Water Retention Capacity in Intensive Tillage System, Nawungan Agricultural Land, Imogiri

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Abstract. The research was aimed at studying a long-term influence of intensive tillage systems on water availability-related soil properties. This research had been carried out in Nawungan agricultural land, Imogiri in the clay soils dominantly by Lithic Ustorthent. Nawungan has long-term agricultural activities. It was used to be cultivated by rainfed paddy field, however, nowadays it has been cultivated by paddy-paddy-shallot pattern within a year. The seasonal crop rotation is to adjust water availability during dry season, and it must remain significant affect in soil properties. Water retention characteristics of soil was analysed in the study area. pF Curve was applied to study the availability of water, field capacity, and permanent wilting point in 9 soil samples. The soil sampling determination was based on water availability zones of the study area from the previous research. The analysis of water retention characteristics was also maintained by other soil properties analysis i.e. texture, infiltration, porosity, bulk density, and bulk volume. The results showed that the soil texture in the study area was predominantly clay, the bulk volume ranged from 0.87–1.21 gr/cm^3, the specific gravity ranged from 1.78 to 2.10 gr/cm^3, the infiltration rate ranged from 0.1–0.5 cm/hour, and the porosity ranges from 40–58%. Based on the relationship between soil water content and suction matrix (pF) at the study site, the field capacity value (pF 2.54) ranged from 42.56%–53.36%, the permanent wilting point value ranged from 33.29%–41, 55%, the available water content in the soil pores, which ranged from 5.89%–16.78%. Based on the position of the land to the lower slope, it was found that the average available water on the lower slope was 13.83%. This value was greater than if the available water on the middle and upper slopes that were 10.07% and 8.77%, respectively.

Keywords: Water retention · tillage · pF Curve · Agriculture · Nawungan

1 Introduction

The need for agricultural land continues to increase from time to time. This is attempted to realize Indonesia's ideals as the world's food barn in 2045 [1]. Agricultural land development efforts are not only focused on wet agricultural land but are now increasingly being developed on dry land. This fact cannot be denied considering that dry land is the

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largest agricultural resource in Indonesia [2]. The availability of land for agricultural land extensification is one of the success factors in maintaining food self-sufficiency and to make Indonesia a world food barn by 2045 [1]. However, farming in this agro-ecosystem is generally still colored by problems, especially water problems.

Nawungan, Imogiri is one of the areas hit by an agronomic drought. The problem of water for onion farming is a crucial problem in this area. The rainfall in the Selopamioro area is 1,564 mm/year [3]. Nawungan Hamlet has a drought problem in its shallot farmland during the dry season. Drought is a crucial environmental stress factor which impacts on plant growth and development [4]. The physical characteristics of Nawungan are dominated by hilly landforms with a wavy to sloping morphology with a slope of more than 15% and a thin soil thickness due to the basic rocks in the form of limestone and sand [5]. This makes it difficult for runoff to be absorbed into the soil and has a tendency to be difficult to meet water needs, especially for agriculture [6]. In addition, Nawungan has only 23% of rainy days in a year, with a maximum daily rainfall of 454 mm/day [7]. As a result, irrigation methods are needed that can adapt to these conditions. Lack of water availability on land can result in low production which is closely related to low land productivity. To increase land productivity, it is necessary to regulate sufficient water on the land. The availability of water in the land is generally influenced by rainfall and the ability of the soil to hold water. At a regional scale, climate change plays a predominant role in determining soil water dynamics [8]. This is because plants will experience nutrient deficiency, and stress due to lack of water [9]. Proper irrigation of course begins with measuring the right water content [10]. Efforts are often made to increase the productivity of dry land is to implement water conservation strategies, one of which is by making rorak on the land.

The application of rorak is a solution to the limitations in the availability of water for agricultural practice on land. Rorak are small ponds that are applied to agricultural land which aims to accommodate rainwater and runoff which can then be used as irrigation water on land, especially in the dry season. Rorak is one of the conservation methods that can overcome the problem of drought in agricultural land. Rorak is made with a certain size which is built at several points of the planting area. The main purpose of making rorak in areas with high rainfall is to increase infiltration and accommodate transported sediments [11]. The Nawungan agricultural reservoir has not been able to maximally accommodate rainwater which will be used for planting shallots in the dry season. Small streams and irrigation canals in Nawungan agricultural land tend to be dry during the dry season. Dry natural water sources encourage farmers to build agricultural reservoirs to meet their water needs during the dry season [12].

