Application of solid and liquid organic matter to increase P availability in Inceptisol

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Abstract. Phosphorus is an essential nutrient for plant growth, but its supply in the soil is limited by two constraints, namely small in amount and small in its availability. In acidic soil, P is tied up by Al and Fe, while in high soil pH, P is bound by Ca. Thus, to increase the availability of P in the soils, prepared organic matter may be added. The quality of prepared organic matter depends on the type of source material, composting process, and the method of application. To find out the effects of applying solid and liquid organic matter on the availability of P in the soil, this glasshouse experiment involving the application of five treatments of organic matter on corn, which was planted in Inceptisol, was conducted. Two organic matters used were solids: cow manure compost [CMC] and goat manure compost [GMC]; and the other three were in liquid form: composted cow manure extract [CCME], composted goat manure extract [CGME], and humic substance [HS]. Based on the results on the observed parameters, at 7 weeks after planting, the application of CMC produced the highest increase in available-P in the soil, followed by GMC, HS, CGME, and CCME, in that order. In either solid or liquid form, the applied organic matter significantly raised available-P, total-N, organic-C, cation exchange capacity [CEC], soil electrical conductivity [EC], and exchangeable bases in the soil, with the solid organic matters performing better, overall, than their liquid counterparts. Future research on closely related technical and economic aspects is recommended.

Keywords: Available P, cow manure compost, goat manure compost, humic substances, organic matter extract.

1. Introduction

Phosphorus [P] is an essential plant nutrient, but its contribution to enhancing plant growth is limited by its presence in small amounts in the soil, and most of the total P that is present in the soil is not readily available to plants [1] [2] [3] [4]. On a macro-scale, the potential P resources in the earth's crust are also increasingly dwindling and are experiencing an appreciable decrease in quality [5] [6] [7] [8]. The low availability of P in the soil is because of high fixation by dominant cations such as Al and Fe at low pH. In acidic soils, available-P is tied up by the presence of high levels of Al and Fe. On the other hand, soils with high pH contain high levels of calcium and magnesium that can reduce or limit the level of available-P [9] [10]. One method of raising the availability of soil P is by the addition of organic matter [OM], as it can, directly, facilitate the mineralization process and, indirectly, assist in the release of fixed P. During the process of decomposition, OM produces organic compounds such as citric, oxalate, humic, fulvic, and other acids that can significantly hasten the solubility of P [11]. This
was established by previous research, in which the increase in available-P was quite high [12]. Furthermore, treating plants with OM, like plant residue or compost, can improve soil quality, particularly, by raising the level of available-P [13]. Generally, prepared OM comes from manure and compost, but considering the high dosage levels required by plants, there are many constraints in its practical application, especially for small farmers. The main obstacle is the large quantity of compost that must be provided to produce the desired effects, which incurs prohibitive labor and logistical costs. Therefore, there is a need to develop a means of sourcing and utilizing OM that is, optimally, both effective and efficient. Toward this end, OM may be made in solid or liquid form. For example, based on the principle of Dissolved Organic Carbon [DOC], organic matter, which is contained in a soil solution, can be sourced from compost extracts, topsoil, biomass microbe and root exudate [14]. Thus, the objective of this research was to find out the effects of applying solid and liquid organic matter on the availability of soil P.

2. Materials and Methods
In this glasshouse experiment, treatment application of 5 types of organic matter, namely: two solid OMs - cow manure compost [CMC] and goat manure compost [GMC] – and three in liquid form - composted cow manure extract [CCME], composted goat manure extract [CGME], and humic substance [HS] was investigated. The humic substance was extracted from charcoal. Corn was planted in pots containing a growing medium taken from Inceptisol topsoil, followed by treatment with the trial OMs. The types and doses of OM can be seen in Table 1 below. Selected parameters of plant growth were measured during the vegetative phase. Plants were cut 7 weeks after planting for measurement of the dry weight of the plant and root samples. Soil chemical parameters that were analyzed included total-P, available-P, organic-C, total-N, pH, CEC, EC, and exchangeable bases. Experimental data were analyzed using SAS [9.4], as a completely randomized design with applications of organic matter as a single factor with three replication. Statistical analysis of variance of the data was performed to examine the comparative effects of the different treatment combinations. Where the F-test showed significant differences among the treatment results, separation among treatment means was obtained by Duncan’s Multiple Range Test [DMRT] at 5% significant level.

