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Full Length Research Paper

The effect of organic matter amendment on soil water holding capacity change for irrigation water saving: Case study in Sahelian environment of Africa

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The present study uses a computer simulation model to evaluate the improvement of soil water holding capacity through the application of different dosages of organic matter to three types of soil, namely sandy clay loam, sandy loam and sand under Sahelien condition. Additionally, a model for irrigation scheduling is tested for three selected crops (maize, bean and rice) in Ouagadougou region located in Burkina Faso, Sub-Saharan Africa. On the basis of the observed data conditions, the irrigation depths are numerically computed during the growing stages. The computed results are shown to be 5 times of irrigation for both maize and bean and 12 times of irrigation for rice. Rice crop presents high water depth and times of irrigation due to its high water requirement. The employed model provides a convenient tool to the extension agents for manually exploring the irrigation schedule in Burkina Faso. As the content of the soil organic matter increases to 4 tons, the soil holding capacity including permanent wilting point, field capacity, saturation and saturated hydraulic conductivity are improved for all types of soil in Ouagadougou. Thus, the organic matter application is recommended for enhancing the soil holding capacity in low rainfall area.

Key words: Irrigation scheduling, soil holding capacity, organic matter, Sub-Saharan Africa.

INTRODUCTION

Water use has grown more than twice of the population rate, and a number of regions are already chronically short of water (United Nations, 2006). According to Arshad et al. (2008), the scarcity of water is closely linked to food security, and irrigation can be a vital strategy for food security issue in developing countries. In Sub-Saharan African regions, due to the water resources scarcity and the growing of the population, irrigation is nowadays seen as a major strategy for supplementary production to ensure food security. According to Wang et al. (2009a, b), water resources scarcity is becoming a growing concern in Burkina Faso. Irrigation scheduling in water management and productivity has been widely discussed (Pereira et al., 2003; Cancela et al., 2006; Isla and Aragués, 2009; Egea et al., 2009).

In fact, irrigation scheduling was defined by Jensen (1981) as a planning and decision-making activity that the farm manager or operator of an irrigation farm is involved in before and during most of the growing season for each crop that is grown. In Burkina Faso, a continental landlocked African country located in the semiarid zone, the water limitation constraint requires the use of water with high efficiency. Irrigation sector development is one of the top priorities in the country's agricultural

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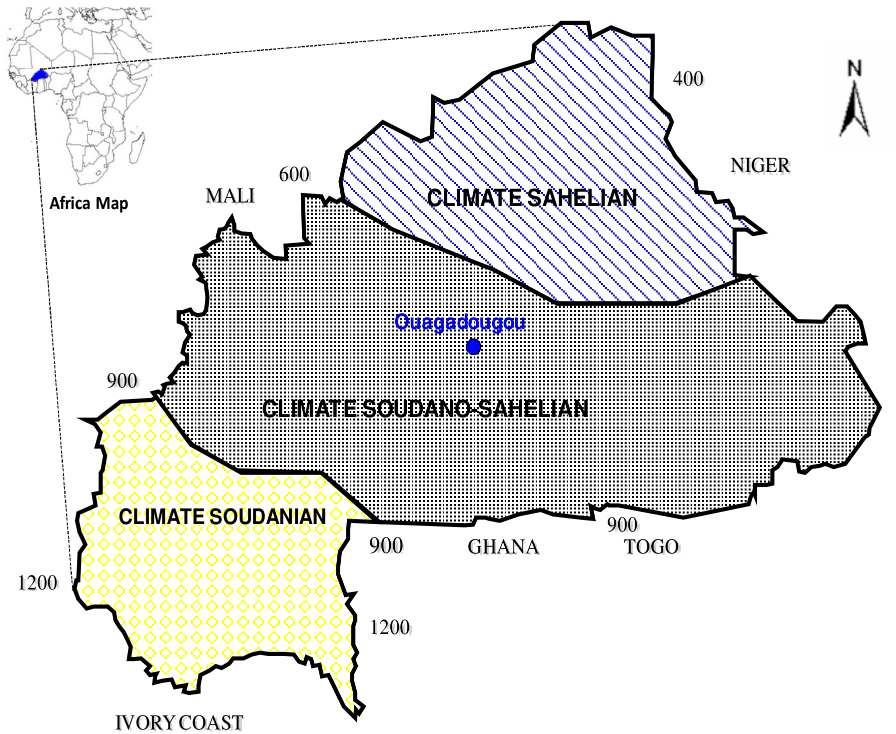

