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Sulfur-aided acidification of compost ameliorates its negative effects and maximize phosphorous availability in calcareous soils

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Abstract
Nutrient solubility, mobility and availability in the soil is mainly controlled by pH which effects the crop growth and yield. High buffering capacity (pH) of the compost limits its use as amendment for calcareous soils. The objective of the current study was to ameliorate the negative effects of high pH compost using elemental sulphur for maximizing its suitability for calcareous soils. Preliminary, in lab experiment, an intended rate of elemental sulphur from four rates i.e. 0, 0.4, 0.45, 0.50 % w/w of compost was selected to manipulate the pH of compost. Acidity of compost was regularly monitored and recorded on three weeks interval using 1:10 compost: water ratio. In a pot experiment suitability of acidified compost was evaluated on mung bean plants. Acidified amendment was applied @ 2% w/w. Results indicated that soil amended with acidified compost significantly improved the growth, yield and quality of mung bean compared to un-amended soil (control). Application of sulphur effected compost significantly increased the acidity in rhizosphere as well as bulk soil compared to un-amended control. Moreover, soil amended with acidified compost significantly improved the Olsen P i.e. 9 mg kg^{-1} compared to un-amended control. Therefore, it may be concluded that bio augmentation of alkaline compost with powdered sulphur may enhance its effectiveness for high pH calcareous soils.

Keywords: acidified compost, calcareous soil, elemental sulfur, olsen P, pH

Introduction

Optimal plant nutrition is one of the most important factor that assures the production of crops in accordance with our productive and economic guidelines. Among various factors that control the availability of nutrient to plants, pH is the most critical one. Phosphorus (P) is an essential element classified as a macronutrient because of the relatively large amounts of P required by plants. Role of phosphorus in different physiological processes as photosynthesis and heredity transfer and other life processes cannot be over emphasized.

The major problem related to the P in soil is its very low solubility and availability which is directly related to the soil pH and binding capacity of clay lattice (Foth & Turk, 1972) [18]. In alkaline soils, availability of P, especially those with excess CaCO3, is relatively low. Calcareous nature of a soil leads to the low recovery of Olsen's phosphorous. Although, it was investigated the phosphorous transformation dynamics, release and fixation pattern in soil (Dibb, Fixen, & Murphy, 1990; Glendinning, 1974) [14, 20]. However, actual amount of labile phosphorous to be made available in a growing season is still in question.

Physio-chemical properties of the soil is greatly influenced by organic amendments (Roig, Cayuela, & Sánchez-Monedero, 2004) [51]. Conventionally, fertility status of the soil has been maintained by using farm manure as an organic amendment but in recent years compost has become an important ingredient of the farming system. Production of compost does not require any sophisticated setup and can be easily prepared from local left overs of agriculture products with little or no expense. Multiple benefits of compost have been reported i.e. increase in moisture holding capacity, increase in porosity, flocculation, stabilization of pH (Drinkwater, Letourneau, Workneh, Van Bruggen, & Shennan, 1995; Stamatiadis, Werner, & Buchanan, 1999) [15, 55]. In addition to soil amendment several other uses of compost include mulching, landfill covering, landscaping, pathogen suppression, soilless media cultivation etc. (Raviv, 2005; Stoffella & Kahn, 2001) [50, 57]. Hence, compost utilization addresses two problems in one time (i) reclamation of agricultural waste for some good cause i.e. reduction in pathogenic infestation (ii) supplementation of soil with organic matter. Several composts can be used as a substitute of the peat being used for the horticulture purpose (Abad, Noguera, & Burés, 2001; Fitzpatrick, 2001; Moore, 2005) [1, 16, 42].

As far as nutrient status of compost is concerned, most of the N in compost is in organic form and needs special conditions for its conversion to plant available form i.e. moisture, temperature, pH, form of organic compound and C: N ratio. Between 5-15% of total compost N is biologically oxidized annually (Sikora & Szmidt, 2001) [53]. Compost P available for plants ranges between 20-40%, while plant available K can be >85% of total compost potassium (He, Yang, Kahn, Stoffella, & Calvert, 2001) [57].

However, most of the composts are neutral or alkaline in nature and high in soluble salts therefore these cannot be used directly. The optimum pH for crops is around 6.0 to 6.5 in water suspension or in saturated paste (Abad *et al.* 2001; Fitzpatrick, 2001; Fitzpatrick, Duke, & Klock-Moore, 1998; Raviv, 2005) [1, 16, 17, 50]. The high pH of compost negatively affect nutrient availability to plants (Bunt, 1988; Handreck, Black, & Black, 2002) [6, 22]. High pH of compost is due to the high cation exchange capacity of the compost as there are only a few H+ ion while excess of exchangeable Ca^{++}, Mg^{++} and in some cases Na+. In addition to these cation, carbonates of these calcium, magnesium and in case of pH >8.4 Na_2CO_3 also exist in compost (Handreck *et al.*

