KnE Life Sciences

ICSAFS Conference Proceedings
2nd International Conference on Sustainable Agriculture and Food Security: A Comprehensive Approach
Volume 2017

Knowledge E
Engaging minds

Conference Paper

Organic Matter and Phosphorus Fertilizer Application to Sustain Maize Growth under Water Stress Condition in Calcareous Soil

Sri Rahayu Utami[1], H. Rohmawati[1], W. J. N. Kumalontang[2], and Sugeng Prijono[1]

[1]Department of Soil Science, Faculty of Agriculture, University of Brawijaya, Jl. Veteran 1, Malang, Indonesia
[2]Department of Soil Science, Faculty of Agriculture, Sam Ratulangi University, Manado, Indonesia

Abstract

Crop growth is normally rather limited in calcareous soils, due to the low phophorus availability and water scarcity. Organic matter (OM) is commonly applied to reduce P fixation, as also improving other nutrients content and water availability in the soil. Since calcareous soils often encounter water scarcity especially in dry period, the effectiveness of OM under water stress condition is still interesting to study. An incubation experiment was conducted to study the effect of water stress, P-fertilizer and organic matter application on P-uptake and maize growth in calcareous soil. Soil samples used for this study, were taken from 0-20 cm depth, in Pagak, South Malang, East Java. A complete randomized design was used, with 3 factors and 3 replications. Factor 1 was consisted of 3 water stress level, i.e no stress (S_0), slightly stress (S_1), and moderately stress (S_2). Factor 2 was consisted of 2 Phosphorus level: with (200 kg SP36 per Ha). and without P-fertilizer. Factor 3 was OM application (12 Mg Ha^{-1}), i.e. without OM (B_0), *Tithonia diversifolia* (B_1), *Gliricidia sepium* (B_2), and combination of *Tithonia diversifolia* and *Gliricidia sepium* (B_3).Soil samples were added with fertilizer and organic matter, and incubated within 2 weeks. Water stress treatment were conducted after incubation period. Phosphorus availability (P-Olsen and P-labile) in the soil was measured at 0, 28, and 56 day after planting (dap). Crop height was measured at 14, 28, 42, and 56 dap. Whereas P-uptake and biomass dry weight were measured at 56 dap. The results showed that OM application increased P-uptake, crop height and biomass dry weight. The effect was slightly improved by P-fertilizer application, but decreased as the water stress level increased. With or without P fertilizer, *Tithonia diversifolia* was more effective than *Gliricidia sepium*, when water was sufficient. At slightly water stress condition, the different between the two OM sources became less significant, especially when P fertilizer was added. Under moderately water stress condition, application of OM and P-fertilizer had no significant impact on maize growth.

Keywords: P-availability;P-uptake; sustainable agriculture; water scarcity.

Corresponding Author:
Sri Rahayu Utami
sriyutami@gmail.com

Received: 28 July 2017
Accepted: 14 September 2017
Published: 23 November 2017

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICSAFS Conference Committee.

How to cite this article: Sri Rahayu Utami, H. Rohmawati, W. J. N. Kumalontang, and Sugeng Prijono, (2017), "Organic Matter and Phosphorus Fertilizer Application to Sustain Maize Growth under Water Stress Condition in Calcareous Soil" in *2nd International Conference on Sustainable Agriculture and Food Security: A Comprehensive Approach*, KnE Life Sciences, pages 216–227. DOI 10.18502/kls.v2i6.1043

1. Introduction

Pagak Region in South Malang, is a hilly area with slope of 3-75%, having a dry climate with annual rainfall less than 1000 mm and 6-7 dry months. The soils were developed from calcareous parent materials, and containing 5-35% Ca in A horizon dan 35-80% in C horison with pH averaging from neutral to alkaline [7]. In such soils, phosphorus supply for crops is often low, due to relatively high fixation by Ca. Hence, phophorus deficiency is a common agronomic problem encountered in calcareous soils. Farmers normally apply P-containing fertilizers, in anorganic and organic form. However, application of anorganic fertilizer such as SP-36 was apparently not effective and inefficient. This fertilizer releases P quikly after being applied to the soils, resulting only 8-13% which was readily available to plant, and the rest was transformed to a poorly soluble Ca-phosphate [1]. Beside anorganic fertilizer, application of animal manure, plant residue, and wild crop cover to the soils were also common practices in the study area. Many researches in other soil types had shown that organic matter (OM) application siginificantly increased P-availability [11, 12, 16], compared to unamended soils [3]. Previous study in similar soils, showed that annual application of biomass of *Tithonia diversifolia* dan *Gliricidia sepium*at the dosage of 12 Mg.ha^{-1}increased available P content in calcareous soils due to a decrease amount of the adsorbed P. Decomposition of OM may increase available P, following the increase of P in labile form [14]. Organic acids released during decomposition proccess, provide the competitive adsorption between organic acids and phosphate, hence inhibit adsorption of phosphate on the active surfaces [2]. This effect was also shown when organic acids such as citrate, malate, and tartrate were directly applied to the soils [12], as these acids had chelating effect with Ca^{2+}, hence releasing P from Ca-P fixation. Besides, OM decomposition also release CO_2 which easily soluble in water, enhancing weathering of P- bearing minerals through the formation of carbonate acids [10].