Figure 1. Map of the study area in Burkina Faso.

development policy seen as the supplementary production strategy for overcoming the food deficit. Nowadays, a number of computer simulation programs for proper irrigation scheduling planning are available, but their application is very limited even in quasi-inexistent areas where the irrigation practitioners do not have both skills and access to computer.

The lack of such tool makes the irrigation scheduling very hard in regional scale where most of the irrigated lands are. Among the irrigation scheduling models world widely developed, to the know-ledge of the authors, these noteworthy models extensively well documented have no application reported in literature in Burkina Faso. Therefore, the numerical computations of irrigation depth and time in Burkina Faso are extremely important particularly in the irrigation production areas. A scheduling model can be applied by extension agents and revolutionize considerably, the issue of water efficient management in the country.

Mismanagement of irrigation has adverse effect on both soil and crop. Excessive irrigation delays maturity (Hagan et al., 1967), maximizes the farm operation cost (Molle, 2009); while its insufficiency induced the water stress to the crop (Tolk and Howel, 2002). In both cases, productivity level declines seriously, particularly, in low rainfed areas. As recently suggested by Kundu and Sarkar (2009), the application of irrigation water must be optimum for achieving high yield and high crop water use efficiency. Several authors such as Pereira et al. (2002) and Cancela et al. (2006) have discussed the impact of irrigation scheduling performance under water scarcity condition. Therefore, for achieving this goal in Burkina Faso, the objectives of this study are to: (i) Test a model for irrigation scheduling in Ouagadougou region located in Burkina Faso in Sub-Saharan Africa; and (ii) Evaluate the soil holding capacity improvement through different dosages of organic matter application under computer simulation assistance with soil data generated.

MATERIALS AND METHODS

Study site

The area under study is Ouagadougou located in North Soudano-Sahelian zone of Burkina Faso at 306 m altitude, 12°35'N latitude and 1°52'W longitude (Figure 1). Ouagadougou region has a semiarid tropical climate. The region has two seasons; rainy season from May to October, and dry season from November to April. The annual average rainfall during the last ten years is 698.49 mm. In the region, 83.20% of rainfall occurs between June and September with at peak in August (196.04 mm). The annual minimum and maximum air temperatures are ranged from 17.72 - 27.45 and 31.42 - 39.82°C, respectively. The temperatures fluctuate according to the seasonal trend with low and high values during the dry and wet season, respectively (Figure 1). The relative humidity means are 33.90% in dry season and 65.92% in rainy season with an annual average of 48.49%. The relative humidity also has a seasonal trend, being low in dry season and high in wet season. Wind velocity recorded during the study period at 2 m above the ground has an annual average of 145 km day^{-1}. For the purpose of this study, the decadal climatic data were recorded from 1996 - 2007. The data were comprised of maximum and minimum air

Table 1. Suitable dates for planting and length of growing stages information for the crops selected from Ouagadougou region.

	Crop		
	Rice FKR-28	Maize	Bean
Suitable planting dates	5-Jun	15-Jun	20-Jun
Total growing stage (day)	125	105	95
Initial	30	20	15
Development	30	30	25
Mid season	35	35	35
Late season	30	20	20

Table 2. Rooting depth during the different growing stages for the crops selected from Ouagadougou region.

Growing stage	Crop rooting depth		
	Rice FKR-28	Maize	Bean
Initial	0.6	0.5	0.5
Development	0.7	0.7	0.7
Mid season	0.8	0.9	0.8
Late season	0.9	1.0	0.9

Table 3. Textures of the three types of soils used to evaluate the effect of soil organic matter amendments in soil water holding properties for dry environment condition.

