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Evaluation of surface water drainage systems for cropping in the Central Highlands of Ethiopia

W.A. Welderufael *, Y.E. Woyessa

School of Civil Engineering and Built Environment, Central University of Technology, Free State, Private Bag X20539, Bloemfontein 9300, South Africa

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ABSTRACT

In Ethiopia vertisols cover about 10% of the total land area and is the fourth most important soil used for crop production, accounting for nearly 23% of the total arable land used for crop production. More than half of the vertisols are found in the Central Highlands of Ethiopia, with an altitude of more than 1500 m above mean sea level. The unique physical and chemical properties of these soils and the high rainfall during the main cropping season create severe surface waterlogging problems which hinder crop production activities. Severe surface waterlogging affects the growth of plants by impeding nutrient uptake and creating oxygen deficiency around the root zone. To address this crop production problem, three surface water drainage methods, namely broad bed and furrow (BBF), ditch, and flat (traditional) methods were evaluated using the water balance of the plant root zone and wheat as a test crop. The experiment was conducted at the Ginchi Research Station in the central highlands of Ethiopia over two consecutive seasons (2000 and 2001). The results showed that both the BBF and the ditch drainage methods gave about 33% and 22% more grain yield than the flat treatment, respectively. However, there were no significant differences between BBF and ditch for both grain and biomass yield during both experimental seasons. During both seasons the total water balance (ΔW_r) at the root zone especially, in the months of June, July and August on all the treatments was higher than the crop water requirement (ETc) and showed no significant difference between the treatments. Thus, the results of this study indicated that the soil water in the root zone was not significantly altered by surface drainage systems and therefore implies the need of further improvement of the different surface drainage methods regarding improving the waterlogging condition and hence the productivity of the vertisols in the Central Highlands of Ethiopia.

1. Introduction

In Ethiopia vertisols cover about 10% (12.7×10^6 ha) of the total land surface and they are the fourth most important soil order (Srivastava et al., 1993) in crop production. This soil order accounts for nearly 23% of the total arable land used for crop production (Debele, 1985). More than half of the vertisols (7.6×10^6 ha) are found in the Central Highlands with an altitude of more than 1500 m above mean sea level (a.m.s.l.). In these Central Highlands, only 30% of the vertisols are used for crop production. The remaining 70% are under natural pasture (Srivastava et al., 1993). In this region, vertisols are dominant on land with slopes ranging from 0% to 8% (Debele, 1985). The unique physical and chemical properties of these soils and the high rainfall (787 mm) during the main cropping season (June–September – about 70% of annual rainfall), create severe surface waterlogging problems, which challenge crop production activities. According to a survey of the farming systems in vertisol areas of the Central Ethiopian Highlands (Asamenew et al., 1993), one of the major constraints in crop production is surface waterlogging. At Ginchi, the waterlogging problem is aggravated by low infiltration and poor sub-soil permeability (Welderufael and Regassa, 1993). Poor surface drainage affects the growth of plants by impeding nutrient uptakes and by creating oxygen deficiency in the root zone (Mamo et al., 1993; Sevenhuijsen, 1994). The relationship between yield and depth of the groundwater table demonstrates that crops seem to be more affected by 'too wet' than 'too dry' conditions (Sevenhuijsen, 1994). A 'too wet' condition not only affects the nutrient uptake of the crops but also causes deterioration of soil structure, slowing down the nitrogen mineralization process in the soil and affects timely farming operations (De Ridder, 1994; Sevenhuijsen, 1994; Feddes et al., 1996; Busman and Sands, 2002).

At Ginchi, a research station of the Ethiopian Institute of Agricultural Research (EIAR) in the Central Highlands of Ethiopia, different improved surface water drainage systems were introduced to solve the problem of surface waterlogging of the root zone

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* Corresponding author. Tel.: +27 51 507 3241; fax: +27 51 507 3254.
E-mail address: wwelderu@cut.ac.za (W.A. Welderufael).

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during the main rainy season. These include camber beds, broad bed and furrows (BBF), and ditches. The main objectives of these drainage systems were to remove excess surface water and to create an optimum soil water condition for crop growth. This allows for easy farming operation and creates favourable aeration of the root zone. These different surface water drainage systems reportedly increased crop yields, extended the growing period and allowed early coverage of the soil surface (Abebe, 1982; Jutzi et al., 1987; Mamo et al., 1993). The traditional practices, flat seed bed preparation and late planting, largely depend on the residual soil water content. A study by Srivastava et al. (1993) investigated the nature and fluctuation of the soil–water table during the main rainy season and revealed the existence of a shallow perched water table, which rises up to 50 mm from the soil surface during some time in the main rainy season. Hence, the relationship between groundwater table depth and crop yield was considered to be a poor parameter to be used for evaluation of the effect of waterlogging on crop yield (Sevenhuijsen, 1994).

