IMPROVEMENT OF CROP YIELD, SOIL MOISTURE DISTRIBUTION AND WATER USE EFFICIENCY IN SANDY SOILS BY CLAY APPLICATION

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ABSTRACT

Cultivating sandy soil is a promising solution to overcome the fight against hunger especially in the developing countries. The main problems of sandy soil are moisture holding capacity and nutrients deficiency. A containers experiment was carried out to study the enhancement of water productivity and crop yield of sandy soils treated with clay. The container size was 31 x 15 x 60 cm with one transparent side for visual viewing of the root development beside growth characteristics. The soil with bulk density of 1.5 g/cm^3 mixed with CaCO3 and P2O5 fertilizers was packed in the containers to 50 cm height. Three treatments: control, overlay and incorporate with four replicates were studied. The control treatment was only sandy soil, 4 % by weight of clay was overlay on the surface of sandy soil to constitute the overlay treatment (5.6 kg soil with 21.4 % clay overlay on 28.4 kg sandy soil with 93 % sand) while the same percentage of clay was incorporated with the upper 20 cm of sandy soil to represent the incorporate treatment. All the treatments received the same amount of irrigation water and fertilizers during the growing stage.

The results indicated that the leaf area in cucumber and stem length, stem diameter and number of leaves in maize were increased in the treatments treated with clay. About 2.5 times of yield was obtained due to those treatments compared to the controlled ones, i.e. without treatment. Roots grew intensively in the layers treated with clay. The incorporate treatment retained higher amount of water compared to those controlled but with small differences compared to overlay treatment. The water use efficiency and water saving was highly increased by clay application and about 45% -64% of irrigation water could be saved compared with the controlled ones.

Keywords: sandy soil, clay amendment, Cucumber, Maize, water use efficiency

INTRODUCTION

Irrigation water is gradually becoming scarce not only in arid and semi-arid regions but also in the regions where rainfall is abundant. Therefore, the water saving and conservation is essential to support agricultural activities, which account for 85% of the total water consumed. On the other hand, sandy soils suffer due to water deficiency, while intensifying mineral fertilization with irrigation water supply endangers the environment. Therefore, there is need to cultivate the sandy soils to fight against hunger in the world but with the least amount of irrigation water and mineral fertilizers. Treating sandy soil with clay is one of the good options to increase water and productivity with the least use of mineral fertilizers. Water repellency of sandy soil can be reduced by adding small increments of clay content [4]. Reuter [16] reported that clay-substrate application in sandy soil significantly improved soil water regime, especially on the percolation processes. Important consequences of day addition are reduction of plant nutrient losses and ground water contamination.

Addition of clay to the top of sandy soil has been shown to be highly effective in reducing water repellency and increasing crop yield [3, 12]. The most predictive factor which has the greatest effectiveness of clay soil materials in reducing water repellency in sandy soil was texture [10, 11]. Al-Omran et al. [2] reported that the sandy soil treated with clay deposits increased the crop yield of squash (*Cucurbita Pepo*) by 12.8 % compared with control treatment. The present study aimed to investigate soil moisture distribution, yield improvement, and water use efficiency of cucumber and maize in sandy soil treated with clay and also to figure out whether overlay the clay on top of soil surface or incorporate it with the surface layer is better.

MATERIALS AND METHODS

Containers experiment was carried out in a greenhouse situated at JIRCAS Okinawa Subtropical Station, Ishigaki, Japan. The container size was 31 x 15 x 60 cm with one transparent side for visual viewing of the root development beside growth characteristics. The soil with bulk density of 1.5 g/cm^3 mixed with CaCO3 and P2O5 fertilizers was packed in the containers to 50 cm height. Three treatments: control, overlay and incorporate with four replicates were studied. The control treatment was only sandy soil, 4 % by weight of clay was overlay on the surface of sandy soil to constitute the overlay treatment (5.6 kg soil with 21.4 % clay overlay on 28.4 kg sandy soil with 92.2 % sand) while the same percentage of clay was incorporated with the upper 20 cm of sandy soil to represent the incorporate treatment. Two different sandy soils textured, one grown with cucumber (*var. Shin toki wa*) and the other grown by maize (*var. Gold dent KD 777*) were investigated under each treatment (Table 1).

