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Effect of Organic Soil Conditioners on the Water Retention Characteristics of Selected Fine-Textured Soils in Laguna

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Abstract

This study investigated the effect of organic matter (OM) soil conditioners (SC), with rice bran as major ingredient, on the water retention characteristics of fine-textured soils in Bay and Los Baños, Laguna, Philippines. Soil samples from both barren and vegetated areas were mixed with varying amounts of SC, thus changing their OM content. A standard pressure plate was used to determine the field capacity (FC) and the permanent wilting point (PWP) of the samples, which were used as basis for determining the available water holding capacity (AWHC).

Regression and correlation analyses were performed to determine the degree of relationship of OM to FC, PWP and AWHC. The results clearly indicated that OM generally has strong linear relationship with FC ($0.70<R^2<1.00$). On the other hand, the OM-PWP relationships were observed to be quadratic rather than linear ($0.66<R^2<1.00$). In general, the AWHC decreases with increased OM at very low OM values; however AWHC increases with the increase in OM content at high values of OM. Thus, with higher amounts of organic soil conditioners in soils, there is greater amount of water retained for plant use.

Keywords: soil conditioner, organic matter, available water holding capacity, field capacity, permanent wilting point

Introduction

Food security and environmental protection are two of society's biggest concerns. With increasing populations, the pressure to produce more food through agriculture has led to the intensified use of inorganic fertilizers which has unfortunately resulted to the degradation of soils, particularly the loss of organic matter. Degraded soils require ever more fertilizers to be useful, thereby increasing agricultural production costs and CO_2 emissions (Riding, Herbert, Ricketts, Dodd, Ostle, and Semple, 2015).

To reverse the negative effects of inorganic fertilizers on soil quality, some researchers consider application of soil conditioners which contain high amounts of organic matter to improve soil structure. In their work on the amelioration of degraded and hard-setting soil, Chan and Sivapragasam (1996) demonstrated that the organic matter content of soil is important in soil structure stabilization. Using sesame oil cake, rice bran, and molasses to improve the organic matter content of soil in an onion farm, Lee (2010) found that high organic matter content results to more stable pH and NO3-N levels over the growing season and increased microorganism populations. Ultimately, this resulted to better onion productivity. The biological activity that is sustained by organic matter causes soil aggregation which facilitates water infiltration, provides adequate habitat space for soil organisms, facilitates oxygen supply to roots and soil organisms, and prevents soil erosion (Franzluebbers, 2002).

Organic matter is believed to increase the water holding capacity of soils, which in turn is an important aspect of water conservation processes. Some soil parameters related to water retention include field capacity (FC), permanent wilting point (PWP), and available water holding capacity (AWHC).

Field capacity approximates the optimum wetness for easy tillage and excavation, and is taken to correspond to the amount of water retained by the soil when the water potential is -33 kPa. At FC, the soil is holding the maximum amount of water useful to plants and the soil is near its lower plastic limit. Moreover, at FC, sufficient pore space is filled with air to allow optimal aeration for most aerobic microbial activity and for the growth of most plants (Brady and Weil, 2008). As such, effective water conservation management is best performed when irrigation water does not exceed FC since any excess water will only be lost to deep percolation, evaporation, or runoff (Al-Rumikhani, 2002).

Permanent wilting point is taken to be the amount of water retained by the soil when the water potential is -1500 kPa (Brady and Weil, 2008). At this condition, plants will be unable to draw water from the soil since water from the progressively smaller pores and thinner water films have lower matric water potential and tend to remain on soil grain surfaces.

The available water holding capacity is the amount of moisture the soil can store and is available for use by plants. It is the water held between FC and PWP in the water retention curve (USDA, 1998). AWHC is a major hydraulic property that governs soil functioning in ecosystems. Data on AWHC are used in hydrology, agronomy, meteorology, ecology, environmental protection, and many other fields related to soils (Rawls, Pachepsky, Ritchie, Sobecki, &Bloodworth, 2003). It is also extensively used in determining the net irrigation application depth for a given crop for purposes of irrigation system planning and design.

Although organic matter has generally been known to increase the water handling capacity of soils, some studies have shown contradictory results with some authors claiming that organic matter content is not useful in estimating soil water retention. Rawls et al. (2003) attribute this contradiction to other soil properties such as texture and initial organic carbon content. For example, in sandy soils with high initial organic carbon content, soil water retention is also high but the opposite happens in fine-textured soils. Working on the same principle, Balland, Pollaco, and Arp (2008) considered the textural characteristics of soil in estimating the values of FC and PWP using the organic matter content of soil.

Despite some reported contradictions on the effect of organic matter on soil water retention, most studies uphold the widely accepted and verified view that organic matter improves water retention. One compelling evidence to this outcome is the result of the research conducted by Rasool, Kukal, and Hira (2008) on the long-term (32 years) effect of organic matter application in the form of farmyard manure versus that of inorganic fertilizers ($N_{100}P_{50}K_{50}$, $N_{100}P_{50}$, and N_{100}) on soil water retention. In all comparisons made for soil depths of 0-60 cm, soils with high organic matter manifested better water holding capacities.

In the Philippines, there are currently no reported studies on the effect of organic matter or soil conditioners on soil water retention characteristics. As such, this study was designed to validate and quantify the relationships between organic matter (OM) content and water-retention characteristics, namely FC, PWP, and AWHC, in the Philippine setting through use of soil conditioners from rice bran. In particular, soils in Bay and Los Baños, Laguna were used in this research. Relationships that will be established from this study may be used in determining values of OM content that could provide the greatest AWHC. A high AWHC is desired since it means low surface runoff during storm events and possibly low chance of flash floods as well.