2002) [22]. Bioavailable portion of soil nutrient pool can be increased by using acidifying agents (Iqbal, Puschenreiter, Oburger, Santner, & Wenzel, 2012) [28]. However soil application of acidifiers is expensive rather a laborious job (Carrión *et al.* 2005; Lucheta & Lambais, 2012) [8, 35]. Therefore, there was a dire need of such amendment that would be efficient and eco-friendly at the same time. Different chemical fertilizers (aluminium sulphate, potassium sulphate, gypsum, ferrous sulphate) have been used to acidify the growth media. But application of these fertilizer as acidifying agents have some limits. For example, Al_2 $(SO_4)_3$ is more expensive, quantity of $Al_2(SO_4)_3$ is 6 times that of S^o and may cause some toxic effects to fruits like blueberries. Likewise, $FeSO_4$ is needed 8 times more than that of elemental sulphur and less efficient to acidify growth media (Carrion *et al.* 2008). Ca_2SO_4 and K_2SO_4 have potential to manipulate the pH of growth medium but it is documented that efficiency of SO^{-4}-S containing fertilizers i.e. Ca_2SO_4 and K_2SO_4 is less in pH manipulation. Previously, compost like Sphagnum peat (Garcia-Gomez *et al.* 2002; Moore 2005) [42]. has been acidified by applying acids i.e. H_3PO_3 and HNO_3 (Mazuela, Salas, & Urrestarazu, 2005; Raviv, 2005) [50]. and elemental sulphur (Marfà, Tort, Olivella, Cáceres, & Martínez, 1997; Martinez, Casasayas, Burés, & Cañameras, 1987) [36, 37].

Different organic amendments respond differently to acidifying agents due to their high pH buffering capacity (Curtin, Campbell, & Messer, 1996) [12]. The amount of H^+ required per unit decrease in compost pH is termed as buffering capacity of compost. Soil buffering capacity has been a subject of great interest (Liu, Lan, & Cheng, 2004; Van Breemen, Mulder, & Driscoll, 1983) [34, 60] but a little is known about the buffering capacity of organic amendments. Curtin and Rostad (1997) [13]. reported that organic fraction in soils are more resistant to change their pH than inorganic portion.

Mung bean is a short duration summer legume with high nutritive value known for its multiple health benefits (Arnoldi, Zanoni, Lammi, & Boschin, 2015) [4]. It is cultivated on more than 6 million ha area of warmer region of the world and among the important food and feed crop. Being short duration crop it has wide adaptability to the environment and needs low inputs (Nair *et al.* 2012) [43].

Thus, keeping in view all above mentioned facts this study was design to investigate (i) whether compost enrichment with sulphur can ameliorate its negative effects on calcareous soils. (ii) Whether the acidified compost effect growth and yield of mung bean crop. (iii) Effect of acidified compost on phosphorous availability of soil.

Material and Methods

Experimental conditions

Collection of experimental soil and preliminary analysis

Soil used in this experiment was collected from local crop land area in Ayub Agricultural Research Institute Faisalabad, Pakistan. Prior to use, soil was homogenized, air-dried and passed through 2 mm mesh size sieve. A soil sub sample was taken and various physico-chemical analyses were done by following standard protocols (Table 1)

Composting process

The compost was prepared using plant material leaf and yard pruning in a locally manufactured composter (Ahmad, Khalid, Arshad, Zahir, & Naveed, 2006) [2]. After oven drying the plant material, it was manually ground to 2 mm size. The crushed and sieved material was transferred to composting unit with control conditions of temperature and aeration. During the whole time period moisture contents were maintained at 40% v/w using tap water. Initially composting temperature was rose on second and third day of composting from 35 to 70°C and then gradually reduced to 35°C after 4th day of composting.

Acidification of compost

Elemental sulphur was used for slow and steady soil acidification of leaf and yard pruning’s compost. Under aerobic condition, biological oxidation of elemental sulphur yields sulphur acid that produces acidity:

$$S^0 + 1.5O_2 + H_2O \rightarrow H_2SO_4$$

To estimate the rate of elemental sulphur needed to acidify compost to target pH 5. An incubation study was conducted in glass house of Agricultural Biotechnology Research Institute, Ayub Agricultural Research Institute Faisalabad, Pakistan during September-November 2016. During a preliminary study, 500 g compost was incubated in plastic trays with three rates (0.4, 0.45, 0.50% w/w of compost) of powdered elemental sulphur. Before mixing of sulphur, it was ground to powder manually with the help of pestle and mortar and sieved through 2 mm mesh size. After adding sulphur compost was incubated for 120 days. Compost was moistened with distilled water and humidity was maintained to 50% during the whole experiment. Temperature of glass house was maintained 28±2°C. Experimental compost was mixed manually with the help of spatula on daily basis to keep the aeration well. With 2 weeks of interval, the samples were then suspended in deionized water at a soil:solution ratio of 1:10 and measured for pH. Least fluctuations in pH was observed where sulphur was used to @ 0.5 **%** w/w of compost, hence it was selected for further studies in pot experiment.

