Comparison of measured changes in seasonal soil water content under rainfed maize-bean intercrop within a semi-arid area

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Abstract

Seasonal water content fluctuation within the effective rooting depth was monitored during the growing season for an additive maize-bean intercrop (IMB), sole maize (SM) and sole bean (SB). Comparisons were made at progressive depths of extraction 0-300 mm; 300-600mm and 600-900 mm respectively. These enabled the understanding of water extraction behavior of the cropping systems within the topsoil, which is normally influenced substantially by soil evaporation under semi-arid conditions. The additive intercrop had almost similar seasonal extraction pattern as the sole crops. This was against expectation given its higher plant density. It was concluded that the early and larger canopy modified the microclimate, reducing the soil water used as surface evaporation and increasing the overall efficiency of the system. During both 2000/01 and 2001/02 seasons the water extraction limits (DUL-CLL) were determined. The potential extractable water by the cropping systems were: 121 mm (IMB), 114 mm (SM) and 103 mm (SB). These differences reflected the atmospheric demand for water, soil profile and cropping system characteristics. An examination of the seasonal soil water extraction for the 0-900 mm profile depth among the systems showed minor differences. Layerwise examination showed that the cropping systems water extraction was influenced by factors imposed upon it by the nature of both the above and below ground growth as well as competition for soil water resource.

Media summary

The outcome of the research confirmed that the seasonal soil water depletion patterns for the additive intercrop system does not significantly differ from the component sole crops, and therefore conserves water and can be adopted under conditions of low and poorly distributed rainfall, as experienced in southern parts of Africa.

Key Words:

Additive intercrop, soil water extraction

Introduction

Rainfall amount and variability limit crop production in the semi-arid areas. Large areas of southern Africa experience low and variable rainfall. The low mean annual rainfall of 450 to 550 mm, and high annual evaporation of 2000 to 2500 mm, result in severe crop water stress during most seasons on these ecotopes. Maize (*Zea mays*) is the staple food for smallholder farmers in Southern Africa and is commonly grown in association with dry beans (*Phaseolus vulgaris*). The majority of smallholder farmers have adopted the cropping system mainly to reduce risks due to low and variable rainfall. It also provides a more balanced dietary intake for resource poor smallholder households. Maize is normally grown as the principal crop, with plant densities corresponding to those in the sole crop, with the legume as the secondary crop. This cropping system is associated with low inputs, and essentially depends on the natural resource base, mainly rainfall. There is substantial agronomic evidence regarding yield advantage by intercrop systems (Willey, 1979, Ahmed & Rao, 1982; Willey, 1990; Mukhala, 1998; Ogindo, 2003). The objectives is to compare the measured seasonal progress of soil water extraction within the soil profile for the three cropping systems within the semi-arid area of South Africa.

Materials and methods

Experimental site and agronomic details

The field experiment was conducted over two seasons at the University of the Free State, Agrometeorology experimental site (latitude 29? 06′S, longitude 26? 11′E, elevation 1354 m above sea level). The soil type is pseudo duplex with higher clay mineralogy at 700-800 mm depth. The bulk density at the site ranged between 1.35-1.72 g cm^3. During the experimental seasons of 2000/01 and 2001/02 meteorological weather variables were recorded by an automatic weather station at the site. The mean weather data for the 2000/01 season were; rainfall: 255 mm, solar radiation: 318.5 W m^{-2}, wind speed: 2.2 m s^{-1}, maximum temperature: 29.2 ^oC, minimum temperature: 15.6 ^oC, and vapour pressure deficit: 2.1 kPa. Mean weather variables during the 2001/02 season were; rainfall: 324.0 mm, solar radiation: 297.0 W m^{-2}, wind speed: 1.8 m s^{-1}, maximum temperature: 27.6 ^oC, minimum temperature: 15.3 ^oC, and vapour pressure deficit: 1.2 kPa.