Materials and Methods

Soil Sampling

Soil samples were taken from the two sites in Laguna. The first site is located at the municipality of Los Baños, Laguna, Philippines (see Figure 1). Textural classification and soil series of the area belongs to Macolod clay loam covering an area of 5,740 hectares. The topographic feature of Los Baños is rolling to hilly and mountainous characterized by a good drainage. The course skeleton on the surface soil and the upper subsoil is a mixture of rounded and angular fragments of andesite rocks. Crops grown in the area include rice, bananas, root crops, sugar cane, corn, lanzones and coconuts (Mendoza 2005).

The samples were taken from an area along Pili drive within the University of the Philippines Los Baños. About 7 kg of soil was taken from barren land and another 7 kg from a nearby vegetated area. Barren lands refer to areas with soils that are generally exposed. Vegetated lands are non-tilled areas that are generally covered with tall grasses and bushes. With a liquid limit ranging from 33.4% to 34.9% and a plasticity index ranging from 7.2% to 9.8%, the soil is organic silty clay with low plasticity.

The second sampling area is located at Bay, Laguna (see Figure 1), whose topography is characterized from level to undulating and consisting of flood plains with wide terraces. Annually, two rice crops are grown because of the availability of irrigation water (Mendoza 2005). The textural classification and soil series in this location belongs to Calumpang clay. This type of soil represents that of one of the best lowland rice areas of the province of Laguna.

The soil samples were taken from barangay Puypuy, Bay, Laguna. Again, about 7 kg of soil was taken from a barren area and another 7 kg from a nearby vegetated area. With a liquid limit ranging from 36.9% to 40.9% and a plasticity index ranging from 8.4% to 13.0%, the soil is organic silty clay with low plasticity.

Measured from the surface, all soil samples were obtained from a depth of 0-20 cm.

Soil Preparation and Sample Mixing

All soil samples were air dried for a week, pulverized, and passed through a number-40 screen by mechanical shaking for five minutes.

Each sample was then divided into four. Three parts were mixed with different concentrations of soil conditioners (1%, 5%, and 10%) and one part served as control. The choice of concentrations of soil conditioners used was based on actual field application rates and possible accumulation in soils during field application. The soil conditioners were in powdered form, with rice bran as major ingredient. Figure 2 illustrates the soil sampling and mixing procedures used and Figure 3 shows the examples of these soils. Prior to the AWHC test, all samples were evaluated for their organic matter content at the Agricultural Systems Cluster, College of Agriculture, University of the Philippines Los Baños, College, Laguna.

Field Capacity

Sixteen small PVC containers were filled with approximately 15 g of dry soil samples. The soil samples and also a porous ceramic plate were then soaked in water for 24 hours. After soaking,

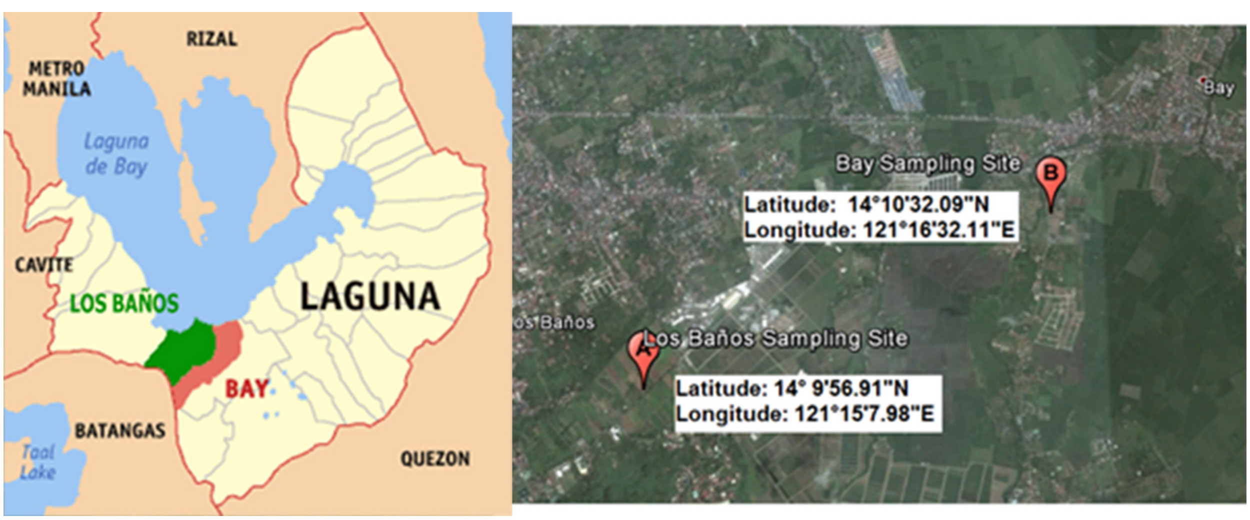

Figure 1. Location map of the sampling sites (source: https://earth.google.com). Location map of Bay and Los Baños, Laguna (source: en.wikepedia.org).

