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DETERMINATION OF THE APPROPRIATE IRRIGATION METHODS BASED ON SOIL ANALYSIS FOR UPLAND FIELDS IN MIE PREFECTURE OF JAPAN

*Abdul Saboor Rahmany [1], Hajime Narioka[2], Takamitsu Kajisa[3] and Homayoon Ganji[3]

[1]Directorate of Agriculture Irrigation and Livestock, Herat, Afghanistan
[2]Laboratory of Terrestrial Land and Water Engineering, [3]Laboratory of Water Resource Engineering,
Graduate School of Bioresources, Mie University, Japan

*Corresponding Author, Received: 12 Dec.2017, Revised: 29 Jan. 2018, Accepted: 10 April 2018

ABSTRACT: Inappropriate irrigation methods lead to loss much water in most upland fields worldwide. Land suitability is one of the good management practices for determining appropriate irrigation methods in upland fields. To determine land suitability, various soil experiments as determination of basic physical soil properties, permeability, saturated hydraulic conductivity and soil moisture characteristics method are important. This study was conducted on soil experiment with the aim to provide a detailed comprehensive understanding of soil capabilities for applying certain irrigation methods in two upland fields, broccoli field (BF) and tomato field (TF), in Mie prefecture of Japan. Soil physical structure properties, water holding capacity, and hydraulic properties were determined using disturb and undisturbed soil samples on laboratory bases. The results obtained showed that TF had deeper effective soil layer of 30 cm, better structure (more porosity, better pores connectivity, and channeling), the water holding capacity of 0.082 mm mm^{-1}, and higher hydraulic conductivity, compared to BF. It is concluded that TF is suitable for applying shallow surface irrigation method, while the BF have better response on micro-irrigation methods which prevents water pounding in this fields. Application of this approach can improve irrigation practices and efficiency and decreases water loses through accurate irrigation scheduling and application management of irrigation water in upland field agriculture system, especially in dry areas.

Keywords: Upland field, Soil analysis, Soil structure, Irrigation, Irrigation methods

1. INTRODUCTION

Demand for food and raw materials are increasing with world population growth. To ensure food security for world’s increasing population, a great concern should be put on sustainable use of natural resources, especially freshwater resources, which is even more important for arid and semi-arid climates.

More than a third of the world's food is now requiring irrigation for production [1], wherein average in the world, irrigation demands more than 70% of consumptive allocated fresh water, while irrigated agriculture occupies approximately 17% of the cultivated regions [2,3].

Sustainable use of freshwater resources in agriculture is partially possible through improvements of water use efficiency [4]-[5]. Furthermore, high water use efficiency can be ensured when good irrigation planning, precise irrigation scheduling, good management and agronomic practices are practiced alongside extra technology [6-8].

Lack of proper irrigation planning and irrigation scheduling can create and increase water stress in the crop, as a result, economic yield loss; on the contrary, it can cause water loss and fertilizer leaching due to excess application of irrigation water. Optimal irrigation planning and scheduling can only be achieved when detailed information about soil, water, and climate is available. Detail information about soil includes those parameters that determine the land suitability and the ability for irrigation and production, such as; effective soil depth (ED), soil pores system and matrix interaction, soil water holding capacity (SWHC), and hydraulic properties.

Different water use efficiency models have been practiced and proposed for irrigation scheduling. Weather-based models are good for estimating evapotranspiration (ET) and future irrigation needs over large areas [9-11].

Alminana [12] and Cid-Garcia [13] proposed mathematical multidisciplinary models for irrigation planning and scheduling that cover a broad range of variables of soil, water, irrigation network, technical conditions, and logistics.

Computer application models that are available for irrigation scheduling include FAO-CROPWAT and Irrigation Scheduling Model – ISM [14]. Both programs need many components for planning and calculation as weather data, soil information, and crop data to be inputted manually. For example; FAO-CROWAT is a good application for large-scale water demand calculation and canal discharge design, while for small scale if detailed laboratory results for soil water holding capacity is not provided, the result is not accurate enough since the data for soil is set-up as a general estimate.