Short season maize (*Zea mays* L cv. PAN 6804) and inderteminate bean cultivar (*Phaseolus vulgaris* L cv. PAN 148) with a maturity period of 120 days was planted. The intercrop components were sown simultaneously and in an additive scheme resulting in 120,000 plants per hectare. The seeding rate for the sole maize was 40,000 plants per hectare and for the sole bean 80,000 plants per hectare. The fertilizer application (240 kg N, 96 kg P and 48 kg K per ha), sowing and weeding were done by hand. A completely randomized block with each plot being 18 m x 12 m was used. There were three treatments within each block: sole bean (SB), sole maize (SM) and inter-crop maize and bean (IMB). Each treatment had three replications.

Soil water measurement

A neutron water meter (NWM) was used to monitor soil water changes on weekly to dekadal basis from planting to final harvest. Access tubes were located both within and between the row for the sole-crop maize and beans. To determine the drained upper limit (DUL), a dam measuring 3 m x 3 m was made with earthen bunds along its perimeter (Hensley et al., 2000; Mukhala, 1998) with two access tubes installed to a depth of 1310 mm (Mukhala, 1998). The dam was wetted for a period of two weeks then covered by a polythene sheet, to ensure a good seal around the protruding access tubes to prevent wetting by subsequent rain. Measurement of water content for the whole profile was performed at depths of 150, 450, 750, 1050 and 1310 mm. The DUL was the highest measured water content after the drainage became practically negligible and the decline in profile water content was 0.1-0.2% per day (Ratliff et al., 1983). The crop lower limit (CLL) was measured on three plots (4m by 4m) protected from run-on and run-off with two access tubes installed in the SB and SM plots and three in the IMB. The plots were watered until two weeks to flowering, after which the soil surface was completely sealed with plastic sheeting to stop further direct water inputs from rain. Soil water was measured by a NWM on a weekly basis until wilting beyond recovery point was reached. The final and lowest NWM reading for each layer gave the CLL for each cropping system at the respective depths.

Leaf area and mass yield

Leaf area from three plants sampled in each plot (i.e nine plants per treatment) was measured. The final harvest separated into cobs, stems and leaves and weighed (12 m^2 per treatment). The final grains mass was at 12.5% moisture content.

Results and discussions

The DUL for the effective rooting depth of 0-900 mm was 262 mm. It was determined for the respective layers as well as the effective profile depth. Clay content increased with depth down the profile reaching a maximum within the 600-900 mm layer (Mukhala, 1998). Consequently, the water holding capacity for the soil profile increases down the profile with highest DUL in the 600-900 mm layer. The IMB exhibited slightly higher potential total extractable soil water than SB and SM, probably as a result of the higher root ramification of the soil profile due to the high plant density. The IMB also exhibited the lowest CLL value indicating greater extraction than SM and SB.

Season 2000/01 was harsher than 2001/02 due to the lower and poorly distributed rainfall, higher solar radiation and temperature, and higher vapour pressure deficit. The initial soil water was lower in 2000/01 than 2001/02 (Fig. 1). Season 2000/01 had poor leaf area growth, especially, during the vegetative period while season 2001/02 was more conducive for leaf growth due to more and better distributed rainfall. The cropping systems exhibited a more rapid extraction during the 2000/01 season compared to 2001/02 such that by 80 DAS the soil water content was at CLL (Fig. 1). There was no statistically significant difference between the cropping systems during both seasons in total water use despite the additive IMB planting (Ogindo, 2003).

The 0-300 mm layer showed similar extraction trend for all the cropping systems during both seasons (Fig.2). Season 2001/02 showed higher initial water content for the layer compared to 2000/01 till 20 DAS. The season 2000/01 had a faster depletion within this layer compared to 2001/02, however, the final water content were about similar at the end of the season. The reason for the quicker depletion during 2000/01 was most likely the lower leaf area index during the harsher season, exposing the soil surface to higher evaporation compared to the 2001/02 when the top growth was larger.