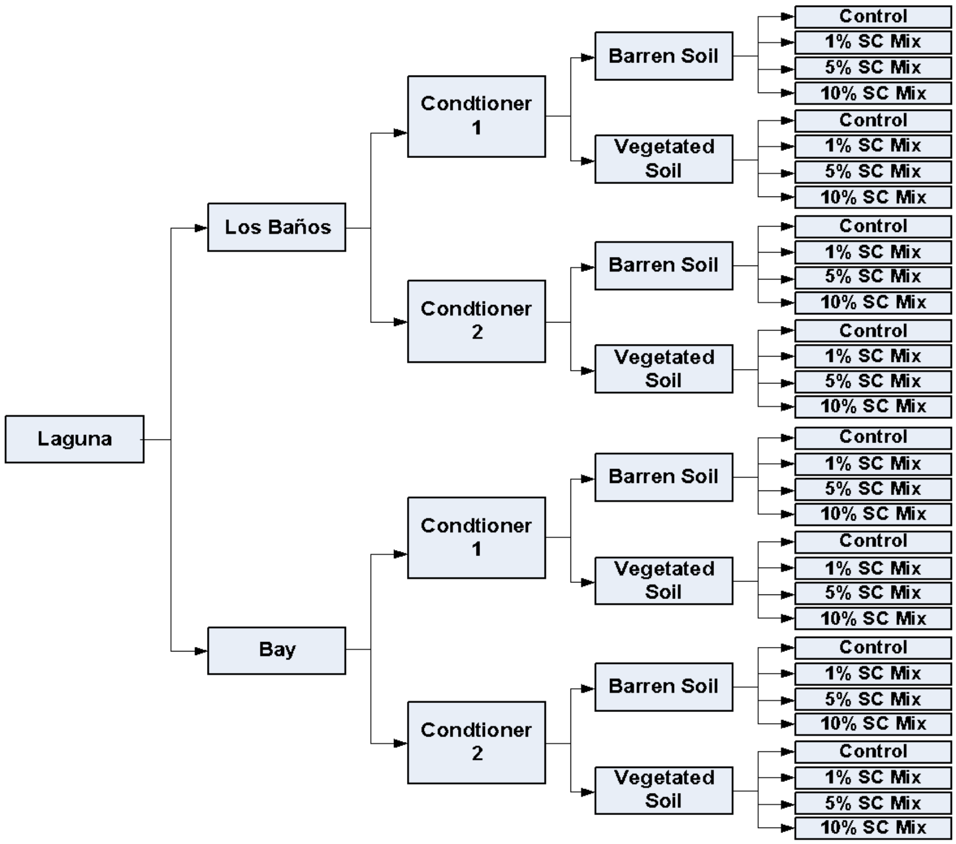

Figure 2. Origin of samples and soil conditioner mixes.

Figure 3. Examples of soil sample mixes.

the ceramic plate with the samples was placed inside the pressure plate. The soil samples were subjected to 1/3 atm of suction pressure until no water is leaving the plate. After the mass of each soil sample was determined, the soil was dried in an oven for at least 24 hours at 105°C. The difference in mass before and after drying determined the moisture content that corresponds to the field capacity (see Equation 1).

$$FC = (W_{FC} - W_{DRY})/W_{FC} \times 100 \quad \text{(Equation 1)}$$

Permanent Wilting Point

The procedure for determining the permanent wilting point was the same as that for determining the field capacity except that this time the soil samples were subjected to a pressure of 15 atm. The difference in mass before and after drying determined the moisture content that corresponds to the permanent wilting point (see Equation 2).

$$PWP = (W_{PWP} - W_{DRY})/W_{PWP} \times 100 \quad \text{(Equation 2)}$$

Available Water Holding Capacity

The differences between the moisture contents at field capacity and permanent wilting point were taken. This yielded the Available Water Holding Capacity (see Equation 3).

$$AWHC = FC - PWP \quad \text{(Equation 3)}$$

Data Evaluation and Statistical Analysis

The FC, PWP, and ASWC of each sample were plotted against organic matter content. The dependence of most of the mentioned properties on the organic matter content was measured through simple linear regression. However, for the available soil water capacity, a quadratic equation was utilized, as the graphs for this property consistently follow a curve for this type of equation. The strengths of relationships were quantified through the coefficient of determination (R^2).

Results and Discussion

Analysis of Soils and Soil Conditioners

Results of the soil analyses are shown in Table 1. Generally, soils from vegetated areas contain significantly higher amounts of organic matter than soils from barren areas. This is consistent with the observation of Dominguez, Camilobedano, and Becker (2010) that the soil organic carbon is influenced by tillage practices with lesser tillage corresponding to higher organic carbon content.

The soil conditioners used were organic. Thus, the chemical analysis of the soil conditioners revealed that they have very high organic matter content. As shown in Table 2, Soil Conditioner 1 (SC1) and Soil Conditioner 2 (SC2) have 76.86% and 73.93% organic matter content, respectively.

On the contrary, the nitrogen (N), phosphorus (P), and potassium (K) are of very small quantities. As the amounts of soil conditioners to be mixed with the samples only range from 0 to 10 percent, the effects of NPK to the soil properties were considered negligible for this particular study.

Table 1. Organic matter (%) content of the soil samples.

Soil Condition	Los Baños	Bay
Barren	2.73	1.54
Vegetated	6.77	4.01

Table 2. Basic chemical properties of the soil conditioners.

Component	SC1	SC2
% OM	77.86	73.93
% N	1.68	1.22
% P_2O_5	1.22	1.86
% K_2O	1.34	2.32
pH	5.6	5.8

Organic Matter Content and Field Capacity

Tables 3 and 4 show the effect of increasing the concentrations of SC on FC, for soil samples taken from Los Baños and Bay, Laguna, respectively. Significant increases in FC were observed for the 5% and 10% mixes. However, for the 1% mixes, three out of eight values exhibited lower FC values relative to the control. This implies that FC does not vary significantly with OM conditioning at low OM contents.

The correlation between OM and FC for SC1 and SC2 for samples taken from Los Baños, Laguna are shown in Figures 4 and 5, respectively. The coefficients of determination observed range from 0.92 to 1.00 for individual analyses. These are all above the lower limit at 5% level of significance. This indicates that the changes in FC are strongly affected by the OM content of the samples. The combination of data from the barren and vegetated areas also shows strong correlation between OM and FC. For SC1, the coefficient of determination was 0.90; for SC2, it was 0.91. This result also shows that the relation between OM and FC for the sampling areas in Los Baños is not significantly affected by land-cover conditions.