Adding to the soil chemical problems, calcareous soils in the study area are also facing low availability of water. The availability of sufficient water in the soil will determine the level of uptake, hence affecting the whole metabolic functions which ultimately affect plants growth and production. Plants will experience water stress if the water content in the soil is below field capacity.The level of water stress gets stronger as water content farther away from the field capacity, or approaching wilting point. Under water stress condition, the leaf relative water content is low, enclosing stomata to reduce transpiration from the leaves.At this condition, the diffusion resistance of leaves will increase, thus inhibiting CO_2 entries into the leaf, and lowering the saturation to the light intensity, and as a result plant growth and yield will decreased. Water stress affects plant growth by inhibiting the development of leaf, stem extension, leaf area index and dry weight. Water deficiency symptoms was also shown by reducing root traits, plant uptake of P and yield of soybean [6]. Whereas in corn, a shortage of water at the beginning of growth resulted a 35% decrease of production.

Organic matter which normally applied to reduce P fixation, may also improving other nutrients content and water availability in the soil. Organic matter application together with anorganic fertilizer improves fertilizer effectiveness. Reference [4] compared P fertilizer effectiveness in the soil, when P fertilizer and goat manure applied separately and when they were applied together. The results showed that maize yield increased with the separate application of P fertilizer and goat manure, and further increased when they were combined. Reference [17] also showed that the uptake of P from rock phosphate by plant was 4 to 5 fold higher in soils treated with compost than control, due to the enhancement of biological properties such as the microbial biomass P. However according to Reference [3], this could also be due to a considerable release of P to the soil from the OM amendment itself.

Despite of the many research reports on the positive impacts of OM in combination with P fertilizer, very few studies however, were conducted under water stress condition. Since calcareous soils often encounter water scarcity especially in dry period, the effectiveness of OM under water stress condition is still interesting to study. The objectives of the research were 1) to study the effect of P-fertilizer and OM application on P-availability; 2) to study the impact of these treatments on maize growth in calcareous soil; and 3) to compare the effectiveness of these treatments under different level of water availability.

2. Materials and Method

The experiment was conducted in the period of March–September 2012, involving 3 research steps, i.e. 1) Selecting soil sampling location (Pagak Region, South Malang, East Java); 2) Pot experiments in the Glass house; and 3) Laboratory analysis which were conducted in the Laboratory of Soil Science, University of Brawijaya (UB).

Calcareous soils in Pagak, South Malang, East Java, was selected for this study. Bulk samples were taken from 0-20 cm depth, sieved with 2 mm. The fine earth (<2mm) was used for the incubation and growing media for maize. The characterization of the soils before the treatments and organic materials was performed by standard laboratory methods of Soil Laboratory, University of Brawijaya. The results showed that the studied soil has a silty clay texture, 0.77% organic C (very low), 0.17% N (low), 12.16 $mg.kg^{-1}$ P-Olsen (low), pH of 6.9, CEC of 25.4 $cmol.kg^{-}$(high), and 11.7 (high), 0.16 (very low), 0.13 (low) and 1.11 (very high) $cmol.kg^{-1}$respectively of exchangeable Ca, Mg, K, and Na. Fresh leaves of plants locally available in the area, namely *Tithonia diversifolia* and *Gliricidia sepium* were used as organic amendment. Fresh leaves of

Tithonia diversifolia contained 46% organic C, 5.31% total N, 0.47% total P, whereas fresh leaves of *Gliricidia sepium* contained 45% organic C, 4% total N, 0.27% total P.

