC No: Q-80254;* ***Revised:*** *05 December, 2022, Manuscript No: R-80254;* ***Published:*** *10 December, 2022.*

A field study was conducted to determine the growth, nodulation and yield response of mung bean (*Vigna radiata* L. (*Wilczek*) to bio-chemical fertilizer integrations. There were sixteen treatment combinations comprising of four bio-slurry levels (control, 12.3 m^3, 24.6 m^3 and 36.9 m^3) and four inoculant/N fertilizer treatments including control (0.23 kg N ha^{-1}, Rhizobium strain MB-001 and 23 kg ha^{-1}N+Rhizobium strain MB-001) were laid out in factorial randomized complete block design with four replications. The results revealed that the main effect of bio-slurry and inoculant/N fertilizer as well as their interaction had a significant effect on phenology, nodulation and yield parameters of mung bean. Integrated application of bio-chemical fertilizers resulted in significant improvement in plant height, leaf area, leaf area index, shoot fresh and dry weight, and nodulation of mung bean. The combined application of fertilizer had positive impacts on nodulation performance. Integrated application 0f 36.9 m^3 bio-slurry with 23 kg ha^{-1} N resulted in the highest plant height. Whereas highest leaf area, LAI, shoot fresh and dry weight, were recorded in plots received 36.9 m^3+23 kg N+rhizobium strain integrated application compared with the control treatment. Nodulation was also significantly affected by the integrated application of bio-chemical fertilizers. The maximum grain yield was obtained from the combination of 24.6 m^3 bio-slurry with Rhizobium inoculation compared to control treatment. Therefore, the integrated application of bio-chemical fertilizers enhanced the nodulation, growth and yield performance of mung bean.

Keywords: Bio-slurry, Nitrogen, Rhizobium inoculation.

Introduction

Mung beans (*Vigna radiata* L. (*Wilczek*), are short-lived, herbaceous, self-pollinating pulses grown for grain, food, vegetables, green manure, and feedstock (Cheng, 2016). In many tropical and sub-tropical regions of the world, it is one of the most significant crops (Kumari et al., 2012; Khan et al., 2012). It is Indian origin as evidenced by its occurrence at archeological sites in the continent and the world's largest production comes from India (Singh et al., 2011).

Mung bean can fix nitrogen *via* symbiosis with nitrogen-fixing Rhizobium bacterium (Allito et al., 2015). It is a great and simple source of protein for people, promoting food security in the process. The seeds, both mature and raw, are full of vitamins, minerals, antioxidants including flavonoids (Quercetin-3-O-glucoside), and phenolic compounds. They also include a lot of carbs, protein, fiber, and carbohydrates (Guo et al., 2012). Despite being an economically important crop, overall production of mung bean is low due to abiotic and biotic stresses (Bangar et al., 2018).

Mung bean is a recently introduced crop in Ethiopian pulse production and it is produced in the drier and warmer regions of the country (Itefa, 2016; EPP, 2004). It grown twice a year covering 41,633.20 ha and a production level of 51,422.741 t ha^{-1} per year with an average yield of 1.235 t ha^{-1} (CSA, 2018). Studies and analyses indicate that Ethiopia's mung bean production is significantly lower than that of other nations', especially when it comes to soil fertility. This is reportedly because fertilizer application has been limited (Asrat et al., 2012; EEPA, 2004).

With the suitable rhizobium, pulses can fix atmospheric nitrogen in symbiosis and can supplement chemical fertilizers by saving 20-30 kg N/ha (Khurana and Sharma, 1995). Organic manures although not use as sole sources of nutrients, are, however good complementary sources with inorganic fertilizers (Chaudhary et al., 2004). The most practical alternative for smallholder farmers, and one that improves crop productivity as well as soil physic-chemical properties including soil pH, organic carbon, and accessible N, P, and K in sandy loam soil, is the combined use of organic wastes and chemical fertilizers (Rathour et al., 2015). Thus, integration of bio-chemical fertilizers for optimization of pulses production on sustainable basis assumes much importance as the present yield of pulses is too low. Keeping these things in view a field experiment was carried out to evaluate the growth, nodulation and yield response of mung bean to the integrated application of bio-chemical fertilizer at Hawassa, Southern Ethiopia.

