Soil Water Content Estimation using Pedotransfer Functions in Drylands of Sumbawa Regency

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Abstract. The research aims to estimate soil moisture content using pedotransfer functions in drylands of Sumbawa Regency from March to July 2019. The research method used is descriptive-comparative design against the soils’ physical properties in three different locations. Soil sampling is conducted through undisturbed soil sampling using sample rings for soil analysis and file input assembly and simulation using the Soil, Plant, Atmosphere, Water Field and Pond Hydrology Model (SPAW) program of Version 6.02.75. The soil sample analysis for soil physical properties is conducted at the Soil Physics Laboratory of Soil Department, Faculty of Agriculture, Brawijaya University, Malang. The analysis results indicate that soil moisture characteristic values using PTFs method with minimum parameter inputs that include soil texture (sand and clay) and organic matter could be implemented in drylands. There are differences in the available moisture content between measurement at the laboratory and simulation. The available moisture values from the field result measured at the laboratory are far smaller than those of the simulation results. The values indicate a variation of $0.31-0.47 \text{ cm}^3/\text{cm}^3$ (KL) and $0.05-0.32 \text{ cm}^3/\text{cm}^3$ (TLP), AWC ($0.11-0.17 \text{ cm}^3/\text{cm}^3$), and hydraulic conductivity (soil permeability) ($0.19-6.45\text{mm/hr}$) for all locations.

1. Introduction

Soil water content characterization that include water content in field capacity (FC) and permanent wilting point (PWP) play an essential role in limited water resource utilization in agricultural drylands and direct measurement in field is not always feasible [1]. Soil water characterization is a part of soil physical quality that cannot be directly measured; instead it could be estimated through porosity, bulk density, penetration resistance and water content available for plants [2]. Water content measurement in field requires a thorough soil analysis and it is expensive as well as not always precise due to the high spatial and temporal variability of the soil hydraulic properties; therefore, pedotransfer functions (PTF) are developed to estimate soil water retention in FC and PWP in drylands of dry climate. Numerous efforts have been done to build relationship between soils that are routinely measured for their properties, such as soil texture, organic material, FC and PWP [3]. The pedotransfer functions (PTF) provide an alternative by estimating soil parameter from simpler available soil data [4]. The water content estimation is useful to estimate water availability for plants [5]. Water availability in soil strongly and directly influences plant growth [6]. In order to maximize the water availability for plant would require data on the soil maximum ability to hold water and soil moisture dynamics. Water
adequacy in early growth is an absolute requirement to achieve good plant growth [7]. Water deficiency in early growth will have a negative effect on plant growth and yield [8] since it could inhibit photosynthesis process and nutrients absorption process in the ground by plant roots [9]. The research aims to estimate soil water content using pedotransfer functions in drylands of dry climate. The information is valuable for water and soil management in drylands of dry climate in terms of water conservation to support crops production evaluation planning in dryland condition at Unter Iwes Sub-district, Sumbawa Regency.

2. Method and Experiment

2.1. Research Time and Location
The research was conducted from March to July 2019 at Kerato Village, Nijang Village and Uma Bringin Village, Unter Iwes Sub-district, Sumbawa Regency, West Nusa Tenggara Province. The soil analysis was conducted at the Physics and Chemistry Laboratory of Soil Department, Faculty of Agriculture, Brawijaya University, Malang.

2.2. Materials and Tools
Soil materials used consisted of intact soil and disturbed soil samples in three land utilizations, namely: rain-fed, moorland and upland. Tools used in the research included computer with Soil-Plant-Air-Water (SPAW) program of Version 6.02.75.

2.3. Implementation Method
Design used in the research was descriptive-comparative against the characters of physical properties and pedology of soils taken from three different locations, namely: study plots located at the Kerato Village (KE profile), Uma Bringin Village (UB profile) and Nijang Village (NI profile). The pedotransfer functions in the research location were made based on data resulted from laboratory analysis supported by result of profile characteristic analysis in the fields.

Disturbed soil sampling for soil physical and chemical analysis referred to field soil observation guidance that consists of soil depth, soil color, soil texture, soil structure, soil consistency, soil pores and rooting condition. The laboratory analysis comprised soil physical and chemical analyses. Observation was conducted on the soil physical properties (texture, bulk density, specific gravity, porosity, permanent wilting point and soil moisture level) and chemical properties (organic material).

2.4. Data Analysis
Data analysis on the results of laboratory analyses supported by the results of profile characteristic analysis in the field generated water budget data. The recording and assembly of data file-input were conducted through a series of observation data copied to a directory in the form of data files of soil profile stored in the computer directories as a simulation that could be accessed on various combinations of SPAW program of Version 6.02.75. The simulation was performed by inputting soil description using data screen and conducting description of soil hydraulic conductivity classification. Field data required as the input of the SPAW model consisted of: soil texture and organic materials originated from the laboratory analysis of soil physical properties. Data output produced by the model included field capacity, saturation, moisture availability, and saturated hydraulic conductivity.