Greenhouse pot experiment

A pot experiment was conducted to evaluate effect of acidified compost on biological yield of mung bean and P availability in calcareous soils. Prior to sowing a composite, dried and homogenized sample of soil was mixed with powered elemental sulphur @ 0, 0.4, 0.45, 0.5% w/w of soil. Similarly compost (leaves and yard trimming) was mixed with same rates of sulphur (0, 0.4, 0.45, 0.5% w/w). Both amended and un-amended compost were mixed with the 6 kg soil @ 2% w/w. Mung bean seed were sown (5 seed per pot) after 28 days of mixing of amendments. The soil moisture contents were kept close to field capacity. Recommended dose of fertilizer N: P: K was applied using DAP (Diammonium Phosphate), SOP (Sulphate of Potash) and Urea as fertilizer source. All the phosphate was applied before sowing, while half of the N and K were applied at the time of sowing and other half after thinning and before second irrigation. Pots were irrigated with canal water. Proper weeding (manual) was done. After four weeks of germination; three uniform and healthy plants per pot were maintained. Olsen P of soil was measured on 3 weeks interval. Upon maturation plants were harvested to determine yield parameters and available P status of soil.

Determination of pH (Rhizosphere and Bulk soil)

Rhizosphere and bulk soil pH was measured by following the protocol described by (Monsant, Tang, & Baker, 2008; Tagliavini, Masia, & Quartieri, 1995) [41, 58]. Briefly, for rhizosphere soil pH measurement soil directly adhering to the roots of plants is termed as rhizosphere soil, was harvested on the clean paper with the help of brush by carefully uprooting and separating of plants from bulk soil.

For bulk soil sample, 2-5 cm area surrounding the roots was explored and about 20 g of soil is collected. Both samples were air dried and homogeneous sample was prepared by through 20 mm mesh size sieve. The Soil: water suspension with 1:10 ratio was prepared, shaken for 1 hour and pH values of rhizosphere and bulk soil is measured using standardized pH meter (HI-2211-p H/ORP meter, HANNA Instruments)

Agronomic measurements

When 90% pods became golden yellow then mung bean crop was harvested carefully. Plant agronomic parameters root dry weight, shoot dry weight, 1000 grain weight and grain yield per plant was recorded. Shoot and root mass were recorded after sun drying and then oven dried at 70^{o} C till constant weight. Oven-dried samples were ground to 40 mesh with a grinder for further analysis.

Elemental composition of mung bean seed

The elemental concentration of mung bean was determined in seed digest mixture. Mung bean seeds were cleaned, oven dried and ground to 40 mesh size using grinding mill. Ground samples were digested in diacid mixture (HNO3:HClO4 ratio of 2:1) (Jones and Case 1990). Concentration of Fe and Zn was determined using atomic absorption spectrophotometer (PerkinElmer, AAnalyst 100, Waltham, USA), while P and N was determined by following protocols proposed by Buresh, Austin, and Craswell (1982) [7]. Chapaman and Pratt (1961) [9]. respectively.

Proximate analysis of mung bean seed

Mung bean seeds were cleaned to remove dust, trash, stone and foreign matter. A portion of seeds was ground by passing through "UDY Cyclone Mill" to get powder. Sample was analysed for moisture, ash, protein, fiber and fat by following the methods of AOAC 2003. Briefly, for ash determination, one gram of sample was taken in crucible and was heated at 550^{o}C until grey white ash was obtained. Grey white indicate the complete oxidation of organic matter in the sample. Similarly, Ether extract method was used for fat determination by using Soxhlet apparatus (Chemists, 1925) [10]. Kjeldahl method was used for protein determination. Likewise standard protocol was followed to determine fiber contents in mung bean seeds (Chemists, 1925) [10].

Measurement of chlorophyll a, b contents

Chlorophyll contents in leaves were measured by following the protocol given by Hassan *et al.* (2015) [24]. Briefly, 0.5 g of leaf sample from each treatment was homogenized with 80% acetone (v/v) and homogenate was filtered through filter paper. Absorbance of the resulting solution was read by spectrophotometer (SPECTRONIC GENEYS 5 MULTON ROY) at 663 and 645 nm for chlorophyll a and b respectively.

Statistical analysis

A pot experiment was conducted in a completely randomized design, and the results were analysed by one-way ANOVA by using Statistix 8.1 software package (Copyright 2005, Analytical Software, USA). Reported means are the average of three replicates and expressed with their standard error (SE). Least significant difference (LSD) at $P < 0.05$ was considered significant for treatment means.