Soil characteristics have an important role in retaining water contained in the soil. Soil water retention parameters characterize water holding capacity, and thus are important for plant growth [13]. Most of the plant's water needs are taken from the soil. Water absorbed by plants is water that is in the pores of the soil in the root layer. Therefore, the ability of the soil to hold water is the main factor that determines plant growth and production. Water that can be absorbed by plants is the water content that is between the field capacity conditions and the permanent wilting point in the soil pores. Field capacity conditions occur when the gravitational potential is equal to the matrix potential. Soil

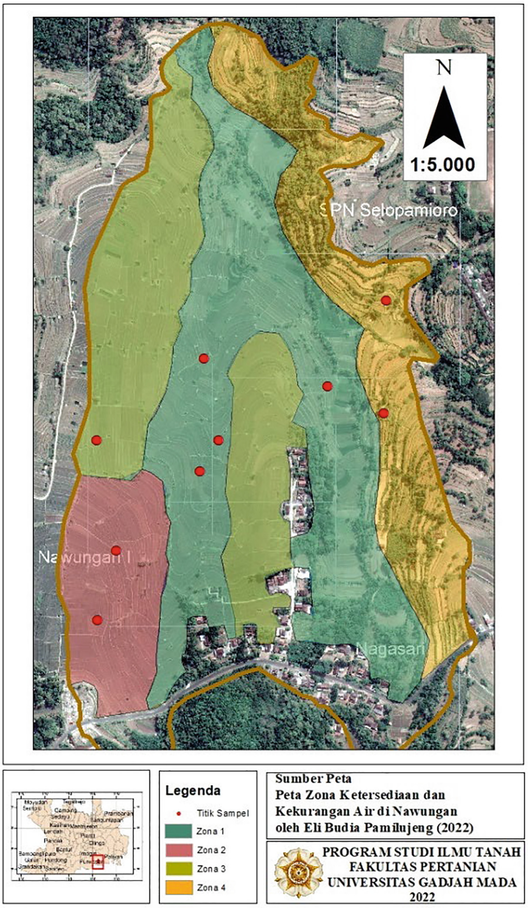

Fig. 1. Study area with soil sampling distribution

water content is the most limiting factor for plant growth [14, 15]. The purpose of this study was to determine the nature of water retention in the area around the reservoir.

2 Methodology

The research is located on the Onion Farming Area in Nawungan, Imogiri, Bantul Regency, Special Region of Yogyakarta (Fig. 1).

2.1 Materials

The materials and tools used were a map of the water availability and dryness zone of Nawungan agricultural land, undisturbed soil samples in 4 different zones, ring samples, auger, pressure plate apparatus, paralon, oven, and scales.

2.2 Data Collecting

The research method is through field survey methods and analysis of soil physical properties in the soil laboratory, Department of Soil, Faculty of Agriculture, UGM. Soil samples were taken at several points scattered based on 4 water availability zones from previous research. These sample points are topographically also included in 3 different slope classes, namely upper, middle, and lower slopes. There are nine undisturbed soil samples taken using a ring sample and in disturbed form at a depth of 0–15 cm from the soil surface.

2.3 Data Analysis

Primary data analysis was carried out on water retention parameter data. The stage of carrying out the analysis of water content, field capacity and permanent wilting point using the pressure plate apparatus method (pF). Pressure at 1/3 atm or pF 2.54 for field capacity measurement and pressured at 15 atm or pF 4.2 for permanent wilting point measurement.

Available water = Water content at field capacity - Water content at permanent wilting point ………… [16].

*) where water content (% volume) at pF 2.54 refers to field capacity (FC) and water content (% volume) at pF 4.2 refers to permanent wilting point (PWP).

Data analysis was also carried out using secondary data based on previous research at the same research location [5]. This secondary data consists of analysis of soil physical properties in the form of texture, bulk volume, bulk density, porosity, and infiltration rate. Bulk density was conducted using gravimetric method, bulk volume was conducted using ring measurement, porosity was conducted using empirical method of bulk density and bulk volume, infiltration rate was conducted using double ring infiltrometer, and soil texture analysis was conducted using pipette analysis and sieving methods through the Stokes Law method and the determination of the texture class used a soil texture triangle (textural triangle).

