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Effect of soil amelioration on high value vegetables grown under protected conditions

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ABSTRACT

High-value vegetable production under open field in northeast India's hilly ecosystem often suffers from abiotic and biotic stresses (low temperature, soil acidity and moisture deficit during winter, and infestation of pests-diseases during humid summer). Protected cultivation with soil ameliorative measures may help in overcoming these limitations while sustaining year-round production. An experiment was conducted at the Horticulture Experimental Farm, ICAR Research Complex for NEH Region, Meghalaya for three consecutive years (2016–18) to study the yield performance of 4 high-value vegetables (tomato, capsicum, king-chilli and cucumber) grown under naturally ventilated polyhouse in the strong acid soils (*p*H<4.80) of mid-altitude (960 m amsl) sub-tropical hilly ecosystem of northeast India. Crops were grown with three ameliorative measures (liming @2.5 q/ha, black polythene mulching, and both) and yields were compared with control (without liming and mulching). Liming increased soil *p*H by 0.39–0.5 units, available phosphorus by 3.8–4.6 kg/ha and bases (calcium and magnesium) by 1.0–1.2 meq/100 g soil. On black polythene mulching, temperature (air and soil) increased by 5.5–8.7°C and 3.9–5.8°C, respectively, during extremely cold periods (December–February). Soil moisture retention was 3.8–5.2% higher over control plots. Ameliorative measures (liming or mulching) increased tomato yields by 15.0–28.5%, capsicum by 21.1–59.9% and king-chilli by 5.76–24.5% while cucumber yield in mulched plot increased 2-fold over respective control plots. The yields of all the vegetables further increased on the combined application of lime and mulch together. Findings suggest ameliorative measures promises better productivity of vegetables under controlled environment.

Keywords: Mulching, Protected cultivation, Soil amelioration, Tomato

With hilly topography in more than 2/3rd of geographical area (26.2 mha), the northeast India barely provides 1/4th geographical area for cultivation practices. The agriculture in the region is rainfed, less mechanized, marginal input-intensive, mainly cereal (rice/maize) based system, and comparatively less economical over the high value vegetable crops. The high value crops like tomato, capsicum, cucumber and king-chili have been found profitable under protected conditions with B:C ratio >2.0 (Verma *et al*. 2018). These crops are also rich sources of vitamins and minerals, and playing an important role in nutritional security. By virtue of geographical setting in the eastern Himalaya with the prevailing mild weather throughout the year, protected cultivation with low-cost naturally ventilated polyhouses may be feasible in the region and mid-hills (≈1000 m amsl) in particular.

The soils of the region are strongly acidic in reaction (*p*H<5.0) and the upland soils of the region suitable for vegetable growing in particular often suffers from deficiency of nutrient (P) by fixations and leaching of the bases (Ca, Mg), and micronutrients (B, Mb, and Zn) from extensive rainfalls and limits the crop productivity. Application of agricultural lime with chemical fertilizers in strong acid soils of the region helps increase the bio-availability of P, Ca, Mg and micronutrients while improving the productivity of field crops (Patiram 2007, Kumar *et al*. 2013). Availability of water at critical crops growth stages is another major limiting factors, particularly during dry pre- and post-monsoon months in the region. Mulching helps in modifying favourable soil hydro-thermal regimes, reducing evaporation loss, physiological processes, including water and nutrient uptakes, and enhancing yield and quality of the produce (Paul *et al*. 2013, Dhaliwal *et al*. 2017, Laulina and Hasan 2018).

Keeping above facts in view, the present study was aimed to study the effect of ameliorative measures (liming for soil acidity stress and mulching for moisture stress) on the performance of four most commonly grown (in open condition) high value vegetables under naturally ventilated polyhouse in the strong acid soils (*p*H<5.0) at mid-altitude hilly ecosystem of Meghalaya.

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MATERIALS AND METHODS

An experiment was conducted at the Horticulture Experimental Farm, ICAR Research Complex for NEH Region, Meghalaya for three consecutive years (2016–18). The study area experiences an average annual rainfall of 2450 mm, with 70% of it received during July–September. The measured temperature (day/night) inside the polyhouse ranged from 22–27°C/15–20°C while relative humidity ranged from 47–68%. Composite soil samples from the polyhouse were collected randomly and initial soil properties were characterized following standard procedures (Jackson 1973). The soil of the region is sandy, low in plant available water content (12–14%); strongly acidic in reaction (*p*H≤5.0); very low in exchangeable bases (3.0 meq/100 g soil) while high in Walkley and Black organic carbon (>2.10%) contents. Soils were low in available nitrogen (N: 200 kg/ha), and phosphorus (P_2O_5 <20 kg/ha), while medium in available potash (K: 280 kg/ha).