Results

Effect of elemental sulphur on pH manipulation of compost

Three different rates of S were applied for acidification of compost as 0.4, 0.45 and 0.5 mg kg^{-1} compost and pH were calculated as 3rd, 5th, 7th and 9th weeks intervals (Fig 1). Un-amended compost has pH approximately 7.5 but different rates of S decreased compost pH with different values. Compost pH decreased rate was fast from 3 rd to 5th week but we observed stability in pH variation from 7th to 9th week. From 3rd to 9th week, highest pH decreased rate of compost was calculated from 6.3 to 3.9 with 0.5 mg kg^{-1} S followed by 0.45 mg kg^{-1} S (6.7-4).

Effect of acidified compost on rhizosphere and bulk soil pH

Rhizosphere and bulk soil pH were affected with all applied treatments. Acidified soil decreased more rhizosphere and bulk soil pH as compared to acidified compost applied soil (Fig 2) Decreased rate of rhizosphere and bulk soil pH was different with different rates of S, either applied in soil or acidified compost. In un-acidified soil (control), rhizosphere pH was 7.89 while 0.5 g S kg^{-1} soil decreased rhizosphere pH up to 7.44. In un-acidified compost applied soil, rhizosphere pH was 7.76 while acidified compost with 0.5 g S kg^{-1} compost decreased rhizosphere up to 7.49 (Fig 3). In un-acidified soil (control), bulk soil pH was 7.9 while 0.5 g S kg^{-1} soil decreased bulk soil pH up to 7.79. In un-acidified compost applied soil, bulk soil pH was 7.81 while acidified compost with 0.5 g S kg^{-1} compost decreased rhizosphere up to 7.76. In both cases, acidified soil and acidified compost, high rates of S proved as better for pH reduction (Fig 4)

Effect of acidified compost on available P (Olsen P)

Plant available phosphorus (Olsen P) increased with S applied soil but increased rate was more in acidified compost applied treatments (Fig 3). In un-amended (control) soil, from 3rd to 9th week, Olsen P was only 7.7 mg kg^{-1}, while in un-acidified compost amended soil it ranges from 8 to 8.25 mg kg^{-1}. In S applied acidified soil, the highest concentration of Olsen P was calculated with 0.5 g kg^{-1} soil and it ranges 8.2 to 8.5 mg kg-^{1} soil from 3rd to 9th week. Acidified compost proved as a better option for Olsen P as compared to acidified soil. Like acidified soil, the highest rate of S (0.5 mg kg^{-1} soil), increased maximum Olsen P that ranges from 8.7 to 9 mg kg^{-1} as calculated from 3rd to 9th week.

Effect of acidified compost on growth and yield of mung bean crop

Application of acidified compost showed the significant improvement in growth and yield of mung bean crop compared to un-amended control (Table 2). Maximum increase in shoot dry weight i.e. 56% was observed where sulphur was applied @ 0.5% w/w in combination with compost compared to control. Results also depicted that application of acidified compost significantly increased shoot dry weight i.e. 1.1 folds when compared to un-amended control. Likewise, maximum increase in 1000 grain weight and grain yield per plant was recorded 31% and 42% respectively where pH manipulated compost was mixed with soil @ 2% w/w compared to control. Application of sulphur @ 0.5% w/w improved the chlorophyll a, b contents of mung bean crop by 42% and 29% respectively compared to control. However, this increment went up to 64% and 39% respectively where sulphur amended compost was applied @ 2% w/w compared to control. Likewise, application of acidified compost significantly improved the water uptake capacity (89%) and relative water content i.e. 35% compared to control (Table 2).

Effect of acidified compost on nutrient contents of mung bean

Acidified compost showed statistically significant results for seed nutrient reserves when compared to un-amended control (Table 3). Application of acidifying agent significantly improved micro i.e. Fe, Zn and macro nutrient N, P, K of mung bean crop. Our results showed that, application of compost @ 2% w/w improved N and K by 7% and 6% respectively when compared to control followed by sulphur @ 0.5% w/w i.e. 28% and 15%. However, sulphur-amended compost improved the N and K status of mung bean by 37% and 27% respectively compared with control. Likewise, Fe and Zn contents were improved by 46% and 69% respectively where acidified compost was applied @ 2% w/w compared to control. Maximum increase i.e. 21% in total P was recorded where compost was treated with sulphur @ 0.5% followed by sulphur (17%) compared to un-amended control.

Biochemical attributes of mung bean crop

Results depicted that application of acidified amendment significantly improved the grain proximate contents (Table 4). Data showed that, application of acidifying agent alone or in combination with organic amendment significantly improved ash contents of mung bean (44% and 69% respectively) compared with un-amended control. Similarly, a marked improvement in fat, protein and fibre contents was observed where acidified compost was applied @ 2% w/w compared to control (Table 3). Application of sulphur @ 0.5% w/w improved the grain fiber contents by 35% compared to control. However, application of acidified amendment improved the grain fibre contents by 75% when compared with control. Likewise, 21% increase in protein contents were observed in sulphur treated compost compared with un-amended compost (Table 4).