Table 3. Observed values of field capacity at various SC concentrations under barren and vegetated condition for Los Baños soil.

% SC Mix	SC1		SC2	
	Barren	**Vegetated**	**Barren**	**Vegetated**
0%	44.0	45.5	39.6	42.2
1%	44.3	45.3	40.3	41.2
5%	46.3	47.5	42.6	44.5
10%	49.2	51.4	43.4	47.5

Table 4. Observed values of field capacity at various SC concentrations under barren and vegetated condition for Bay soil.

% SC Mix	SC1		SC2	
	Barren	**Vegetated**	**Barren**	**Vegetated**
0%	50.5	41.8	43.6	42.6
1%	50.4	48.1	45.8	44.4
5%	50.8	48.8	47.5	46.6
10%	54.3	51.8	50.5	49.4

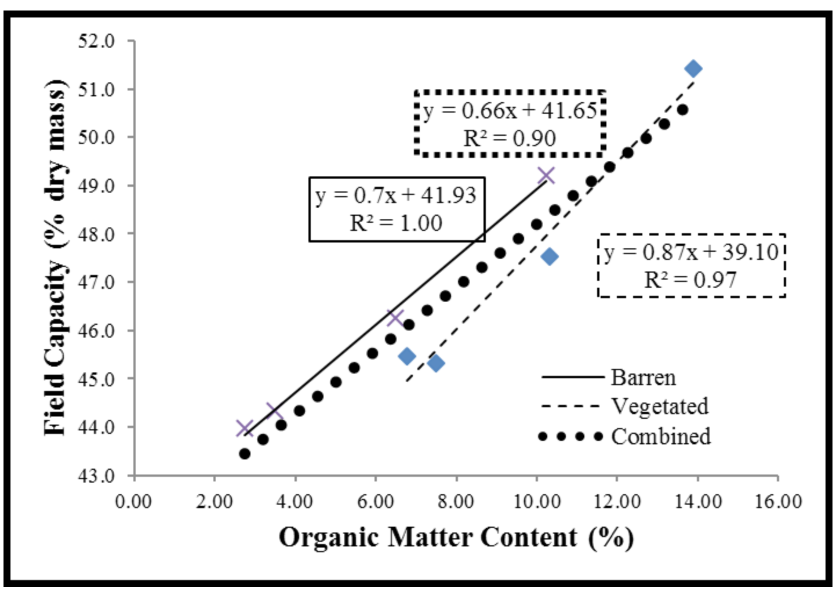

Figure 4. Relationship of OM and FC for Los Baños soil using SC1.

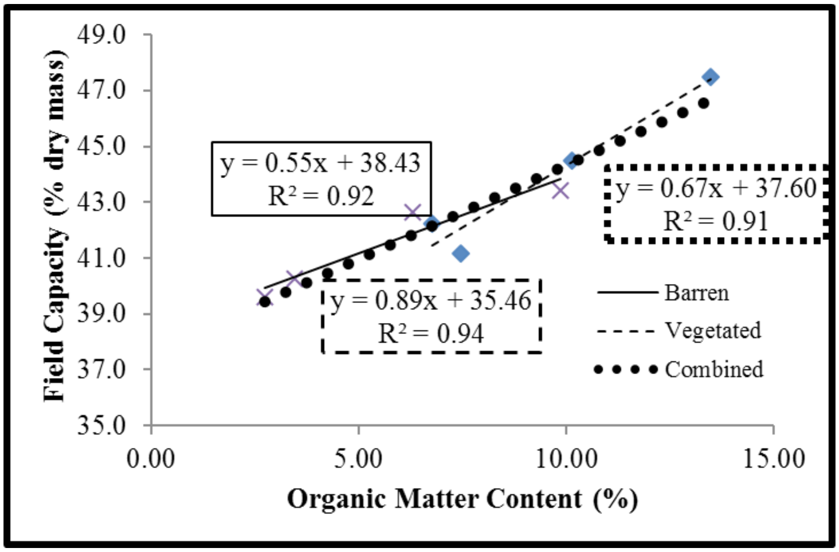

Figure 5. Relationship of OM and FC for Los Baños soil using SC2.

Figures 6 and 7 present the effect of OM on FC with changing values of OM for soils from Bay, Laguna, for SC1 and SC2, respectively. The coefficient of determination for the barren and the vegetated area using SC1 are 0.82 and 0.70, respectively. Also, a very low explained variance of 0.16 resulted from combining the data from the two sampling areas. This could indicate that the relationships between OM and FC for barren and for vegetated areas with this treatment behave differently, as affected by land-cover conditions.

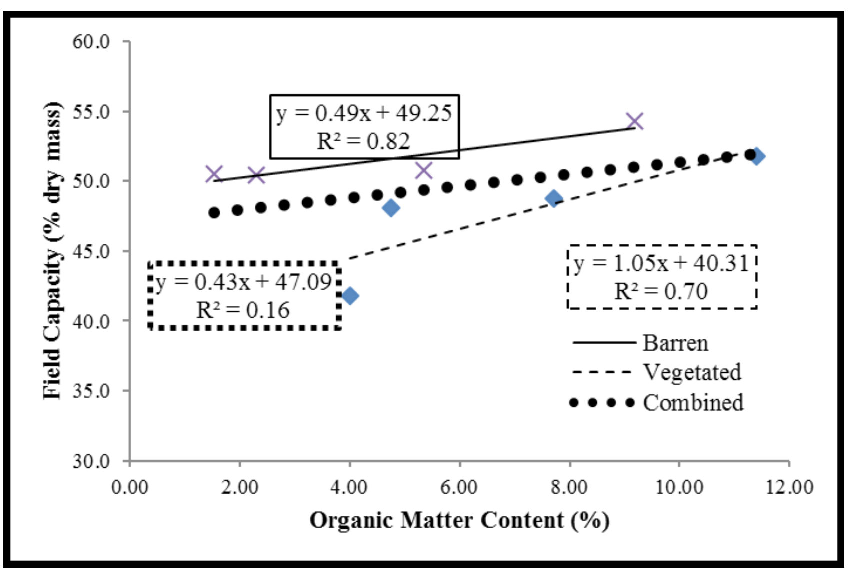

Figure 6. Relationship of OM and FC for Bay soil using SC1.