Treatments were applied on four high value crops namely tomato (var. Megha Tomato–3), capsicum (var. California Wonder), king-chilli (local landrace Red Long) and cucumber (var. Long Green) grown in the naturally ventilated playhouse. The tomato and capsicum duration was January–June (harvest), cucumber from July–December while king-chili being a long duration crop was grown from February–December. The experiments were laid down in Complete Randomized Block Design with three replications.

Total 4 treatments (including control) were imposed on all the crops, viz. T_1, Control (only recommended dose of fertilizer as in open condition-RDF); T_2, RDF + Lime (@2.5 q/ha); T_3, RDF + Mulch (black polythene) and T_4, RDF + Lime (78% $CaCO_3$ equivalent, @2.5 q/ha) + Mulch (black polythene). The plot size of each treatment was 5 m × 2 m. The recommended dosage of fertilizers N, P, and K were 120:80:60 kg/ha respectively, for solanaceous crops (tomato, capsicum and king-chili) and 80: 50: 50 kg/ha for cucumber. In addition, farmyard manure (FYM: 0.81% N, 0.28% P, 0.34% K contents) was applied @10 t/ha across all treatment combinations for all the crops. The manure and fertilizers were applied following standard package of practices. Black polyethylene mulch film of 40 micron thickness was used to cover the planting rows/beds.

Thirty days old seedlings of tomato and capsicum while 40 days old seedlings of king–chili were transplanted in the double row system at 60 cm × 45 cm, 50 cm × 30 cm and 90 cm × 75 cm spacing, respectively. The seeds of cucumber were sown directly in the pits (2 seeds per pit) at 1.5 m × 0.8 m spacing. The observations for growth and yield related attributes were taken from the six randomly selected plants in each replication across all treatment combinations. Similarly, periodic (30-days interval) soil moisture content from the root zone (up to 30 cm) from all plots was determined by gravimetric method (w/w). Soil thermometers were installed at two depths (15 cm and 30 cm) to measure the variation in soil temperatures.

Statistical analysis was performed with SAS Version 9.2 (SAS Institute Inc., Cary, NC, USA). Multiple means comparison was completed by comparing the least squares means of the corresponding treatment combinations with Duncan's Multiple Range Test (DMRT) at 0.05 and 0.001 probability level of significances. Significant differences were graphically represented by Diffogram using PROC GLM SAS (SAS Institute, version 9.2) (SAS Institute 2010).

RESULTS AND DISCUSSION

The results showed significant effects of soil amelioration measures on yield attributes of tomato, capsicum, king-chilli, and cucumber. Tomato (var. Megha Tomato-3) under control condition (only RDF), produced fruit yield of over 46 tonnes/ha during all the three years (Table 1, Fig 1). On liming the soil @2.5 q/ha, fruit yield increased by another 15.0–28.5% and was comparable to the proportionate increase (16.9–23.2%) with black polythene mulching. Combined application of liming and mulching, further increased fruit yield significantly ($P<0.05$) and almost double (79.8 tonnes/ha) amount recorded in controlled plots. Diffograms also reflected significant ($P<0{\cdot}05$) differences among the treatment combinations on yield of tomato during all the years (2016–18) (Fig 1). However, the interaction of year on average yield among the treatments was non-significant ($P<0.05$), reflecting a similar trend of significant differences among the treatments across the years.

The observation recorded on major fruit yield attributing characters like fruit dimensions (length, diameter and

Table 1 Effect of soil ameliorative measures on plant growth and yield attributes of tomato and capsicum

Treatment	Tomato						Capsicum						
	Plant height (cm)	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	No. of fruits/ plant	Yield (t/ha)	Plant height (cm)	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Pericarp thickness (cm)	No. of fruits/ plant	Yield (t/ha)
Control	108.7[c*]	3.50[c]	34.13[c]	57.33[b]	20.60[c]	46.29[c]	57.33c*	4.17d	3.70c	47.33c	0.44b	9.20b	22.25[c]
Lime	121.60[a]	4.10[b]	4.20[c]	62.67[b]	26.33[b]	55.62[b]	66.00[b]	5.87[b]	4.63[b]	54.53[b]	0.58[a]	11.00[a]	31.15[b]
Mulch	125.57[a]	4.20[b]	4.43[b]	59.00[b]	28.67[b]	52.60[b]	69.33[a]	4.40[c]	4.03[c]	53.00[bc]	0.47[b]	12.33[a]	31.76[b]
Lime + Mulch	130.93[a]	4.77[a]	4.60[a]	70.33[a]	34.67[a]	79.82[a]	72.33[a]	6.17[a]	5.50[a]	66.50[a]	0.56[a]	14.67[a]	41.24[a]
$LSD_{0.05}$	11.73	0.36	4.12	5.87	4.03	4.70	3.10	0.20	0.50	6.17	0.07	5.23	5.73