Table 1. Types and dose of organic matter

| Organic Matter                        | Dose           | Code   |
|---------------------------------------|----------------|--------|
| Control                               | Without treatment | T0     |
| Cow Manure Compost [CMC]              | 5 tons/ha      | CMC1   |
| Cow Manure Compost [CMC]              | 10 tons/ha     | CMC2   |
| Goat Manure Compost [GMC]             | 5 tons/ha      | GMC1   |
| Goat Manure Compost [GMC]             | 10 tons/ha     | GMC2   |
| Composted Cow Manure extract [CCME]   | 1:1000         | CCME1  |
| Composted Cow Manure extract [CCME]   | 1:500          | CCME2  |
| Composted Goat Manure Extract [CGME]  | 1:1000         | CGME1  |
| Composted Goat Manure Extract [CGME]  | 1:500          | CGME2  |
| Humic Substance [HS]                  | 20.000 dilution| HS1    |
| Humic Substance [HS]                  | 10.000 dilution| HS2    |
3. Results and Discussion

3.1. Results of Initial Soil Analysis

The soil material that was used in this study had, initially, a slightly acidic reaction, with very high total-P and available-P, low total-N and organic-C, and low-to-moderate CEC and exchangeable base cations [Table 2]. The high available-P content in this soil was suspected to be due to the amount of P-fertilizer added to the soil that exceeded the soil's ability to absorb and added to the low organic matter content of the soil.

| Parameter                  | Unit           | Status         |
|----------------------------|----------------|----------------|
| pH H$_2$O                  | 6.2            | Slightly Acidic|
| Organic Carbon             | %              | 1.26 Low       |
| Total-N                    | %              | 0.1 Low        |
| Available-P                | Ppm            | 29 Very High   |
| Total-P                    | Ppm            | 410 Very High  |
| Cation Exchange Capacity   | cmol[+/]kg     | 8.4 Low        |
| Exch-K                     | cmol[+/]kg     | 0.55 Moderate  |
| Exch-Na                    | cmol[+/]kg     | 0.14 Low       |
| Exch-Ca                    | cmol[+/]kg     | 7.78 Moderate  |
| Exch-Mg                    | cmol[+/]kg     | 0.6 Low        |
| Base Saturation            | %              | >100 Very High |
| Exch-Al                    | cmol[+/]kg     | 0.1 Very Low   |

* Criteria based on the Soil Research Institute [2009]

Table 2. Analysis of initial soil chemical properties

In general, the cow manure compost [CMC], which exhibited a slightly higher pH, contained higher amounts of nutrients than goat manure compost [GMC]. In particular, its total-P was almost 6 times more than that of GMC [Table 3]. Interestingly, the humic substance that was tested yielded very low total-P content. The high total-P levels in manure compost could be attributed to the type and range of variation of plant materials that constitute the available forage being browsed or grazed by cows and goats, respectively. The same pattern was observed in the OM in liquid form, with CMC yielding over 3 times more total-P than GMC [Table 4]. On a comparative scale, the OMs in liquid form had, generally, lower levels of nutrients compared to their solid counterparts. Apparently, this reduction in the number of nutrients was brought about by the dilution process. For instance, it was observed that, during the extraction of OM, K appeared to be more soluble than the other elements. In the case of humic substance [HS], the OM extract was subjected to as much as 10,000 to 20,000 dilution ratios. The soil EC [electrical conductivity], which is a measure of how much electrical current is conducted by the soil, and based on the amount of dissolved salts in the soil-water solution, indicated a finer CMC texture than that of GMC, while HS was composed of much finer particles that affected the movement, solubility, and sorption of the nutrient elements in the soil.
Table 3. Analysis of solid organic matter

