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Sorptivity of an Inceptisol under Conventional and Reduced Tillage Practices

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ABSTRACT

The amount of water captured and stored in the soil profile until the next precipitation events is of great importance in dryland agro-ecosystem for successful crop production. The soil's ability to rapidly capture and store water precipitation can be accessed through measuring soil sorptivity. The objectives of this study were to evaluate the effects of tillage, *i.e.* reduced and conventional tillages, on soil sorptivity, and to understand how sorptivity is related to surface soil bulk density and water stable aggregates. The experiment was conducted on a site, which has been continuously planted with corn twice a year for more than 10 years. The predominant soil in the study site is *Typic Haplusteps*. Ponded infiltration measurements were used to determine soil sorptivity. Six positions, 15 meters a part, were chosen within each treatment to measure sorptivity, bulk density and water stable aggregates. Conventional tillage resulted in higher sorptivity (p<0.05), lower surface bulk density (p<0.05), and significantly lower water stable aggregates (p<0.01) than reduced tillage treatment. Sorptivity was negatively correlated to bulk density and positively correlated to water stable aggregates. Better correlations were found between sorptivity and both bulk density (R^2 = 0.67) and water stable aggregates (R^2= 0.81) under reduced tillage than under conventional tillage treatment. Conventional tillage was found to enhance soil sorptivity in comparison to reduced tillage system. Appropriate soil management is important to maintain proper soil porosity in the field for better rainfall harvesting and plant growth especially in the dryland ecosystem.

Keywords: Conventional tillage, reduced tillage, sorptivity, bulk density, water stable aggregates.

ABSTRAK

Jumlah air yang tertahan dan tersimpan dalam profil tanah sampai hujan berikutnya sangat menentukan dalam keberhasilan produksi tanaman di agro-ekosistem lahan kering. Kemampuan tanah menahan dan menyimpan air hujan dapat dievaluasi melalui pengukuran sorptivitas tanah. Tujuan penelitian ini adalah untuk mempelajari pengaruh pengolahan tanah, yaitu pengolahan tanah terbatas dan konvensional, terhadap sorptivtas tanah, dan hubungan sorptivitas dengan berat isi tanah permukaan dan kestabilan agregat. Percobaan dilakukan di lahan dimana jagung ditanam dua kali dalam setahun secara berkelanjutan selama lebih dari 10 tahun. Jenis tanah di lokasi penelitian adalah *Typic Haplusteps*. Pengukuran infiltrasi menggunakan tabung infiltrometer digunakan untuk penetapan sorptivitas tanah. Enam titik pengamatan, berjarak 15 meter satu dengan lainnya, dipilih pada setiap perlakuan untuk mengukur sorptivitas, berat isi, dan kestabilan agregat tanah. Pengolahan tanah konvensional memberikan nilai sorptivitas yang lebih tinggi (p<0,05), berat isi lebih rendah (p<0,05), dan nilai kestabilan agregat yang sangat rendah (p<0,01) dibanding pengolahan tanah terbatas. Sorptivitas berkorelasi negatif dengan berat isi dan berkorelasi positif dengan kestabilan agregat tanah. Korelasi yang lebih baik didapatkan antara sorptivitas dengan berat isi (R^2 = 0,67) dan kestabilan agregat (R^2 = 0,81) pada perlakuan pengolahan tanah konvensional. Pengolahan tanah konvensional meningkatkan sorptivitas tanah lebih baik dibandingkan dengan pengolahan tanah terbatas. Pengelolaan tanah yang tepat sangat penting untuk mempertahankan porositas tanah di lahan pertanian sehingga pemanenan air hujan dan pertumbuhan tanaman dapat lebih baik, khususnya pada agro-ekosistem lahan kering.

Kata kunci: Pengolahan tanah konvensional, pengolahan tanah terbatas, sorptivitas, berat isi, kestabilan agregat tanah.

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INTRODUCTION

The availability of water during cropping season is crucial for crop establishment and satisfied production in all agro-ecosystems, especially in dryland agriculture. The United Nations Convention to Combat Desertification (UNCCD) classifies dryland based on the ratio of annual precipitation to potential evapotranspiration (P/PET), when the ratio is between 0.05 and 0.65, it is considered as dryland (UNCCD 2000). The definition implies that the potential of water deficit for crops during the cropping year due to evapotranspiration greatly exceeds annual precipitation. It also implies that farming in dryland agroecosystems depends largely on the amount of water captured and stored in the soil profile until the next precipitation for successful crop production. Soil management practices that can enhance rapid rainfall capture thereby reduce water loss through runoff and evaporation is the key point to sustain crop establishment (Peterson *et al*. 2012).