Table 1 Physical characteristics of investigated soils

Characteristics		**Soil 1 (Source of clay)**	**Cucumber Soil**	**Maize Soil**
Particle size analysis	Clay %	21.4	6.0	5.2
	Silt %	9.2	1.8	0.8
	Coarse sand %	48.7	87.6	91.3
	Fine sand %	20.7	4.6	2.7
Texture grade		Sandy clay loam	Sand	Sand
Saturation cm^3/cm^3		0.45	0.36	0.35
Sat. hydraulic Conductivity cm/hr		0.54	6.8	8.64

At the start of the experiment the containers were saturated with water while they were irrigated manually every 2-3 days during the growth period by adding equal amount of water for all treatments. The plants were fertilized with a Nutricoat fertilizer containing 14% N, 12% P2O5 and 14% K2O. A dosage of 10 g fertilizer was added twice on soil surface during the growing season. Growth characteristics include leaf growth, chlorophyll content in cucumber and stem diameter and length, number of leaves and chlorophyll content in maize were measured. The chlorophyll content measured in leaf number five from the top of the plant in cucumber and in the last complete upper leaf in maize. Cucumber yield for each plant was harvested and recorded twice a week. Soil water content was measured in all treatments during the growing season by Profile Probe method. At the end of the experiment the weight of the aboveground biomass for both cultivars were recorded after dried at 70ºC. The development of roots was observed from the transparent side of the containers during the growing season. At the end of the growing season the roots for each 10 cm depth were collected separately and washed and weighted after dried at 70ºC to study the roots mass over depth for each soil type.

RESULTS

Growth characteristics

The growth characteristics of cucumber and maize are presented in Figures 1 and 2. The results revealed that there were large differences leaf areas, higher in overlay and incorporate treatments than control in cucumber (Fig. 1). The leaf area in overlay and incorporate treatments was similar in the beginning but increased slightly in incorporate treatment from the mid to the end of growing season compared to overlay treatment. Chlorophyll content was the highest in control treatment while there were no differences between overlay and incorporate treatments.

There were no differences in growth characteristics of maize between overlay and incorporate treatments (Fig. 2). The stem length and diameter, number of leaves per plant and chlorophyll content were similar for both treatments. The lowest stem length, stem diameter and number of leaves were found in control treatment. Chlorophyll content was similar up to the mid of the growing season in all the treatments. Thereafter, chlorophyll content increased at a constant rate in control treatment while it decreased followed by increased with the same rate in overlay and incorporate treatments.