Shang [15] proposed a simulation-optimization model of irrigation scheduling with limited water, which soil water balance is an important component of the model. However, they did not point out other soil parameters that influence water balance in the soil.

Some soil-based methods and models measure the soil state variables, soil water potential, that indicate water status of the substrate by means of tensiometers. These models allow water saving and improve crop growth [16]-[17]. However, irrigation control based on sensors like tensiometers can suffer from some technical problems, like their placement, the establishment of good contact with soil particles and need for constant controls.

Result for some researchers and studies highlight the importance and need for detailed soil investigation for the planning of irrigation and scheduling. For example, Home [18] studied the effect of soil moisture depletion based on irrigation scheduling and method of irrigation. He found that water loss through deep percolation is significantly influenced by irrigation method, timing and amount of applied water.

Smith [4] showed the dependency between deep drainage and irrigation management. He mentioned that magnitude of deep drainage is greater on light textured soils and where the depth of irrigation water applied is high. He suggested for maximum irrigation performance and minimal deep drainage, accurate measurement of soil moisture deficit should be applied.

Guo [19] optimized supplemental irrigation for winter wheat based on measured water content of various soil layers and the result showed that the increase in yield, yield component, and water use efficiency was related to soil water consumption. In other studies, Zuo [20] indicated how soil water distribution from the soil surface to maximum rooting depth was significantly affected by irrigation method and quantity. Shi [21] in his research indicated that besides arithmetic average of soil water content, the relative distribution of water and roots were important factors affecting plant water status.

These researches address the fact that the soil resource is a dynamic freshwater reservoir and its ability to plant-available water varied temporally and spatially [22]-[23] and require detailed investigation of soil for soil-based irrigation planning.

Soil physical structure as the main attribute of soil quality is an important and unavoidable property of soil for agriculture, since each property of physical structure of soil, directly and indirectly, can affects, limits, and favors management practices, “soil-plant-water” relationship, plant growth, and yield. Irrigation planning and water use efficiency as management practices are quite dependent and interrelated to soil physical structural properties, therefore determining land suitability is one of best practices.

2. MATERIALS AND METHODS

2.1 Study Site and Laboratory Experiments

The study sites were selected for their location in the upland area in Mie prefecture of Japan. Details about the fields are shown in Table 1. Three different steps were conducted for soil determination. The first step was field investigation. This investigation consisted of determination of soil profile cross-section and on-site physical properties such as determination of soil texture, soil structure, effective depth and the existence of hardpan.

The second step was the collection of disturbed and undisturbed soil samples for laboratory analysis, and the third step was laboratory analysis. Soil analysis experiment was done in a soil physic laboratory. Four different experiments, basic physical soil properties, permeability-saturated hydraulic conductivity and soil moisture, using disturbed and undisturbed soil samples were conducted.

Basic physical properties, bulk density, particle density, soil particle distribution, porosity, and soil three phase ratios of soil samples were determined under standard laboratory condition and procedures.

Permeability-saturated hydraulic conductivity was determined, using core soil samples for capillary saturation which were left over 24 hours. The constant head saturated hydraulic conductivity was conducted based on Darcy law which is shown by Eq. (1).

$$\boldsymbol{k_{\mathrm{sat}} = \frac{Q}{At}\frac{l}{h}} \qquad (\mathbf{1})$$

Where: $\boldsymbol{k_{\mathrm{sat}}}$ is saturated hydraulic conductivity (cm sec^{-1}), Q is drainage discharge volume (cm^3), A is core cross section area (cm^2), l is core length (cm), t is drainage measurement time (sec), and h is difference of water height from drainage point to water level in water supply, bottle, (cm).