A completely randomized design was used, with 3 factors and 3 replications. Factor 1 was consisted of 3 water stress level, i.e no stress (S_0), slightly stress (S_1), and moderately stress (S_3), representing respectively sufficient water (kept at field capacity), irrigated after 1/3 and after 2/3 available water was used. Factor 2 was consisted of 2 Phosphorus level: with (200kg SP36 per Ha). and without P-fertilizer. Factor 3 was OM application (12 Mg ha^{-1}), i.e. without OM (B_0), *Tithonia diversifolia* (B_1), *Gliricidia sepium* (B_2), and combination of *Tithonia diversifolia* and *Gliricidia sepium* (B_3).Soil samples were prepared in plastic pots (diameter 30cm, and height 50cm), added with fertilizer and organic matter, and incubated within 2 weeks. During the incubation period, soil moisture was maintained at field capacity. Two seeds of maize that have been germinated were planted on 10 kg growing media described above. About 1 week after planting, we selected 1 of the two with the best growth, kept it grown for 56 days (maximum vegetative). Before planting, each pot received basal fertilizers of 100kg Urea.ha^{-1} and 100 kg KCl.ha^{-1}. Water stress treatment were conducted after planting. Phosphorus availability in the soil (P-Olsen) and P-labile [5] was measured at 0, 28, and 56 days after planting (dap). Crop height was measured at 14, 28, 42, and 56 dap. Whereas P-uptake and biomass dry weight were measured at 56 dap.

3. Result and Discussion

3.1. Available phosphorus

Organic matter and P-fertilizer increased P-available content at 0 dap (after 2 weeks incubation), decreased at 28 dap, and increased again at 56 dap. No clear pattern however can be deducted, because measured available P content in the soil did not reflect total available P content, since P available was partly taken up by plants in accordance to the growing stage.

Figure 1 showed the variation of labile P during the incubation as affected by OM and P fertilizer treatment. If water was sufficient (S_0), OM treatments with or without P fertilizer significantly increased P-labile content in the soils. The effect was then slightly decreased with increasing level of water stress. If no P-fertilizer applied, P-labile on the OM treated samples were slightly higher than control. Under moderately water stress condition, only B_1 (*Tithoniadiversifolia*) showed a higher amount of P-labile, especially at 56 dap.

The effect of OM application on P-labile was increased by the addition of P-fertilizer. The content of P-labile kept increasing after 56 dap. Surprisingly, the content of P-labile in P_1S_1 was a little bit lower than P_0S_1 at the end of incubation period. At S1(slightly stress), addition of P fertilizer was apparently lowered P-labile content. This could indicate that increasing amount of readily available P (which added by P-fertilizer), enhance the precipitation of P with possiby Ca, hence reduce the mobility of P.

The results also showed that at S_0, B_1 (*Tithonia diversifolia*) was fast P-labile release, compared to B_2 (*Gliricida sepium*) and B_3 (mixed OM). Regelink *et al.* (2015) suggested that phosphate solubility increases with increasing content of soil organic carbon. Phosphate and OM compete for P adsorption to metal (hydr) oxides. These authors used surface complexation modelling, which revealed that a decrease in the adsorption affinity of phosphate was closely related to the increasing OM loading on to the metal (hydr)oxides. As a consequence, phosphate will be replaced by OM on adsorption sites in calcareous soils.

This interesting results could be related also to a higher P content and C/P ratio in *Tithonia diversifolia* leaves (0.47%; 97.5) than *Gliricida sepium* leaves (0.27%; 163.7). A much lower Lignin/P, Polifenol/P and (Lignin+Polifenol)/P ratio in *Tithonia diversifolia* leaves (11.3; 4.4; 15.7) than *Gliricida sepium* leaves (50.2; 6.5; 56.7), indicated that *Tithonia diversifolia* leaves might decomposed faster than *Gliricida sepium* leaves. This results were also supported by Reference [3], which found that increasing P-available content in the soils amended by compost manure was not only due to increasing amount of water soluble inorganic P, but also to considerable release of P to the soil from decomposition of amendment [13]. Added manure or litter have significant impact on P retention. Manure, not only affect sorption and precipitation of P, but often contains significant amount of P, which is deliberately or incidentaly added to soils. Whereas humic materials, as the final decomposition products of the total biota generally are not a principal source of P, but they may act as mobilizing agents for unsoluble elements, included P [15].