Discussion

Compost acidification

The results of in-vitro acidification of compost showed the significant effect of time, treatment and treatment interaction on pH manipulation of leaf and yard trimming compost (Fig I). Our results depicted that no change in pH of compost was observed in first three weeks in all levels of sulfur (i.e. 0.4%, 0.45% 0.5%) after that a rapid increase in compost acidity was recorded till 5th week of incubation (Fig 1). Ramzani *et al.* (2017) [49]. reported that application of acidifying agent sulfur manipulates and stabilize the pH of compost from 30 to 120 days of incubation. These results are in accordance with our observations where from 7th to 9th week of incubation pH of compost was stabilized after a rapid change during 5th to 7th week of incubation. Proliferation of soil micro-biota (autotrophic and heterotrophic bacteria, actinomycetes, fungi, and yeasts) involved in biological oxidation of sulfur might be the driving force behind the marked acidity production (Carrión *et al.* 2005) [8]. They observed that addition of elemental sulfur significantly increased the population of sulfur oxidizing autotrophic bacteria (from 10^7 to 10^{10} CFU g^{-1}) from the beginning of the experiment till 7th week of incubation. Afterwards a gradual decrease in SOBs were recorded and after 14th week of experimentation the community reached to the initial level. For heterotrophic bacteria, a moderate increase in population was observed (from more than 10^6 to about 10^8 CFU g^{-1} compost) for first 50 days of incubation. Studies reported that Thiobacillus species are particularly involved in biological oxidation of sulfur to sulfuric acid in sulfur enriched compost (Michael, John, & Jack, 2006). Studies found a synergistic relation between autotrophic and heterotrophic bacteria in sulfur oxidation to sulfuric acid (Carrión *et al.* 2005) [8]. However, other soil biota i.e. actinomycetes (Yagi, Kitai, & Kimura, 1971) [64]. fungi (Wainwright & Killham, 1980) [62]. and yeasts (Vitolins & Swaby, 1969) [61]. also have potential to oxidize sulfur, but their response are variable because Carrión *et al.* (2005) [8]. found these microbes indifferent to compost enrichment with elemental sulfur. All these findings strongly support our results.

Rhizosphere and bulk soil pH

In pot experiment it was observed that application of either acidified amendment or direct acidifier increased the acidity of rhizosphere as well as bulk soil. Our results are in accordance with the (Hashemimajd, Farani, & Jamaati-e-Somarin, 2012; Ramzani, Iqbal, *et al.* 2016; Ramzani, Khalid, Naveed, Ahmad, & Shahid, 2016. Hashemimajd *et al.* (2012)) [47, 48, 23] reported that application of sulfur increased the acidity of growth medium on 4th, 8th and 16th week of inoculation. Several reason might be involved in the pH reduction of rhizosphere as well as bulk soil (a) increase in sulfur oxidizing biomass like autotrophic, heterotrophic, fungi, yeast actinomycetes (Starkey, 1966) [56]. (b) protonation and deprotonation (c) root exudation (d) respiration (e) redox reaction (Hinsinger, Plassard, Tang, & Jaillard, 2003) [27].

legumes require more cations than anions hence their rhizosphere is more acidic by excessive release of protons (Jarvis & Robson, 1983; McLay, Barton, & Tang, 1997; Tang, Hinsinger, Drevon, & Jaillard, 2001) [29, 39, 59]. Several organic acids like citric acid, malic acid and oxalic acid are mainly responsible in lowering of rhizosphere pH (Jones & Brassington, 1998; Jones, Dennis, Owen, & Van Hees, 2003) [30, 31]. A slight change in bulk soil pH was recorded it might be due the thinning of microbial biomass away from root surface (Chowdhury, Schmid, Hartmann, & Tripathi, 2009; Paul, 2014) [11, 46].

Effect of acidified compost on available P (Olsen P)

Plant available phosphorus (Olsen P) increased with S application in soil, however, the increased rate is more in acidified compost applied treatments. Like acidified soil, highest rate of S (0.5 mg kg^{-1} soil), increased maximum

