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Response of spinach to organic and inorganic fertilizer sources with liming in acidic soil

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Abstract
Spinach cultivation in acidic soil is challenging due to unavailability of nutrients which can be achieved by proper fertilizer management. This study was conducted to evaluate the effect of different nutrient amendments (T_1: control, T_2: cowdung, T_3: compost, T_4: vermicompost and T_5: lime+100% inorganic fertilizer dose) on spinach in acidic soil. The treatments were replicated thrice following randomized complete block design. The shoot length, root length, number of leaves plant^{-1} and total plant population were found significantly higher in T_5. The uptake of nutrients (Ca, Mg, K, Zn, Fe and B) was also found significantly higher for lime+inorganic fertilizer application (T_5) except sulphur. Micronutrients uptakes were almost similar for the organic amendments (T_2, T_3, T_4). Highest spinach yield was found for T_5 (7.49 t ha^{-1}). Liming made the nutrients more accessible that would have remained trapped due to acidic pH. Future studies should be highlighted on the lime application with different organic amendments to precisely identify the best amendment source among them.

Keywords: spinach, fertilizers, acidic soil, quality and yield

1. Introduction
Spinach (*Spinacia oleracea* L.) is a popular winter vegetable belonging to the amaranth family (Amaranthaceae) [1]. It is a leafy vegetable which is grown in many countries around the world including the Indian subcontinent [2]. It contains many essential nutrients [3] including vitamins, minerals, and many phyto-chemicals that maintain good health [4]. Statistics shows that, the average production and total cultivable land of spinach in Bangladesh is increasing day by day [5] which indicates its popularity.

Intensive use of inorganic fertilizer in agriculture causes human health hazard and persistent environmental contamination [6]. Fertilizers are costly and increase nitrate pollution and loss of carbon in soil [7]. Moreover, it contaminates soil and water as well as negatively influences human health. Spinach plants grown with high levels of nitrogen fertilizer contain carcinogenic substances such as nitrosamines [8]. To check all these soil, environment and health hazards, there is no other option but shifting to organic agriculture. Though organic amendments are usually low in nutrient contents and release nutrients slowly in soil, they supply balanced nutrients, support microbial activities in soil and keep the soil healthy by suppressing certain plant and soil borne diseases [9].

Efficient organic fertilizer management is crucial for sustainable and quality crop production [8, 10, 11, 12]. In Bangladesh, the use of synthetic fertilizer is relatively new practice compared to organic fertilizer. Though the application of the latter has been practiced widely for over a few centuries, the popularity of inorganic fertilizer surpassed mainly due to quick release of nutrients, mass production and availability, among others [13]. Especially in Bangladesh, where scarcity of land increases every day, sole application of organic fertilizer is often considered as luxury.

Predominantly Sylhet region's soils are acidic. Despite the downsides of using inorganic fertilizers farmers in this area mostly use them like the rest of this country. To our knowledge the comparison between organic and inorganic fertilizers on spinach cultivation has not been performed for the soil types of this area. Moreover, the contribution of liming to alleviate soil acidity problems for spinach growth and nutritional quality is yet to be studied. Therefore, the present study was conducted to assess the growth and yield of Spinach under different organic farming practices compared to inorganic fertilizers with lime.

2. Materials and Methods
Experimental location and weather
The experiment was carried out at the field of Sylhet Agricultural University, Sylhet, Bangladesh to observe the effect of different organic fertilizers on growth, yield, and nutrient

uptake of spinach. The site is situated with 24^0 54'- 33.73" N latitude and 91^0 54'- 05.69" E longitude. The soil belongs to the Agro-ecological Zone of Northern and Eastern Piedmont Plains (AEZ-22) under the “Pritim Pasha” soil series. During the field experimental period (December 28, 2018 to February 10, 2019) meteorological data was collected from Sylhet Meteorological Station. The minimum and maximum temperature was recorded at 32.0°C and 8°C, respectively and the mean monthly relative humidity was approximately 79%. No rainfall occurred during the study period. Initial soil sample was collected before plot preparation. Five soil samples were collected from each plot (0-15 cm) for physical and chemical analyses (Table 1).