3. Results and Discussion

3.1. Characteristics of Soil Water Retention
Soil water information in the research was obtained by means of laboratory measurement and SPAW model to determine moisture level and permeability as described below.
a) Laboratory Measurement

An accurate available water evaluation for plant use is vital in developing optimum water management for plant production in drylands. Laboratory estimation of the upper and lower limits of soil water availability was used to calculate soil water reservoir. Available water observation was done in water level between pF 2.54 and pF 4.2. Soil water retention at pF 2.54 and pF 4.2 were used gradually to determine water adequacy index, and planting time selection for agricultural commodities [10].

The laboratory measurement results at water content between pF 2.54 and pF 4.2 indicated a variation, namely 0.31-0.47 cm$^3$/cm$^3$ (KL) and 0.05-0.32 cm$^3$/cm$^3$ (TLP)(Table 1).

| Profile | Depth (cm) | Horizon | $pF_{2.54}$ (cm$^3$/cm$^3$) | $pF_{4.2}$ (cm$^3$/cm$^3$) |
|---------|------------|---------|-----------------------------|-----------------------------|
| KE      | 0-50       | A       | 0.31                        | 0.05                        |
|         | 50-140     | Bw1     | 0.47                        | 0.30                        |
| UB      | 0-24/30    | A       | 0.31                        | 0.15                        |
|         | 24/30-120/140 | Bw1    | 0.36                        | 0.24                        |
| NI      | 0-24/30    | A       | 0.36                        | 0.16                        |
|         | 24/30-44/47 | Bw1     | 0.39                        | 0.32                        |
|         | 45/47-120/140 | Bw2   | 0.42                        | 0.22                        |

Source: Research (2018)

All together, the TLP values were lower than KL values. The lowest TLP value was found in KE profile of A horizon (0-50 cm), which was 0.5 cm$^3$/cm$^3$, and the highest was found in NI profile of Bw1 horizon (25/30-45/47 cm), which was 0.32 cm$^3$/cm$^3$. The TLP was greatly affected by soil texture, especially higher clay content and micro pores that play a more important role compared to soil aggregation. Sandy soil has large pores compared to clay soil; thus, it has a low ability to hold water. Sandy-textured soils have smaller surface area; hence it is hard to absorb or hold water and nutrients. As a consequence, the soils prone to water shortage during dry season. An ideal soil texture is those with proportional content of clay, dust and sand [11]. Soils in drylands and semi-arid are marked with low content of clay soil and organic material so as producing low water retention capacity and fertility [12]. The soil property of water retention ability affects how long a land could be cultivated in drylands [13].

The tendency in fluctuating water content increased gradually with horizon depth. An increase in water content is mostly influenced by clay condition in the A horizon (46-50%) as well as an increase in dust in Bw horizon. Similar condition found in the moorland utilization in UB profile. The increase occurred in the upper and lower layers reflected soil capacity to store moisture needed by the plants to grow. The accumulation of dust or clay particles could increase the ability to hold water; hence, soil moisture available is higher [14]. Field capacity is substantially induced by micro pores, clay, sand, and organic materials [15].

Fine texture soils have numerous micro pores and capillary movement; as a result, more water supplies to the soil surface compared to those in coarse texture soils. Soil moisture resistance is mostly due to very small pores that could absorb and hold rainwater that penetrates under the capillaries. Therefore, water could not get out and it could only be removed with plant roots or slow evaporation to every space containing air in the soil. In comparison, soil with sandy texture has large pores and it easily releases water and holds a little water in the profile. On the contrary, soil with clay texture is very complex thus rainwater comes in and out slowly.

Water content in the moorland utilization (NI profile) indicated a tendency of an increase in WP (0.31-0.47 cm$^3$/cm$^3$). WP water content (0.36-0.39 cm$^3$/cm$^3$) and FC that experienced a decrease were found in Bw2 horizon. Differences in the increase of water content in each layer were related to the texture condition, organic material content, and porosity. Different water content was caused by sand factor condition that influences water movement in the soil. Sand factor has larger pores compared to...
clay factor; thus, water could move easily. The existence of rock fragments scattered on the soil layers (NI profile) could influence the existence of clay and organic materials to bind moisture in the soil causing a horizontal water flow. The higher the soil porosity value, the lower the soil bulk density thus the more pore spaces that could be filled with water [16,17]. A high bulk density causes difficulty for the soil to pass on the water and as a consequence, water becomes inhibited [18].

Soils with sand factor had the smallest percentage compared to clay and dust in most profiles in the research sites. KE profile had the highest sand percentage compared to other profiles. Sand texture affects water resistance through large pores; thus, water easily moves or escapes. Different soil pore characteristic influences the moisture binding or moisture movement.

Water content differences in available moisture observation between pF 2.54 and pF 4.2 in each location suggested that the available moisture condition in the research locations was low, which was < 1 cm$^3$/cm$^3$, in this case 0.07-0.26 cm$^3$/cm$^3$. It reflected soil capacity to store moisture for the plants. The available moisture value was higher in A and Ap layers and it decreased with an increase in horizon depth. In several locations, moisture availability showed a gradual decrease with an increase in soil horizon. KE, UB and PU profiles had higher available moisture in the A horizon. Differences in soil surface condition, organic materials, texture, structure and vegetation are among the causative factors of the differences in water holding capacity [19].