Olsen P that ranges from 8.7 to 9 mg kg^{-1} as calculated from 3rd to 9th week. The reason might be the solubilization of nutrients from decomposition of acidified compost (Paradelo, Vázquez-Nion, Silva, González, & Barral, 2016) [45]. Rhizosphere pH reduction promotes mineralization of nutrient from compost thus availability of P increases (Silber, Levkovitch, & Graber, 2010; Tagliavini *et al.* 1995) [54, 58]. Studies also suggested that application of acidifying amendment significantly improved the P concentration in soil at 4th, 8th and 16th week of experiment and maximum increase was recorded on 8th week of study (Hashemimajd *et al.* 2012). Highest oxidation of sulfur to sulfuric acid was observed from 4th to 8th week of experiment (Neilsen, Hogue, Hoyt, & Drought, 1993) [44]. In our experiment P availability was increased with increasing soil acidity from 3rd to 5th week compared to control. This reason might be the release of P from insoluble compounds on lowering of pH with oxidation of sulfur Kaplan and Orman (1998) [32]. Our results are similar to the findings of Hashemimajd *et al.* (2012) where they reported the increase in phosphorous contents with different time intervals. Zhang, Heaney, Henriquez, Solberg, and Bittner (2006) [65]. suggested that Olsen P was increased on compost decomposition. Havlin, Tisdale, Nelson, and Beaton (2016) [25]. confirmed a strong correlation between soil acidity and P availability (r = -0.63) in alkaline soil. In addition to this, plant roots and/or microbes secrete many enzymes that can alter the nutrient availability in the rhizosphere (Gianfreda, 2015) [19]. These extra cellular enzymes hydrolyze the organic N, S, and P thus make them available to plants (Gianfreda, 2015) [19]. Rhizosphere dwelling microbes plays the vital role in nutrient cycling. A naturally occurring, heterogeneous group of microbes is phosphate solubilizing bacteria (Sharma, Sayyed, Trivedi, & Gobi, 2013) [52]. The mode of action of PSB are much likely to the PGPR as they provide plant nutrients especially P and other growth promoting substances like auxin (Alia, Shahida, Bushra, & Saeed, 2013; Sharma *et al.* 2013; Wakelin, Warren, Harvey, & Ryder, 2004) [3, 52]. These PSB might also be the reason for the provision of P in our study.

Acidified amendment and nutrient contents of mug bean

Soil acidity leads to mineralization of nutrient element that has a positive effect on growth and yield of mung bean crop. Our results depicted that all agronomic and yield parameters were significantly improved under acidified amendment. Our results are similar to the findings of Silber *et al.* (2010); Tagliavini *et al.* (1995) [54, 58]. They suggested that pH manipulation with acidified organic amendment dissolved the nutrient from organic and colloidal surface of compost and increased the availability to the tested crop. However, onfirmed the increasing soil nutrient pool under sulfur effected organic amendments. Compost and other organic amendments are rich in nutrients and upon decomposition release a handsome amount of nutrient in soil that ultimately assimilated into plant body hence nutrient status of plant also improved (Hammer, Forstreuter, Rillig, & Kohler, 2015; Jones *et al.* 2003; Lehmann *et al.* 2011) [21, 31, 33]. Plant survival and growth is mainly depends how beautifully plant-microbe interaction occur in soil microenvironment (Gianfreda, 2015) [19]. pH manipulation, multiplication of biomass in rhizosphere, release of root exudates and enzymes that mineralize the nutrients hence increase the bioavailability of nutrient for uptake by plants might be the explanations of better growth and yield of mung bean (Broadley, 2012; Zhang *et al.* 2006) [5, 65].

Proximate parameters of mung bean crop

Application of acidified compost lowered down the rhizosphere pH and improves the nutrient solubilization and bioavailability of mung beans crop. This leads to the better assimilation of nutrient into seed. This can be attributed to the increase proximate contents like, ash, fat, fiber, protein contents of mung bean crop. Our results were similar to the findings of (Ramzani, Iqbal, *et al.* (2016); Ramzani, Khalid, *et al.* (2016); Ramzani *et al.* (2017)) [47, 48, 49]. where they found that increasing acidity of rhizosphere can lead to mineralization of nutrient and hence uptake by plants was also increased.

Conclusion

Different rates of elemental sulphur and their corresponding effect on the pH of compost was determined in an incubation study. The sulphur effected compost was then mixed as amendment in soil and it effect on nutrient status of soil, growth and yield of mung bean crop was evaluated in a pot experiment. Results indicated that sulphur treated compost could maximize its efficiency when used in high pH calcareous soil as growth and yield of mung crop was significantly improved compared to sole application of either compost or sulphur. It may be concluded that, sulphur effected compost could be effectively used in calcareous soils.