3 Result and Discussion

Tillage in this research area has been applied for more than 5 years. In this system, soil tillage is carried out maximally by turning/unloading the soil to a depth of ±20 cm, carried out repeatedly before planting rice. After that, every time the cropping pattern changes to shallots, the tillage technique applied is strip tillage combined with minimum tillage. In this tillage system, tillage is carried out conservatively, i.e. processing as needed on the strips or furrows to be planted which are made to follow the contours parallel or perpendicular to the contours. The part of the land between the two strips is left uncultivated/disturbed and leaves a zone around the strip without any mulch. Soil cultivation applied to Nawungan agricultural land has an impact on the formation of soil physical characteristics.

Table 1. Measurement of BV, BJ, Porosity, and Infiltration Rate on Nawungan Agricultural Land

Slope	Bulk Volume (gr/cm^3)	Bulk Density (%)	Porosity (%)	Infiltration Rate (cm·hour^{-1})
1.1	1.10	1.92	42	0.16
1.2	1.21	2.03	41	0.13
1.3	1.13	1.97	43	0.74
2.1	1.14	2.10	44	0.29
2.2	0.87	2.07	58	0.49
2.3	1.01	1.78	45	0.09
3.1	1.17	2.10	43	0.11
3.2	1.17	2.01	42	0.19
3.3	1.17	1.97	40	0.21

Source: [5]

3.1 Soil Physics Characteristics

The physical characteristics of the soil are the basic principles of water available to plants. The amount of available water will be influenced by the type of clay minerals, organic matter, soil texture and structure and the type of cations adsorbed. So to avoid the occurrence of water stress or groundwater stress on plants, it is necessary to study the physical properties of the soil that affect the availability of ground water.

The physical characteristics of the soil (volume weight, specific gravity, porosity, and infiltration rate) at the study site are presented in Table 1. These soil characteristics were taken from secondary data from measurements of previous studies at the same research location. Soil samples were taken at nine locations including ridges, slopes, and valleys from the catchment area of the study site. Soil physical properties may affect soil water content by changing the proportion of the water input into the soil among the outputs through drainage, soil evaporation and plant uptake [17].

The volume weight of soil in Nawungan ranged from 0.87–1.21 (Table 1). This is in accordance with the opinion of Ref. [18] which states that clay-textured soils have a soil volume weight range of 1.0–1.3 g/cm^3. Volume weight (BV) is the ratio between dry soil weight and soil volume including soil pore volume. The denser the soil, the higher the volume of the soil. The weight of this volume of soil is related to the movement of water, if the value of the weight of the volume is high it will make it more difficult for the soil to carry water so that the movement of water becomes hampered. This is due to a decrease in soil pores so that the ability to hold water becomes small or the water content of the soil will decrease [19]. Bulk density (BV) is one of the most studied soil physical properties, both in the field and at the laboratory scale, because it is closely related to soil management related to soil density, ease of penetration of plant roots, soil aeration, tillage [20].

Soil density shows the density of solid particles as a whole [21]. The specific gravity at the study site ranged from 1.78 to 2.10% (Table 1). Soil density is related to soil texture. The finer and coarser the texture of the soil, the smaller the value of b. This is because the finer the texture of the soil, the looser the composition of the soil particles and the lower the specific gravity of the particles [22]. In addition, the density of the soil is important in relation to the available water because the presence of specific gravity can determine the porosity. Specific gravity, bulk density and porosity are used to determine the ability of the soil to store available water.

The rate of soil infiltration in Nawungan is classified as slow. The value of the infiltration rate at the study site ranged from 0.1–0.5 cm/hour (Table 1). This range is included in the slow category based on the classification of infiltration rates according to [23]. Infiltration is one of the main sources of groundwater availability. The amount of infiltration greatly affects the availability of water in the soil and infiltration itself is influenced by the physical properties of the soil, such as soil texture, organic matter, bulk density, porosity, aggregate stability/stability and water content. Therefore, the availability of water in the soil also depends on the physical properties of the soil related to the ability of the soil to absorb water and its ability to conduct water. The movement of water in saturated soil will affect runoff and infiltration, while the movement process is strongly influenced by the physical properties of the soil.