3.2. Plant P-uptake

Statistical analysis showed that OM, P-fertilizer and water stress treatments, either as separate treatment or in combination, significantly affect the amount of P-uptake, both in shoot and root biomass. Figure 2 represented the amount of P-uptake as an impact of OM and P-fertilizer applications under different levels of water stress. The results showed that all OM application increased P-uptake by plant, which further increase after the addition of P fertilizer. On the samples without P-fertilizer, OM amendment with *Tithonia diversifolia* leaves (B_1) resulted in a higher amount of P-uptake than samples with *Gliricidia sepium* leaves (B_2) or the combination of the two (B_3) irrespective with water stress level. In samples treated with phosphorus fertilizer, OM amendment with *Tithonia diversifolia* leaves were still efective at S_0 (no stress) and S_1 (slightly stress). At S_2 (moderately stress) however, OM amendment with *Gliricidia*

DOI 10.18502/kls.v2i6.1043

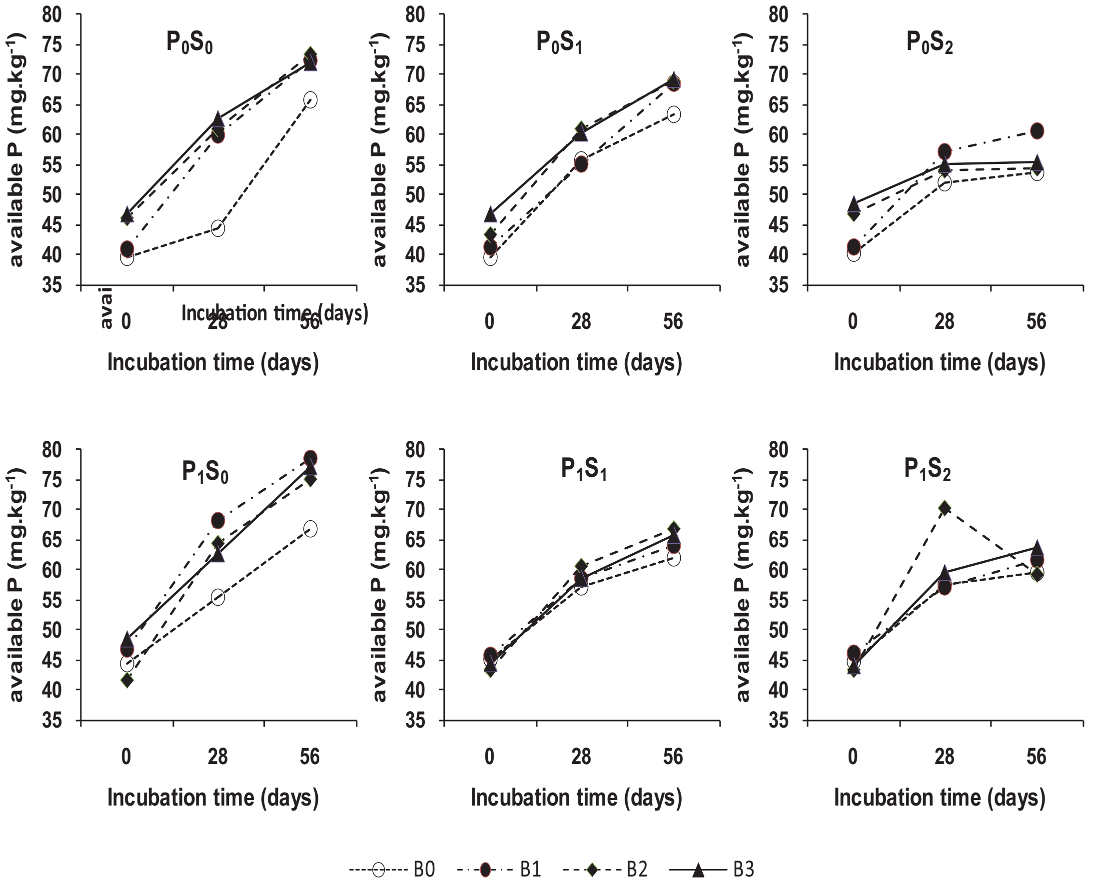

Figure 1: The effect of OM and P-fertilizer treatment on the content of P-labile at different levels of water stress.

sepium leaves performed a better result.A relatively high P content, C/P ratio, (L+Pf)/P ratio played an important role in determining the amount of plant P uptake in the soils amended with *Tithonia diversifolia* leaves. A high P content and easily decomposed character of *Tithonia diversifolia* leaves, enable to play multiple roles, as P source, inhibitor for P sorption and precipitation, and as P mobilizer.

