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Characterization of the effect of tillage on furrow irrigation hydraulics for the Dire Dawa Area, Ethiopia

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ABSTRACT

Soil water infiltration is one of the most important processes affecting the volume, transport route and water quality of agricultural drainage. Tillage method and depth have also effects on the ability of soil to store water and the furrow irrigation hydraulics of irrigated fields. A study was conducted to evaluate the effect of tillage method and depth on furrow irrigation hydraulics and soil water storage during the dry season at Dire Dawa, Eastern Ethiopia. Treatments in the study included were chisel, moldboard and disk ploughing to 150 mm and 250 mm depths; and "*Maresha*" (local plough). Data obtained through field measurement and/or observations and laboratory analysis included soil data, irrigation water, advance and recession times, inflow–outflow volumes, available soil moisture, and infiltration rate at each irrigation event. Extending tillage depth from 150 mm to 250 mm significantly increased irrigation infiltration (mm) from 34 to 38%, increased irrigation water advance time from 55 to 75%, increased application efficiency from 33 to 55%, and increased saturated hydraulic conductivity from 23 to 48%; and significantly decreased tail water ratio and distribution uniformity ($p < 0.05$) in the first two irrigations, but had little effect during the successive irrigations.

1. Introduction

Tillage practices and crop residue management play an important role in the performance of irrigation systems. Tillage practices affect the way water moves into (infiltration) and off of the soil (runoff) and the rate of water loss from the soil into the atmosphere through evapotranspiration. Tillage is an important technique with which farmers influence soil and microclimate to maximize agricultural yield. Ever since primitive societies learned to manipulate soil using simple tools, cultivation has been an essential component of farming and its usefulness has never been questioned. It is only recently that tillage and its consequences have been a concern to the scientific community. Since the 1950s, mechanized tillage with its sometimes-drastic effects on soil and environments have been widely used (FAO, 1995). The large energy requirements of tillage operation had led to a closer examination of the need for such expensive, time consuming and potentially degrading techniques. The consequences of tillage on soils and environments are hard to generalize. The effects vary among soils, climate, initial conditions and subsequent management.

In general, agricultural management practices can change the characteristics of the soil surface and influence the hydrothermal properties of the soil. Disruption of soil structure affects the soil biological and hydraulic processes. Pores are arguably the most important soil physical feature, because most soil processes that have immediate consequences for soil biological activity or soil conservation occur either within pores or on the surfaces of the particles that form their walls. It is not only the size and number of these pores which are important but also their continuity; obviously isolated pores will play a much less central role in soil processes including infiltration.

Soil water infiltration is one of the most important processes affecting crop production and the volume, transport route and water quality of agricultural drainage. Except in regions of timely and/or excessive precipitation, any practice which increases water availability to crops is looked upon favorably. It is generally believed that when depth of ploughing is shallow, it results in very shallow loosened soil below a furrow bottom which results in reduced infiltration; whereas depth of ploughing increases the rate of infiltration, especially significantly right after tillage (Allen, 1985).

Primary tillage operations can increase infiltration by increasing soil porosity and establishing channels or voids in the surface layer of soil, that conduct water into soil profile. Secondary tillage operations reduce soil porosity to some extent and break the continuity of channels and fill most large voids. Deep sub soil tillage operations can greatly increase the macro porosity and infiltration in surface soil layers (Mizuba and Hammel, 2001). Dexter and Richard (2009) reported that tillage affects total, macro- and structural porosity, bulk density, and water

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retention on Pacolet and Wedowee sandy clay loam soils. The study also concluded that, the soil water retention curve varied with tillage system.

Straw mulching (SM) systems can conserve soil water and reduce temperature because they reduce soil disturbance and increase residue accumulation at the soil surface (Baumhardt and Jones, 2002; Zhang et al., 2009). Soil mulching with plastic film, which results in reduced water loss and more even regulation of soil temperature, has been widely used in agriculture (Zhang et al., 2005). Humberto and Lal (2007) showed that saturated hydraulic conductivity (K_{sat}) of mulched treatments were 123 times greater and retained 40 to 60% more water than the un-mulched treatment. Pore volume of macro- and mesopores were also greater in mulched treatments and that of fine mesopores was greater in the un-mulched treatment in the 0- to 3-cm depth.

Deep chiseling increases infiltration and reduces surface runoff by increasing the vertical component of hydraulic conductivity (K) of the top layer and adjacent layers of soil (Moriasi, 2004). Unfortunately, the benefits of deep chiseling in increasing K and hence infiltration are only temporary because the soil surface seal (Assouline and Mualem, 2002; Daniel, 2004; Martinez-Gamino, 1994; Slattery and Bryan, 1994) and soil compaction increases gradually as fine particles fill the soil pore spaces after subsequent rainfall events (Allen and Musick, 2001; Freebairn et al., 1991; Rao et al, 1998b). The gradual increase in soil surface seal formation and soil compaction over time causes a gradual decrease in K (Moriasi, 2004).

Kim and Chung (1994) found that average saturated hydraulic conductivity on a tilled sandy loam soil layer gradually decreased exponentially as a function of cumulative rainfall energy after tillage. According to Rao et al. (1998a), the decline in infiltration rate since tillage on an Alfisol was found to have an exponential relationship with cumulative rainfall since tillage. Allen and Musick (2001) found that deep ripping increased infiltration on a clay loam soil (Torrertic Paleustoll) by 26 to 29% immediately after primary tillage but the benefit of ripping was lost because of the subsequent furrow traffic and soil consolidation from irrigation and rainfall.