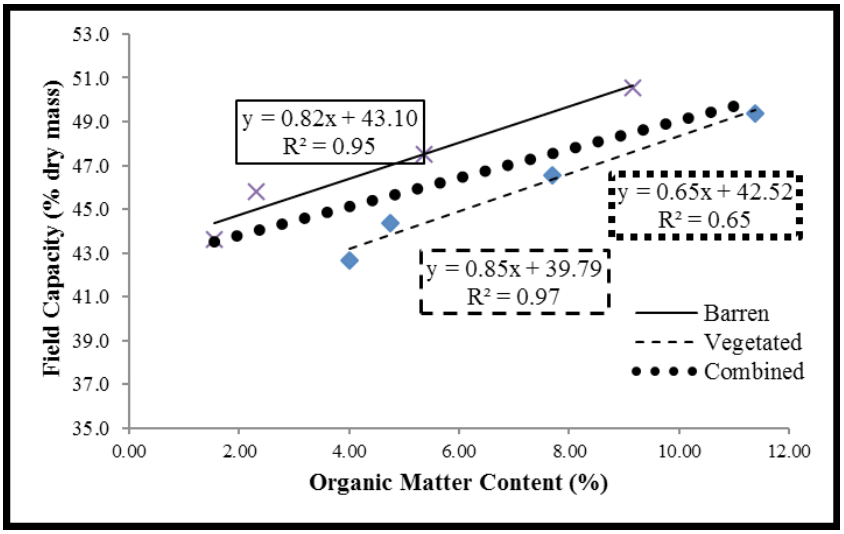

Figure 7. Relationship of OM and FC for Bay soil using SC2.

On the other hand, a very strong relationship exists between OM and FC with the use of SC2. The values for the explained variance are 0.95 and 0.97 for barren and vegetated areas, respectively. The explained variance for the combined data shows a value of 0.65, which shows highly significant correlation.

However, analysis using all observed values for OM and FC shows a very high correlation between OM and FC (Figure 8). The value of the coefficient of determination of 0.45 is much higher than the lower limit of 0.20 for 1% level of significance. Equation 4 shows the relationship between OM and FC, based on the combined data.

$$FC = 0.72(OM) + 41.02 \quad \text{(Equation 4)}$$

Overall, the change in FC is strongly affected by the change in OM. This is shown by very high values of the coefficients of determination. Also, in most cases, the changes in FC become more abrupt as the OM increases in value. This could have an implication on the AWHC. Abrupt changes in AWHC could be expected at high values of OM.

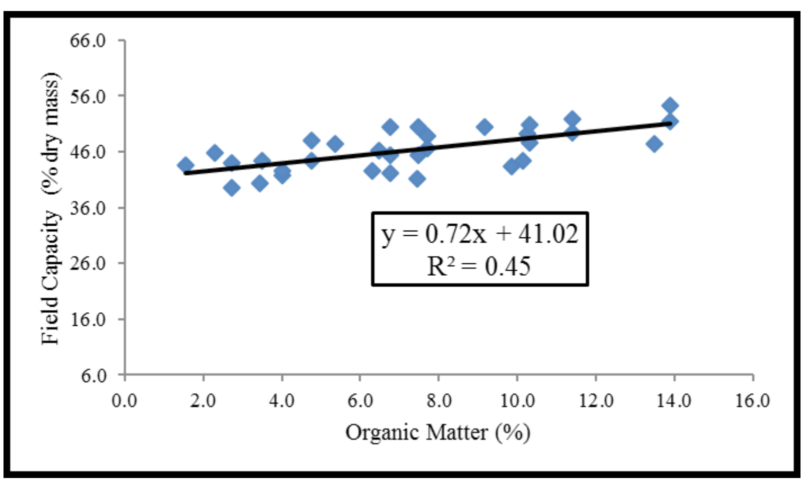

Figure 8. Relationship of OM and FC using all observed values.

Organic Matter Content and Permanent Wilting Point

Tables 5 and 6 present the effect of increasing the concentration of the soil conditioners on the PWP of soils for samples taken from Los Baños and Bay, respectively. From 1% to 10% SC mixes, there were significant increases in the PWP observed. It could be noticed, however, that in most cases the PWP increase is more sensitive at low organic carbon content. There were slight changes, after shifting from 5% to 10% mix.

Table 5. Observed values of permanent wilting point at various SC concentrations under barren and vegetated condition for Los Baños soil.

% SC Mix	SC1		SC2	
	Barren	Vegetated	Barren	Vegetated
0%	23.7	19.5	27.6	29.6
1%	24.5	21.2	28.8	31.9
5%	28.8	26.8	30.9	32.0
10%	25.0	29.5	33.3	32.6

Table 6. Observed values of permanent wilting point at various SC concentrations under barren and vegetated condition for Bay soil.

% SC Mix	SC1		SC2	
	Barren	Vegetated	Barren	Vegetated
0%	25.4	16.2	28.2	30.9
1%	25.9	27.8	34.4	37.0
5%	28.6	24.6	38.8	39.1
10%	28.1	25.9	39.2	37.9

In Figure 9, the correlation between OM and PWP for samples from Los Baños with SC1 treatments is illustrated. It is apparent that the correlation between OM and PWP is not linear but quadratic. The values of the explained variance for both barren and vegetated areas are very high at 0.97 and 1.00 for barren and vegetative areas, respectively. However, the two curves have different trends. Combining the data would give a very low value of explained variance. This implies that the difference in land-cover conditions affect the relationship of OM and PWP for the soil treated with SC1.