The results of the porosity analysis at the study site showed a range of 40–58% (Table 1). Porosity describes the total pore space in the soil [21]. These results indicate that the porosity value of the soil in Nawungan is categorized into the medium class because it has a porosity value of <63% [24]. Porosity shows the empty space contained in a volume of soil that can be filled by water and air. So the larger the pore space in the soil, the easier it is for water to continue to flow following gravity. The total pore space which tends to be small is closely related to the diversity of the soil texture components. According to Ref. [25] that clay soils have more total pore space so that the weight of the contents is lighter or less than sandy soils. In addition, the application of an intensive tillage system by turning/unloading the soil maximally causes aggregate dispersion and pore blockage which can result in a decrease in macro pores and an increase in micro pores [26].

3.2 Soil Water Retention

The nature of soil water retention reflects the ability of the soil to hold water [26]. It can be seen from the curve of groundwater characteristics and field capacity [27]. The groundwater characteristic curve shows the amount of water that the soil can still hold after a certain pressure (a certain pF). 'Water-retention curve' refers to the relationship between matric potential and volumetric water content (θ) at equilibrium [28]. The maximum amount of water that can be retained is considered to be equivalent to the field capacity water content which is defined as the soil water content in the field when the drainage water due to gravity has stopped or almost stopped flowing after the soil was completely saturated [29].

Soil water retention parameters are closely related with soil texture [13]. Soil texture is very important to note because it will determine the properties of the soil and will have a major influence on the rate of water entry into the soil and water storage in the

Table 2. Soil texture in the study area

Slope	Sand (%)	Slit (%)	Clay (%)	Texture Class
1.1	22	27	51	Clay
1.2	23	27	53	Clay
1.3	23	30	47	Clay
2.1	23	29	48	Clay
2.2	25	28	48	Clay
2.3	22	22	56	Clay
3.1	23	24	52	Clay
3.2	22	27	51	Clay
3.3	22	29	49	Clay

soil [30]. Based on the results of the texture test, Ref. [5] showed that the soil texture at the research site was klei (Table 2). The results of the analysis at all points produced almost the same data and it was concluded that the research location had a high clay texture, namely $> 40\%$. Range value of clay percentage is about 47–56% (see Table 2). In general, clay soils have a higher soil suction that sandy soils.

The high clay fraction in the study area is strongly influenced by the parent material of the soil underlying the agricultural land. The soil classification units that underlie agricultural land are the Glinggang series, the Kalidedep series and the Ngolorejo series. The Glinggang series is the most extensive soil series in the study area [5]. The Glinggang series includes shallow dry soils with a taxonomic class of Lithic Ustorthents, Clay, Mix, Not acidic, Isohyperthermic [31]. The Glinggang series soil has characteristics of high clay content because it is a soil formed from the parent material of andesitic volcanic tuff on the physiogram of the colluvial plains, the hills of the force, the slopes of the mountains of the force and the escarpments. Another soil unit classification, namely the Kalidedep Series, consists of deep dry soils with slow drainage with taxonomic classes in the form of Typic Hapluderts, Very fine, Montmorillonitic, Isohypertermic [31]. The Kalidedep series soil is formed from the parent material of clay deposits in the physiography of the basin plain. On the other hand, Seri Ngolorejo is a deep dry soil with moderate drainage with a taxonomic class in the form of Vertic Ustropepts, Very fine, Mix, isohypertermic [31]. The Ngolorejo series of soils are formed from the parent material of clay deposits in the physiography of the plains of the valley, with slopes ranging from 0 to 2 percent [31].

Soil texture greatly affects the ability of the soil to hold water [20]. According to Ref. [18] that soil with a texture of klei (fine) will have a greater ability to hold water than soil with a texture of sand (coarse) so it can store more water. Clay textured soils have a large adsorptive surface area [20] so that they have good absorption capacity to changes in moisture content (water content). In addition, clay-textured soils are also electrically charged, where the electric charge gives the properties of clay to be able to bind water and plant nutrients on its surface. This has a strong effect on the water retention capacity of soil.

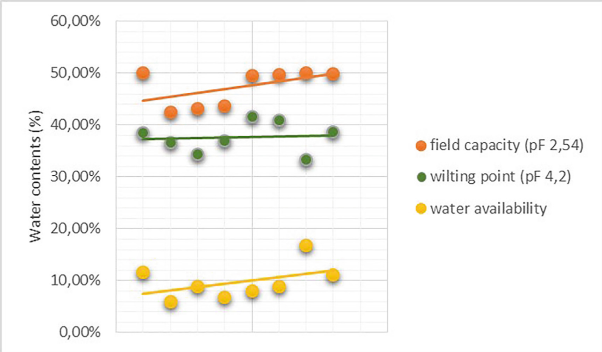

Fig. 2. Graphic of water availability in the study area.