Extending primary tillage depth from 150 mm to 250 mm increased the net average intake, as a result there was a significant increment of application efficiency in the first two irrigations but showed no significant difference for the successive irrigations ($p < 0.05$) (Berhe et al., 2012). However, the same study concluded that unlike the depth treatments, tillage method treatments showed no significant difference in irrigation infiltration, grain yield, biomass yield, and the associated irrigation water use efficiencies.

Soil bulk density, penetration resistance (PR), water movement in the soil, soil compactness and porosity depend on the depth and method of tillage (Hamza and Anderson, 2002, 2003, 2005). Therefore, assessing the effect of tillage depth and method on these soil physical properties may explain variability in crop growth, crop development, yield, and quality (Berhe et al., 2012; Hamza and Anderson, 2002, 2003, 2005).

The aim of the present study was to evaluate the effects of tillage method and depth on furrow hydraulics. The specific objective of the study is to evaluate the effects of tillage implements and depth of ploughing on (1) soil water conductance, retention, and hydraulics of irrigation water flow in furrows, and (2) the temporal variability of these parameters. We assessed infiltration rates, hydraulic conductivity, irrigation water advance, irrigation performance indices (i.e. Application Efficiency (AE), Tail Water Ratio (TWR), Deep Percolation Ratio (DPR) and Distribution Uniformity (DU)); and soil water storage parameters. This study was performed in an effort to demonstrate our hypothesis that increasing depth of tillage from 150 mm to 250 mm would increase soil water storage through increased infiltration opportunity time and ultimately improve crop yields by loosening the subsoil for greater root exploration volume and extraction of soil water.

2. Materials and methods

2.1. Description of the study area

2.1.1. General

The research was conducted in Tony Farm of Haramaya University located in Dire Dawa, eastern Ethiopia (Fig. 1). The site is located at the eastern escarpment of the Rift Valley, 9.26°N, 41.8°E, and at an altitude of 1210 m. The area experiences a bimodal type of rainfall; the mean annual precipitation is 650 mm. The mean annual maximum and minimum temperature are 34 °C and 18 °C, respectively. Soils of the area are predominantly sandy loam with pH of 5.8 to 6.8. (Ketema, 2003).

The seasonal rainfall pattern at Dire Dawa shows a bimodal distribution with peaks in April and August. The mean annual average daily air temperature is 25.3 °C, with mean annual daily maximum and minimum values of 31.6 °C and 19.0 °C, respectively. The mean monthly daily relative humidity ranges from 73.5% (February) to 80.9 % (August) and the mean monthly daily minimum relative humidity is between 36.8% (November) and 43.8% (September). The mean annual daily wind speed of the study areas is 199.4 km/day. The maximum mean monthly daily average wind speed value is 319.7 km/day (July) and the minimum is 129.6 (January). The mean monthly daily average sunshine duration varies between 7.5 h (April) and 9.3 h (November) while the mean monthly daily average solar radiation between 20.4 MJ/m^2/day (December) and 22.7 MJ/m^2/day (May).

As cited by Heluf (2004), UNESCO (1979) and Thornthwaite (1948) define different classes of aridity based on the ratio of annual precipitation (P) to potential evapotranspiration (ET_p). Accordingly, UNESCO defines four arid zones, namely hyper-arid zone ($P/ET_p < 0.03$); arid zone ($0.03 < P/ET_p < 0.2$); semi-arid ($0.2 < P/ET_p < 0.50$) and sub-humid zone ($0.5 < P/ET_p < 0.75$) where P and ET_p are mean annual precipitation (mm) and mean annual potential evapotranspiration (mm), respectively. Similarly, Thornthwaite defines arid boundary when $I_m < -66.7$ and semi-arid boundary when $-33.3 > I_m > -66.7$; where I_m is aridity index. Hence, as per both the UNESCO and Thornthwaite classification, the study area is classified as semi-arid.

2.1.2. Cropping pattern

The rural population of Dire Dawa area could be grouped into crop grower, agro-pastoral and pastoral. The agro-pastoral systems occur in the foothills of the mountains, particularly in the southeastern part of the Dire Dawa Region, where the farming system is agro pastoral and the main subsistence component is the outcome of cropping while extensive livestock rearing is also important as a subsidiary component. The main crop grown here is sorghum being followed by maize.

Land preparation for sorghum and maize crops is carried out using the *Maresha* (a traditional ploughing tool), and for vegetables, perennials and for garden crops (homesteads) digging or hoeing tools are used. Sorghum is cultivated in the main field and it is the major cereal crop grown in the area, while maize is grown in the homestead. Depending on the onset of rainfall, sorghum is sown starting from the mid of April, whereas the other crops are sown any time of the year with the help of irrigation.

2.1.3. Ethiopian local plough ‘Maresha’

At present, over 80% of Ethiopia's population is engaged in agriculture. The majority of the farming community lives in the highlands. Crop-livestock mixed farming is the common practice and farmers use pairs of oxen for land cultivation. Horses and mules are used as work animals in some areas but oxen provide the main traction power (Fig. 2).

The traditional cattle economy of the highlands is directed to raising ploughing oxen. Meat and milk are by-products from it. The only implement used for land preparation and planting is the traditional plough or ‘*Maresha*’ which is a pointed, steel-tipped, tine attached to a draught