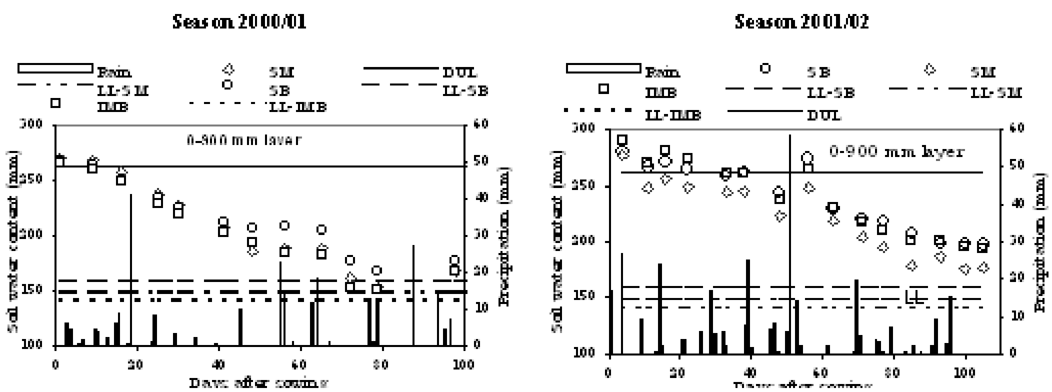

Figure 1. The 0-900 mm depth soil water extraction during the 2000/01 and 2001/02 seasons for the cropping systems.