Table 1: Chemical properties of soil

pH	OM%	Ca (meq $100g^{-1}$)	Mg (meq $100g^{-1}$)	K (meq $100g^{-1}$)	Total N%	P (µg g^{-1})	S (µg g^{-1})	B (µg g^{-1})	OC%	Fe (µg g^{-1})	Zn (µg g^{-1})
5.3	2.2	5.3	1.8	0.1	0.1	15.5	15.0	0.4	1.3	98.5	2.7

Treatments and design

The experiment consisted of five treatments, control (T_1), cowdung (T_2), compost (T_3), vermicompost (T_4), and lime+100% recommended inorganic fertilizer dose (T_5) for spinach. The nutrient composition of organic amendments and lime is given in Table 2. Total number of experimental plots was fifteen (15) having the size of $0.48m^2$ (80 cm × 60 cm) of each plot. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Seeds of locally cultivated ‘Sathi’ spinach variety (a commercial variety from Lal Teer Seed) were sown continuously in 20 cm spaced rows. Before sowing, seeds were soaked into water for 14 hours and then air dried for 6 hours. In the lime treated plots, lime was applied 15 days before applying organic amendments. All the organic fertilizers were applied three days before seed sowing whereas inorganic fertilizer was added during final land preparation according to the treatment (Table 2).

Table 2: Quality and composition of organic fertilizers and lime

Organic amendments	Nutrient elements (%)									Application rate	Application rate in plot (g)
	Ca	Mg	K	N	P	S	B	Fe	Zn		
Cowdung	0.87	0.52	0.56	1.10	0.24	0.11	0.012	0.36	0.01	5 tons ha^{-1}	240
Compost	2.29	1.38	0.88	0.89	0.11	0.46	0.018	0.36	0.048	5 tons ha^{-1}	240
Vermicompost	1.16	0.97	0.9	1.93	0.83	0.27	0.016	0.36	0.019	4 tons ha^{-1}	192
Lime	39.84	0.001	0.01	0.58	0.08	0.04	0.013	0.31	0.001	4 kg decimal $^{-1}$	47.41
Inorganic recommended fertilizer										180-125-125 kg ha^{-1} of NPK, respectively	8.64-6-6 g of NPK, respectively

Crop husbandry

Plants were irrigated twice a week with a sprinkler method and hand weeding was done once a week. Extra plants were thinned out after one week of seed germination from each plot. No severe disease or pest infestation was reported; therefore, no control measures were taken in this regard.

Data collection and analysis

Ten plants were randomly selected from each plot to record the data. Shoot and root length, number of leaves $plant^{-1}$, shoot and root fresh and dry weight, root shoot ratio, total plant population, harvest index, and yield data were collected as growth and yield parameters during harvest. Dry weight was taken by drying the plants in an oven at 60°C for 48 hours. To determine iron (Fe), zinc (Zn), potassium (K) and phosphorus (P) soil and plant samples were digested in an acid mixture (1:3 ratio of perchloric: nitric acid). P was determined by phosphomolybdate blue method using a spectrophotometer. Composition of cations in samples were determined using an atomic absorption spectrometer (AAS). Soil pH was measured by making a 1:10 ratio of soil: solution and waiting for exactly 10 minutes. The statistical analyses of the recorded data were done by using SPSS software (version 27) and the means were separated by using Least Significant Difference (LSD) test.

3. Results and Discussion

Agronomic parameters

Spinach yield significantly varied among treatments (Figure 1). Control (T_1), compost (T_3) and vermicompost (T_4) treated plots had almost similar yields, whereas the highest yield was found in T_5 (i.e., lime+100% recommended fertilizer). Inorganic fertilizer being readily available with lime application might have caused the highest growth of spinach [14]. Cowdung application (T_2) produced the second highest yield. Application of composted manure significantly increases growth and nutrient uptake by plants [15], especially in spinach [16].