*Within column, means followed by the same letter (a-d) are not significantly different ($P>0.05$)

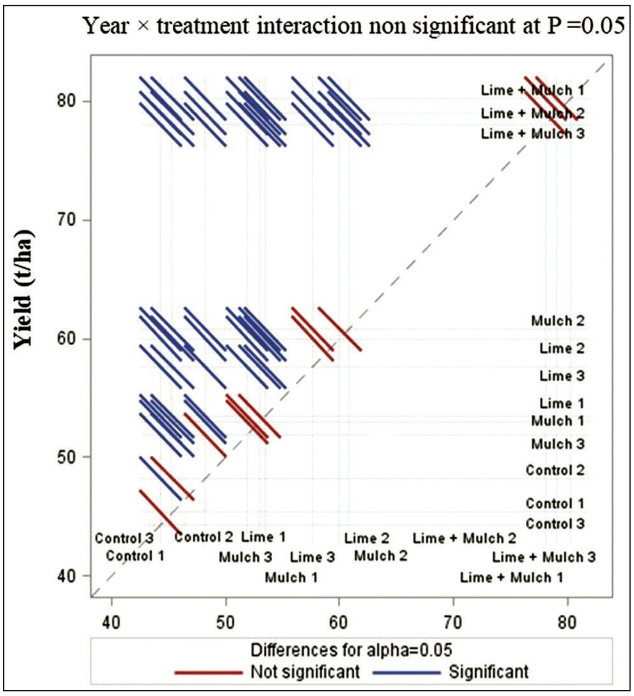

Fig 1 Diffograms showing significant differences among treatment effects (liming and mulching) on yield of tomato.

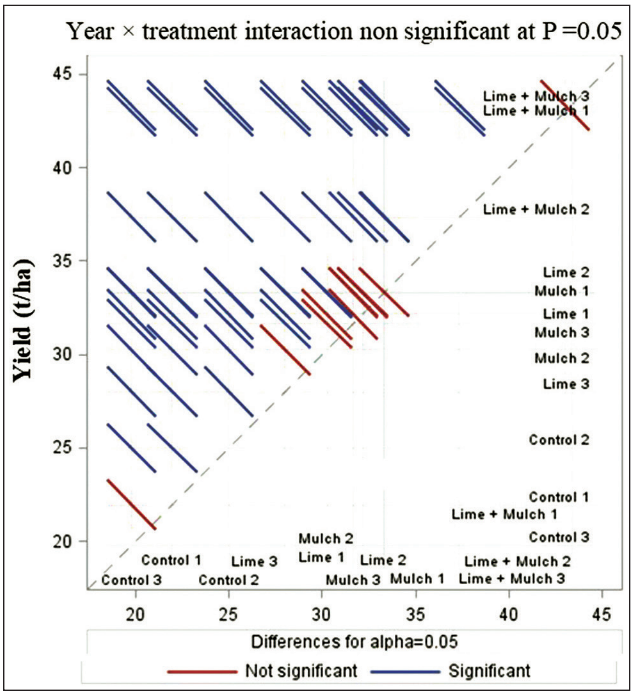

Fig 2 Diffograms showing significant differences among treatment effects (liming and mulching) on yield of capsicum.

weight), pericarp thickness and number of fruits per plant were significantly (P<0.05) improved by the imposition of soil ameliorative measures (Table 1). The effect was more distinct when ameliorative measures were adopted in integration. As a result, fruit yield obtained under ameliorative measures outperformed control plots inside the same controlled environment (polyhouse).

In capsicum (var. California Wonder), the soil amelioration measures (liming/mulching) significantly (P<0.05) improved fruit yield attributes (fruit length, fruit diameter, fruit weight, and number of fruits per plant) and so the overall fruit yield (Table 1). Liming of strong acid soils (*p*H<5.0) inside the polyhouse across the years (Fig 2) in comparision to non-mulched plots produced relatively more yield (24.9–31.8% over 22.3 tonnes/ha in control), similarly in black polythene mulch (21.1–59.9% over control). However, when liming was done in mulched plots, the fruit yield increased by 49.4–119.0% over control (19.8–25 tonnes/ha). Diffograms also reflected significant (P<0·05) differences among the treatment combinations on yield of capsicum across the years (Fig 2).