The low soil moisture level in the research locations was affected by different organic material and soil structure condition; therefore, a varied soil moisture reserve occurred in the upper layer and lower layer and only a fraction absorbed by compact plant roots. Water deficit due to transpiration and a release through rooting zones in evaporation process could trigger plant roots to move to absorb water in the lower parts of the soil; hence, low water content in the soil.

b) Estimation using Pedotransfer Functions

The analysis results indicated that soil moisture characteristic values using PTFs with minimum parameter inputs, namely soil texture (sand and clay) and organic materials for each location points resulted in KL, TLP, AWC, SAT and hydraulic conductivity (soil permeability) values.

The PTFs analysis suggested similar variation to the laboratory measurement. It was indicated by differences in WP and FC values on each horizon layer that had different profile. The analysis result of moisture resistance with PTFs model had the same values as water content measurement in the laboratory, namely in KE, UB and NI profiles where the WP water content experienced a gradual decrease with the increase in soil horizon depth.

An increase in available moisture content implied that texture and organic materials influenced the amount of water content that could be retained by the soil. The amount of available water for plant reflects the soil fertility condition in a land [20,21]. The pedotransfer functions are developed as soil water content predictor using a relatively limited sample data including texture and organic materials [22] with acceptable accuracy for tropical soils [23].

c) Soil Permeability (Hydraulic Conductivity)

The result of soil permeability measurement in each depth in various land utilizations indicated that the permeability value (Ks) in each profile in the research location was known as having a tendency to increase and fluctuate (Table 2). As a whole, the Ks value at 0.01-0.29 in/hr was equal to 0.02-0.73 cm/hr with very slow-rather slow class. The Ks value at <0.125-2.00 cm had saturated hydraulic conductivity with very slow-rather slow class [24].

Overall, the Ks values for all A horizon layer were smaller than those in Bw layer that tended to be fluctuating. The KE, UB and NI profiles had a fluctuating Ks value. An increase in Ks value in every land utilization was influenced by organic materials, porosity, pore size distribution, total pore, and soil structure. Soil organic materials could improve soil organism activity that able to increase macro pores. Soil structure, soil texture and organic material content could control saturated soil conductivity [25]. The result of available water analysis indicated value differences between measurement at the laboratory and model simulation. Through the simulation model, the saturation and permeability
values for each soil could be identified. The available moisture values in the field result measured at the laboratory were far smaller than those in the model simulation. The differences were due to a significant value between soil physical and chemical properties with different schemes.

### Table 2. Characteristics of Soil Moisture Retention using PTFs

| Profile | Depth (cm) | Texture (%) | BO Saturation (cm³/cm³) | Field Capacity (cm³/cm³) | Wilt Point (cm³/cm³) | AWC (cm³/cm³) | Hydraulic Conductivity (mm/hr) |
|---------|------------|-------------|-------------------------|--------------------------|----------------------|--------------|-------------------------------|
| KE      | 0-50       | 46          | 0.14                    | 0.43                     | 0.37                 | 0.25         | 0.11                          | 0.65               |
|         | 50-140     | 20          | 0.38                    | 0.44                     | 0.34                 | 0.19         | 0.15                          | 2.29               |
| UB      | 0-24/30    | 33          | 0.29                    | 0.47                     | 0.42                 | 0.29         | 0.12                          | 0.37               |
|         | 24/30-120/140 | 36   | 0.43                    | 0.41                     | 0.28                 | 0.14         | 0.14                          | 6.45               |
| NI      | 0-25/30    | 38          | 1.20                    | 0.47                     | 0.43                 | 0.31         | 0.12                          | 0.19               |
|         | 25/30-45/47| 13          | 0.43                    | 0.45                     | 0.36                 | 0.19         | 0.16                          | 2.39               |
|         | 45/47-120/140 | 7   | 0.71                    | 0.47                     | 0.37                 | 0.20         | 0.17                          | 2.59               |

Source: Research (2018)

The use of SPAW model in several soil parameters as a reliable and quick scheme could determine difficult-to-find soil parameters values. The pedotransfer functions (PTFs) are equations that connect simple soil properties to gain a more-difficult-to-obtain soil property and it could bridge data limitation generated from the field during soil survey [26,27].

### 4. Conclusion

Estimation of soil moisture content with minimum parameter inputs, namely soil texture (sand and clay) and organic matter could be implemented at drylands of the aridic climate. It resulted values of soil moisture content between pF 2.54 and pF 4.2 that indicated a variation, namely 0.31-0.47 cm³/cm³ (FC) and 0.05-0.32 cm³/cm³ (TLP), AWC (0.11-0.17 cm³/cm³), and hydraulic conductivity (soil permeability) (0.19-6.45mm/hr) for all locations.

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