Table 1: Pre-analysis of soil and the compost

Characteristics	Soil	Characteristics	Compost
Textural class	Clay loam	Organic carbon	43.5±3.4 %
Sand, silt, clay	39.5±2.1 %, 28.5±1.8 %, 31±2.5 %	pH	7.5±0.5
pH	7.9±0.45	EC	3.81±0.1 dS m-1
EC	8.8±0.6 dS m-1	Ash	9.2±1
O.M	0.44±0.02 %	N	275± 11.4 mg kg^{-1}
N	108±6.7 mg kg^{-1}	P	339±14.9 mg kg^{-1}
P	7±0.37 mg kg^{-1}	K	394±16.8 mg kg^{-1}
K	106±6.6 mg kg^{-1}	S	56.8±4.1 mg kg^{-1}
S	119±7.4 mg kg^{-1}	SAR	9.7±0.8 mg kg^{-1}
SAR	17.9±1.3	C:N ratio	28.5±1.6
DTPA-Zn	3.75±0.2 mg kg^{-1}	DTPA-Zn	169±8.9 mg kg^{-1}
DTPA-Fe	0.74±0.03 mg kg^{-1}	DTPA-Fe	256±10.9 mg kg^{-1}

Data is the average of three repeats ± SE

Table 2: Effect of acidified compost on growth and yield parameters of mung bean crop

Treatments	Root Dry Weight g/pot	Shoot Dry Weight g/pot	1000 rain Yield (g)	Grain Yield pot^{-1}g	Chlorophyll (a) mg/g fresh weight	Chlorophyll (b) mg/g fresh weight	Water Uptake Efficiency (%)	Relative Water Contents (%)
Control	1.23 g	4.3 f	127.67 e	4.5 f	1.46 g	1.2 e	0.66 f	64.00 f
Sulphur @ 0.4%	1.7e	5.47 d	146.67 cd	5.13 de	1.71 ef	1.36 cd	0.78 de	73.76 de
Sulphur @ 0.45%	1.9 d	5.8 cd	151.33 bcd	5.47 cd	1.83 de	1.46 bc	0.88 cd	79.76 cd
Sulphur @ 0.5%	2.2 c	6.2 abc	162.33 ab	6.1 ab	2.07 bc	1.55 ab	0.97 bc	84 bc
Compost	1.46 f	4.83 e	139.00 de	4.83 ef	1.58 fg	1.27 de	0.71 ef	69.00 ef
Compost + Sulphur @ 0.4%	2.1c	6.00 bc	150.00 bcd	5.65 cd	1.95 cd	1.48 bc	0.94 bc	79.76 cd
Compost + Sulphur @ 0.45%	2.4 b	6.3 ab	159.67 abc	5.9 bc	2.2 b	1.57 ab	1.03 b	86.00 ab
Compost + Sulfur @ 0.5%	2.6 a	6.63 a	167.67 a	6.4 a	2.44 a	1.67 a	1.25 a	90.33 a

Means bearing same letter(s) are statistically non-significant according to Duncan's multiple range test ($p<0.05$).

Table 3: Effect of acidified compost on soil N, K and extractable Zn and Fe after crop harvest

Treatments	N (mg/kg)	K (mg/kg)	P (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Fe (mg/kg)
Control	100.00 e	120.00 f	256.00 e	0.77 f	3.6 f
Sulphur @ 0.4%	110.00 d	129.00 def	275.33 de	0.79 ef	4.00 def
Sulphur @ 0.45%	116.33 cd	131.67 cde	282.67 bcd	0.87 de	4.2 cde
Sulphur @ 0.5%	128.00 ab	138.67 bcd	296.33 abc	1.02 bc	4.33 cd
Compost	107.00 de	128.00 ef	263.67 de	0.76 ef	3.8 ef
Compost + Sulphur @ 0.4%	120.33 bc	142.00 abc	281.67 cd	0.95 cd	4.43 bc
Compost + Sulphur @ 0.45%	124.67 bc	145.00 ab	301.33 ab	1.06 b	4.83 ab
Compost + Sulfur @ 0.5%	137.33 a	152.33 a	310.33 a	1.3 a	5.26 a

Means bearing same letter(s) are statistically non-significant according to Duncan's multiple range test ($p<0.05$).

Table 4: Grain biochemical attributes as affected by different organic and inorganic amendments

Treatments	Ash (%)	Fat (%)	Protein (%)	Fiber (%)
Control	2.45 e	1.73 e	13.15 e	3.06 f
Sulphur @ 0.4%	2.87 d	2.05 cd	13.83 cde	3.64 de
Sulphur @ 0.45%	3.21 c	2.09 c	14.10 cde	3.73 cde
Sulphur @ 0.5%	3.55 c	2.32 b	14.63 bc	4.12 c
Compost	2.70 de	1.86 de	13.65 de	3.35 ef
Compost + Sulphur @ 0.4%	3.38 c	2.11 c	14.45 bcd	4.02 cd
Compost + Sulphur @ 0.45%	3.80 b	2.43 ab	15.17 ab	4.87 b
Compost + Sulfur @ 0.5%	4.14 a	2.54 a	15.93 a	5.35 a

Means bearing same letter(s) are statistically non-significant according to Duncan's multiple range test ($p<0.05$).