King-chilli, an important indigenous landrace of *Capsicum* spp. originated as a natural inter-specific hybrid, grown widely in the region. The crop prefers mild warm and humid weather for growth and yield. Being a high value crop, it is grown under open condition in mid-hills with duration of 6–8 months (April–October). In protected cultivation, the crops' duration extends from 8–9 months, resulting in higher yield than open condition. Like capsicum, yield of king-chilli also significantly (P<0.05) influenced by soil ameliorative measures (Table 2). Liming and mulching with black polythene individually increased the fruit yield by 5.76–24.5% and 10.4–22.2% over control (8.1–9.9 t/ha). When liming was done in mulched plots, the fruit yield increased further (76.8–106.0% over control).

The soil ameliorative measures resulted in significant (P<0.05) improvement on growth and yield attributes in cucumbers under protected condition (Table 2). On an average fruit yield was more than two fold higher in mulched and lime plus mulched treated plots in over control (13.0–15.3 tonnes/ha). The proportionate increase in lime treated plots was substantially less (10.0–28.0% over control) than mulched plots.

The fruit yields of tomato, capsicum and cucumber with recommended doses of nutrients (fertilizer and organic manures) under open field condition in the region, Meghalaya in particular during 2018 was on average 17.57 tonnes/ha, 8.19 tonnes/ha and 8.33 tonnes/ha, respectively (Anonymous 2018). Growing the same cultivars for all the three crops with comparable nutrient doses as in open field condition in controlled plots under protected cultivation (polyhouse), recorded 2.6 times higher yield in tomato (control: 45.3–48.2 tonnes/ha) while in capsicum, it was 2.7 times higher (control: 19.8–25.0 tonnes/ha) than the open field condition. The corresponding increase in cucumber yield was 1.5–1.8 times higher (control: 13.0–15.33 tonnes/ha). The higher fruit yield of the these vegetables might be from better growing environment inside polyhouse since it protects plants from high intensity rainfall, low temperature, particularly during extreme cold months (November–February), high winds and high pest and diseases infestations (Singh *et al.* 2003) in the region. Many researchers also reported substantial increase in yields of these high value vegetable crops including tomato, capsicum, cucumber etc

Table 2 Effect of soil ameliorative measures on plant growth and yield attributes of king-chilli and cucmber

Treatment	King-chilli						Cucumber						
	Plant height (cm)	Fruit length (cm)	Fruit diame-ter (cm)	Fruit weight (g)	No. of fruits/ plant	Yield (t/ha)	1st flowering node female	Days to 1st harvesting	No of fruits/ plant	Fruit length (cm)	Fruit diameter (cm)	Fruit weight (g)	Yield (t/ha)
Control	132.67^{c*}	4.47^{c}	2.80^{c}	5.00^{b}	107.5^{c}	8.87^{d}	4.6^{c*}	55.0^{b}	9.0^{c}	15.7^{c}	4.5	280.0^{b}	13.9^{d}
Lime	145.33^{b}	5.77^{b}	3.67^{b}	5.57^{b}	161.0^{b}	12.36^{b}	5.5^{bc}	52.7^{c}	10.2^{b}	18.8^{b}	4.9	340.0^{a}	17.0^{c}
Mulch	148.0^{b}	5.80^{b}	3.33^{a}	5.53^{b}	138.6^{b}	10.31^{c}	6.7^{a}	57.0^{a}	12.6^{ab}	18.4^{b}	5.2	328.0^{a}	27.0^{b}
Lime + Mulch	165.6^{a}	6.70^{a}	5.07^{a}	6.57^{a}	198.7^{a}	16.50^{a}	5.6^{ab}	53.3^{c}	15.2^{a}	20.7^{a}	5	345.0^{a}	31.8^{a}
$LSD_{0.05}$	9.87	0.12	0.88	0.87	13.86	1.52	1.4	1.5	3.1	1.42	NS	72.2	2.27

*Within column, means followed by the same letter (a-d) are not significantly different (P>0.05)

under protected cultivation over open field condition (Singh *et al.* 2003, Paul *et al.* 2013, Dhaliwal *et al.* 2017, Laulina and Hasan 2018).