Plant P-uptake significantly decreased in accordance to the increasing level of water stress. Firstly, increasing soil moisture means increasing amount of soluble nutrients, hence easily available nutrients. Secondly, under water stress condition, the leaf relative water content is low, enclosing stomata to reduce transpiration from the leaves. Reducing transportation will lower the nutrient movement through lateral and vertical water flows, what so called mass flow mechanism, which in turn decrease plant P uptake. Thirdly, soil moisture enhances biological properties such as the microbial biomass P and population density [17], which in turn affect elements mineralization. The amount of plant P uptake was apparently closely related to total water applied to the soils and the content of P labile (Figure 3). About 80% variation in plant P uptake

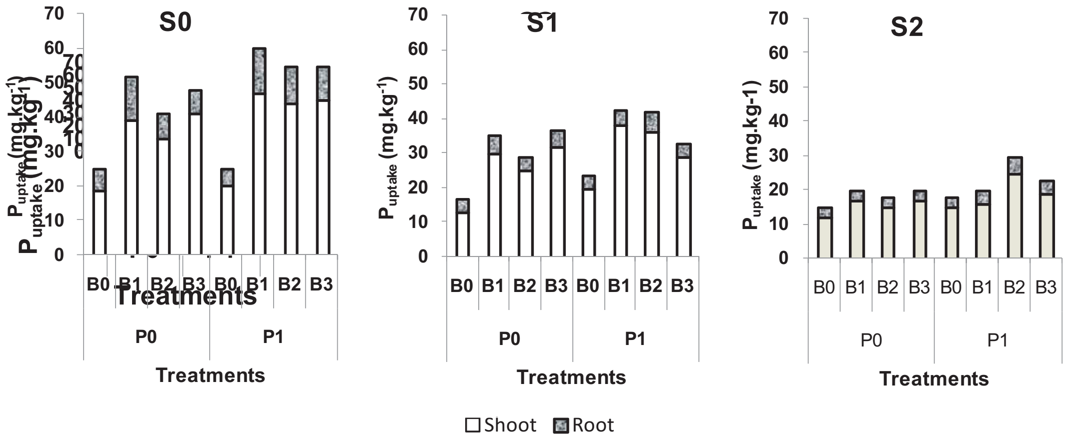

Figure 2: Plant P uptake at 56 dap as affected by OM and P-fertilizer treatments at different water stress levels.

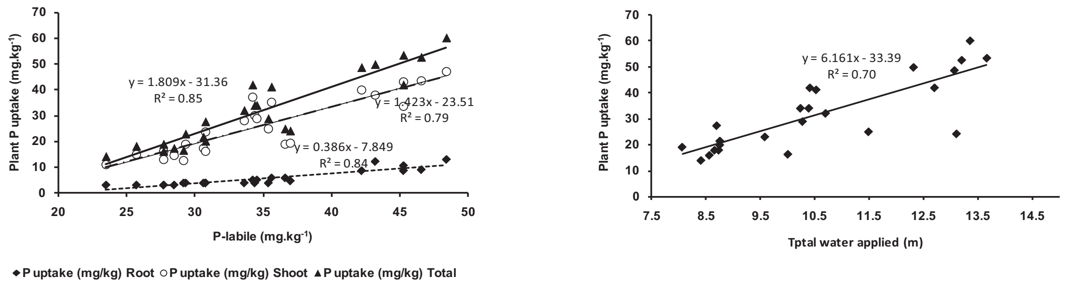

Figure 3: Relationship between the content of P-labile (left), total water applied (right) and plant P uptake.

could be explained by the variation of P labile content. Hence increasing amount of P labile due to OM application would increase plant P uptake.

3.3. Plant Growth

Water stress treatments and P fertilizer application strongly determined crop height at 14,28, 42and 56 dap. The effect of OM application was also significant, except at 28 dap. Interaction between OM and water stress treatments was significant at 7 and 42 dap. Figure 4 showed that crop growth, as indicated by crop height decreased following the increasing level of water stress. At initial growth stage, crop height was even lower in S_0 (sufficient water condition), than in S_1 (slightly stress) and S_2 (moderately stress). This indicated that less water is required at initial stage, hence the differences in water supplies unsignificantly affected crop height. Water stress symptoms was start to recognize in maize older than 42 dap. At this stage, water demand was apparently increasing that a slight water stress already inhibited crop growth.