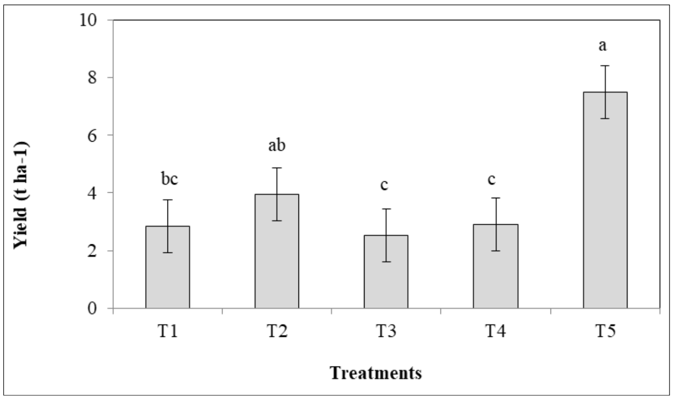

Fig 1: Yield of spinach in different organic and inorganic nutrient sources. Different letters indicate significant treatment differences ($p<0.05$), whiskers indicate individual standard deviation of the mean

There were significant differences among the treatments for different agronomic parameters (Table 3). T_5, *i.e.*, lime+100% recommended inorganic fertilizer application showed significantly higher number of leaves $plant^{-1}$, root length and total plant population. Control plot had lowest values for the aforementioned parameters except shoot and root length.

Application of cowdung, compost and vermicompost produced almost a similar number of leaves $plant^{-1}$. Application of amendments especially compost or manure are proven sources of plant nutrients. Irshad *et al*. (2002) [15] also confirmed higher biomass production in manure amended soil. Shoot moisture percentage was found highest in the control plots. Lower dry matter production in plants due to low nutrient availability in soil might be the reason for this.

Root-shoot ratio was highest for control plots, meaning plants in those plots allocated much of their resources for root elongation to explore deep into the soil for nutrients and water. The opposite was true for T_5, indicating that plants had enough resources to focus on vegetative growth. Moreover, lime application played an important role in nutrient availability. Since the soil was slightly acidic, fertilizer application with lime helped immobilize nutrients that would otherwise remain inaccessible by the acidic pH [17]. Moreover, increased soil pH facilitates microbial growth and activity [18, 19] that results in faster decomposition of organic matter (OM) [31, 21].

Table 3: Agronomic parameters of spinach

Treatment	Shoot length	Root length	No. of Leaves plant^{-1}	Total plant population	Shoot moisture%	Root shoot ratio	Harvest Index
T1: control	9.5±0.32ab	3.6±0.46a	4.8±0.3a	202.8±17.3a	16.5±1.8c	0.21±0.04	0.64±0.01a
T2: cowdung	11.0±2.25ab	4.0±0.61a	6.4±0.4b	581.3±37.0b	10.9±0.6ab	0.15±0.04	0.78±0.02b
T3: compost	7.8±0.20a	3.2±0.45a	6.2±0.3b	597.2±107.5b	9.9±1.2a	0.17±0.02	0.80±0.03b
T4: vermicompost	12.1±1.85b	4.0±0.20a	6.6±0.3b	707.6±72.3b	12.2±0.7ab	0.14±0.03	0.79±0.02b
T5: lime+100% recommended fertilizers	17.3±1.21c	5.2±0.15b	9.0±0.4c	885.4±50.5c	13.8±0.8bc	0.08±0.00	0.89±0.00c
LSD0.05	1.43	0.4	1.6	378.5	5.6	0.06	0.15
F-test	**	**	**	**	**	*	**

Nutrient composition

There were significant differences in different nutrient composition of plants except sulphur (S) among the treatments (Table 4). In case of T_5, P uptake was found more than double than in control plots. It indicates the readily availability of P in soil after lime application in acidic soil [22].

Inorganic fertilizers release nutrients in soil at a faster rate than organic manures which might be the cause of highest P uptake in T_5. In acidic conditions P remains fixed due to presence of high Fe and aluminium (Al) in soil [23]. Since decomposition rate increases due to liming, Al and Fe get released and subsequently P concentration in soil increases [24]. However, compost (T_3) and vermicompost (T_4) applications also showed significant increase in P uptake than in control (T_1).