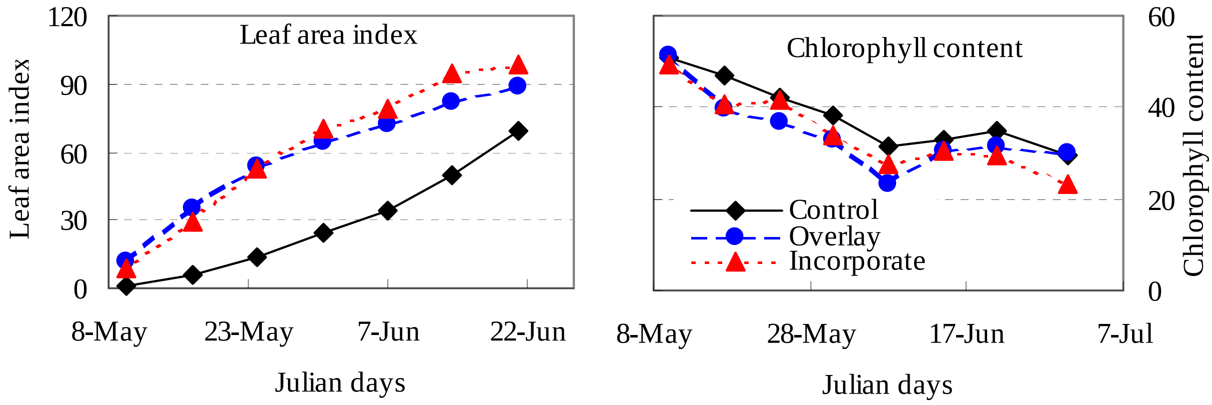

Figure 1 Leaf area index and chlorophyll content in cucumber

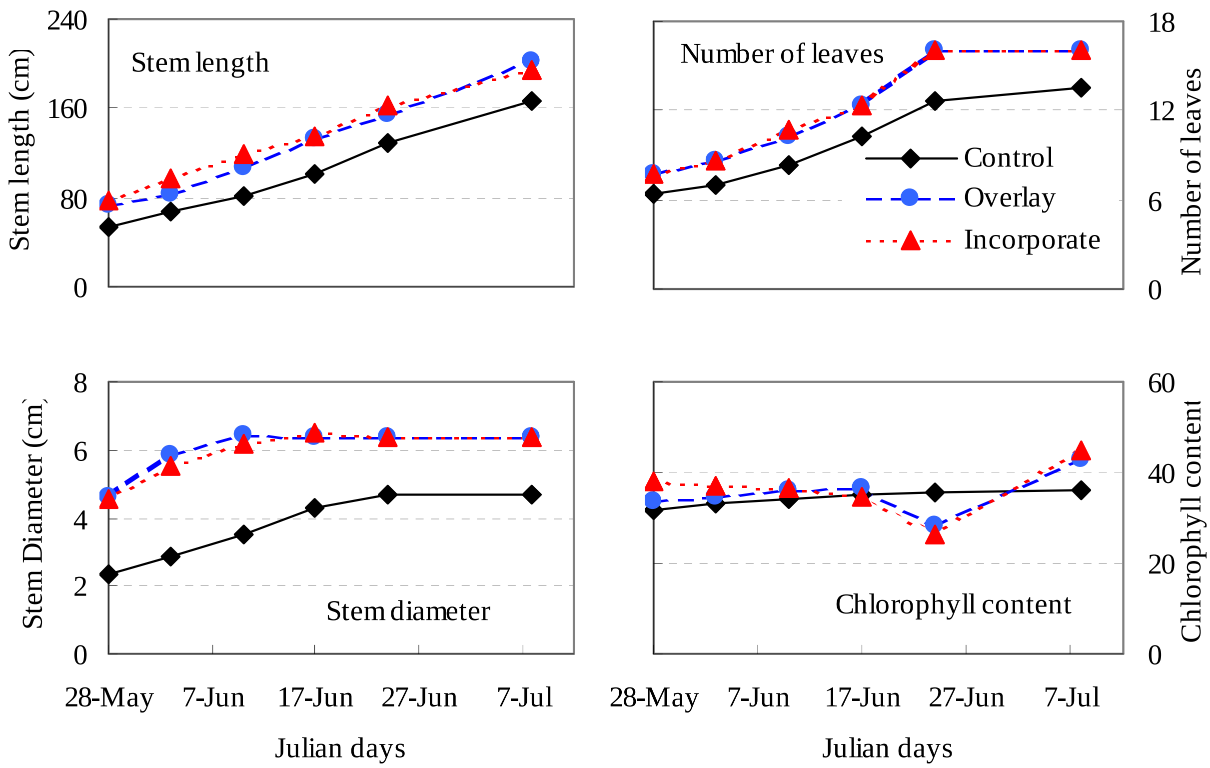

Figure 2 Stem length, number of leaves, stem diameter and chlorophyll Content in maize

SHOOT AND ROOT DRY WEIGHTS

The results of shoot and root dry weights and root-shoot ratio in cucumber indicated that the highest shoot dry weight was obtained in incorporate followed by overlay and control treatments (Fig. 3). The highest shoot dry weight in maize was obtained in overlay while the least obtained in control treatment (Fig. 3a). Root dry weight was recorded the least in control treatment for both cultivars while no differences were found in root dry weight in overlay and incorporate treatments either in cucumber or maize (Fig. 3b). The highest root-shoot ratio in cucumber was obtained in control treatment followed by overlay and incorporates treatments (Fig. 3c). On the contrary, in maize the highest root-shoot ratio was found in incorporate followed by overlay and control treatments.

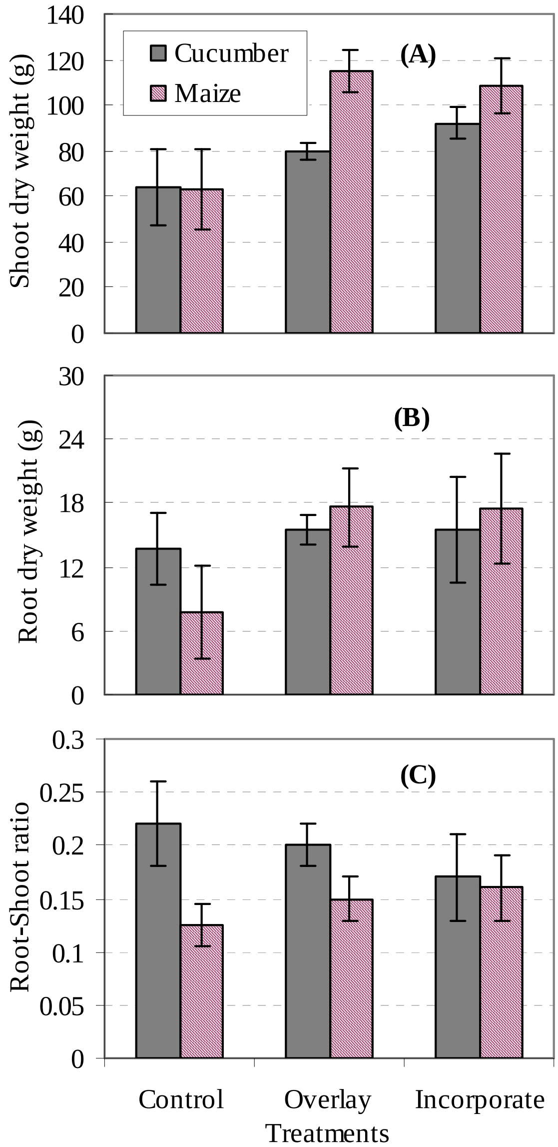

Figure 3 Average shoot dry weights (A), root dry weights (B) and root-shoot ratio (C) in maize and cucumber