Materials and Methods

Experimental site

An experiment was conducted in 2019/2020 at Hawassa, Southern Ethiopia. The site is located 270 km south away from the capital city Addis Ababa. Geographically the area lies at 7°03' 05.7'' N and 38°30' 21.1'' E (Fig. 1) with a mean altitude of 1712 m above sea level. It receives a mean annual rainfall of 952 mm with a mean minimum and maximum temperature of 13.9 and 26.5°C, respectively (Ethiopia meteorology agency, Hawassa Meteorological Center, 2019).

Treatments and experimental design

A randomized complete block design (RCBD) was used to set up the experiment, which included a factorial arrangement of bio-slurry and inoculant/N fertilizer sources. Thus, four levels of bio-slurry (0, 12.3 m^3, 24.6 m^3, and 36.9 m^3) were combined with four inoculant/N fertilizer applications including control (0.23 kg N, Rhizobium strain MB-001 and 23 kg N+Rhizobium strain MB-001). The total numbers of treatments were 16 replicated four times with a total of 64 plots.

Each experimental plot was 1.8 x 1.5 m (2.7 m^2) in size, with a total area of 326.7 m^2 with plot and block spacing of 0.5 and 1 m, respectively. Treatments were assigned to each plot at random. Planting was done at a distance of 0.3 m x 0.1 m between rows and plants. Data were gathered from plants in the center rows of plots, avoiding plants in the two border rows as well as those at both ends of each row, in order to limit border effects. The bio-slurry level was adjusted depending on the required inorganic N rate for legumes and their N content. Representative 1liter sample of liquid bio slurry was oven-dried, its nitrogen content was measured, and the rate was adjusted as necessary. Urea was employed as a source of nitrogen at a rate of 23 kg ha^{-1}. Commercial Rhizobium strain MB-001 obtained from Menagesha Biotech, priv. plc was used at the rate of 500g ha^{-1} for legume production. Mung bean variety MH-97-6 was used for this study which was obtained from Hawassa Agricultural research center. Prior to planting, representative soil samples were collected from depths of 0-20 cm throughout the experimental area for physio-chemical investigation. The samples were properly mixed to make a single representative sample. Before being used as a treatment, the bio-nutrient slurry's content was also examined. The water content, organic matter, pH, total N, and accessible P were all determined after oven drying the combined 1L representative sample of bio-slurry. Instead of using a 1 kilogram soil sample for manure analysis, the oven dried 1 kg bio-slurry sample was digested.

The land was cleared, leveled, and prepared for planting before a field layout was made in accordance with the design criteria. To reduce the burning effects of the crop, the plots were treated with prepared bio-slurry a week prior to sowing. Rows were spaced 0.3 meter between, plants were planted 0.1 meters apart, and the soil was lightly coated at a depth of 3-5 cm during sowing. When planting the seed, it was soaked in a solution of sugar and rhizobium inoculant. The addition of sugar in the solution ensures that the strain adheres to the seed coat and that Rhizobia quickly infiltrate the interior of the plant following germination. To maintain cell viability, seed inoculation was carried out as soon as possible before planting under shade at a rate of 10 g/kg of seed. Seeds were allowed some time to air dry before planting in order to prevent fungal growth. The un inoculated seed was sown first to protect the other seeds from bacterial infection.

Data collection and measurements

Growth parameters

The average height of plants was determined by measuring the height of five randomly selected plants from the ground surface to the top of the main stem in centimeters at maturity. Shoot fresh weight and dry weight (g) were recorded by measuring the above ground biomass at the mid flowering stage from plants that were sampled for nodulation. The samples were placed in labeled perforated paper bags and oven-dried for 48 hours at 70^{o}C to constant weight. The averages were recorded as shoot dry weight plant^{-1}. Leaf area was measured from plants harvested for shoot weight determination from each plot at mid flowering stage. The average of the five plants leaf area was taken as the leaf area of the plant. It was measured by using portable leaf area meter LI-3000A. The leaf area index was determined by the ratio of leaf area to the ground area covered.

lAI=(leaf area)/(grand area)

Nodule determination

Number of nodules was taken from five randomly selected plants at the mid-flowering stage from each plot and counted carefully to determine the average number of nodules plant^{-1}. Nodule diameter was determined from nodules collected from each plot six nodules were randomly selected and the diameter was measured and the average data was recorded as nodule diameter. After recording nodule numbers, nodules were weighed immediately with the sensitive balance to record nodule fresh weight. After recording the fresh weight, the same nodules were oven-dried at 70°C for 48hr to determine nodule dry weight.