Table 4: Nutrient uptake of spinach under different sources of organic and inorganic nutrients

Treatment	Ca (%)	Mg (%)	K (%)	P (%)	S (%)	Zn (ppm)	Fe (ppm)	B (ppm)
T1	2.1±0.08a	1.1±0.03a	1.8±0.02a	0.3±0.07a	0.39±0.04	130.2±1.1a	1300.3±88.5a	34.7±3.8a
T2	2.2±0.11a	1.1±0.02a	1.8±0.03a	0.5±0.06ab	0.50±0.04	126.6±1.7a	1490.7±74.0b	38.0±3.0a
T3	2.4±0.06a	1.1±0.02a	1.8±0.04a	0.6±0.07b	0.44±0.03	121.0±2.2a	1565.1±18.2b	43.0±3.0ab
T4	2.3±0.21a	1.0±0.15a	2.0±0.42a	0.6±0.10b	0.41±0.11	109.7±22.2a	1605.3±71.1b	38.0±3.6a
T5	2.9±0.03b	1.8±0.01b	3.0±0.03b	0.8±0.03c	0.52±0.03	182.7±1.0b	1947.3±43c	50.0±4.6b
LSD0.05	0.16	0.02	0.02	0.12	0.11	3.6	190	3.3
F-test	**	**	**	**	NS	**	**	**

Where, Values are given as mean ± standard deviation. NS means no statistically significant difference, * significant difference at $p \leq 0.05$, **significant difference at $p \leq 0.01$. Within each column, means followed by different letters are significantly different according to the Duncan test at $p \leq 0.05$

Potassium (K) uptake was not significantly increased except for lime application (*i.e.*, T_5) (Table 4). In acidic conditions cation exchange capacity (CEC) decreases thereby inducing K deficiency in soil [25]. Because of liming, acidic ions become neutralized and alleviates K^+ absorption inhibition [26]. Lime application with K fertilizer indirectly induces plant uptake compared to no lime treatment [27]. But sole lime application without any amendment [17] or without any K amendment [28] does not have any effect on K availability in soil.

Plant uptake of calcium (Ca) and magnesium (Mg) significantly increased by lime application (Table 4). Han *et al*. (2019) [27] reported a positive correlation between lime application and exchangeable Ca^{2+} in soil compared with no lime treatment. They found a similar trend of Ca^{2+}+Mg^{2+} with soil exchangeable Ca^{2+}. There is a competitive relationship between exchangeable Ca^{2+}+Mg^{2+}, especially Ca^{2+} and K^+ in soil. They compete for adsorption sites in colloids, and Ca^{2+} from lime increases the chance of K^+ to be uptaken by plant roots [26]. This phenomenon explains the lower uptake of Mg than Ca as well as slightly higher uptake of K^+ than Ca^{2+} (Table 4).

Uptake of micronutrients were also significantly affected by liming (Table 4). Boron (B) uptake was increased by both organic and inorganic amendments, while liming resulted in highest uptake by plants. Intrinsically B availability is low in acidic soil and high rainfall deteriorates the situation with leaching of B that become adsorbed to Fe and Al oxides. Compost treated plots showed second highest B uptake by plants which might correspond to the highest B contents of compost among the applied organic amendments (Table 2). Liming also increased Zn and Fe concentrations in plants. The substantial increase of Zn and Fe uptake with liming can also be attributed to increased solubility of nutrients in soil. Because of increased pH after liming, the negative charge of OM in soil becomes higher and gets hydrated. Hence, they become more soluble in soil solution rendering them more accessible to microbes and degradation [29]. Above all, micronutrients uptakes were more or less equal for organic amendments. This might be due to the nature of organic matter. OM forms stable and insoluble organometallic chelates with -OH and -COOH groups, consequently limiting solubility in soil [30].

4. Conclusion

Significant effects of liming were evident for most of the physical and chemical parameters studied in this experiment. Though application of lime with recommended inorganic dose showed the best performance, impacts of liming mostly caused the differentiation of nutrient availability in soil. This experiment showed that choosing the best soil amendment is not enough unless it is coupled with liming for spinach cultivation in acidic soil. It again highlights the century old concept of "not all fertile soil is productive". Apart from this, compost and vermicompost also showed potential increase of growth and quality of spinach. Therefore, future experiments should be carried out on the liming effects combined with compost and vermicompost to sort out the best choice for organic amendments to get better yield and quality of spinach.

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