Soil water dynamics under cereal and forage legume mixtures on drained vertisols in the Ethiopian highlands

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Abstract

At the Debre Zeit Station cereals (wheat and maize) and forage legumes (lablab, cowpea, vetch and clover) were grown as sole crops and as cereal/forage combinations on the broadbeds separated by drainage furrows (BBF). This is an improved land management system, developed by ILCA in collaboration with other national and international partners, to raise productivity of Vertisols. Soil water content monitored at soil depths of 0–50 cm and 50–100 cm indicated that lablab and cowpea deplete significantly greater amounts of available soil water during the growing season than vetch and clover. Deep rooted forage legumes lablab, cowpea and vetch are more suitable for combination with cereals such as maize than with wheat due to the phenological differences between the two crop types. Grain yields of wheat and maize were higher when intercropped with legumes than as sole crops in the absence of external N input. Moisture use by the various crop–forage land use types are discussed.

Keywords: Broadbed and furrow; Intercropping; Soil water; Vertisols

1. Introduction

Ethiopia cannot meet its food and feed targets using the prevailing land use systems (FAO, 1983). For the past several years the International Livestock Centre for Africa (ILCA) has been researching the improvement of Vertisol management in the Ethiopian highlands. Improvements of the traditional plough 'maresha' to make it more versatile for different farm operations on Vertisols was an important research area. A product of this research is the land shaping implement, the broadbed maker (BBM), which has been tested on-farm for a number of years. Removal of excess water during the wet season is one of

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the most crucial management practices for Vertisols, which differentiates them from most other soils. Vertisols are clayey and due to the montmorillonitic mineralogy, they have a high water holding capacity resulting in a very low hydraulic conductivity and low infiltration rates. Vertisols prepared into broadbeds and furrows (BBF) with BBM drain the excess water faster than traditional or flat seed beds (Astatke et al., 1991). This enables early planting of crops as opposed to the traditional late planting towards the end of the main rains, and crops mature on the residual soil water. As early planting became a possibility on the drained Vertisols, several cereal and forage spatial and temporal combinations were investigated, with a view to intensifying highland land use for the benefit of the land constrained smallholder farmer in Ethiopia.

Relative advantages of intercropping under conditions of soil water stress have been observed by Natarajan and Willey (1980). In semi-arid tropical areas Baker and Norman (1975) attributed such yield advantages to better water use efficiency (WUE). A possible reason for the increased WUE with intercropping is the windbreak effect of taller plants such as cereals on shorter plants such as the common grain legumes (Steiner, 1982). Complimentary use of soil resources by intercrops is another reason for better WUE whereby interference of root systems of the component crops is minimized by exploiting different soil layers (Willey, 1979). Soil water use during the growth period of cereal crops, grown in association with forage legumes, is less researched. This paper reports on a study that assessed soil water under wheat and maize and their individual combinations with forage legumes on drained vertisols.

2. Materials and methods

The experiment was conducted the Debre Zeit Research Station (50 km south of Addis Ababa, 1850 m asl). The soil type at the experimental site is a chromic Vertisol (FAO-UNESCO, 1974) with 59% clay, 22% silt and 19% sand. The experimental site has a bimodal rainfall, a short rainy season between March and April and a longer rainy season between mid June and mid September. The long term mean annual rainfall shows that the short rains contribute 30% of the annual precipitation averaging 860 mm. During the experimental period, the longer rains contributed 650 mm, which corresponds to the long term average. The monthly rainfall variations during the experimental period and the long term average were small. In the main season of the study period precipitation in June, July, August and September was 74 mm, 240 mm, 231 mm and 105 mm, respectively while the long term average rainfall was 89 mm, 250 mm, 227 mm and 116 mm for June, July, August and September, respectively.

This experiment was laid out to periodically assess the available soil water during the growing period as influenced by forage legumes in different land use combinations. The two cereals were: maize (Zea mays) and wheat (Triticum aestivum). The forage legume, lablab (Lablab purpureus) was grown as a mono crop as well as intercrops with the two cereals. Clover (Trifolium steudneri), cowpea (Vigna unguiculata) and vetch (Vicia dasycarpa) were grown only as intercrops with maize and wheat.

The seed bed was prepared by ploughing the field three times with the traditional tine plough (maresha). After broadcasting the seeds, the BBF were made along a gradient of
1% slope, using ox-drawn broadbed makers. To establish crop/forage combinations, seeds of the respective forage legumes were mixed with cereals and broadcast. Each BBF was 1.2 m wide from the center of the two furrows on either side, making the bed 0.8 m for establishing crops. The height of the bed was 0.2 m from the furrow depth and each furrow was 0.4 m wide.