| Compost | pH  | Organic-C | Total-P | Total-N | K    | Ca  | Mg  |
|---------|-----|-----------|---------|---------|------|-----|-----|
| CMC     | 8.9 | 21.07     | 2.45    | 1.13    | 2.41 | 3.22| 0.50|
| GMC     | 7.9 | 19.23     | 0.41    | 1.11    | 0.20 | 2.13| 0.34|

*CMC = Cow manure compost, GMC = Goat manure compost

Table 4. Analysis of liquid organic matter

| Compost Extract | pH  | EC [dS m⁻¹] | Total-N | Total-P | K    | Ca  | Mg  |
|-----------------|-----|-------------|---------|---------|------|-----|-----|
| CCME            | 7.70| 0.26        | 28      | 593     | 15844| 9100| 103 |
| GCME            | 8.1 | 0.12        | 28      | 186     | 1086 | 2354| 315 |
| HS              | 8.8 | 0.08        | 35      | 0.64    | 11978| 860 | 54  |

CCME = Composted cow manure extract, GCME = Composted goat manure extract, HS = Humic substance

Effect of Solid and Liquid Organic Matter on P Availability

Further to the observations stated above regarding the status of P-content of the OMs tried in this study, a discussion on the incremental effects of the added OM on total-P and available-P gives more telling insights.

Table 5. The effect of solid and liquid organic matter on some properties of the soil

| Treatment   | pH  | Organic-C | Total-N | Total-P | Available-P | Total-S |
|-------------|-----|-----------|---------|---------|-------------|--------|
|             |     | %         |         |         | ppm         |        |
| Control     | 4.3 d| 1.34 e    | 0.11 d  | 497 f   | 100 f       | 157    |
| CMC1        | 4.6 b| 1.53 b    | 0.14 ab | 592 b   | 140 b       | 157    |
| CMC2        | 4.8 a| 1.62 a    | 0.14 a  | 614 a   | 152 a       | 395    |
| GMC1        | 4.3 d| 1.44 cd   | 0.11 d  | 536 c   | 111 cd      | 265    |
| GMC2        | 4.4 c| 1.61 a    | 0.13 bc | 544 c   | 114 c       | 249    |
| CCME1       | 4.3 d| 1.39 de   | 0.11 d  | 503 ef  | 103 ef      | 211    |
| CCME2       | 4.3 d| 1.46 c    | 0.11 d  | 510 de  | 108 cde     | 237    |
| CGME1       | 4.2 e| 1.42 cd   | 0.11 d  | 511 de  | 107 de      | 207    |
| CGME2       | 4.3 d| 1.48 c    | 0.12 cd | 518 d   | 110 cde     | 145    |
| HS1         | 4.3 d| 1.45 c    | 0.12 cd | 503 ef  | 111 cd      | 107    |
| HS2         | 4.3 d| 1.48 bc   | 0.12 cd | 517 d   | 112 cd      | 121    |

*Values with the same letters at the same column are not significantly different at a significance level of 5% [DMRT].

From the statistical analysis of data in Table 5, it can be inferred that adding any OM into the soil can significantly raise its total-P as well as available-P. Among the three OMs tested in this study, cow manure compost [CMC] produced the highest incremental increase, followed by goat manure compost [GMC]. Humic substance [HS] provided the lowest incremental rise in P. All treatments [cow manure compost, goat manure compost, and humic substance], in both solid and liquid forms, did
significantly raise the levels of total-P and available-P in the soil by as much as 6 to 117 ppm [reckoned from Control]. However, the highest increase in soil total-P and available-P was produced by CMC2 [10 tons/ha dosage] at 117 ppm and 52 ppm. Moreover, cow manure compost [in solid form] proved to have a greater incremental effect on P-content of the soil, as compared to its liquid form.

