Chapter 7

Analysis of Soil Profile Water Storage under Sunflower × Cowpea Intercrop in the Limpopo Province of South Africa

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62764

Abstract

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop in South Africa. Its production in semi-arid area is limited by low rainfall exacerbated by high temperatures that deplete soil moisture. Cowpea (*Vigna unguiculta*) intercropped in sunflower could reduce evaporation of soil moisture by increasing soil cover. A field study was carried out 2007/2008 and 2008/2009 seasons in the Limpopo Province (South Africa) to compare (i) the changes in soil profile water storage, (ii) water use efficiency, and (iii) productivity of the sunflower–cowpea cropping systems. Extraction patterns by layers showed no significant differences in all cropping systems in the 0–300, 300–600, and 600–900 mm during 2007/2008 and 2008/2009 seasons. Sole sunflower (SS) significantly extracted more soil water than sole cowpea and the intercrop from the 1200- to 1500-mm layer after 56 days after planting (DAP) during 2007/2008 season. There were no significant differences in soil water extraction by cropping systems in the whole profile during both cropping seasons. Intercropping of sunflower resulted in grain yield reduction of sunflower of up to 50 and 30% of cowpea during 2007/2008 and 2008/2009, respectively. Water use and water use efficiency by SS were significantly greater than other cropping systems during the second cropping season.

Keywords: Cowpea, Intercropping, Semi-arid, Sunflower, Water use

1. Introduction

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop in South Africa. It is the third largest grain crop produced in South Africa after maize (*Zea mays*) and wheat (*Triticum* *aestivum*) [1]. Sunflower seed is utilized in the manufacture of sunflower oil and oilcake for animal feed. Sunflower is adapted in both hot and dry climate. This makes Limpopo Province ideal for growing the sunflower crop [2]. However, its production in the semi-arid area is limited by variable and low rainfall amount. Soil moisture loss is further exacerbated by evaporation due to high temperatures during the growing season [3]. Soil moisture loss under these conditions is further worsened by the fact that sunflower residue is fragile and does not provide adequate ground cover [4]. However, research has shown that legumes such as cowpea (*Vigna unguiculata*) intercropped in sunflower could increase soil cover and suppress soil moisture loss by evaporation [5]. Furthermore, previous research has shown that intercrops can improve water use efficiency [6, 7].

Cowpea is an important food and fodder legume crop in the semi-arid tropics, South Africa included. Being a drought tolerant and warm weather crop, cowpea is well adapted to the drier regions of the tropics where other food legumes do not perform well. It can fix atmospheric nitrogen through its nodules. It is reported that about 30 kg N ha^{-1} can be contributed to the soil by cowpea. The amount of N fixed is a function of cowpea cultivar [4]. It grows well in poor soils with high sand content, little organic matter, and low phosphorus content, such as those found in smallholder farming sector of the Limpopo Province. Also, it is shade tolerant and therefore, compatible as an intercrop with several field crops, including sunflower. Its rapid growth habit and quick ground cover prevents soil erosion. Furthermore, the in-situ decay of its roots and nitrogen-rich residues improves soil fertility and soil structure. These qualities have made cowpea an important component of the subsistence agriculture particularly in the dry savannas of the sub-Saharan Africa [8]. Cowpea is important to food security in less developed countries of the tropics particularly Asia and Africa. As a vegetable, it is consumed as young leaves, green pods, and green seeds. In addition, dry seeds are used in various food preparations. Its high protein content (>25%) in its seeds and tender leaves makes it ideal diet for the rural and urban poor whose diet consists of starchy foods [5]. Apart from improving the diet of the rural poor, it is envisaged that the sunflower and cowpea crop mixtures could also offer advantages, such as, yield advantage [9, 10], yield stability [11], and better weed control [12].

Cowpea and groundnut (*Arachis hypogeae*) are often grown as intercrops among smallholder farmers of the Limpopo Province. However, little scientific research has been conducted to quantify the agronomic value of this practice [13]. Sunflower is grown mainly as a sole crop under commercial production [14]. Its cultivation by the smallholder farming sector is little known. However, sunflower crop has a potential in smallholder farming sector if integrated into the existing traditional farming systems which are based on growing crops in mixtures [8]. There is evidence of sunflower production in mixtures by the smallholder farmers in the Limpopo Province. However, no scientific research is documented. In particular, there is no information on the productivity of sunflower × cowpea intercropping systems. There is a need therefore to evaluate the productivity of sunflower and cowpea mixtures in order to optimize their production. The major objectives of this chapter are to compare (i) the changes in soil profile water storage, (ii) water use efficiency, and (ii) productivity of the three cropping systems under semi-arid conditions of South Africa.

http://dx.doi.org/10.5772/62764

2. Trial site

A 2-year field experiment was conducted during 2007/2008 and 200820/09 growing seasons at the University of Venda in Thohoyandou, South Africa (22°58′S, 30°26′E). Altitude is 596 m above sea level. The terrain is characterized by a slope of 8%. The daily temperatures at Thohoyandou vary from about 25 to 40°C in summer and between approximately 12 and 26°C in winter. Rainfall is highly seasonal occurs between October and March. Crop failure and low yields are associated with midsummer drought [15]. Rainfall varies temporarily and ranges between 500 and 800 mm per year. The study site is characterized by deep and red clayey classified as Rhodic Ferralsols [16]. The soil is composed of 10% sand, 30% silt, and 60% clay. Soil pH is low (pH 5.5). Selected chemical and physical soil properties were previously presented in [17].