Type	Soil	Sand (%)	Clay (%)	Silt (%)
Type I	Sandy clay loam	50	30	20
Type II	Sandy loam	60	20	20
Type III	Sand	90	5	5

temperature (℃), precipitation (mm), relative humidity (%), wind velocity (km day^{-1}) and sunshine duration (h).

Soil and crop information

The soil surface layer (0 - 30 cm) in Ouagadougou is sandy, loam and clay with 40% of sand, 30% of silt and 20% of clay, approximately. The field capacity, Permanente wilting point and bulk density are 28.0% Vol, 13.7% Vol and 1.43 g/cm^3, respectively. The three major crops selected are the maize; dry bean and upland rice have been selected for the present study. As suggested by Brouwer and Heibloem (1986), the crops growth parameters such as growing duration, rooting depth provided by the agricultural extension services were obtained from local information. Table 1 gives the selected crops length of growing stages and suitable planting dates. The suitable planting dates have been obtained from a previous study done by Wang et al. (2008) in Ouagadougou. Table 2 shows the crop rooting depth during the different growing stages in Ouagadougou. For evaluating the importance of organic matter on the soil water holding capacity, this study simulated the soil organic matter content of three important types of soil mostly found in Ouagadougou, by using the Soil Water Characteristics software 6.02.74 implemented by the USDA Agricultural Research Service for generating the soil information. Table 3 illustrates the types of soil taken into account.

Irrigation scheduling model

Irrigation depth will bring soil moisture content back to field capacity; thus equal to the depleted soil moisture in the root zone. The irrigation scheduling should take into account the soil properties that affect the soil moisture-holding capacity. Irrigation depth to be applied depends on the soil available water content (AWC) in the actual plant root zone, the crop grown and stage of growth and the crop evapotranspiration or water requirement which is used to compute how often the irrigation depth must be supplied. Allen et al. (1998) have widely discussed in FAO56, the general form of the irrigation water depth determination from soil and crop information. Based on this basic concept, this study computes the irrigation water depth using the following equation:

$$d = \frac{Pac}{100} * AS * D_i \quad (1)$$

where d is the irrigation depth (mm), AS is the bulk density (g/cm3), D_i is the root zone depth (m) for the corresponding i stage, and Pac is given as $Pac = \frac{1}{2}(FC - PWP)$ with the FC and PWP standing for the Field Capacity and Permanente Wilting Point, respectively.

The time of irrigation is determined by using the ratio between irrigation water depth and the estimated crop water requirement (ETc in mm day^1) which is computed from the FAO56 Penman-Monteith reference evapotranspiration (ETo) and crop coefficient (Kc) as:

$$ETc = Kc * ETo \quad (2)$$

The relative impact of climate on crop required the adjustment of Kc. The crop coefficients were adjusted to local climate condition according the method suggested by Allen et al. (1998). For specific adjustment of Kc mid and late season in climates where RHmin differs from 45% or where wind speed (u_2) is larger or small than 2.0 m/s, the procedure is given as (Allen et al., 1998; Allen, 2000; Smith, 2000):

$$K_{c.mid} = K_{c.mid(Tab)} + \{0.04(u_2 - 2) - \\ - 0.004(RH_{min} - 45)\}(\frac{h}{3})^{0.3} \quad (3)$$

Where $K_{c.mid(Tab)}$ is the value for kc mid season referred to (FAO56), u_2 is the mean value of wind, RH_{min} is the mean value of relative humidity and h is the mean plant height during the mid season.

This study used the physically-based complex Penman-Monteith (PM) equation, which is universally recommended by the Food and Agriculture Organization of the United Nations as the sole accurate method to calculate the reference evapotranspiration (Allen et al., 1998). PM model incorporates thermodynamic and aerodynamic aspects, and has unanimously proved to be a relatively accurate method in both humid and arid climates. The equation always performs the highest accuracy results of reference

Table 4. Irrigation water depth computed during the crops growing stages.