The hydrological water balance equation is one of the tools that can be used to estimate the incoming and outgoing water fluxes at the boundary of the root zone in a given time step, i.e. daily, weekly, or monthly (Raes et al., 2005; Kowalik, 2006). The water balance of the root zone (ΔW_r) can also be used as agricultural criterion to determine drainage system efficiency. Several researchers (Tanner and Sinclair, 1983; Walker, 1986; Hattingh, 1993; Passioura, 2006) established direct relationships between transpiration and biomass in the natural soil–plant-atmosphere continuum (SPAC) using a root-zone water balance approach (Fig. 1). The aim of this study was to evaluate the effect of two improved drainage systems using grain yield, biomass yield and root-zone water balance as indicators.

2. Material and methods

2.1. Experimental site

The experiment was conducted at Ginchi, a research station of the Ethiopian Institute of Agricultural Research (EIAR) during 2000 and 2001. The station is located in the Central Highlands of Ethiopia, about 85 km west of Addis Ababa (longitude 38°13′09″ E and latitude 9°01′05″ N). The altitude is 2200 m a.m.s.l. The long-term mean annual rainfall is 1124 mm with a short (March–May) and a long rainfall season (June–September) (Fig. 2). Although some crops are grown during March–May, the main season for producing most of the major crops is June–September as it comprises more than 70% of the annual rainfall. The maximum temperature ranges between 22 and 27 °C, while the minimum ranges between 5 and 10 °C (Fig. 2). Reference crop evapotranspiration (ETo) is higher than rainfall in all months except for the main cropping seasons (June–September). The soil is characterized as heavy clay with 58.7% clay, 17.6% silt and 23.7% sand. Some of the physical and chemical properties of the soil at the experimental site are presented in Table 1.

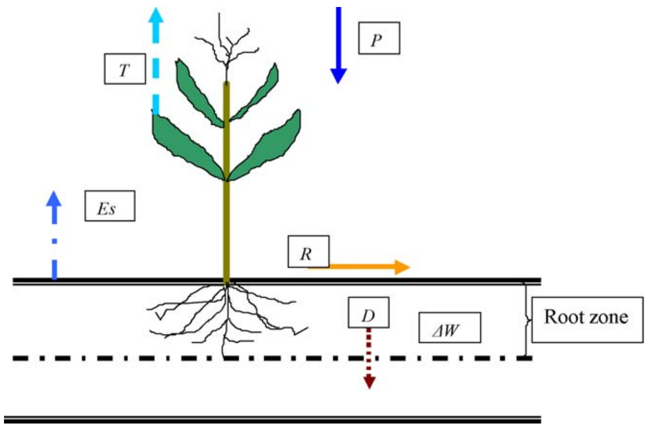

Fig. 1. Diagrammatic representation of the SPAC water balance (P = precipitation, T = transpiration, R = runoff, Es = soil evaporation, D = deep drainage and ΔW = change of root-zone water content).

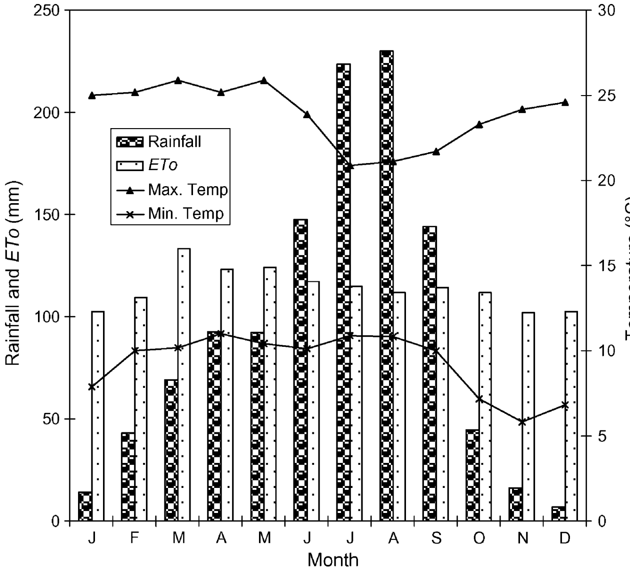

Fig. 2. Long-term average rainfall and temperature at Ginchi research station, Ethiopia.

2.2. Experimental layout

Plots with dimensions of 4 m × 22 m were prepared and excess surface water-collecting devices (Pathak et al., 1992) were installed to measure the excess surface water after each rainfall event, hereafter referred to as runoff. The plots were fenced by sheet metal to prevent inflow and outflow of runoff. The

Table 1
Physical and chemical properties of the soil at Ginchi Research Station, Ethiopia.

FAO soil classification (FAO, 1984) – soil type	Pellic vertisol
Physical and chemical properties	Average values of the top 1 m soil
Sand (%)	23.7
Silt (%)	17.6
Clay (%)	58.7
Saturated hydraulic conductivity, Ks (mm h^{-1})	
0–15 cm	16.2×10^{-2}
15–30 cm	9.2×10^{-2}
30–60 cm	Negligible
Soil water content (%)	
At 33 kPa	62.4
At 1500 kPa	44.1
pH (H_2O 1:1)	6.98
Organic matter (%)	0.94
Available P (Bray II mg l^{-1})	5.11
Total N (%)	0.046
Exchangeable cations (cmol$_c$ kg^{-1} soil)	
Na	1.15
Ca	60.17
K	1.41
Mg	10.84

Source: Kamara et al. (1989), Welderufael and Regassa (1993).