To sustain upland crop productivity in open fields, liming (agricultural lime) at differential doses is a recommended practice in the region and its beneficial effect on overcoming soil fertility, stress while improving upland crop (maize, mustard, potato, etc) productivity up to 70% over without liming has been reported by various workers of the region (Patiram 2007, Kumar *et al.* 2013, Marwein *et al.* 2017). On liming alone, we observed significant increase in fruit yield of four vegetables grown inside the polyhouse: average yield increased from 20% (in tomato) to 28.66% (in capsicum) over respective control (without liming) plots. The soil *p*H in limed plots across four vegetables increased by 0.39–0.55 units from the controlled plots (*p*H: 4.87–4.92). Similarly, availability of P increased by 3.8–4.6 kg P/ha while the concentration of bases (Ca + Mg) increased by 1.0–1.2 meq/100 g from the controlled plots (Ca + Mg: 3.15 – 3.25 meq/100 g). We also observed small increase in available moisture content (by 1.1–1.56%) in limed plots over non-limed controlled plots (12.2–14%, wt./wt.). An increase in soil moisture availability on liming under water stress condition from a pot experiment on maize crop from the study area was also reported by Marwein *et al.* (2017). Thus, the cumulative beneficial effect of liming on soil environment might have influenced the crop to produce more fruit yields. Among the four vegetables, capsicum is more sensitive to soil acidity and low bases (particularly Ca) since it prefers near neutral *p*H (6.0) and higher soil calcium concentration. This might have caused differential proportionate increase in fruit yields among the vegetables, 24.9–31.75% increase in capsicum over 16% increase in other three vegetables over respective control plots.

Use of black polythene mulch in the polyhouse modifies soil hydro-thermal regimes and makes micro-climate in the vicinity of the crop more conducive for better productivity (Paul *et al*. 2013, Dhaliwal *et al*. 2017, Laulina and Hasan 2018). We observed an increase in plant available water content on average by 3.8–5.5% in mulched plots across all four crops over the control plots (12.2–14%, wt./wt.) during the crop growth periods. The region is known for extreme low temperature (soil and air) induced chilling damage of crops in the winter months (November–February) under open field condition. We recorded a minimum air temperature of 4.2–8.7°C (November to February) during crop growing seasons (2016–18) under open field condition in the vicinity of polyhouse. For the same period, minimum temperature inside the polyhouse was 5.5–8.7°C higher. In non-mulched plots inside the polyhouse, soil temperature at 15 cm depth was recorded at 11.2–15.5°C during extreme winter months (November–February) across all four crops. However, on plots mulched with black polythene, soil temperature increased by 3.8–5.5°C over non-mulched plots. Laulina and Hasan (2018) also reported an increase of soil surface (at 10 cm depth) temperature by 3–5°C on using black polythene mulch over non-mulched plots during winter months in a ventilated greenhouse at Delhi, India. Since irrigation was stopped after 15 days of planting and the crops were allowed to grow as rainfed crop, thus, mulching played a significant role in providing conducive soil hydro-thermal regimes for better productivity. However, due to variation in preference of growing micro-environmental requirements among the four vegetables, the response to mulching in proportionate increase of fruit yields varied among the four vegetables. Being sensitive to low temperature, low relative humidity (RH) and less soil moisture, cucumber's response to modification of hydrothermal regime towards higher temperature, RH and soil moisture on mulching was most significant than other three vegetables. On mulching alone, cucumber yield increased 2-fold over control (without mulch and lime) across the years.

However, when liming was done in mulched plots, the fruit yields increased further and recorded the highest yield across all vegetables compared to plots treated with either liming or mulching alone. The synergistic effect of mulching and liming in modifying soil hydro-thermal regimes and ameliorating soil acidity induced fertility stresses both at a time was distinctly visible on fruit yield of all the vegetables. Thus, the combined application of mulching and liming under protected cultivation in the strong acid soils of the region promises better productivity than either mulching or liming the soils. Since, lime is locally available and cheap in the region, resource poor farmers of the region could get higher returns from the protected cultivation if they integrate liming with mulching in the production system.

The study affirms that protected cultivation of selected sensitive, high value vegetables assures better productivity than the open field cultivation in hill agriculture's stressed environment. Liming, a recommended practice for amelioration of strong acid soils in the uplands of the region also proved equally good to ameliorate soil acidity stress in protected cultivations while improving productivity. Black polythene mulch would be helpful in beneficial modification of soil hydro-thermal regimes to achieve higher productivity. Thus, black polythene mulching along with liming under protected cultivation of high-value vegetables may improve fruit productivity and thus assures higher income generation round the year *vis-a-vis* livelihood security of small farmers in the hilly ecosystem of northeast India and other similar regions.

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