Growing stage	Irrigation water depth (mm)		
	Rice FKR-28	Maize	Bean
Initial	6.13	5.16	5.10
Development	7.15	7.16	7.00
Mid season	8.18	9.20	8.00
Late season	9.00	10.22	9.00

evapotranspiration. Its calculation equation is given by Allen et al. (1998) as follow:

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (4)$$

where ET_o is the reference evapotranspiration [mm day^{-1}]; R_n the net radiation at the crop surface [MJ m^{-2} day^{-1}]; G the soil heat flux density [MJ m^{-2} day^{-1}]; T the mean daily air temperature at 2 m height [°C]; u_2 the wind speed at 2 m height [m s^{-1}]; e_s the saturation vapour pressure [kPa]; e_a the actual vapour pressure [kPa]; e_s - e_a the saturation vapour pressure deficit [kPa]; Δ slope vapour pressure curve [kPa $°C^{-1}$]; and γ psychrometric constant [kPa $°C^{-1}$].

RESULTS AND DISCUSSION

Irrigation depth

The study was conducted under no rainfed condition by neglecting the rainfall data. From the observed data conditions, the irrigation depths were numerically computed during the four growing stages of the three majors' crops, which are the maize, bean and rice selected in this study. The irrigation water depths for each growing stage are given in Table 4. The application of the computed water depth will bring back the soil moisture content to field capacity; thus equal to the depleted soil moisture in the root zone. Indeed, the water depth difference observed among growing stage under the same soil condition for the considered crops is due to the rooting depth variation. The development of the crop rooting system is dependent of the crop water demand which usually increases from the development stage to mid season stage. The deeper the rooting depth, the higher the water depth to be applied. To accurately estimate the water depth when scheduling, the rooting must be considered as an important variable. According to Rumikhani (2002), the amount of applied irrigation water depends on crop requirement at each growth stage and the soil capacity to hold water. The crop rooting system has significant role in the time and amount of water needed to be applied in the soil.

Time of irrigation

Irrigation may vary among different climates and soils condition, and crop water needs. The time of irrigation for the selected crops determined during their growing stages were 5 for both maize and bean, and 12 for the rice. The sandy loam clay soil in Ouagadougou with 40% of sand has a low water holding capacity; this induce frequent irrigation in the scarcity of rainfall. James et al. (1982) reported that the irrigation scheduled with soil of low water-holding capacity would have to be more frequent with smaller amounts applied each time to attain the best efficiency. The results show that more frequent irrigation is required for rice due to its high crop water consumption.

In African Sahelian regions, studies revealed that rice crop has high water demand which limits its cultivation in several areas under rainfed condition (Traore et al., 2007; Wang et al., 2008). The high water requirement of rice crop in the observed condition is evidenced in Figure 2, which shows the change in cumulative daily crop evapotranspiration (ETcrop) under time compared to the effective rainwater supply in the study area. The total ETcrop computed were; 406.03, 434.61 and 699.88 mm for bean, maize and rice, respectively. From Figure 2, with the advancement of the growing period, linear increase in cumulative ETcrop was obtained with rice conversely to maize and bean. This implies that from early to maturity stage, rice water demand increases continuous, which is higher than the two other crops, and also higher than the rainwater supply. In propagating maize and bean from the suitable planting dates, irrigation must be applied 5 times during the entire growing season. While, for rice during its entire growing stages, irrigation should be applied 12 times.

The irrigation intervals from this study determined for rice shows high values of water requirement during the initial and development stages. This implies that the higher the crop water demand, the more frequent the time of irrigation in order to compensate evapotranspiration loses. In line with this observation, an irrigation schedule that varies according to crop, the growth stages can save irrigation water and increase the yield.

Since it is well known that water stress significantly affects the yields and its component (Onder et al., 2005) and excess water have negative impact the maturity (Hagan et al., 1967), the irrigation scheduling based on the computation model should be suggested in Burkina Faso. The numerical model employed in the present study provides an important tool to irrigation practitioners in Burkina Faso in order to compute the irrigation water depth and interval, easily.

Effect of organic matter on soil water holding capacity

The soil holding capacity is a fundamental component in scheduling, therefore, has been evaluated through different dosage of organic matter application under computer simulation assistance with soils data generated.