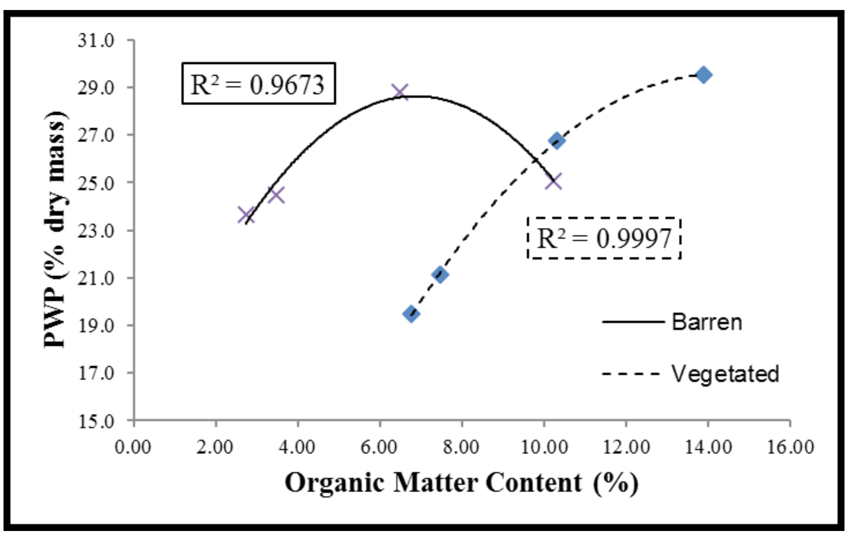

Figure 9. Relationship of OM and PWP for Los Baños soil using SC1.

Figure 10 shows the same relationships but with the use of SC2. Similarly, the plots followed a quadratic curve path instead of a line. This could be attributed to the effect of the added soil conditioner to the soil particle size distribution, which then affects the water suction head (Ding, Zhao, Feng, Peng, and Si, 2016). Also, good correlations existed between OM and PWP. The explained variance for the samples from a barren area went as high as 0.99. The combined data also yielded a very significant correlation coefficient of 0.87. This is much higher than 0.70, which is the minimum value for 1% level of significance. This suggests that the difference in land cover condition does not significantly affect the relationship between OM and PWP for Los Baños soil treated with SC2.

The OM and PWP relationship for Bay soil using SC1 is illustrated in Figure 11. Similar to the trends from previous OM-PWP relations, the data followed a quadratic curve. Although the R^2 for the samples from the vegetated area was very low, the R^2 for the samples from the barren area was as high as 0.99. Also, correlation does not exist with the combination of the two sets of samples. Since the two sets of samples exhibit

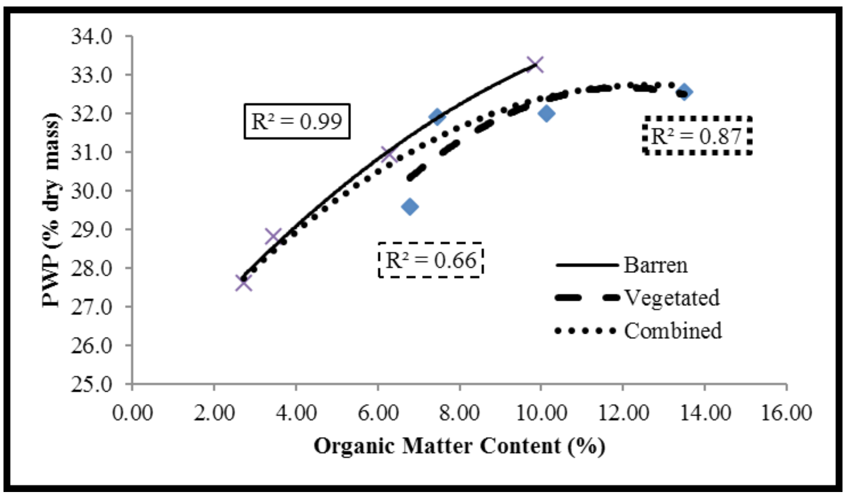

Figure 10. Relationship of OM and PWP for Los Baños soil using SC2.

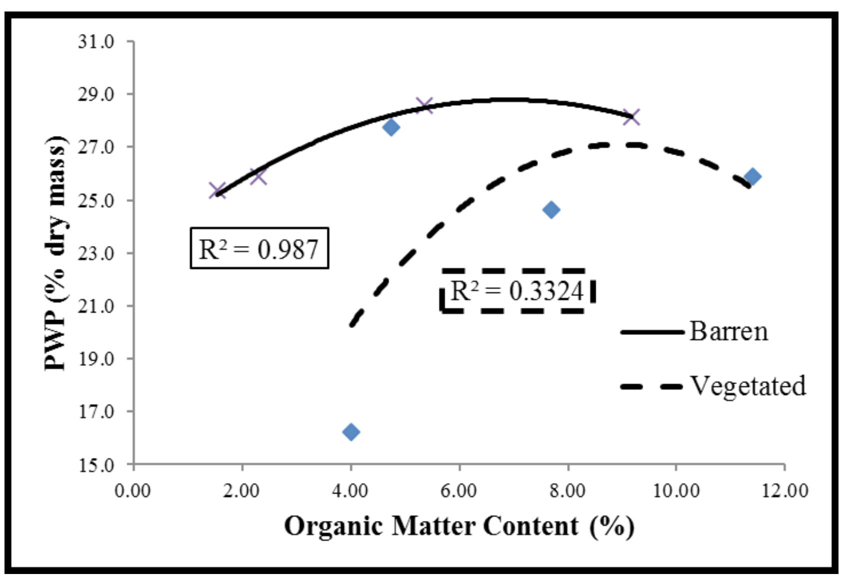

Figure 11. Relationship of OM and PWP for Bay soil using SC1.