The experiment utilized a randomized complete block design with four replications. Each plot measured 48 m². Two nitrogen (N) levels (0 and 100 kg N ha⁻¹) were imposed and N was applied as urea. The crops and the forages were harvested separately when they reached physiological maturity. Yield measurements were made from 24 m² on each plot.

Two soil samples were randomly taken from the mono crop plots and combinations and N-fertilized treatments every 15 days. Each soil sample was obtained after mixing two sub-samples. Soil moisture was gravimetrically determined for soil depths (0–50 cm) during the growing period between June and October, and from November to February an additional (50–100 cm) depth was included. Available soil water for plant use in the profile was determined using the formula:

\[ \text{ASWP} = \text{AW} - \text{PWP} \]

where \( \text{AW} \) is the amount of water in the soil depth \( d \) (mm), \( \text{PWP}_d \) is the calculated amount of water in the soil depth \( d \) that will not be available for plants (1.5 MPa; mm), \( \text{ASWP} \) is the available soil water to plants at depth \( d \) (mm).

The moisture at 1.5 Mpa (permanent wilting point) was determined for each depth by the pressure plate technique while the soil bulk density was determined by a 100 mm diameter core method (Peters, 1965) and cracks were avoided when taking soil samples during the dry season.

Analysis of variance was used for comparisons of grain and dry matter yield between various combinations. Moisture data comparisons were carried out separately for each sampling date. The statistical package SAS was used for all the analyses (Statistical Analysis Systems, 1987).

3. Results

3.1. Crop yield

Grain and total dry matter yields of wheat, maize and their combinations with forage legumes at two levels of N, 0 and 100 kg ha⁻¹, are given in Tables 1 and 2. There was no significant difference in grain yields of maize between mono or intercrops in association with legumes at zero kg N ha⁻¹ application. Total fodder dry matter of maize in combination with forage legumes was higher than the mono maize crop, except for the clover combination at zero N level. Nevertheless, both grain and DM yields obtained from maize were significantly greater when maize was intercropped with lablab at 100 kg N ha⁻¹ than intercropped with the other legumes at the same fertilizer level (Table 1). The grain yield of wheat at zero N application was significantly lower compared with its combination with lablab and clover. Crop residue yield of sole wheat and its combination with lablab and vetch were higher than with cowpea and clover. At 100 kg N ha⁻¹ the sole wheat produced significantly
Table 1
Grain and total dry matter yields (t ha⁻¹) of sole maize and its combinations with forage legumes of lablab, cowpea, vetch and clover at Debre Zeit research site in 1991/1992

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fertilizer Rates</th>
<th>100 kg ha⁻¹ N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kg ha⁻¹</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grain* t ha⁻¹</td>
<td>Residueb (DM) t ha⁻¹</td>
</tr>
<tr>
<td>Maize (sole)</td>
<td>2.0ab</td>
<td>9.5ab</td>
</tr>
<tr>
<td>Maize + lablab</td>
<td>2.4a</td>
<td>13.7b</td>
</tr>
<tr>
<td>Maize + cowpea</td>
<td>2.3a</td>
<td>13.3b</td>
</tr>
<tr>
<td>Maize + vetch</td>
<td>2.3a</td>
<td>12.1bc</td>
</tr>
<tr>
<td>Maize + clover</td>
<td>2.2a</td>
<td>7.3a</td>
</tr>
</tbody>
</table>

*aCereal grain yield only. bResidue included cereal straw and forage dry matter. cDifferent letters within each column indicate significant difference at P<0.05.

Table 2
Grain and total dry matter yields (t ha⁻¹) of sole wheat crop and its combination with forage legumes of lablab, cowpea, vetch and clover at Debre Zeit research site 1991/1992

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fertilizer Rates</th>
<th>100 kg ha⁻¹ N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kg ha⁻¹</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grain* t ha⁻¹</td>
<td>Residueb (DM) t ha⁻¹</td>
</tr>
<tr>
<td>Wheat (sole)</td>
<td>1.7a</td>
<td>6.6b</td>
</tr>
<tr>
<td>Wheat + lablab</td>
<td>2.3b</td>
<td>6.1b</td>
</tr>
<tr>
<td>Wheat + cowpea</td>
<td>1.7a</td>
<td>4.2a</td>
</tr>
<tr>
<td>Wheat + vetch</td>
<td>1.8a</td>
<td>5.4a</td>
</tr>
<tr>
<td>Wheat + clover</td>
<td>2.3b</td>
<td>4.9a</td>
</tr>
</tbody>
</table>

*aCereal grain yield only. bResidue included cereal straw and forage dry matter. cDifferent letters within each column indicate significant levels at P<0.05.

higher grain yield than crop/forage combinations except wheat/lablab. Total dry matter of wheat/clover combination at this level of fertilizer application was the lowest (Table 2).