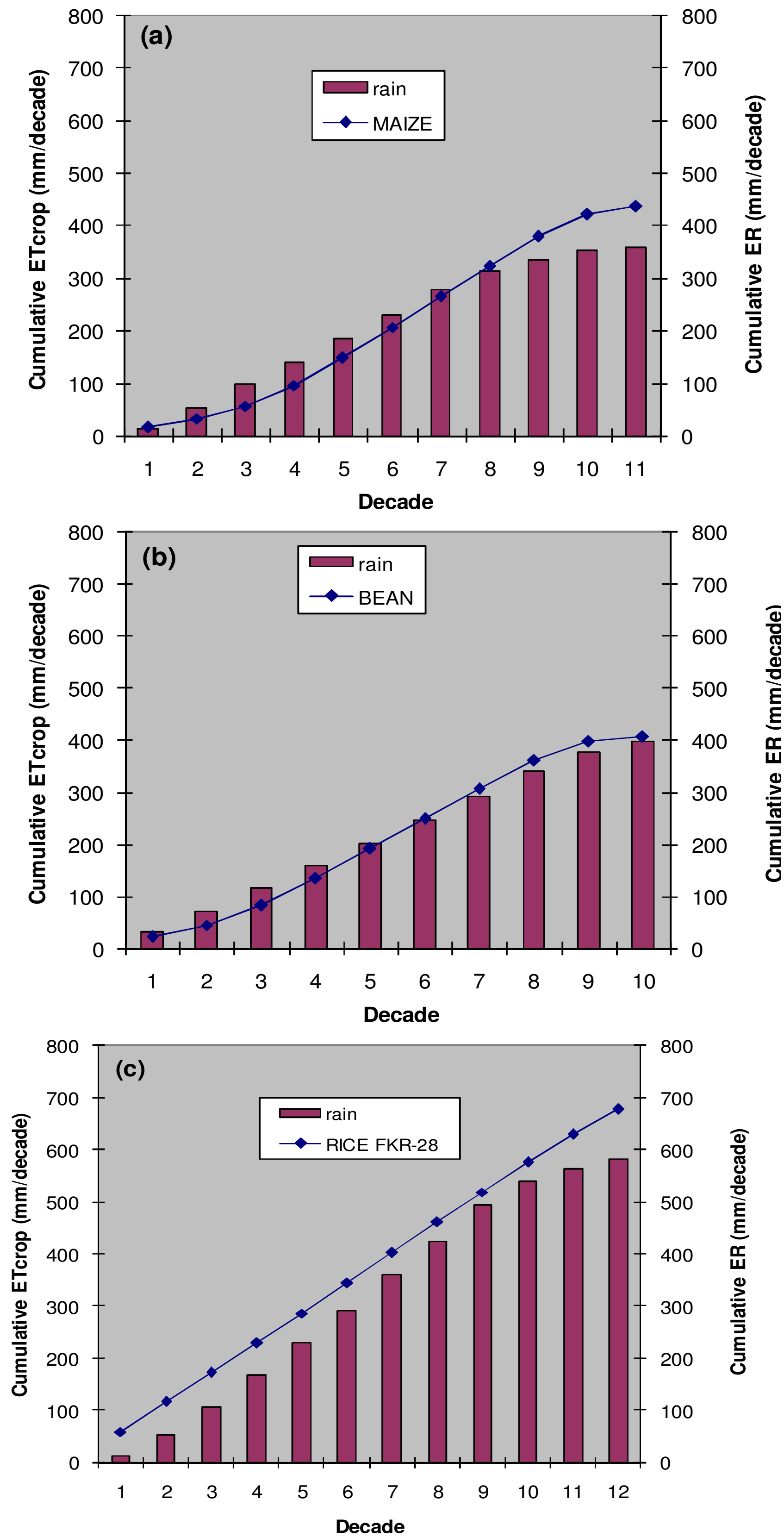

Figure 2. Comparison of the change in cumulative daily crop evapotranspiration (ETcrop) under time to effective rainfall (ER) for: (a) Maize (b) Bean and (c) Rice in Ouagadougou region.

Table 5. Sandy clay loam (Type I) soil physical properties under the variation of the organic matter content.