Grain yield was determined by Plants harvested from the three central rows of each plot after sun drying for four days and it was threshed, adjusted at 10% moisture level to determine grain yield.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using a General Linear Model in SAS software version 9.0 (SAS Institute, 2002) and mean separation was made based on LSD at 5% (P<0.05) level of significance.

Results and Discussion

Physio-chemical properties of the soil and bio-slurry

The laboratory analysis of soil sample indicated that the soil was clay loam in texture (40% sand, 32% clay, 28% silt) with a pH value of 7.17, which is within the ideal pH range for mung bean production (Ryczkowski, 2018). The total N, available P, OC, C:N ratio and CEC of the soil before planting were 0.15%, 51.7 ppm, 1.69%, 11.2 and 22.7 cmol kg^{-1}, respectively. The total N content was within medium range (Tekalign, 1991), the available P of the soil high range (Olsen et al., 1954), the soil OC (1.69%) low content (Landon 1991), CEC (22.7 cmol kg^{-1}) medium ranges, respectively. According to the results of the experimental bio-slurry analysis, slightly alkaline pH (7.33) value, medium amount of total N (1.53%), medium amount of OC (17.7%), high amount of available P (301.4 ppm), medium CEC 64.0 (cmol kg^{-1}), as noted by Singh et al. (2007) (Table 1).

Table 1. Pre-planting Physico-chemical properties of soil and bio-slurry.

	PH H_20 (1:2.5)	Total N%	OC%	C/N	CEC meq/100 g soil	Ava. P ppm	Texture%			Texture type
							Sand	clay	Silt	
Soil	7.17	0.15	1.69	11.2	22.7	51.7	40	32	28	Clay loam
Bio-slurry	7.33	1.53	17.7	11.5	64	301.4	-	-	-	

Effects of integrated fertilizer application on growth parameters of mung bean

Plant height

Analysis of variance revealed that plant height was significantly (P<0.001) affected by the integrated fertilizer application. The tallest plant was recorded from the combined application of 36.9 m^3 bio-slurry+23 kg N ha^{-1} (54.5 cm) which was followed by a combined application of 36.9 m^3 bio-slurry with both stain MB-001 and 23kg N ha^{-1}. Whereas, the shortest plant (34.0 cm) was recorded from the control treatment (Table 2). Increasing bio-slurry levels from 0 to 36.9 m^3 in combination with inoculant/N fertilizer resulted in an increasing trend in the plant height of mung bean. The increment in plant height might be due to that the organic fertilizer improves the soil structure and aggregation; hence improving the availability of nutrients as well as encouraging the plant to have good root development by improving the aeration in the soil, which leads to higher plant growth. The increased availability of N in the soil for absorption by plant roots that promoted vegetative growth through increasing cell division and elongation may also be responsible for such an increase in plant height caused by the increasing bio-slurry rates with N fertilizer application (Warnars and Oppenoorth 2014; Widowati et al., 2012).

The result agrees with previous findings which reported an increased plant height in green gram due to the combined use of vermicompost+NPK (Krishnan 2016). The result of the current experiment was also in close conformity with (Meesam et al. 2014), reported an increment in plant height due to the integrated use of *Rhizobium*, compost, and mineral N. Similar findings have also been reported that the plant height increased due to the integrated application of fertilizers (Yalemtsehay 2019; Shweta, 2014; Shah et al., 2007; Irshad et al., 2002).

Leaf area and leaf area index

Analysis of variance revealed that there was a significant (P<0.001) interaction effect on leaf area and leaf area indices. Maximum leaf area and leaf area index were recorded from combined application of 36.9 m^3 bio-slurry+23 kg N ha^{-1}+strain MB-001 (1533.1 cm^2 and 5.1); followed by plots received 36.9 m^3 bio-slurry+23 kg N ha^{-1} (1447.5 cm^2 and 4.8), 36.9 m^3 bio-slurry+strain MB-001 (1440.6 cm^2 and 4.8), and 24.6 m^3 bio-slurry+strain MB-001 (1439.5 cm^2 and 4.7), statically similar to each other respectively. On the other hand, the control treatment showed the lowest leaf area and leaf area index (510.4 cm^2 and 1.7) (Table 2). The increment of the leaf area and leaf area index of mung bean to applied N sourced treatments might be due to the fact that N is the most essential nutrient element and its adequate supply increases the growth and yield of a crop. The integrated use of the recommended dose of chemical fertilizer (NPK) in addition to decomposing organic manures and bio-fertilizer considerably increased leaf area at all growth stages of mung bean, according to data that were previously reported. This increase may be the result of more macro-and micronutrients being released into the soil by efficient microbes in the root zone, which is followed by increased plant vigor (Ashour 1998).