The results clearly indicated that OM amendment enhanced crop growth. On the soils without P fertilizer application, at sufficient water supply (S_0) and slightly stress

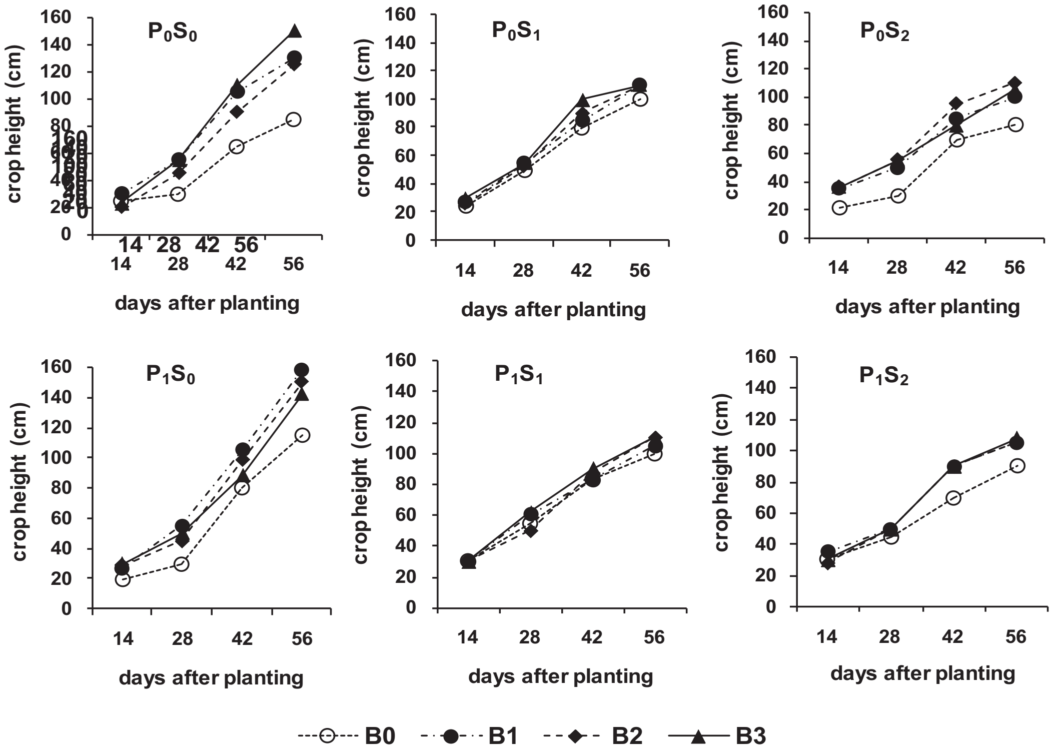

Figure 4: Crop height as affected by OM and P-fertilizer application at different levels of water stress.

(S_1), the combination of *Tithonia diversifolia* and *Gliricidia sepium* leaves (B_3) resulted in better crop gowth than single application. The same effect also appeared in soils applied with P fertilizer under slightly (S_1) and moderately stress condition (S_2). Combination of different OM source with different qualities probaly ensured long term effect on soil physical and chemical properties [7]. But when soil moisture was sufficient, soils added with *Tithonia diversifolia* leaves performed better crop growth. The difference between the OM treatments however became less important with increasing levels of water stress. This results showed that application of OM, independent of its type, tended to be less effective when water supply was low.

Crop height in soils added with P anorganik fertilizer was higher than in soils without P fertilizer, independent of water stress level. This indicated that addition of P anorganik fertilizer was still necessary to enhance crop growth, especially on the soils having serious P limitation problems. The effect of P fertilizer was more effective when it was combined with OM amendment. [6] suggested that application of P fertilizer is an important factor for improving the tolerance to water deficit in many plants. They found that plant uptake of P, root growth, and crop yield were significantly reduced by water deficiency. Application of P enabled to alleviate the adverse effects of water deficits.

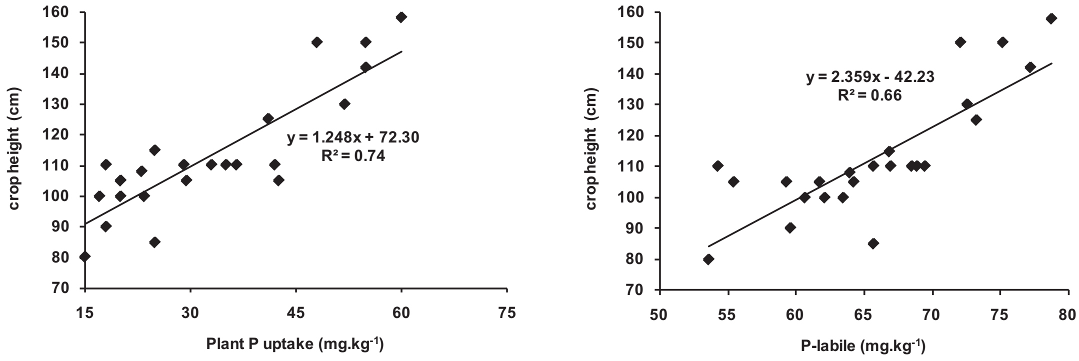

Figure 5: Relationship between plant P uptake (left), P-labile content (right) and crop height.