The results were converted to 20℃ by using Eq. (2) and (3).

$$\boldsymbol{C = \frac{\mu_{\mathrm{T}}}{\mu_{20}}} \qquad (\mathbf{2})$$

$$\boldsymbol{k_{20} = k_{\mathrm{sat}} \times C} \qquad (\mathbf{3})$$

Where: C is water temperature correction coefficient, $\mu_{\mathrm{T}}$is viscosity coefficient of water at T °C in which the experiment was conducted, μ_{20} viscosity coefficient of water in 20℃ and k_{20} is the saturated hydraulic conductivity at 20℃ (cm sec^{-1}).

Soil moisture characteristics were determined, using 100cc core capillary saturated samples which were placed in pressure plate device. The pressure loads were adjusted when equilibrium condition was met at each level of allied pressure. Core sampler with the sample was weighed before and after applying each pressure load. The collected data were used for plotting pF-θ curve. Volumetric water content θ for plotting the curve was calculated, using Eq. (4) and (5).

$$\boldsymbol{m_{\mathrm{w}} = m_{\mathrm{t}} - [m_{\mathrm{c}} + m_{\mathrm{dry}}]} \qquad (4)$$

$$\boldsymbol{\theta = \frac{m_{\mathrm{w}}}{V_{\mathrm{c}}}} \qquad (5)$$

Where: m_{w} is ma ass of water (g), m_{t} is total mass (g), m_{c} is mass of core (g), m_{dry} is mass of dried sample (g), θ is volumetric water content (g cm^{-3}), and V_{c} is volumethe of core (the cm^3).

Table 1 Details about the location, name, and coordination of the study fields

Field Name	Location	Latitude (N)	Longitude (E)	Altitude (m)	Total Area (m^2)
Broccoli Field (BF)	Matsusaka-City	34º38´	136°27´	10	--
Tomato Field (TF)	Yokkaichi Agriculture Center	35°31´	136°33´	45	---

3. RESULTS AND DISCUSSION

3.1 Basic Physical Properties of Soil

Basic physical properties of soil from a depth of 0 cm to greater than 50 cm are presented in Table 2. The particle size distribution shows that the percentage of sand was more than that of silt and clay particles in both fields. This shows that the soil texture was sandy in all layers, except TF in layer B.

The bulk density of BF increased with depth. The ridge layer had an optimum bulk density of 1.32 g cm^{-3}, while the other layers had a bulk density of greater than the optimum range. This shows a compacted soil in those layers. The bulk density of TF ranged between 1.14 to 1.19 g cm^{-3}, shows an optimum range. This means better soil layers in this field.

A reverse relation between bulk density and volumetric water content was confirmed in both fields. The TF shows a greater water content than the BF in all layers. To clarify the soil water storage in both fields, we investigated the distribution of soil thickness using Yamanaka Hardness Meter.

Figure 1 depicts soil thickness of approximately 30 cm and 22 cm in TF and BF respectively. This implies that there was more potential for roots grow in TF than BF because more water and nutrient resource will be available for the plants in deeper soil layer. Hence, waterlogging was a serious problem in BF due to lack of natural drainage system and compacted soil layer, while TF had a better physical condition and no waterlogging problem was observed. Therefore, considering the basic physical properties information and soil thickness, micro-irrigation will give better response in BF, while shallow surface irrigation method is good in TF.

Figure 2 shows the hydraulic conductivity for BF. It was 1.0E^{-03} cm sec^{-1} for ridge layer, then it increases up to 1.5E^{-03} cm sec^{-1} for I layer and again decreases to 1.6E^{-05} cm sec^{-1} for layer II downward. For lateral direction, it is 6.0E^{-05} cm sec^{-1} for layer I and 3.2E^{-05} cm sec^{-1} for layer Ⅱ.

The results indicated that water was not distributed well in layer I in both directions and moves too fast downward, while in layer II it distributed laterally almost double of downward.