3.3 Available Water

The basic principle of available water to plants is related to providing adequate and balanced water for plant growth. This can be seen from the soil moisture content between field capacity and permanent wilting point. Practically, the water content of the field capacity was measured in the laboratory by measuring the water content at the suction pF 2.54 matrix, while the permanent wilting point water content was measured in the laboratory by measuring the water content at the suction pF 4.2 matrix [27]. These parameters are also widely used to determine irrigation needs in agriculture [32, 33], and to simulate soil moisture dynamics in ecosystem models [34–36].

The results of the pF curve analysis showed that the field capacity, wilting point, and available water values varied between sample points (Fig. 2). Intensive processing activities result in varied water availability on soil. Soil moisture characteristics expressed in the form of a curve of the relationship between soil moisture content and suction matrix (pF) at the location of agricultural land are presented in Fig. 2.

Field capacity values (pF 2.54) on tillage soils in the study area ranged from 42.56%–53.36% (see Fig. 2). In general, field capacity water content is defined as the soil water content in the field when the drainage water has stopped or almost stopped flowing due to the force of gravity after the soil was completely saturated [20]. When compared with the wilting point value, the water field capacity value at the research site has a higher percentage. The wilting point value (pF 4.2) on tillage soil at the study site ranged from 33.29%–41.55% (see Fig. 2). By comparing the water content in the potential matrix (pF) of 2.54 and 4.2, it can be seen that the available water content in the soil pores is in the range of 5.89%–16.78% (see Fig. 2). It can be concluded that the water available to plants in the soil pores is generally very low, i.e. $<20\%$. This available water is water that is absorbed by plants. Therefore, to meet water needs for plants, additional water supplies are needed which can be provided through irrigation water.

The topographical position of the land also affects the amount of available water capacity. Available water capacity is the difference in water content at field capacity and permanent wilting point (KA pF 2.54–KA pF 4.2) soil [20], where the water content at field capacity and wilting point is influenced by soil texture and others soil characteristics [37]. The water capacity analysis based on the topographical position of the land shows

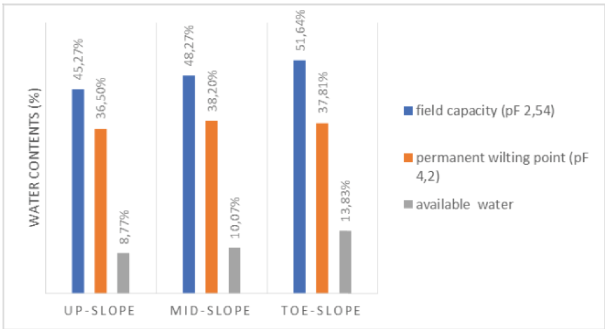

Fig. 3. Water contents related to slope position at the agricultural land.

that the available water capacity on the lower slopes is higher than the middle and upper slopes (Fig. 3). The average available water content on the lower slope is 13.83%. This value is greater than the available water capacity on the middle and upper slopes, namely 10.07% and 8.77%, respectively. The value of available water capacity on the lower slope is also followed by a larger value of the field capacity at this slope position, which is 51.64%.

This situation indicates that the soil on the lower slope has a better pore size distribution than the soil on the upper and middle slopes. This is because the available water is water that is in the soil pores and the better the pore size distribution in the soil, the more water is in the soil pores. Each type of soil has a different distribution and pore size, which will affect the availability of water in the soil [20]. The distribution and pore size of each soil type is strongly influenced by the diversity of soil physical characteristics.

4 Conclusion

Soil water available is one of the important factors that affect plant growth. The results of the analysis of the soil physical properties showed that the soil texture at the study site was dominated by clay. Soil water retention parameters are closely related with soil texture. The clay texture in the study area cause to hold water in pore for about 50%. This type of soil texture also closely influences other soil physical properties which caused slow infiltration rate, small bulk density, light bulk volume, and large total pore space. As a result, the soil water retention properties in the study area were affected by the physical characteristics of the formed soil. The maximum amount of water that can be retained by the soil as reflected by the field capacity (pF 2.54) is quite large, which is around 50%, however, the water available to plants is only less than 20%. Based on the position of the land to the slopes, the field capacity and available water content on the lower slopes are higher than the middle and upper slopes.

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