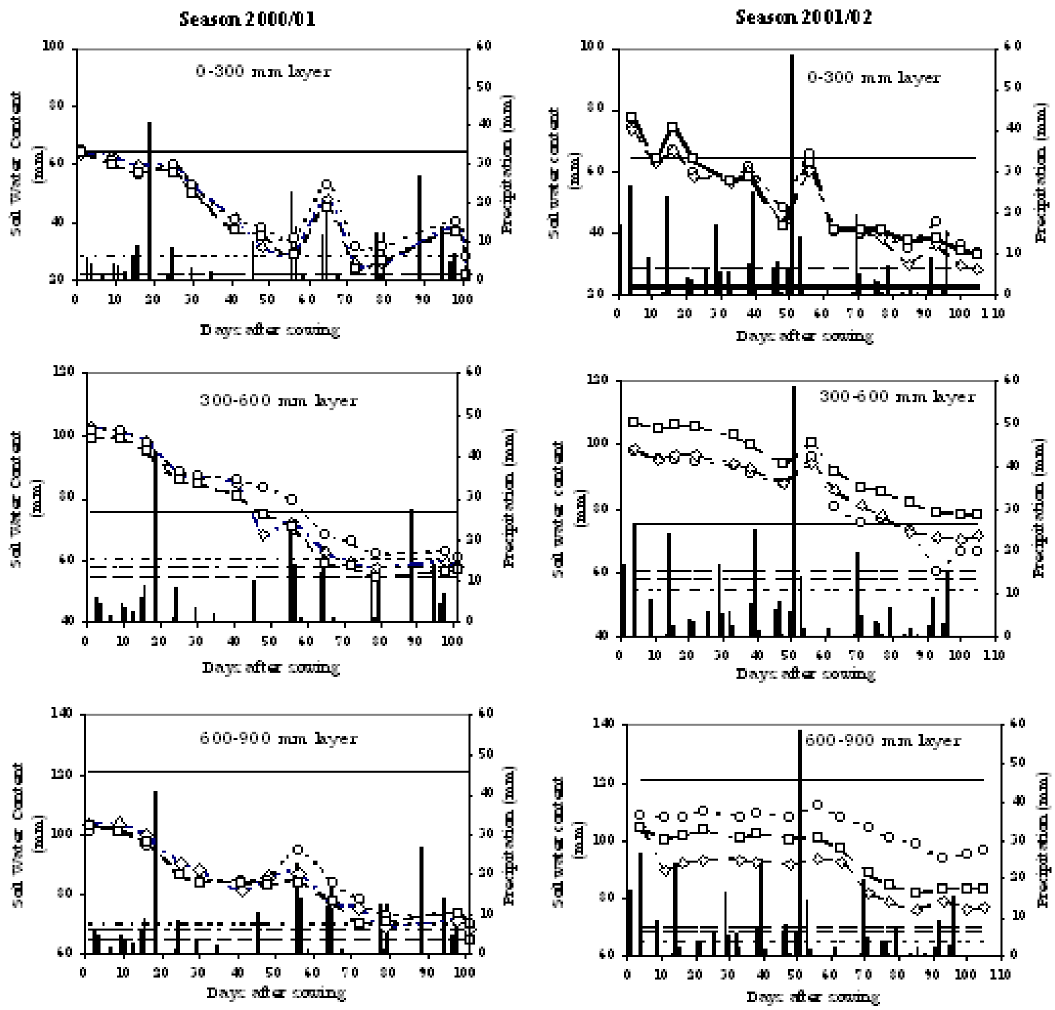

Figure 2. Layerwise soil water extraction by the cropping systems during the 2000/01 and 2001/02 seasons (symbols same as in Fig. 1)

In the 300-600 mm layer (Fig. 2) during season 2000/01, IMB had a slightly higher extraction till 45 DAS, thereafter SM had the highest extraction. SB exhibited the lowest extraction in the layer. The reasons may be the higher root ramification in this layer by both crop components in the IMB. The 2001/02 season has a completely different scenario; IMB had the lowest extraction throughout the season, while the SB and SM had similar patterns. Due to the higher rainfall and soil water, the canopy was larger during this season and hence there was more shading (less radiation load) on the soil surface therefore less soil evaporation. This could explain the lower extraction by IMB assuming that the surface evaporation influenced this layer. Season 2001/02 showed lower depletion by cropping systems throughout the season compared to season 2000/01 for this layer (Fig.2).

The 600-900 mm layer exhibited substantial extraction by all cropping systems during the 2000/01 season, perhaps due to the poor rains necessitating that the crop explored more soil volume for survival. From 50 DAS the SM and IMB had higher extraction than SB. During the season 2001/02, the SB showed the lowest extraction followed by the IMB and SM. The SM therefore seemed to have explored more of the soil layers. This may have been due to the lower soil water content in the upper layers. IMB exhibited lower extraction due to higher LAI cover thereby reducing the soil surface evaporation and making more water available in the profile layer and hence lower depletion.

Conclusions

There was poor leaf growth and rapid drawdown of the soil water during the 2000/01 than 2001/02 as a result of water and temperature stress. There definitely seemed to be some compensatory root growth exhibited by the extraction patterns in all systems. During 2001/02 initial soil water conditions was higher resulting in better top growth, more shading and therefore more water conserved for transpiration rather than soil evaporation. The difference in depletion between the cropping systems layerwise was more evident during this season. There was no statistically significant differences in the total water use by the cropping systems although the planting in the IMB was additive (Ogindo, 2003).

Walker and Ogindo (2003) in the same study found that the intercrop had the lowest soil evaporation as a percentage of precipitation and evapotranspiration. This confirms many studies finding that intercropping system, due to an early and higher LAI, is able to reduce the amount of energy available for soil surface evaporation between crops. Ogindo (2003) showed that the vapour pressure deficits were lower in the intercrop, indicating a lower evaporative demand within the cropping system. This also explains the lower soil surface evaporation and the almost similar water use during the seasons despite the fact the intercrop had a much higher plant density than both sole crops. The IMB had a yield advantage during both seasons showing that intercropping has better water use but also used resources more favourably. It was concluded that higher yields were due to the more complete utilization of environmental resources by the mixture compared to the sole crops.

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