3.2. Moisture

Fertilizer use did not influence moisture dynamics. Crops varied in water use efficiency. During the period from the end of June through October the available soil water was in excess of evapotranspiration and it was replenished by the frequent rainfall during that period (Fig. 1). At a depth of 0–50 cm there were no significant differences in moisture availability either under sole crops or/between their combinations (Fig. 1) throughout the growing season. However, significant differences occurred at greater soil depths later in the season. In November, at a soil depth of 50–100 cm, the available soil water in lablab and cowpea plots were significantly (P ≤ 0.01) lower (83 mm and 87 mm, respectively) than
Fig. 1. Available soil water at a soil depth of 0–50 cm grown to wheat, maize and lablab with rainfall and evaporation at Debre Zeit, 1991/1992.

Fig. 2. Available soil water at a soil depth of 50–100 cm in Debre Zeit Vertisols grown to wheat and its combinations with forage legumes, November 1991/February 1992.
those in plots of vetch and clover (140 mm and 141 mm, respectively) in their combinations with wheat (Fig. 2). In January, available moisture at (50–100 cm) depth was generally low across all wheat/legume combinations. However, it was significantly lower again in lablab and cowpea fields (49 mm and 51 mm, respectively), than in clover and vetch (60 mm and 66 mm, respectively). Lower moisture availability also prevailed at a soil depth of 50–100 cm under sole lablab compared with sole wheat and maize (Fig. 3). The available soil water during the same period in November was also lower at a soil depth of 50–100 cm in the lablab and maize plots than the other legume combinations with maize.

4. Discussion

During the first 3 months of the crop growth period soil water was in excess of evapotranspiration. The competition between the cereal and forage legumes in the intercrops for soil water was minimal. The cereal crops were harvested early November. This suggests that they reached full maturity by the end of the main rainy season, and their major water needs for the physiological process were met when rainfall was in excess of the evapotranspiration. The forage legumes, especially lablab and cowpea depleted soil water faster by exploring the deeper layers. During mid-November, sole lablab depleted the soil water by 55 mm and 18 mm more than sole wheat and maize, respectively, at the lower depth of 50–100 cm (Fig. 3). The amount of available soil water stored by Vertisols in the Ethiopian highlands is higher at greater depth (Astatke et al., 1991).

The total available soil water in the top 50 cm of vertisols at Debre Zeit as assessed by Kamara and Haque (1987) was 200 mm (4 mm cm$^{-1}$). The highest measured available
soil water in the top soil layer (0–50 cm) was found to be 200 mm in mid September for lablab however, under maize and wheat plots, it was found to be 184 mm and 120 mm, respectively. Wheat and maize reached full vegetative stage in September and, therefore were at their peak water needs compared with lablab. Starting end of October, soil water depleted faster from the top layer in lablab plots than in the two cereals as they started to dry up. The short rains in January facilitated recharge of the bare plots after the harvest of wheat and maize, thus explaining higher water content in the upper soil layer (0–50 cm). Conversely, soil moisture continued to decline under lablab which was actively growing during that period. Hence, the January rainfall did not affect the overall soil moisture status of plots under lablab. The excess water that drained off from the vertisols during the main rains was not useful for the soil water recharge.

The grain and total dry matter yields of the combinations of wheat and maize with forage legumes varied considerably. Tedla et al. (1992) found that undersowing wheat with clover did not reduce grain yield significantly but increased the total dry matter. In this trial it was found that the grain yield with clover combinations was slightly increased while the total dry matter was reduced. This is attributed to the earlier maturity of the clover and shedding of some of its leaves by the time wheat was harvested. The trial also suggests that twining legumes such as vetch, cowpea and lablab is more suitable for compatible association with cereals such as maize than wheat. Greater availability of soil water in the deeper soil layer during the start of the dry season will be an advantage for long duration crops or forage legumes that have an indefinite growth habit.

5. Conclusion

The broadbed and furrow seed beds facilitate faster evacuation of the excess water than the traditional or flat seed beds, even though the amount of soil water stored by the Vertisols was not affected. Legumes can be intercropped with cereals if they are phenologically and physiologically compatible. Deep rooted forage legumes such as cowpea, lablab and vetch are suitable for intercropping with cereals, like maize and wheat in vertisols.

The moisture in the vertisols seems sufficient to grow more crops than that traditionally grown in this soil type. As demographic pressure increases there is a compelling need for land productivity intensification and, the study suggests that Vertisols in Ethiopia can be intensively cropped to raise the grain and fodder productivity. However, more work is needed to tailor crop and forage combinations to Vertisols at different altitudes.

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References