Figure 4 shows the dry weights distribution of roots in 0-50 cm soil depth in cucumber and maize. About 55 % to 65% of the dry weight was present in 0-10 cm layer in both crops. In this layer, roots dry weight was recorded the highest in overlay followed by incorporate and control treatments. In 10-20 cm depth, the root dry weight in cucumber was the highest in incorporate treatment while the least in overlay treatment. The cucumber root dry weight in 40-50 cm depth was highest in control treatment. The maize root dry weight of incorporate and overlay treatments at 10-20 cm depth was similar but higher than that in control. In maize, the highest maize root dry weigh in 20-30 cm depth was recorded in incorporate treatment, while no differences were found between treatments in 30-40 and 40-50 cm depth.

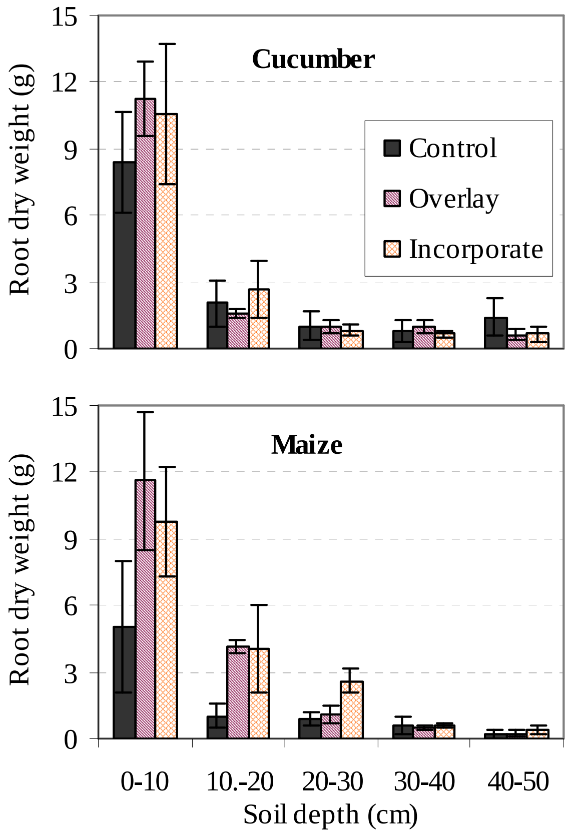

Figure 4 Root dry weights distribution at 50 cm soil depth in both cultivars

YIELD

The results of cucumber yield presented in figure 5 indicated that there were large differences between control and the other treatments. The overlay or incorporate treatments produced 2.5 times higher yield than the control. The overlay treatment produced 793 g/plant, incorporate treatment 786 g/plant and control treatment produced 312 g/plant. Because of poor pollination in maize, the plants failed to produce grains therefore; the evaluation of the yield was made on the basis of dry matter production. The highest dry matter was produced in overlay followed by incorporate and control treatments (Fig. 3a).

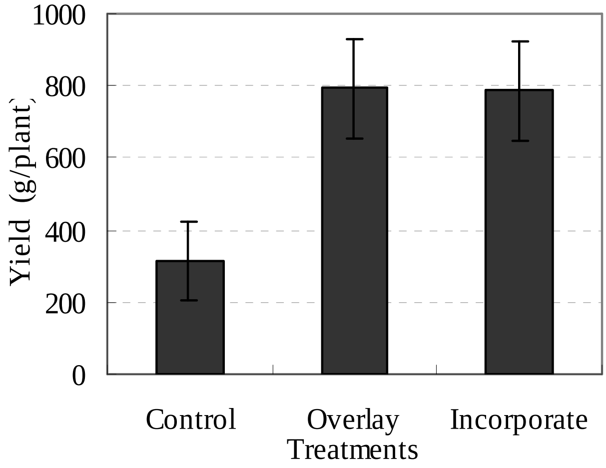

Figure 5 Yield of cucumber

SOIL MOISTURE DISTRIBUTION

Soil moisture distribution during the growing season at 5, 25 and 45 cm depth for cucumber and maize is shown in Figure 6. The highest soil water content was measured where the highest clay content existed. At 5 cm soil depth, the highest soil water content was obtained in overlay followed by incorporate and control treatments. At 25 cm depth, the highest soil water content was obtained in incorporate while small differences were found between overlay and control treatments. At 45 cm depth, the soil water content in control treatment was the highest except in the last month in maize when it was recorded the lowest. A large variation in soil moisture distribution was found in maize in the last month of the experiment. The soil water content of overlay and incorporate treatments increased while that of the control treatment decreased. The results also indicated that increasing soil depth under both crops increased the soil water content in the control treatment.