Figure 5 showed that the content of plant P uptake and P-labile strongly determined crop height. Any possible increase of P-labile, would increase plant P uptake, which in turn affected crop height.

3.4. Biomass dry weight

Phosphorus fertilizer and water stress application, and interaction between OM and water stress application significantly affected total, shoot and root dry weight. Figure 6 showed that biomass dry weight decreased following the increased level of water deficiency. Water sufficiency determined nutrients translocation process from soils to upper part of plants, affecting metabolism process.

OM application increased biomas dry weight (both shoot and root), under sufficient water condition as well as under slightly and moderately water stress condition. At sufficient water supply (S_0) andslightly water stress condition (S_1), with (P_1) and without P fertilizer (P_0), OM amendment with *Tithonia diversifolia* leaves showed the highest total biomass dry weight. There was considerable decrease of biomass dry weight at moderately water stress condition (S_2), hence there was no significant difference between OM types, OM treatedand untreated soils. This biomass weight pattern seems to follow the amount of plant P uptake.

Adding P fertilizer to the soils, slightly increased biomass dry weight, compared to soils without P fertilizer. The increase in biomass dry weight by P fertilizer application, however was much lower than the increase of OM application amount, even under sufficient water supply (S_0). This result indicated that OM amendment was more effective to increase biomass dry weight.

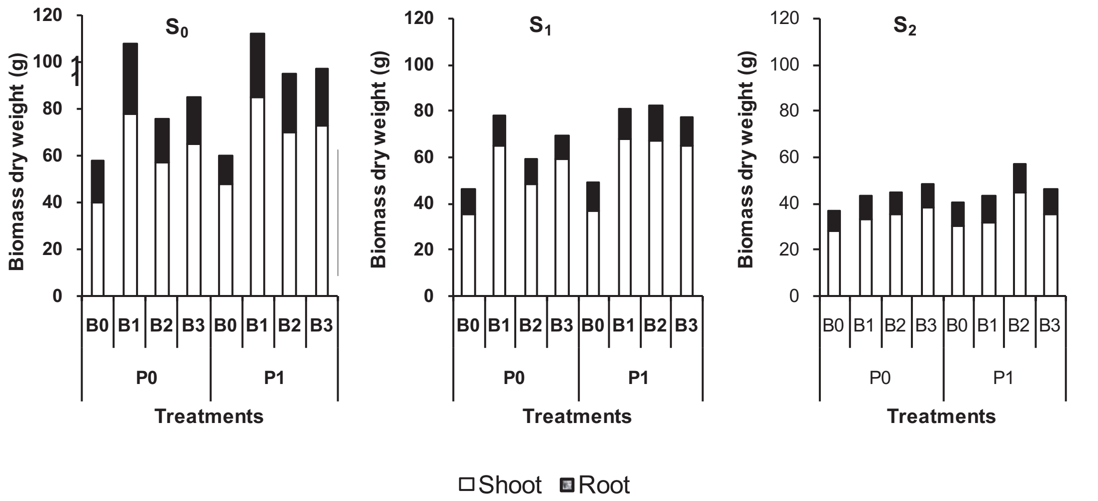

Figure 6: Biomass dry weight at 56 dap, as affected by OM and P fertilizer application, under different levels of water stress.

4. Conclusion

The results showed that OM application increased the content of P labile, and therefore plant P uptake, crop height and biomass dry weight. The effect was slightly improved by P-fertilizer application, but decreased as the water stress level increased. The application of OM seems to be more effective than P fertilizer. Plant P uptake was apparently determined by P labile and total amount of water applied. Whereas crop height was closely related to plant P uptake and P-labile.

With or without P fertilizer, *Tithonia diversifolia* was more effective than *Gliricidia sepium*, when water was sufficient. At slightly water stress condition, the different between the two OM sources became less significant, especially when P fertilizer was added. Under moderately water stress condition, application of OM and P-fertilizer had no significant impact on maize growth. Therefore, water scarcity should be taken into account first to improve management strategies in the study area.