Soil properties	Organic matter (tons)								
	0	0.5	1	1.5	2	2.5	3	3.5	4
Permenante wilting point (% Vol)	18	18.2	18.5	18.8	19	19.23	19.6	19.8	20.1
Field capacity (% Vol)	28.8	29.2	29.6	30	30.5	30.9	31.3	31.7	32.2
Saturation (% Vol)	40.4	41.2	42	42.8	43.7	44.5	45.3	46.1	47
Available water (cm/cm)	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12
Saturated hydraulic conductivity (mm/hr)	3.92	4.32	4.75	5.21	5.69	6.2	6.74	7.32	7.92
matric bulk density (gcm/^{3})	1.58	1.56	1.54	1.51	1.49	1.47	1.45	1.43	1.41
Matric potential (Kpa)	814	915	1027	1150	1287	1438	1500	1500	1500
Hydraulic conductivity (mm/hr)	3.07*10-6	2.30*10-6	1.73*10-6	1.3*10-6	9.9*10-7	7.56*10-7	6.79*10-7	6.76*10-7	6.74*10-7

Table 6. Sandy loam (Type II) soil physical properties under the variation of the organic matter content.

Soil properties	Organic matter (tons)								
	0	0.5	1	1.5	2	2.5	3	3.5	4
Permenante wilting point (% Vol)	11.9	12.3	12.7	13	13.4	13.8	14.1	14.5	14.8
Field capacity (% Vol)	21.1	21.7	22.3	22.9	23.5	24.1	24.7	25.3	25.9
Saturation (% Vol)	38.6	39.6	40.7	41.8	42.8	43.9	45	46.1	47.1
Available water (cm/cm)	0.09	0.09	0.1	0.1	0.1	0.1	0.11	0.11	0.11
Saturated hydraulic conductivity (mm/hr)	13.39	14.43	15.52	16.67	17.88	19.14	20.46	21.84	23.29
matric bulk density (gcm/^{3})	1.63	1.6	1.57	1.54	1.52	1.49	1.46	1.43	1.4
Matric potential (Kpa)	59	71	85	101	121	144	171	203	240
Hydraulic conductivity (mm/hr)	1.77*10-4	1.17*10-4	7.78*10-5	5.23*10-5	3.55*10-5	2.44*10-5	1.69*10-5	1.19*10-5	8.42*10-6

The study simulated the soil organic matter content of three soil categories mostly found in Ouagadougou, by using the soil water characteristics software for generating the soil required data. The general texture of desert soil is dominated by the sand. Generally speaking, sandy soils tend to be low in organic matter content and native fertility, low in ability to retain moisture and nutrients, low in cation exchange and buffer capacities, and rapidly permeable to water and air. An increase of the soil organic matter also improves the soil water holding capacity (Tables 5, 6 and 7).

It was found that the poor water quality. Organic matters improve soil water properties (e.g., infiltration, water-holding capacity, and plant-available water). In Burkina Faso, this can be crucial for water resources management with its implication in crop high productivity. Organic matter effect on improving the soil water holding capacity is evidenced from the simulation results of this study. In the desert region where there is low rainfall combined with the low soil water holding capacity, organic matter application in the field improves significantly the use of rainwater. Besides, it improves the soil hydraulic conductivity by improving the water movement through pore spaces and fractures. To conclude, this will improve the efficiency of the irrigation scheduling by reducing the water depth to be applied and increasing the irrigation interval.

Conclusions

Scheduling irrigation is imperative in the areas where water resources are scarce. Numerical computation can be a key component of reducing agricultural water demand in the country where climatic features remain the natural constraints. A numerical model based on soils and crops information was used for determining the irrigation schedule of crop production. As a result, the amount and frequency of irrigation water depend on the soil available water content in the actual plant root zone, the crop grown and stage of growth and the rate of evapotranspiration of the crop. The numerical model was proved to be an important approach for Burkina Faso to improve the irrigation water use efficiency for helping the farmers engaged in the small scale irrigation production. Globally, the computational results from this study are required for high efficient management of irrigation water for the entire nation. Adopting the present model, agricultural extension agents can help farmers to improve the farm irrigation at low cost by saving and using water efficiently, throughout the production areas. The organic matters applications into the soil from the simulation results were found to improve the soil water holding capacity. This can be a strategy for improving the efficiency of the irrigation scheduling by reducing the water depth to be applied and increasing the irrigation

Table 7. Sandy (Type III) soil physical properties under the variation of the organic matter content.