The treatment of liquid organic matter [CGME, CGME, HS1, and HS2] also had a significant effect on increasing the availability of soil P, but at a lower extent than in solid form [15]. Humic substances can help to increase nutrients through the conversion of nutrients into available forms and stimulate to increase soil microbiological activity and better root growth was also reported [12][16][17][18][13].

Table 6. The effect of solid and liquid organic matter on the CEC and exchangeable bases

| Treatment | CEC [cmol[+]/kg] | Exchangeable Bases [cmol[+]/kg] |
|-----------|-----------------|---------------------------------|
| Control   | 8.09 e           | K 0.75 de Na 0.14 de Ca 7.38 cd Mg 0.56 f |
| CMC1      | 8.60 de          | K 1.11 b Na 0.31b Ca 8.67 a Mg 0.91 b |
| CMC2      | 8.71 de          | K 1.26 a Na 0.34 a Ca 8.73 a Mg 0.94 a |
| GMC1      | 8.36 de          | K 0.74 de Na 0.16 cd Ca 7.92 bc Mg 0.63 d |
| GMC2      | 8.46 de          | K 0.91 c Na 0.17 c Ca 8.30 bc Mg 0.72 c |
| CCME1     | 8.61 de          | K 0.69 ef Na 0.14 de Ca 7.27 d Mg 0.53 g |
| CCME2     | 9.15 bc          | K 0.82 d Na 0.15 cd Ca 7.61 cd Mg 0.55 f |
| CGME1     | 9.57 ab          | K 0.75 de Na 0.12 ef Ca 7.55 cd Mg 0.56 f |
| CGME2     | 10.01 a          | K 0.65 f Na 0.12 ef Ca 7.59 cd Mg 0.55 f |
| HS1       | 8.53 de          | K 0.75 de Na 0.12 f Ca 7.69 cd Mg 0.57 e |
| HS2       | 8.56 de          | K 0.80 d Na 0.12 ef Ca 7.76 cd Mg 0.56 f |

Values with the same letters at the same column are not significantly different at a significance level of 5% [DMRT]

Cation exchange capacity [CEC] refers to the relative ability of soils to hold nutrient cations. It is an important soil property because it influences soil pH and nutrient availability, among other soil parameters that affect, directly or indirectly, plant growth. Acidic soil contains high levels of iron and aluminum which can limit the movement and sorption of phosphorus. On the other hand, soils with high pH contain high levels of calcium and magnesium that can reduce or limit available-P. Therefore, it is ideal to maintain a neutral soil [pH 7] in order to attain an optimum level of available-P. All OMs, including Control, that were tested in this study were highly acidic [pH 4.2 to 4.8], and this property was reflected in the highly comparable CEC values ranging from 8.09 to 10.01. Regarding exchangeable bases, it is generally known that, aside from phosphorus, there are other nutritive elements [bases] that are also essential for plant growth. However, only calcium [Ca], magnesium [Mg], potassium [K] and sodium [Na] are found in the exchangeable form in the soil. Excess bases result in higher pH, but as these exchangeable bases, especially Ca and Mg, are leached, the soil becomes more acidic.
4. Conclusion
The application of organic matter increased the availability of phosphorus in the soil and the best treatment was obtained by application of cow manure compost with the increase from 100 ppm to 152 ppm. The application of organic matter also increased the organic-C, pH, total-N, total-P, and exchangeable cations. The need to raise the level of soil available-P could be addressed by the addition of OM. The use of solid CMC was preferable over its diluted extract, as dilution tended to reduce the levels of P in the OM. As necessary or feasible, substitute OMs like goat manure compost [GMC] and humic substances [HS] may be resorted to, but they may yield lesser salutary effects than CMC. Likewise, other alternative types and dosages of OM may produce better results, so they should also be investigated.