Figure 3 shows the results of hydraulic conductivity for TF. Downward movement was 2.0E^{-03} cm sec^{-1} for layer A1, drastically decreases to 9.1E^{-05} cm sec^{-1} for layer A2, and greatly increases up to 3.0E^{-03} cm sec^{-1} for layer B. For lateral direction, it was 3.0E^{-03} cm sec^{-1} for layer A1 with a drastic decrease to 8.5E^{-05} cm sec^{-1} for layer A2, and 1.8E^{-05} cm sec^{-1} for layer B. Totally in this field the water infiltration and distribution was high in both directions. However, below of 40 cm depth the downward movements increased, while in lateral direction considerably decreased. The hydraulic conductivity data suggests micro irrigation method which prevents water losses for BF, while shallow surface irrigation method is good for TF.

3.2 Soil Water Content

The relationship between water potential and water content of the soil is shown in figures 4 and 5. Readily available moisture (RAM)was considered in the range between pF 1.8 to pF 3.0. The volumetric water content θ or RAM was between 9.8 % for ridge layer (15 cm thickness), while it was between 6.38 % and 7.24 % for layers I (7 cm thickness) and II (28 cm thickness) in BF, respectively. This characteristic shows that the water holding capacity decreased by depth in this field Fig. 4.

Table 2 Basic physical properties of soil for all three sites

Site	Layer	Depth (cm)	Particle density (g cm^{-3})	Bulk density (g cm^{-3})	Particle size distribution (%)			Texture	Porosity (%)	Gravimetric water content (g g^{-1})	θ (%)
					Sand	Silt	Clay				
BF	Ridge	0-15	2.68	(1.32)	80.4	11.3	8.3	LS	(51)	0.31	41
	I	15-22	2.71	1.52	68.2	12.5	19.3	SL	44	0.25	37
	II	22-50	2.49	1.54	62.2	15.6	22.1	SL	39	0.25	38
TF	A1	0-30	2.54	(1.14)	73.6	14.7	11.7	SL	(55)	0.46	53
	A2	30-50	2.48	(1.19)	59.4	24.1	16.5	SCL	(52)	0.43	52
	B	50>	2.62	(1.15)	37.8	29.1	33.1	CL	(56)	0.44	50

( ) Indicates optimum range. The optimum range of bulk density is <1.4, and for porosity is >50

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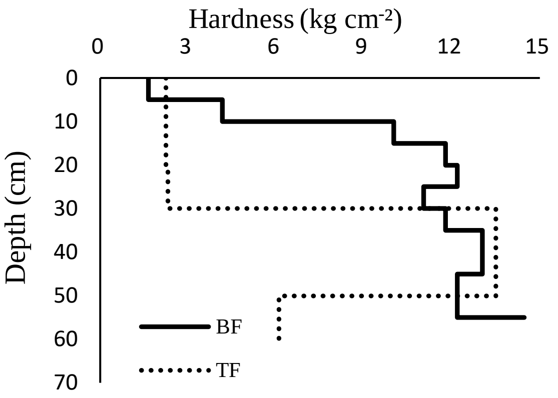

Fig. 1 Hardness distribution across soil profile cross section.

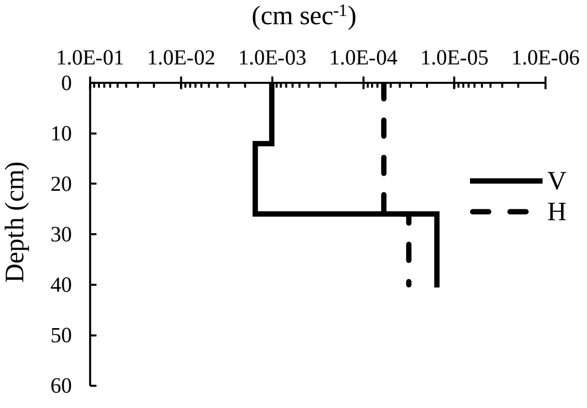

Fig. 2 BF saturated hydraulic conductivity

The *RAM* was shown between 8.25% for A1 layer (30 cm thickness) and 4.49% for A2 layer (20 cm thickness) in TF Fig.5. Although the *RAM* difference between A1 and A2 layers decreased by depth, but since effective soil depth of 30 cm in TF than that of 22 cm in BF provide more RAM to plant.