Soil properties	Organic matter (tons)								
	0	0.5	1	1.5	2	2.5	3	3.5	4
Permenante wilting point (% Vol)	2.2	2.8	3.3	3.9	4.4	5	5.6	6.1	6.7
Field capacity (% Vol)	6.3	7	7.7	8.4	9.1	9.9	10.6	11.4	12.2
Saturation (% Vol)	40.3	41.9	43	44	45.1	46.2	47.3	48.5	49.6
Available water (cm/cm)	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05
Saturated hydraulic conductivity (mm/hr)	106.88	106.21	106.6	107.67	109.22	111.12	113.3	115.7	118.3
matric bulk density (gcm/^{3})	1.57	1.54	1.51	1.48	1.45	1.43	1.4	1.37	1.34
Matric potential (Kpa)	21	22	22	23	24	25	25	26	27
Hydraulic conductivity (mm/hr)	5.35*10-2	1.95*10-2	7.32*10-3	2.85*10-3	1.15*10-3	2.44*10-5	1.69*10-5	1.19*10-5	8.42*10-6

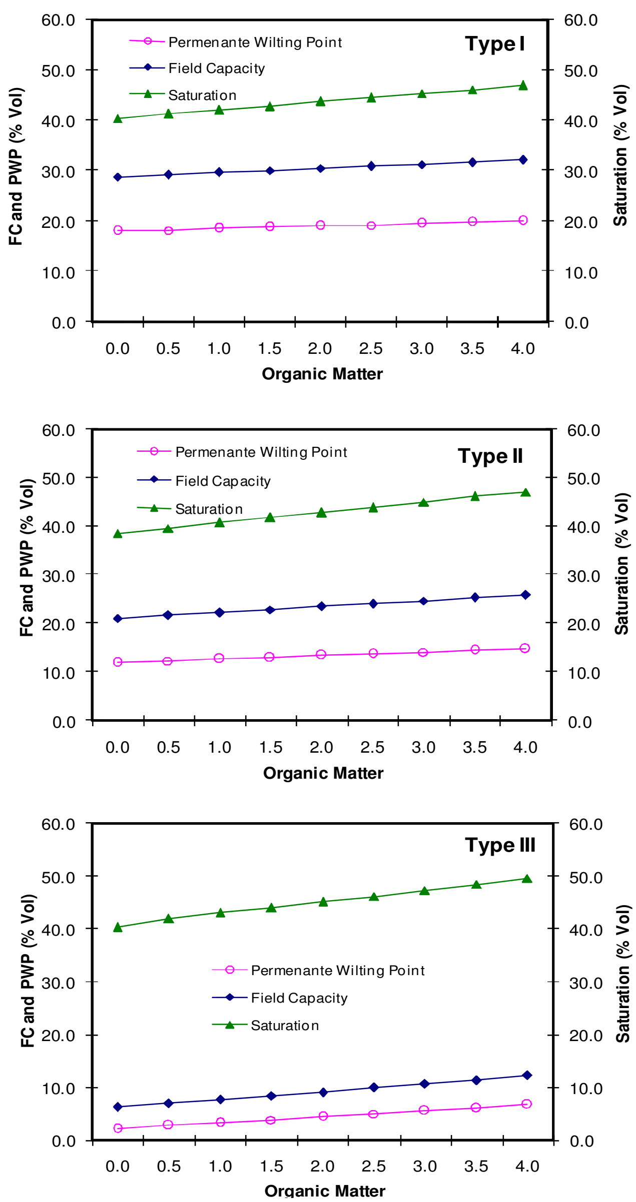

Figure 3. Change in soil water holding capacity (PWP, FC, saturation) under different dosage organic matter for soil Type I (Sand Clay Loam), Type II (Sand Loam) and Type III (Sand).

interval. In other dry areas, the results of this study regarding to the organic matter amendment can be implemented for practical application by supporting farmers through educational training program. Obviously, under the context of climate change, the irrigation water depth and interval will change according to the areas and crop needs.

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