References
[1] Hammond JP, Broadley MR, and White PJ 2004 Genetic responses to phosphorus deficiency Ann Bot. 94 323–32
[2] Lambers H, Raven JA, Shaver GR, and Smith SE 2008 Plant nutrient-acquisition strategies change with soil age Trends Ecol Evol 23 95–103
[3] Veneklaas EJ, Lambers H, Bragg J, Finnegam PM, Lovelock CE, Plaxton WC, Price CA, Scheible WR, Shane MW, White PJ, and Raven JA 2012 Opportunities for improving phosphorus use efficiency in crop plants New Phytol 195 306–20
[4] Kiflu A, Beyene S, and Jeff S 2017 Fractionation and availability of phosphorus in acid soils of Hagereselam, Southern Ethiopia under different rates of lime Chem. Biol. Technol. Agric. 4 21
[5] Cordell D, Drangert J, and White S 2009 The story of phosphorus: Global food security and food for thought Global Environ Change 19 292–305
[6] Van Vuuren DP, Bouwman A, and Beusen A 2010 Phosphorus demand for the 1970–2100 period: a scenario analysis of resource depletion Global Environ Change 20 428–39
[7] Egle L, Zoboli O, Thaler S, Rechberger H, and Zesser M 2014 Anggaran P Austria sebagai dasar untuk optimalisasi sumber daya. Sumber daya Conserv Recy 83 152-62
[8] Schoumans O F, Bouraoui F, Kabbe C, Oenema O, and van Dijk KC 2015 Phosphorus management in Europe in a changing world Ambio 44 180–92
[9] Tan KH 1998 Principles of Soil Chemistry 3rd ed. (New York-Marcel Dekker) pp 292
[10] Siebielec G, Ukalska JA, and Kidd P 2014 Bioavailability of trace elements in soils amended with high-phosphate materials In: Phosphate in Soils: Interaction with Micronutrients, Radionuclides and Heavy Metals CRC Press, 237–68
[11] Kononova MM 1966 Soil organic matter: its nature, its role in soil formation and in soil fertility. 2nd Edition (Pergamon Press –Oxford) pp 54
[12] Li GH, Shen BJ, Zhang SF, and Lambers H 2010 Localized application of soil organic matter shifts the distribution of cluster roots of white lupin in the soil profile due to the localized release of phosphorus Ann Bot, 585-93
[13] Ikbal, Iskandar, and Budi RSW 2016 Utilization of Humic Materials and Compost to Improve the Quality of Nickel Mine Soil as Media Growth of Sengon (Paraserianthes falcatoria) Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan 6 (1) 53-60
[14] Tipping E 1998 Modeling the properties and behavior of dissolved organic matter in soils Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 87 237-52
[15] Kasifah, Syekh Zaini, Nuraini Y, and Handayanto E 2014 Effects of plant residue and compost extracts on phosphorus solubilization of rock phosphate and soil American-Eurasian Journal of Sustainable Agriculture 8 43-49
[16] Baldotto AM, Muniz CR, Baldotto LE B, and Dobbs BL 2011. Root growth of Arabidopsis thaliana (L.) Heynh treated with humic acids isolated from typical soils of Rio de Janeiro State, Brazil. Rev. Ceres (Impr) 58 (4) 504-511
[17] Suwardi and Wijaya H 2013 Increasing Food Crop Production Using Active Material of Humic Acid and Zeolite as Carrier Jurnal Ilmu Pertanian Indonesia (JIPI), 18 (2) 79-84

[18] David J, Smejkalova D, Hudecova S, Zmeskal O, Wandraszka V R, Gregor T, and Kucerik J 2014 The physicochemical properties and biostimulation activities of humic substances regenerated from lignite J Springer plus. 3 (1) 165

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