The change in soil water content variation before and after two hours of irrigation event is presented in figure 7. At 5 cm depth, the variation was the largest in overlay followed by incorporate and control treatments. At 25 cm soil depth, the highest soil water content was recoded in incorporate followed by control and overlay treatments. No change in soil water content occurred at 45 cm soil depth in all the treatments. The water retained in soil profile (50 cm depth) after two hours of irrigation was the highest in incorporate followed by overlay and control treatments in both crops (Fig. 8). The least amount of retained water was obtained in maize control treatment.

WATER USE EFFICIENCY

The amount of water used to produce 1 kg of dry matter in maize or 1 kg of cucumber yield under the condition of this experiment is shown in table 2. The lower the amount of water used to produce 1 kg, the higher the water use efficiency. Water use efficiency was the highest in overlay and the least in control treatments in maize while in cucumber the water use efficiency in overlay and incorporate was identical and very low in control. The applications of overlay or incorporate clay on or with sandy soil dramatically increased water saving in both crops. About 45 % in maize and 60% in cucumber of irrigation water can be saved compared to control treatment.

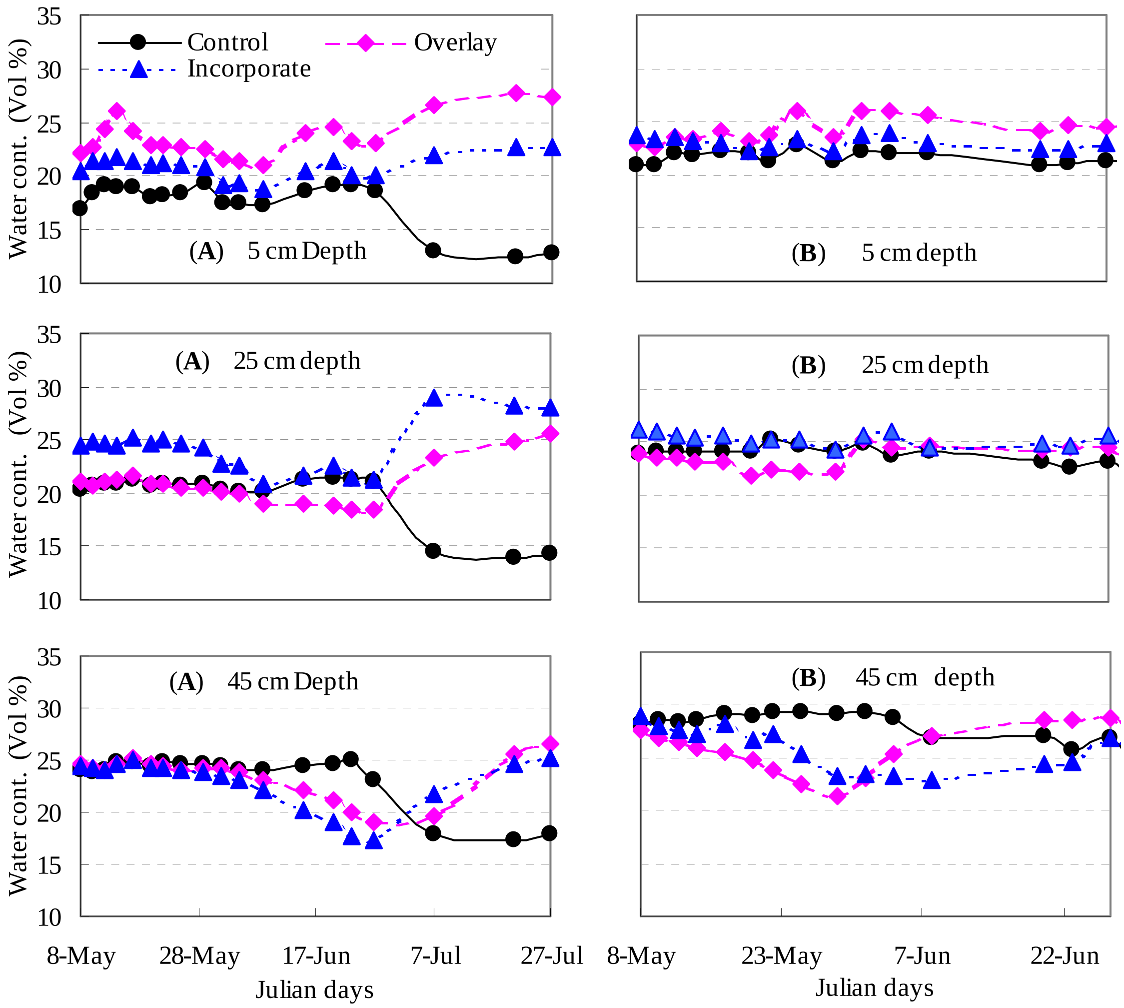

Figure 6 Soil water content distribution at various depths for maize (A) and cucumber (B)