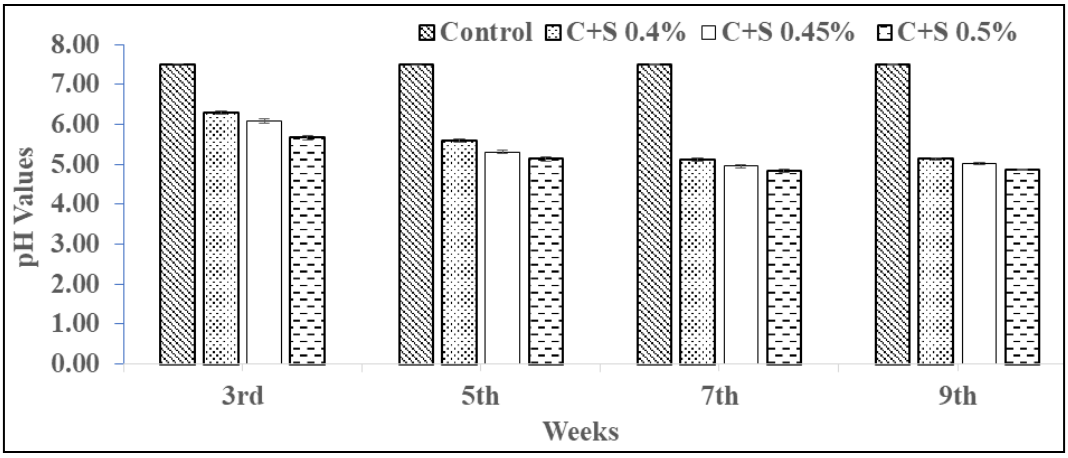

Fig 1: Effect of different rates of elemental sulphur on compost acidity with time

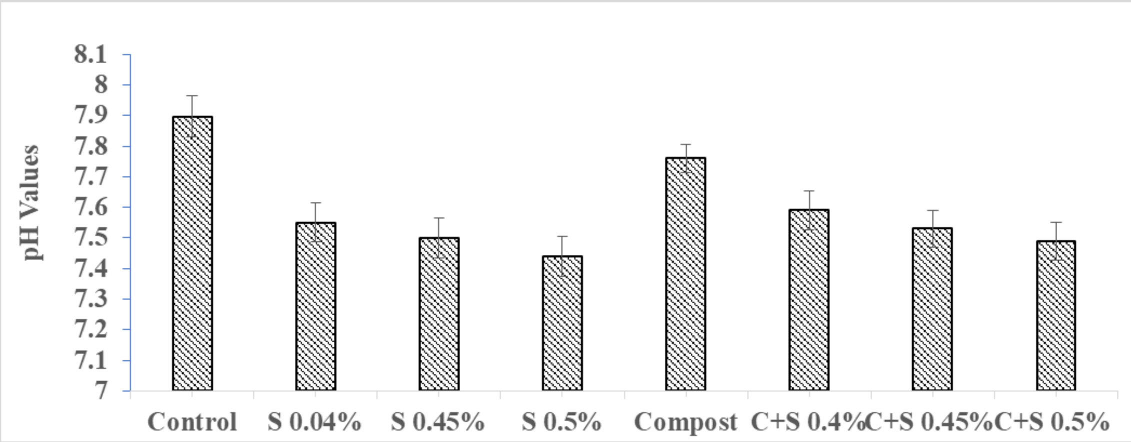

Fig 2: Effect of elemental sulphur, compost and acidified compost on rhizosphere acidity of mungbean

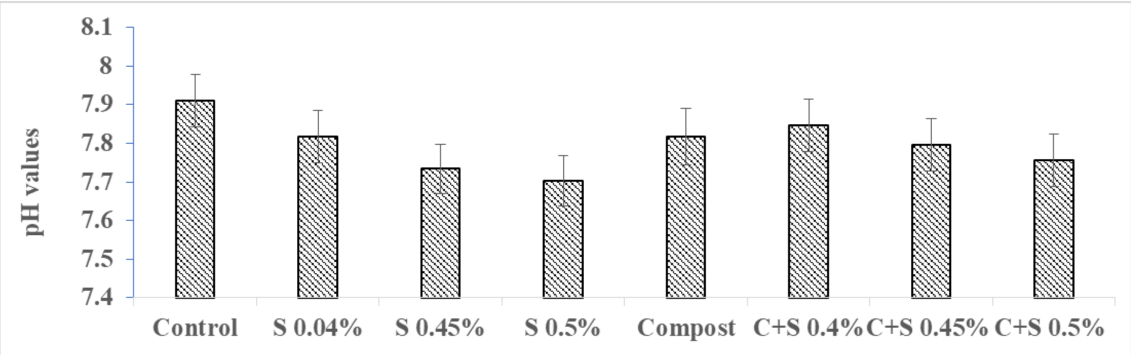

Fig 3: Effect of elemental sulphur, compost and acidified compost on bulk soil acidity of mung bean.

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