Dryland plays a very important role in the agricultural production systems in Indonesia. It is reported that there are around 107.4 million ha of dryland in Indonesia that spread over lowlands to highlands and 41 million ha of them are occupied by Inceptisols (Mulyani *et al*. 2003; Balitbangtan 2015). With such a large area and very diverse agro-ecosystem, dryland provides broad opportunities for the development of various food crops, horticulture, plantation, and livestock. However, crop yield planted on the dryland is still far below its yield potential (Abdurachman *et al.* 2008; Rochayati and Dariah 2012). One of the main challenges for optimizing crop yield on the dry land is water management. Poor water management may cause high proportion of rainfall to become surface runoff that increases the risk of soil erosion and only a small portion of rainfall to be infiltrated into soil profile.

The soil's ability to rapidly capture and store water precipitation can be accessed through measuring sorptivity (Shaver *et al*. 2013). Sorptivity is the ability of porous materials to take up water and transmit it via capillary suction (Culligan *et al*. 2005), and sorptivity is a predominant factor governing the early portion of infiltration (Stewart *et al.* 2013). Management practices that positively alter physical properties of the soil surface may increase soil sorptivity, which can increase water capture to reduce water loss from runoff and surface evaporation (Shaver *et al*. 2003).

MATERIALS AND METHODS

Study Site

The study was conducted on an upland watershed at the Solokuro Agro-techno Park (112^o 25'13.7" E, 6^o 55'25.9" S) in Banyubang Village, Solokuro District, Lamongan Regency, East Java Province. The predominant soil is *Typic Haplustepts* with the slope ranged from 3 to 8%. The surface soil texture is clay (80.1 ± 3.4% clay and 14.2 ± 2.9% silt). The soil moisture regime is ustic with mean annual precipitation of 1,342 mm occurring mostly in November to May. The major crop grown in this area is corn planted twice a year since early 1990s. A detailed description of the study site can be found in Rachman (2016).

Two farmer fields adjacent to each other that have been practicing reduced tillage (RT) and conventional tillage (CT) for corn for at least three years were selected for soil sorptivity measurements. Both farmers apply 2-3 Mg ha^{-1} of cow manure and chemical fertilizers as base fertilizer. The cow manure was applied on the soil surface around the planted seeds. The RT treatment included minimum disturbance of the soil surfaces to place the corn seeds using a wooden stick. No crop residues placed on the soil surface for the first corn growing season, while corn stalks of the first harvested corn were left on the field for the second corn growing season. The CT treatment included moldboard plow that was conducted 2-4 weeks before the first corn was planted, the depth of plow is 10-15 cm, no crop residues placed on the soil surface during plowing and no plowing for the second corn growing season.

Sorptivity Measurement and Analysis

Field measurements of soil sorptivity were carried out using a single-ring infiltrometer (Bouwer 1986; Dariah and Rachman 2006) with a 30-cm inside diameter, a 18.5-cm length, and a 0.3-cm wall thickness for the two treatments with six replicates. The steel ring was driven carefully 15 cm into the soil; care was taken to make sure that the ring was inserted vertically into the soil. A positive head of 50 mm was maintained inside the ring using a Mariotte system during the infiltration test.

The Green and Ampt equation modified by Philip (1957) for time (*t*) vs cumulative infiltration (*I*) was used to predict sorptivity, as follows:

$$t = \frac{I}{Ks} - \frac{[S^2 \ 1n(1 + 2IKs/\ S^2)]}{2\ K_s^2}$$

\in which t (T) is time, I (L) is the cumulative infiltration, S ($LT^{-0.5}$) is the sorptivity, K_S (LT^{-1}) is the saturated hydraulic conductivity. The procedure for estimating the S and K_S based on Green and Ampt equation used the method proposed by Clothier *et al.* (2002).

Soil Sampling for Bulk Density and Water Stable Aggregate Measurements

Intact soil samples were collected from undisturbed areas outside the ring infiltrometer using a core sampler (76-mm inside diameter and 40-mm length). Three soil cores from each sampling point were taken from soil surface (0 to 10-cm depth) for bulk density, total porosity, and water stable aggregate measurements. The soil bulk density was determined using the core method (Blake and Hartge 1986; Agus *et al.* 2006).

Soil samples from one of the soil cores at each sampling point were gently pushed out and spread out to be air dried for 24 h. The air-dried samples were then sieved to retain the 1 to 2 mm aggregates. These aggregates were used to determine the stability of soil aggregates using a wet sieving technique (Kemper and Rosenau1986; Rachman and Adimihardja 2006). The sieving apparatus consisted of eight independent sieves (3.5 cm diameter and 4 cm length) attached to a holder.