Therefore, the application of bio-slurry in combination with inoculant/N fertilizer may have provided the necessary amount of plant nutrients for vegetative growth due to the availability of micronutrients and that can support the crop during and the later growth stages favored by the slow and continuous decomposition and release of nutrients. Similarly, increased leaf area and leaf area index due to the integration of nutrient management were reported previously (Hussain et al., 2019; Larimi et al., 2014; Islam et al., 2010; Garg et al., 2005).

Shoot fresh and dry weight

The analysis of variance revealed that the main effects of bio-slurry and inoculant/N fertilizer had significant (P<0.001) effects on shoot fresh and dry weight of mung bean. Similarly, their interaction had shown a significant (P<0.001) effect on shoot fresh and dry weight of mung bean. Maximum shoot fresh and dry weight were recorded from the integrated application of 36.9 m^3 bio-slurry+23 kg N ha^{-1}+strain MB-001 (131.5 and 33.2 g) which were closely followed by 36.9 m^3 bio-slurry with both inoculant/N fertilizer, whereas minimum shoot fresh and dry weight (55 and 8 g) was recorded from the control treatment (Table 2). The effect of these nutrients, which are a crucial component of many essential plant compounds like chlorophyll, proteins, and amino acids, may account for the increase in shoot fresh and dry weight of mung bean following the application of bio-slurry (a component of several essential macro and micronutrients). The nutrients from supplied treatments promote increased vegetative growth and help plants generate high-quality foliage. These, in turn, encourage the photosynthesis of carbohydrates, which eventually increases plant production (Brady and Weil, 2002).

Another finding stated that treated plots with organic and inorganic fertilizers produced maximum (834 gm^{-2}) fresh weight, while control plots produced a minimum (781 g m^{-2}) fresh weight of mung bean (Anwar et al., 2018). An experiment conducted on peanut at Fedis site eastern Ethiopia, shown that manure compost, and DAP applied with *Bradyrhizobium* caused a significant positive influence on the shoot dry weight (Argaw 2017). Moreover, bio-slurry treatment of 10 t ha^{-1}+25kg N ha^{-1} resulted in the highest fresh weight and dry weight of soybean plants (Yafizhan and Sutarno, 2018).

Table 2. Interaction effects of bio-chemical fertilizer application on the growth parameters of mung bean.

Treatments		**Parameters**				
Bio-slurry (m^3)	**Inoculant/N fertilizer(kg)**	**Plant height (cm)**	**Leaf Area (cm^2)**	**LAI**	**Shoot fresh weight(g)**	**Shoot dry**
0	control	36.5^{e}	510.4^{h}	1.7^{h}	55.0^{i}	8.0^{j}
	23	35.0^{e}	605.5^{h}	2.0^{h}	77.3^{de}	12.2^{i}
	inoculant	34.0^{e}	574.8^{h}	1.9^{h}	74.0^{def}	15.5^{gh}
	23+inoculant	42.2^{bcde}	756.1^{g}	2.5^{g}	113.8^{b}	17.7^{fg}
12.3	control	39.7^{de}	739.0^{g}	2.4^{g}	71.5^{efg}	14.5^{hi}
	23	34.2^{e}	904.4^{f}	3.0^{f}	72.7^{efg}	16.2^{gh}
	inoculant	42.2^{bcde}	943.4^{ef}	3.1^{ef}	$58.0h^{i}$	18.2^{fg}
	23+inoculant	48.7^{abc}	1076.8^{d}	3.5^{d}	67.5^{fg}	21.5^{de}
24.6	control	40.0^{de}	1005.3^{de}	3.3^{de}	74.5^{def}	16.2^{gh}
	23	40.7^{cde}	1277.3^{c}	4.0^{c}	64.5^{gh}	19.7^{ef}
	inoculant	48.7^{abc}	1439.5^{ab}	4.7^{ab}	82.5^{d}	23.7^{d}
	23+inoculant	48.0^{bcd}	1396.6^{b}	4.6^{b}	74.0^{def}	27.5^{c}
36.9	control	42.0^{bcde}	1383.0^{b}	4.6^{b}	101.7^{c}	28.7^{bc}
	23	54.5^{a}	1447.5^{ab}	4.8^{ab}	112.5^{b}	30.5^{ab}
	inoculant	48.2^{abcd}	1440.6^{c}	4.8^{ab}	115.7^{b}	31.3^{ab}
	23+inoculant	50.0^{ab}	1533.1^{a}	5.1^{a}	131.5^{a}	33.2^{a}
CV%		14.1	6.4	6.5	7.8	11.6
LSD (0.05)		8.6	97.9	0.3	9.3	3.4

Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$).

Effects of integrated fertilizer application on nodulation parameters

Number of nodules $plant^{-1}$

The statistical analysis revealed that there was a significant (P<0.001) interaction effect of bio-slurry and inoculant/N fertilizer on nodule numbers. Likewise, the interactive effect of bio-slurry and inoculant/N fertilizer resulted in significant differences on the number of nodule $plant^{-1}$. Concerning the main effects of inoculant/N fertilizer, the maximum nodule number $plant^{-1}$ was obtained from Rhizobium inoculation whereas; the lowest nodule number was obtained from 36.9 m^3 rate of bio-slurry.

Regarding the interaction effect, maximum nodule numbers $plant^{-1}$ (26.15) were recorded from *Rhizobium* inoculation with nil bio-slurry, which is followed by strain MB-001 inoculation with 24.6 m^3 bio-slurry and control (20.00 and 19.95) statistically at par. The lowest mean nodule number (12.7) was recorded from 36.9 m^3 bio-slurry+23 kg N ha^{-1} (Table 3). The nodule formation might be related to the ability of mung bean to form a symbiotic association with bacteria introduced. In the rhizosphere, the number of bacterial colonizes increased along with the plant roots due to the use of bio fertilizer (Ahmad et al., 2014; Meunchang et al., 2005), which thereby increases nodule formation. It has been documented that in the rhizosphere, growth promotion activities of rhizobacteria depend on effective colonization ability and survival in the changing environment (Lugtenberg et al., 2001). Increasing nodule numbers following Rhizobium strain treatment of the seeds suggested that the native Rhizobia population density nodulating the legume may not be sufficient, which in turn brought about the plant's response to the inoculation of the Rhizobium strains (chemining'wa et al., 2007). Similarly, it was well reported that inoculation of *Rhizobium* strains increased the number of nodules significantly for haricot bean varieties. Another study revealed that inoculation with organic and inorganic fertilizer improved the nodulation and yield of peanuts. Thus the nodule number and nodule dry weight of peanut showed a significant response to organic (compost and manure) and inorganic fertilizer (Urea and DAP) integrated with *Bradyrhizobium* inoculation (Argaw, 2017).

The lowest number of nodule plant^{-1} was observed due to the highest rate of application of bio-slurry with mineral N fertilizer. Due to the availability of sufficient N for plant roots in the soil solution, it inhibited the activity of bacteria while preventing the plant from becoming associated with the bacteria and consuming additional energy (Zelalem, 2018). This result is supported by the findings (Tarekegn and Serawit 2017) on the growth, symbiotic relationship, and yield response of mineral N-fertilizer and Rhizobium inoculated common bean showed that the administration of the suggested N fertilizer rate led to a decrease in nodule numbers and dry weight. Mineral N fertilizer application considerably decreased the number of nodules and dry weight per plant in snap bean (Hussien et al., 2015). Thus, when applied at higher rates of N than at lower rates, nodulation was suppressed. In the presence of a significant amount of N, it can decrease the ability of inoculated Rhizobium to fix biological N. Since the plant requires more energy to fix atmospheric N than it does to use NO_3, NO_3-N actually prevents legumes from fixing atmospheric N in the presence of appropriate N feeding (Zahran, 1999). Moreover, the presence of excess NO_3/NH_4 levels affects *Rhizobium* activity in soil by inhibiting the lectin compounds that attract *Rhizobium* towards legumes. Nodulation was decreased due to a higher rate of N application (Habte and Buraka, 2016; and Mozumder et al., 2003). Exogenous N application may boost soil N levels to a point where nodulation may be inhibited (Gao et al., 2020; Zhang et al., 2011; Wang et al., 2006; Laws and Graves, 2005).