Acknowledgements

The authors wish to thank all villagers in Pagak, South Malang for their valuable help in collecting samples. Gratitude is also extended to Ayyu Rahayu, SP., MP. and Nurhadi, SP for their help in data entry. The participation in the International Conference on Sustainable Agriculture and Food Security, Bandung, 12-13 October 2015 is supported by International Research Centre for the Management of Degraded and Mining Lands (IRC-MEDMIND), under the frame of Competitive Grant Theme C, for Strengthening and Developing Research Group, which is funded by University of Brawijaya.

References

[1] Pratikno, H. 2002. The use of flora biomass to increase P availability and soil organic matter in calcareous soils, Brantas Hulu Watershed, South Malang. MSc. Thesis. Post graduate programme, University of Brawijaya. Malang.

[2] Delgado, A., and J. Torrent. 2000. Phosphorus forms and desorption patterns in heavily fertilized calcareous and limed acid soils. Soil Science Society of American Journal, 64, 2031-2037.

[3] Suntoro; Syekhfani; E. Handayanto, and Sumarno. 2001. Use of pruning materials from Cromolena sepium to increase availability of P, K, Ca and Mg in Oxic Dystrudept, Jumapolo, Karanganyar, Central Java. Agrivita, **23**, no. 1, 20-26 (in Indonesian).

[4] Utami, S. R., H. Kurniatun, Supriyadi, and M. Van Noordwijk. 2002. Improving P-availability in Andisol using insitu organic matter. Agroteksos, **12**, no. 3, 196-201 (in Indonesian).

[5] Walker, D. J. and M. P. Bernall. 2008. The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. Bioresource Technology, **99**, no. 2, 396-413.

[6] Erich, M. S., C. B. Fitzgerald, and G. A. Porter. 2002. The effect of organic amendment on phosphorus chemistry in a potato cropping systems. Agriculture, Ecosystems and Environment, **88**, no. 1, 79-88.

[7] Utami, S. R., W. T. Widakdo, W. J. N. Kumalontang, and S. Prijono. 2013. Study of phosphorus fractionation as an impact of water stress and organic matter application in calcareous soils. Proc. The 11^{th} International Conference, The East and Southeast Asia Federation of Soil Science Societies, Land for sustaining food and energy security. Bogor, 21-24 October 2013.

[8] Delgado, A., A. Madrid, S. Kassems, L. Andreu, and M del Carmen del Campilo. 2002. Phosphorus fertilizer recovery from calcareous soils amended with humic and fulvic acids. Plant and Soils, 245, 277-286.

[9] Samadi, A., and R.J. Gilkes. 1999. Phosphorus transformations and theirrealtionship with calcareous soil properties of Southern Western Australia. Soil Science Society of American Journal, 63, 809-815.

[10] Jin, J., G. Wang, X. B. Liu, X. Pan, and S. J. Hebert. 2005. Phosphorus application affects the soybean root response to water deficit at the initial flowering and full pod stages. Soil Science and Plant Nutrition, **51**, no. 7, 953-960.

[11] Gischangi, E.M., P. N. S. Mnkeni, and P. C. Brookes. 2010. Goat manure application improves phosphate fertilizer effectiveness through enhancing biological cycling of phosphorus. Soil Science and Plant Nutrition, **56**, no. 6, 853-860.

[12] Wickranatilake, A. R. P., K. Kouno, and T. Nagaoka. 2010. Compost amendment enhances the biological properties of Andisols and improves phosphorous utilization from added rock phosphate. Soil Science and Plant Nutrition, **56**, no. 4, 607-616.

[13] Hedley, M. J., J. W. B. Steward, and B. S. Chauchan. 1982. Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and laboratory incubations. SSSAJ, 46, 1217-1234.

[14] Regelink, I. C., L. Wang, G. J. Lain, and R. N. J. Comans. 2015. Adsorption of phosphate and organic matter on metal (hydr) oxides in arable and forest soils: a mechanistic modelling study. European Journal of Soil Science, **66**, no. 5, 867-875.

[15] Utami, S. R., S. Kurniawan, B. Situmorang, and N. D. Rositasari. 2012. Increasing P-availability and P-uptake using sugarcane filtercake and rice husk ash to improve chinnese cabbage growth in Andisol, East Java. Can.Jour. Agric. Sci., **4**, no. 10, 153-160.

[16] Von Wandruszka, R. 2006. Phosphorus retention in calcaerous soils and the effect of organic matter on its mobility. Geochemical Transactions 2006, 1-6.