From each soil sample, about 5 g subsample was placed on the numbered sieve. The sample was sieved for five minutes with distilled water to produce unstable aggregates. Aggregates that remained on the sieve after sieving with distilled water (stable aggregates) were then sieved with hydrogen peroxide solution for eight minutes. The wet stable aggregates were calculated using the following formula:

$$WAS = \frac{Wt.2}{Wt.1 + Wt.2} x100 \%$$

in which *WAS* is water stable aggregates (%), *Wt.1* is the weight of the unstable aggregates and *Wt.2* is the weight of stable aggregates.

RESULTS AND DISCUSSION

Soil Sorptivity

The effect of tillage on soil sorptivity was significantly different (Table 1, $p<0.05$). Higher sorptivity was found under conventional tillage (59.48 ± 14.87 mm $min^{-1/2}$) than under reduced tillage (34.01 ± 24.39 mm $min^{-1/2}$). Tillage alters the structural arrangement or porosity of topsoil and their hydrophysical properties (Moret and Arrue 2007; Rachman 2016). Soil dominated with large soil pores allows water to penetrate into the soil with least resistance (Askari *et al.* 2008). Therefore, conventional tillage system applied on this study produced higher sorptivity than reduced tillage system.

Soil Bulk Density

Effects of tillage on the surface soil bulk density were significantly different (Table 1, $P< 0.05$). Higher bulk density was found under reduced tillage (1.12 ± 0.07) than under conventional tillage (1.06 ± 0.05). Reduced tillage system applied in this study was not combined with the application of crop residues as mulch to protect soil surface from kinetic energy of rainfall, therefore soil consolidation may have been occurred, which further increased bulk density. Previous studies found the same trend, in which higher bulk density was found under reduced tillage compared to conventional tillage system (Alvarez and Steinbach 2009; Rashidi and Keshavarzpour 2008; Rachman 2016). Soil bulk density is inversely related to soil porosity, in which the porosity increases with the decrease of bulk density.

Soil sorptivity is negatively correlated to soil bulk density, as bulk density increases with the decrease of sorptivity (Figures 1A and 1B). Lower bulk density under conventional tillage has produced higher sorptivity compared to the reduced tillage system. Under reduced tillage, sixty seven percent of the variability in sorptivity (R^2 = 0.67) can be explained by the bulk density, which is higher

Table 1. Effects of tillage on selected soil physical properties.

Parameter	Tillage		P value
	Reduced	Conventional	
Sorptivity (mm $min^{-1/2}$)	34.01 ± 24.39	59.48 ± 14.87	0.027
Bulk density (g cm^{-3})	1.12 ± 0.07	1.06 ± 0.05	0.035
Total porosity (%)	54.09 ± 1.24	56.33 ± 1.57	0.010
Water stable aggregate (%)	60.44 ± 4.29	51.91 ± 5.84	0.009

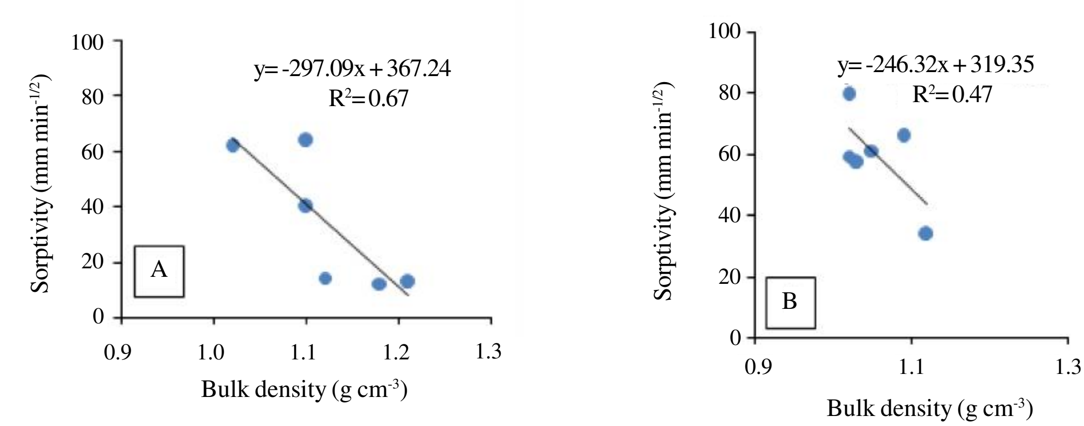

Figure 1. Sorptivity as affected by surface soil bulk density under reduced tillage (A) and conventional tillage (B) systems.