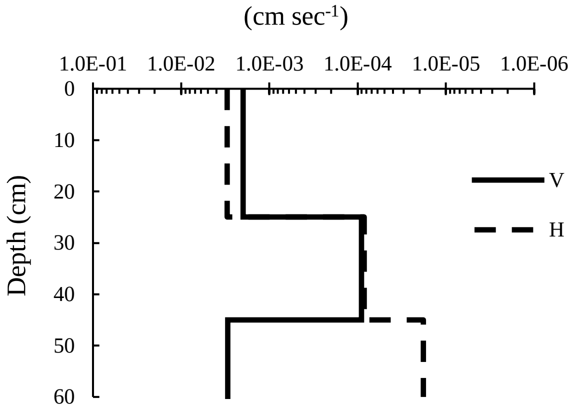

Fig. 3 TF saturated hydraulic conductivity

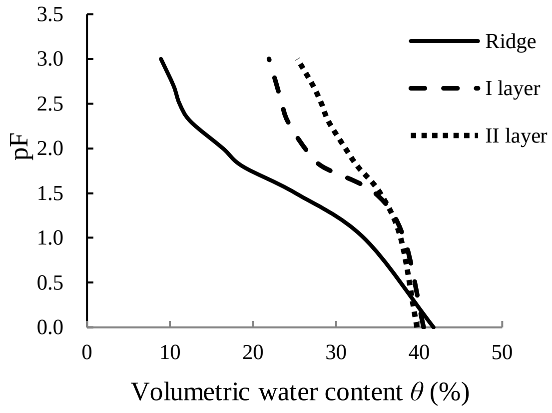

Fig. 4 pF – θ characteristics of BF

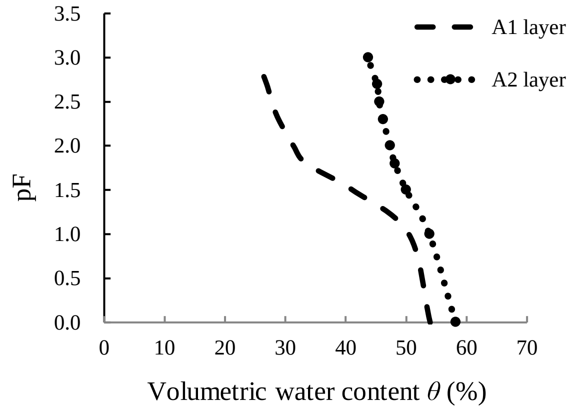

Fig. 5 pF – θ characteristics TF

4. CONCLUSION

By considering the relationship between water potential and water content in the soil layers in both fields, we can conclude that TF showed greater water holding capacity than BF.

This approach provided a detailed understanding of all those parameters that directly affect irrigation practices including, effective soil depth, soil basic structure, water holding capacity, and saturated hydraulic conductivity. The result showed that TF has a better condition than BF, deeper effective soil depth, more porosity, better pores connectivity and channeling, higher hydraulic conductivity, and more readily available water content it can hold. In addition, breaking hardpan and shallow artificial drainage improves irrigation results in BF.

Hence, TF can be used for surface irrigation and micro-irrigation; however, the surface irrigation should be applied very precisely to prevent deep percolation due to soil texture, high hydraulic conductivity, and porosity. While micro irrigation is suggested to be used in BF.

Through this approach, proper irrigation methods can be suggested with the aim to prevent water losses in conditions in which water shortage and scarcity is a major concern, such as arid and semi-arid condition. However, this approach is time-consuming.

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