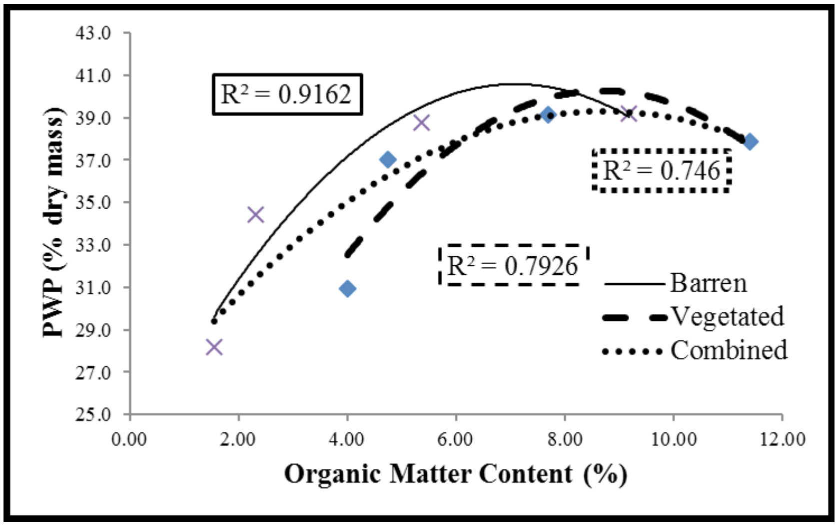

Figure 12. Relationship of OM and PWP in Bay using SC2.

different trends in correlating OM and PWP, results suggest that the OM-PWP relationship was significantly affected by the presence or absence of vegetation.

Figure 12 presents the OM and PWP relationships of samples from Bay using SC2. Again, there is a stronger correlation for the samples from the barren area (R^2 = 0.92) compared to those from the vegetated area (R^2 = 0.79). A highly significant relationship, however, was established after combining the data as reflected by the coefficient of determination of 0.75. This is relatively higher than 0.70 for 1% level of significance.

It can be observed from the previous OM-PWP plots that PWP increases with OM to a certain threshold level and then decreases afterwards. However, the maximum PWP values are not the same for all samples. Table 7 shows the threshold values of OM where PWP would be at its peak beyond which it begins to decrease. The amount of OM should be well above the threshold value if high AWHC is desired for a particular soil. In order to be certain, as shown in the table, the OM should be well above 15.9% for good soil water retention.

No significant relationship between OM and PWP can be established (Figure 13). This is shown by a very low value of R^2 equal to 0.02. This shows that factors coming from the differences in origin of the soil samples affected the OM-PWP relationships.

In general, PWP tends to increase with increasing OM. These increases are initially abrupt but become gradual as OM increases. With this, it could be expected that the AWHC might decrease at increasing OM at very low initial OM values, but may start to increase as OM increases further.

Table 7. Threshold values of organic matter content at maximum values of PWP

Soil Source	SC	Organic Matter Content (%)	
		Barren	Vegetated
Los Baños	1	6.89	14.34
Los Baños	2	15.9	12.11
Bay SC1	1	6.92	8.97
Bay SC2	2	7.1	8.69

Organic Matter Content and Available Water Holding Capacity

The relationships between OM and AWHC are illustrated in Figures 14 and 15 for Los Baños and Bay soils, respectively. Hypothetically, the AWHC should increase with increasing OM. In Figure 14, however, barren SC2 shows a decrease in AWHC. This behavior is possible with fine-textured soils. Rawls et al. (2003) explained that at low OM content, fine-textured soils could decrease in AWHC with an increase

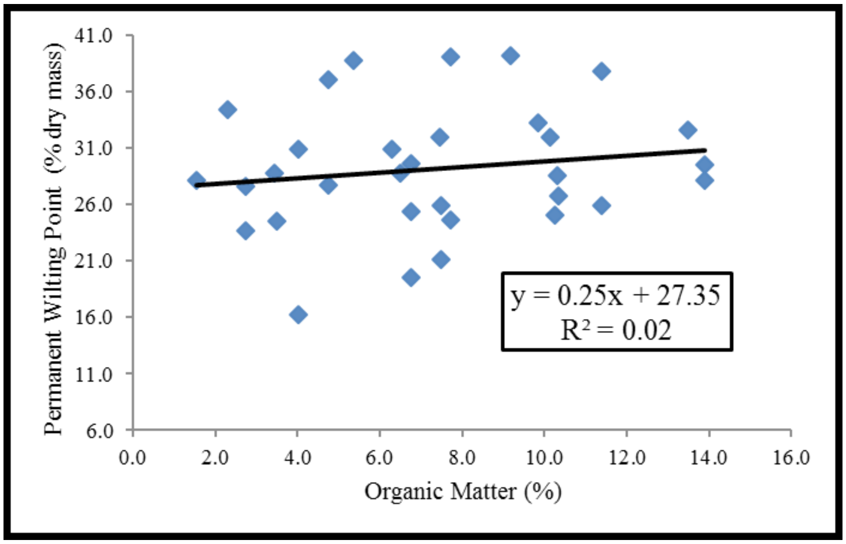

Figure 13. Relationship of OM and PWP using all observed values.