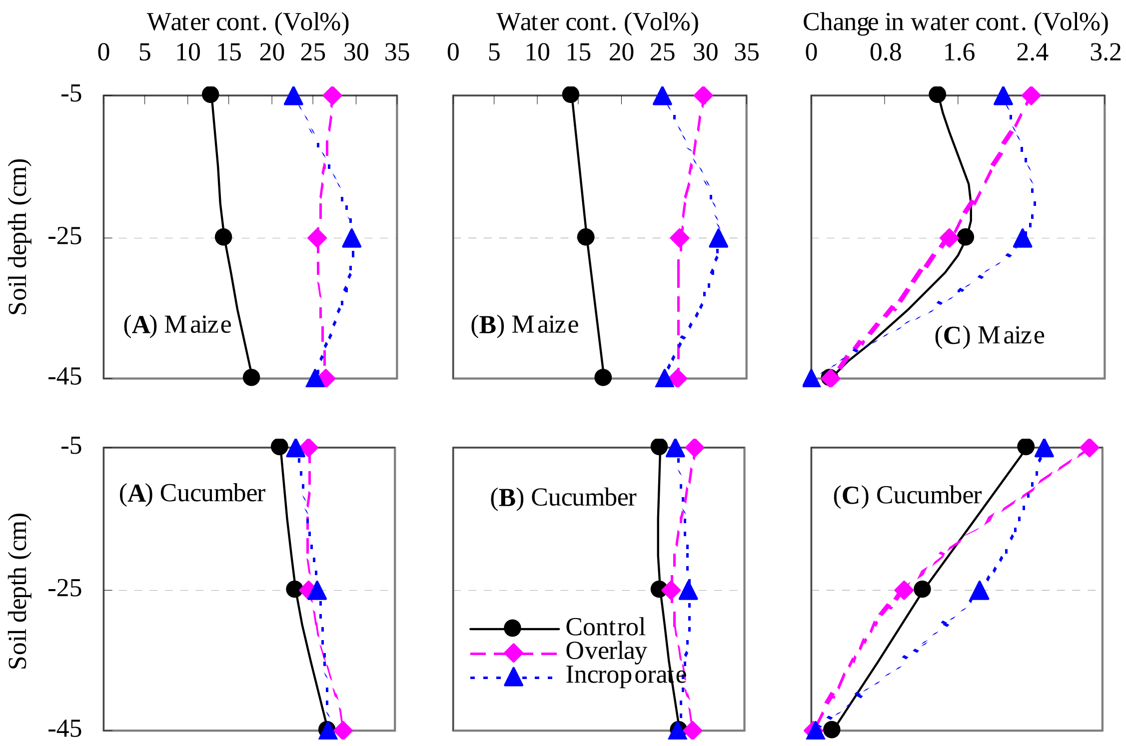

Figure 7 Soil water contented distribution over depth before irrigation (A), after 2 hours of irrigation (B) and the change in soil water content (C)

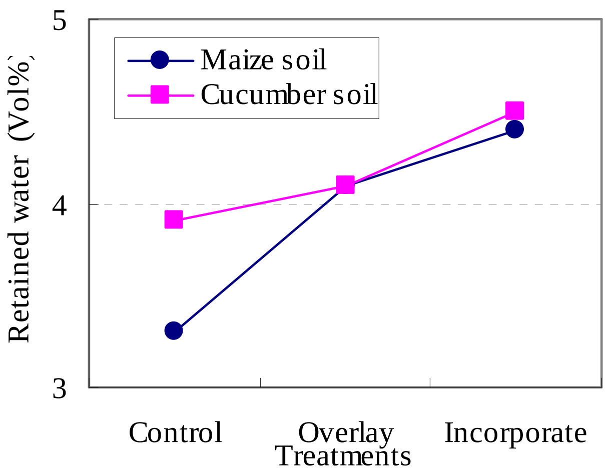

Figure 8 Retained water after 2 hours of irrigation event in maize and cucumber soils

Table 2 Water use efficiency and water saving in relation to control treatment

Treatments	Average water (L) produce 1 kg dry matter	Average water (L) produce 1 kg cucumber yield	Water saving relative to control treatment (%)	
	Maize	Cucumber	Maize	Cucumber
Control	70.7 ± 23.2	17.0 ± 7.6	-	-
Overlay	36.3 ± 2.8	6.1 ± 1.2	49	64
Incorporate	38.7 ± 4.4	6.1 ± 1.1	45	64

DISCUSSIONS

GROWTH CHARACTERISTICS

The results of leaf area index in cucumber (Fig. 1) and stem length, stem diameter and number of leaves in maize (Fig. 2) revealed that the control treatment was very low compared to overlay and incorporate treatments. No significant differences found between overlay and incorporate treatments for both cultivars. The results are due to available soil moisture content especially in cucumber, increase available soil moisture increased the leaf growth and consequentially leaf area index. In a study on the dynamic analysis of water relations and leaf area in cucumber carried out by Kitano and Eguchi [7] found that water deficit decrease leaf growth. Around the fair midday, the larger impact of the evaporative demand was imposed on plant water balance, and the competitive relationship between the higher evaporative demand and transpiration induced the midday water deficit, in which 10% of the shoot water content was lost.