Nodule diameter

Analysis of variance showed that the interaction had shown a significant ($P<0.05$) effect on the nodule diameter. Maximum nodule diameter was recorded from Rhizobium inoculation with nil bio-slurry (4.44 mm^2) followed by Rhizobium inoculation with 24.6m^3 bio-slurry, whereas the lowest nodule diameter (2.1 mm^2) was recorded from 36.9 m^3 bio-slurry+23 kg N ha^{-1} (Table 3). The bigger nodule diameter attributed to the inoculation of Rhizobium improved the effectiveness of the nodule formation. The lowest nodule diameter is due to the application of the highest amount of N from both sources, enough N to the soil from both organic and inorganic sources that the plant and Rhizobia do not make an association for further N_2 fixation. This accommodates the previous finding report that Rhizobium inoculation has increased nodule diameter in legumes compared to un inoculated treatments (Agele et al., 2017). Another finding revealed that the ability of the introduced Rhizobia strain to initiate nodulation with mung bean roots caused inoculated plants to develop bigger nodules than un inoculated plants (Chiamaka, 2014).

Nodule fresh and dry weight

Analysis of variance indicated that the main effects of bio-slurry and inoculant/N fertilizer had a significant ($P<0.001$) effect on the nodule fresh and dry weight. Likewise, interaction among treatments was also significant ($P<0.05$). Therefore, the present study indicated that maximum nodule fresh and dry weight was recorded from Rhizobium inoculation with 24.6 m^3 bio-slurry (0.63 g and 0.29 g) respectively, followed by Rhizobium inoculation with nil bio-slurry, (0.57 g) which was at par. Statically similar results with the highest dry weight were recorded from the application of 24.6 m^3 and 36.9 m^3 bio-slurry with both strain MB-001 and 23 kg ha^{-1} N. The lowest nodule fresh and dry weight was obtained from the control treatment (Table 3). The potential of the bio-slurry to provide the inoculated Rhizobia with C, N, P, and micronutrients may contribute to the increase in nodule fresh and dry weight (Gao et al., 2020). This study is consistent with a previous study suggesting that maximum nodule dry weight was obtained from the combined application of compost, Rhizobium inoculation, and 75% of recommended mineral N (Meesam et al., 2014). It was also noticed that nitrogen applied in combination with Rhizobium increased nodule weight (Mozumder et al., 2003).

Effects of integrated fertilizer application on yield of mung bean

Grain yield

The maximum grain yield was obtained from the combination of 24.6 m^3 bio-slurry with *Rhizobium* inoculation compared to control treatment (Table 4). This could be attributed to the effect of bio-slurry and Rhizobium inoculation, which enhanced net photosynthetic rate and produced the most net grain product. According to reports, the combined application of compost, Rhizobium, and 75% of the authorized amount of N fertilizer greatly increased the grain production of mung bean (Meesam et al., 2014). The grain yield of barley was significantly affected by the combined application of organic FYM and inorganic NP (Tamado and Mitiku, 2014). Additionally, it was reported that the highest grain yield was recorded when NPK and vermicomposting were integrated. (Twinkle 2016).

Table 3. Interaction effects of treatments on the nodulation parameters of mung bean.