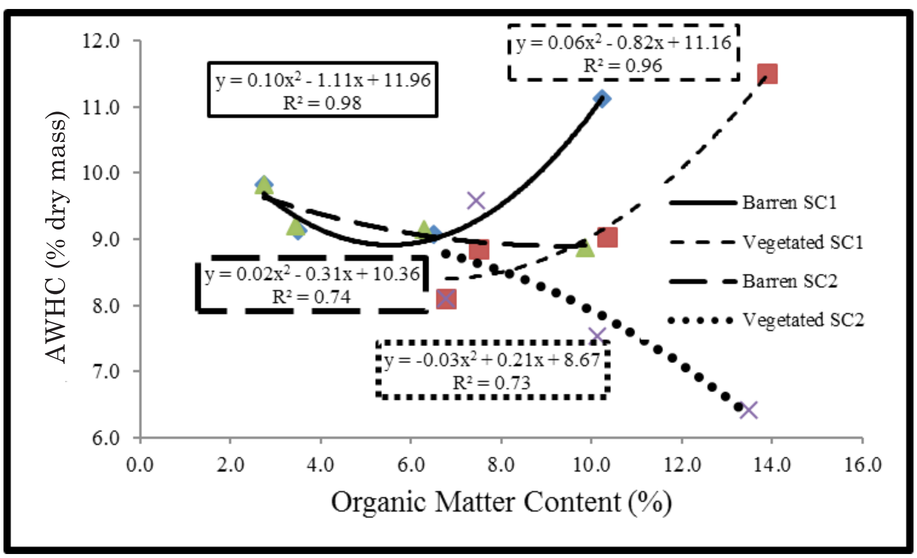

Figure 14. Relationship of OM and AWHC for Los Baños soils.

in OM. With low initial OM of only 2.73%, it is possible for barren SC2 to have a negative slope. Also, vegetated SC1 shows a negative slope. It is noteworthy, however, that the AWHC begins to increase at 10% SC. This is still consistent with the observation of Rawls et al. (2003) that when the OM is high in fine-textured soils, samples begin to increase in AWHC with increasing OM. Figures 14 and 15 show that most samples initially decrease in AWHC but as OM goes higher, the trends become increasing. This behavior is better represented by a quadratic equation rather than a linear equation. However, most values of R^2 are low and do not meet the minimum acceptable value for 5% level of significance.

Table 8 shows the values of OM with the minimum AWHC for the different soil samples and different soil conditioner treatments. In order to produce high values of AWHC, the OM content should be above the given threshold values.

Table 8. Threshold values of organic matter content with minimum values of AWHC.

Soil Source and SC	Organic Matter Content (%)	
	Barren	Vegetated
Los Baños SC1	5.53	6.76
Los Baños SC2	9.37	NA
Bay SC1	11.65	10.41
Bay SC2	NA	NA

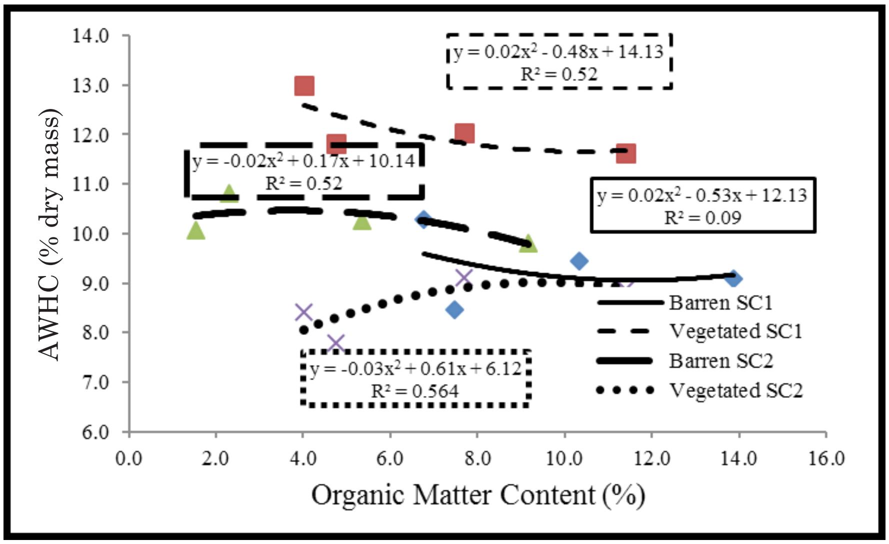

Figure 15. Relationship of OM and AWHC for Bay soils.

Conclusion

This study was conducted to determine the effects of OM soil conditioners on AWHC of selected fine-textured soils. Results have shown linear relationships between FC and organic matter content. All plots were above the R^2 lower limit for 5% level of significance. The general equation derived is FC = 0.72(OM) + 41.02. Thus, there is increase in FC with increasing amount of soil conditioners applied. This implies better initial water absorption after application. This would also potentially lessen losses due to surface runoff.

However, the OM-PWP plots were different. In general, it was observed that the PWP abruptly increased with addition of OM at low initial OM values. However, the increases became gradual at high values of OM. Thus, the OM-PWP relationship was quadratic rather than linear. This indicates the need for higher OM content to decrease the PWP. Decreased PWP would allow crops to acquire water from soils even with low moisture content.

Though it is a common belief that an increase in OM would increase AWHC, results of the study have shown something different. In general, it was observed that AWHC decreases at low values of OM. But as the OM content increases, the AWHC will start to increase as well. Therefore, in order to have greater values of AWHC, the OM content of soils should be significantly increased. With high AWHC, there would be greater amount of moisture in the soil retained for plant use and there would be less water losses. Every percent increase in water retention would also result to a corresponding increase in the length of waiting time for the next irrigation, which would mean reduction in cost for water supply. Also, with higher AWHC, there would be better resistance against dry periods like El Niño. In addition, with the reduction of surface runoff due to an increase in water retention, there would be a potentially significant decrease in soil erosion.

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