This water loss resulted in midday stomatal closure and depression in leaf expansion, which were attributed to decrease in bulk leaf water potential, and turgor. These responses were estimated to relate the effects of midday water deficit on diurnal variations in plant hydraulic conductance and leaf extensibility. Also in maize the stem length, stem diameter and number of leaves were the least at control treatment because of the low available water content compared to the other treatments. The development of water stress led to reduce the shoot development and leaf extension [5, 15, 17].

Moreover, restricted water uptake results in low leaf water potential and cessation of leaf and shoot expansive growth [14]. The chlorophyll content in control treatment in cucumber was the highest compared to the other treatments because the photosynthesis and stomatal conductance were less affected by low soil water content [17], while the number of leaves in control is less than in the other treatments resulting in more chlorophyll content concentration compared to overlay and incorporate treatments (Fig. 1). The decline of chlorophyll content especially in maize for overlay and incorporate treatments at the mid-season may be due to the nutrient deficiency. Due to the large vegetative growth of both treatments and insufficient available nutrients in the soil the chlorophyll content is dramatically decreased compared to control, but after supply the second dosage of the fertilizers the chlorophyll content recovered and increased than control treatment (Fig. 2).

Shoots, root dry weights and root-shoot ratio

The results of shoot dry weight revealed that overlay and incorporate treatments look similar either in cucumber or maize while the least shoot dry weight obtained from control in both cultivars (Fig. 3a). The results were due to the low soil water content for control (Fig. 8) because low soil water content reduced shoot and leaf dry weights [20]. An inadequate amount of available water in soil hampers various physiological processes in plant and finally the crop yield. The high soil water content in incorporate treatment of cucumber (Fig. 8) resulted in the slight increase in shoot dry weight. The condition of limited available water in the soil to support plant growth is the most common form of stress that plants face. Low retained water in control treatment compared to overlay and incorporate treatments for both cultivars reduced root system size of control resulting in low root dry weight (Fig. 3b) because decreasing soil water content reduced root dry weight [9]. Another reason for the increased in root dry weight in overlay and incorporate treatments for both cultivars compared to control is the presence of clay content. Increase clay content in sandy soil encourages root proliferation intensively, resulting in large root system and consequently high root dry weight [2].

The gradually decrease in root-shoot ratio from control to incorporate treatment in cucumber (Fig. 3c) could be also due to soil water content. High soil moisture content at the containers bottom of control (Fig. 6) encourages cucumber to develop its root system at 40-50 cm depth resulted in higher root dry weight (Fig. 4) and root-shoot ratio compared to the other treatments. Sometimes soil water deficits reduce shoot growth before root growth was reduced, resulting in increase in root-shoot ratio because roots grew more than leaves during a period of water stress. Much carbohydrate accumulates into roots, because deceleration of upper plant growth by water stress decreases the carbohydrate translocation to upper plant parts. Much carbohydrate accumulation into roots decreases the root osmotic potential and increases root turgor potential, which lead to enhance root growth [18]. The presence of clay content in sandy soil encourage the maize root to grow intensively especially at the upper 20 cm compared to control. Growing the root rapidly should be met by rapid shoot growth because there is a close correlation between roots and shoot development. The maintenance of a proper balance between them is great importance. If either is too limited or too great in extent, the other will not thrive. Due to the clay treatment large root and shoot biomass were obtained from overlay and incorporate treatments and resulted in increase in root shoot ration compared with the control (Fig. 3c). Similar results reported by Kang et al [6] who said that encouraging the maize root development in soil vertical profile by alternate watering led to an increase in root-shoot ratio.