Treatments		Nodule parameters			
Bio-slurry (m^3)	**Inoculant/N Fertilizer(kg)**	**Number of Nodules Plant^{-1}**	**Nodule Diameter (mm^2)**	**Nodule Fresh Weight (g)**	**Nodule Dry Weight (g)**
0	control	20.00^{b}	3.48^{bc}	0.13^{f}	0.06^{d}
	23	16.90^{c}	2.68^{cde}	0.14^{f}	0.07^{d}
	inoculant	26.15^{a}	4.44^{a}	0.58^{ab}	0.27^{a}
	23+inoculant	13.70^{def}	2.20^{e}	0.21^{ef}	0.10^{d}
12.3	control	16.10^{cd}	2.83^{cde}	0.13^{f}	0.06^{d}
	23	13.40^{ef}	2.93^{cde}	0.14^{f}	0.07^{d}
	inoculant	21.05^{b}	3.10^{cd}	0.29^{de}	0.16^{c}
	23+inoculant	13.20^{ef}	2.82^{cde}	0.17^{f}	0.09^{d}
24.6	control	15.10^{cdef}	2.18^{e}	0.39^{cd}	0.24^{ab}
	23	13.95^{def}	2.74^{cde}	0.40^{cd}	0.21^{bc}
	inoculant	19.95^{b}	4.15^{ab}	0.63^{a}	0.29^{a}
	23+inoculant	14.00^{def}	2.79^{cde}	0.57^{ab}	0.29^{a}
36.9	control	13.90^{def}	2.65^{cde}	0.48^{bc}	0.28^{a}
	23	12.75^{f}	2.12^{e}	0.54^{ab}	0.26^{a}
	inoculant	15.70^{cde}	2.76^{cde}	0.48^{bc}	0.27^{a}
	23+inoculant	13.17^{ef}	2.54^{de}	0.51^{abc}	0.28^{a}
CV%		11.46	20.92	24.19	17.65
LSD (0.05)		2.64	0.86	0.12	0.04

Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$).

Table 4. Interaction effects of treatments on the yield parameters of mung bean.

Treatments		Yield parameter
Bio-slurry (m^3)	**Inoculant/N fertilizer(kg)**	**Grain yield (t ha^{-1})**
0	control	0.70^{f}
	23	0.80^{ef}
	inoculant	0.86^{de}
	23+inoculant	0.82^{def}
12.3	control	0.83^{def}
	23	1.15^{ab}
	inoculant	1.03^{bc}
	23+inoculant	0.95^{cd}
24.6	control	1.16^{ab}
	23	0.93^{cde}
	inoculant	1.20^{a}
	23+inoculant	0.91^{cde}
36.9	control	0.81^{def}
	23	1.05^{bc}
	inoculant	0.88^{de}

Treatments		Yield parameter
Bio-slurry (m^3)	**Inoculant/N fertilizer(kg)**	**Grain yield (t ha^{-1})**
	23+inoculant	0.88^{de}
CV%		10.46
LSD (5%)		0.13

Means followed by the same letter (s) within the column are not significantly different at ($P \leq 0.05$). BS=bio-slurry.

Conclusion

Bio-chemical N fertilizers integration has a significant effect on the growth and nodulation and yield of mung bean. Integrated application of 36.9 m^3 with 23 kg N+*Rhizobium* inoculation has resulted in the highest Leaf area, LAI, shoot fresh and dry weight. The highest nodule number and nodule diameter was recorded from plots received rhizobium inoculation with nil bio slurry, whereas, nodule dry and fresh weight were recorded from the Rhizobium inoculation with 24.6 m^3 bio slurry application. Grain yield was also greatly influenced by combined application of fertilizers and the highest grain yield was recorded from 24.6 m^3 with inoculation. Therefore, significant responses in phenology, nodulation, gas exchange, and yield of mung bean were obtained from the combined applications of bio-slurry and inoculant/N fertilizer. Based on the results of this study, it can be concluded that the integrated application of bio-chemical fertilizer significant improvement in the growth, nodulation and yield performance of mung bean. However, verification of the result on farmers' fields across seasons and locations could be required to put the recommendation on firm ground.

Significance Statement

The study revealed that, biochemical integrated fertilizer application improved the performance growth nodulation and yield of mung bean. This research will help for researchers to understand the effect of the combined effects of fertilizers sources on the performance of mung bean, the optimal rates of biological and chemical fertilizer combination and provide a background information to pursue a research on a related topic. It is also fundamentally important, for farmers producing the crop using organic fertilizers.

Conflict of Interest

The work described has not been published previously, nor is it under consideration for publication elsewhere. All authors approve publication, all sources of funding and reference are duly acknowledged, and no conflicts of interest are applicable.

Acknowledgement

Hawassa University funded 'Urban Waste Management and Utilizations for Agriculture and Energy Production in Hawassa City; Urban Organic Waste Recycling for Crop Productivity' thematic project acknowledged for supporting the field experiment.

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Citation:

Tadewos, T., Ayalew, T., Yoseph, T. (2022). Growth, nodulation and yield of mung bean (*Vigna Radiata* L. (*Wilczek*) as affected by bio-chemical fertilizers integration at Southern Ethiopia. *Ukrainian Journal of Ecology.* 12: 39-49.