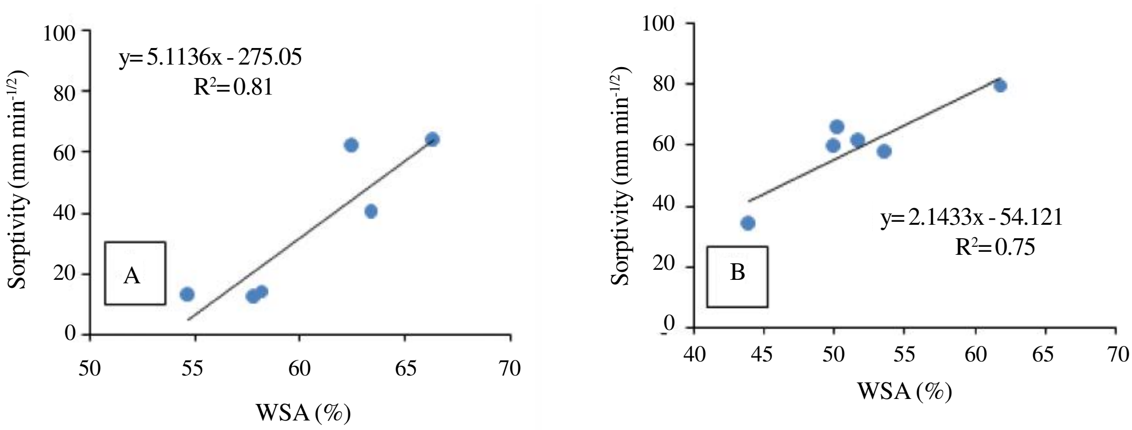

Figure 2. Sorptivity as affected by surface water stable aggregates (WSA) under reduced tillage (A) and conventional tillage (B) systems.

compared to that under conventional tillage (R^2 = 0.47). Therefore, appropriate soil management is important to maintain proper soil porosity in the field for better rainfall harvesting and plant growth especially in the dryland ecosystem.

Water Stable Aggregates

A well-aggregated soil usually has higher infiltration rate, hydraulic conductivity, and more available water capacity. In contrast, unstable aggregates can lead to restricted water flow when detached soil aggregates (slaking) and clay particles (clay dispersion) are carried into the pores, making the pores narrower or discontinuous (Lynch and Bragg 1985; Lado *et al*. 2004). Water stable aggregates under reduced tillage (60.44 ± 4.29%) was significantly higher (p = 0.009) than that under conventional tillage (51.91 ± 5.84%; Table 1). The lower water stable aggregates under conventional tillage indicates that continuous cultivation of dryland negatively affects soil aggregation. Frequent tillage and exposure to raindrop impact generally tend to break down stable aggregates into unstable aggregates that lead to the development of soil surface seals and crusts (Robinson and Phillips 2001; Rachman *et al*. 2003; Sajjadi and Mahmoodabadi 2015).

An increase in water stable aggregates leads to an increase in soil sorptivity (Figure 2). Under reduced tillage, eighty one percent of the variability in sorptivity (R^2 = 0.81) can be explained by water stable aggregates, which is slightly higher compared to that under conventional tillage (R^2 = 0.75). The slope of the regression under reduced tillage treatment is 2.4 times higher than that under conventional tillage treatment, indicating that the soil sorptivity is more sensitive to aggregation on reduced tillage treatment. Meanwhile for conventional tillage treatment, the effect of porosity, which was significantly higher on conventional tillage than on reduced tillage (Table 1), was more dominant on sorptivity than aggregation. Previous studies reported that smaller sorptivity under reduced tillage was associated with lower soil porosity (Lipiec *et al.*2006) and weak correlation between sorptivity and crop residue accumulation (Shaver *et al.* 2013).

CONCLUSIONS

Sorptivity plays a significant role in the early portion of water infiltration into the soil profile, therefore determines the water storage capacity of the soil. A negative correlation was found between sorptivity and bulk density, while a positive correlation was found between sorptivity and water stable aggregates. Sorptivity increased with decreasing bulk density, and it increased with increasing water stable aggregates. Conventional tillage had reduced bulk density and water stable aggregates, however, sorptivity was found higher under conventional tillage than under reduced tillage. These relationships suggest that total porosity was a more dominant factor than water stable aggregates affecting sorptivity. Conventional tillage practices that result in greater soil porosity lead to beneficial impacts on increasing water sorptivity and greatly increasing water capture and storage by soil, which eventually reduce water shortage in dryland agriculture.

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