The largest root biomass was presented in the upper 10 cm of soil depth for all treatments for both cultivars (Fig. 4) because of the availability of water and nutrients in this layer. The highest root dry weight obtained from overlay treatment while the incorporate treatment was in second order because of the high clay content presented in these layers, but the clay content concentrated at 10 cm depth in overlay treatment while distributed in 20 cm depth in incorporate treatment. Distributing clay content at 20 cm depth in incorporate treatment also resulted in an increase in root dry weight at 10-20 cm depth especially in cucumber. Increase clay content resulted in high root dry weight. Root growth extends in all directions and if it encounters an area high in moisture or minerals it grows and branches profusely because of the less resistance in the wet soil [2, 8]. After 20 cm soil depth there were no differences in root dry weight between cucumber treatments except for control at 40-50 cm depth where high root dry weight was obtained. The increase in root dry weight in control at that layer was due to the high soil water content at 40-50 cm depth (Fig. 6). The increase in root dry weight at 20-30 cm depth in maize may be due to the increase in clay content transported with irrigation water and precipitated at that depth. Very low root dry weight was found at 40-50 cm depth especially at maize indicating that the root stay where the water and nutrients are available. Similar results reported by Panda et al [13] who published that the proper root depth to be considered for scheduling irrigation in maize is 0-45 cm.

YIELD

Overlaying or incorporating clay soil with sandy soil resulted in dramatic increase in cucumber yield (Fig. 5) or shoot dry weight in maize (Fig. 3a) compared to control. The ability of clay content to hold water and nutrients is very high compared to sandy soil, overlaying or incorporating clay soil with sandy soil increased the available water and nutrients at the upper 20 cm soil depth results in the large increased in cucumber yield or maize dry matter. Similar results found by Al-Omran et al [2] and Tan et al [21]. Slight increase in crop yield for overlay treatment was found compared to the incorporate treatment for both cultivars. The results may be due to the high soil water content presented in the surface layer of overlay treatment. When water content is decreased crop transpiration rate decreased as well resulting in increased crop canopy temperatures and crop water stress indeed values and resulted in reduced yield, [19].

SOIL MOISTURE DISTRIBUTION

The results of soil moisture distribution over depth (Fig. 6), the change in water content after irrigation (Fig. 7) and the retained water (Fig. 8) revealed that higher soil water content is related to the presence clay content. In the overlay treatment which has the high percentage of clay content at the upper 10 cm has the highest soil moisture content because clay minerals presented in the used soil have higher ability for water holding capacity. The addition of clay to sandy soil as a conditioner improved its hydraulic properties by limiting percolation losses while maintaining adequate infiltration rate and water retention [1]. As the percolation losses is decreased the retained water is increased, the nutrients losses is decreased consequently soil fertility is increased [16]. The improvements in soil water regime and soil fertility depend on the dominant type of clay minerals [10]. Another reason for increasing soil water content in sandy soil overlaid with clay content is the evaporation because the clay amendment decrease the evaporation rate leads to increase in retained soil water

[22]. The high soil water content measured at 25 cm depth in the incorporate treatment is due to the transported of the fine clay particles moved with irrigation water and precipitated at the small pore space between sandy soil particles. Precipitation of clay particles in fine pore spaces help to decrease percolation and increase water retention resulted in higher soil water content. During wetting and drying, some of clay is mobilized. Because of their rough surfaces, some sand grains become quite evenly coated with clay. These changes presumably represent the effect of capillary forces of water adhering to surface of quartz grains resulted in higher soil water content [10]. Due to the high infiltration rate of sandy soil in the control the irrigation water moved rapidly downward and accumulated at the bottom of the containers resulted in high soil water content at 45 cm soil depth in control treatment compared to overlay and incorporate treatments. The sharp decrease in soil water content of control treatment at the last month of maize experiment (Fig. 6) and the low retained water (Fig. 8) could be due to several reasons. Firstly the present of coarse sand in the maize soil is higher than cucumber soil (Table 1). Increase coarse sand resulted in high-saturated hydraulic conductivity; consequently higher water loss occurred in maize soil than in cucumber soil and resulted in sharply decreased in soil water content. Secondly, the high temperature in June-July months increased the evaporation especially from sandy soil. Thirdly, the majority of irrigation water is retained in the upper 20 cm due to high clay content.

WATER USE EFFICIENCY

High water use efficiency obtained from overlay and incorporate treatments compared with control in both cultivars because they consumed the lowest amount of water (Table 2). Comparing the yield production and water consumption of the treatments reveled that adding little amount of clay content can save large amount of irrigation water. The overlay and incorporate treatments saved about 49 % and 45 % in maize and 64 % in cucumber of the irrigation water relative to control treatment.

CONCLUSIONS

Remarkable improvements in crop yield, water retention and water use efficiency were done in sandy soil treated with clay. The leaf area in cucumber and stem length, stem diameter and number of leaves in maize were increased in the treatments, which treated with clay. About 2.5 times of yield was obtained from those treatments compared to control. Roots grew intensively in the layers treated with clay. The incorporate treatment retained higher amount of water than control but with small differences compared to overlay treatment. The water use efficiency and water saving is highly increased by clay application. About 45% - 64% of irrigation water can be saved compared to the control case. In conclusion overlaying or incorporate clay on or with sandy soil is a promising method for increasing yield, improving soil moisture distribution and increasing water use efficiency as well as increasing saved water.

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