2.1 Trial description

The experiment was conducted during 2007/2008 and 200820/09 growing seasons. The trial was complete randomized block design (CRBD) with four replications under conventional tillage (CT). The field was disk ploughed and disk harrowed at the start of the trial. The plots were hand dug to a depth of 20 cm the following season. Three cropping systems consisting of sole sunflower (SS), sole cowpea (SC), and sunflower–cowpea intercrop (ISC) were laid out in 9 m × 10 m plots. Sunflower hybrid (cv. AFG 5551) and local cowpea landrace were planted. The intercrop components were sown manually using row replacement series (1:1) using tramline row spacing (1 m × 2 m). Final sunflower plant population was 30,000 plants ha^{-1} while that for cowpea was 66,666 plants ha^{-1}. This gave the intercrop density of 48,333 plants ha^{-1}. A commercial fertilizer was incorporated a rate of 33 kg N ha^{-1}, 50 kg P ha^{-1}, and 33 kg K ha^{-1}. In the second season, the same fertilizer rate was repeated with an additional 178 kg ha $^{-1}$ limestone ammonium nitrate (LAN) (28) as top dressing on sunflower 5 weeks after planting. Weeding was done manually using hand hoes during the season. Plots were kept clean during fallow period by using glysphosphate (360 g/l). Malathion 50% EC (a.i. Merkaptotion 500 g/l; Mercaptothion 500 g/l) was used to control aphids and beetles.

2.2. Data collection and analysis

2.2.1. Grain yield

Sunflower was harvested at physiological maturity at 87 and 79 days after planting (DAP) during 2007/2008 and 2008/2009 seasons, respectively, by cutting 6-m length of the central rows. The heads were air-dried in the shed. Cowpeas were harvested at 150 and 140 DAP during 2007/2008 and 2008/2009 seasons, respectively, from 4 m^2 (2 m × 2 m). The air- dried cowpea grain was separated from the stalks weighed and oven-dried at 70°C for 24 h. The grain yield was adapted to 13% moisture content.

2.2.2. Soil profile soil storage

Volumetric water content of the soil profile was determined on weekly basis using a calibrated neutron water meter (NWM) (Campbell Pacific Nuclear International 503DR). Galvanized access tubes measuring 50 mm in diameter were inserted to a depth of 1500 mm. Two access tubes were inserted per plot between the 1-m crop rows. Readings were taken in depth increments of 300 mm until 1500 mm. Standard counts (C_s) of the NWM were determined in five replicates. Soil water content was calculated using the following calibration equations developed on site:

$$\theta_{v0-300} = 0.4339 \times CR - 0.2893 \left(R^2 = 0.998 \right) \quad (1)$$

$$\theta_{v300-900} = 0.2678 \times CR - 0.0378 \left(R^2 = 0.921 \right) \quad (2)$$

$$\theta_{v900-1500} = 0.6331 \times CR - 0.5077 \ (R^2 = 0.956) \quad (3)$$

where θ_{v0-300} is the volumetric water content in the soil layer 0–300 mm (mm^{-1} mm^{-1}), CR is the count ratio calculated as count/standard count (C_s). Soil water storage (mm) was calculated by multiplying volumetric water content by soil layer thickness (mm).

2.2.3. Water use and water use efficiency

Water balance was calculated by the following equation:

$$P = R + D + ET + \Delta W \quad (4)$$

where P is precipitation (mm); R is surface runoff (mm); D is deep drainage (mm); ET is evapotranspiration or water use (mm); and ΔW is change of soil water content (mm). The sum of runoff (R) and deep drainage (D) were assumed to be zero during the experimental period, simplifying Eq. (4) as follows:

$$ET = -\Delta W + P \quad (5)$$

Precipitation was measured using an automatic weather station which was located 20 m away from the experimental block. Water use efficiency was calculated using the water balance equation, assuming no drainage, and runoff water, as follows:

$$WUE = Y / ET \quad (6)$$

http://dx.doi.org/10.5772/62764

where WUE is the water use efficiency (kg ha^{-1} mm^{-1}); Y is the grain yield (kg ha^{-1}); and ET is the total evapotranspiration over the growing season (mm). Similarly, intercrop WUE was calculated on the basis of total grain yield of sunflower and cowpea.

2.2.4. Land equivalent ratio

Land equivalent ratio (LER) was calculated according to [18] as follows:

$$LER_T = LER_S + LER_C \tag{7}$$

where LER_T = total land equivalent ratio and, LER_S = partial LER for sunflower per unit area; LER_C = partial LER for cowpeas per unit area.

Partial LER is defined as the ratio of yield per unit area of the specific intercrop (Yi) versus the mono-crop (Y_m) that is as follows:

$$\text{Partial LER} = Yi / Y_m \tag{8}$$

If $LER_T > 1$, intercropping has a yield advantage, if $LER_T < 1$, there is yield disadvantage from intercropping, and when $LER_T = 1$, there is no advantage to intercropping [10].

3. Results

3.1. Variation of soil profile water storage

Rainfall amounting to 391 mm was recorded over 2007/2008 experimental period. Most of the rainfall was >10 mm and accounted for 93% (365 mm) of the total rainfall while the rest were <10 mm. Most of the rainfall, this season occurred in January and was followed by dry spells in February and March. Due to the breakdown of the NWM water measurements started 21 DAP. Soil water content variations in 0–300, 300–600, 600–900, 900–1200, and 1200–1500 mm layers measured in 2007/2008 season for the three cropping systems are shown in **Figure 1**. Soil water content was high at 21 DAP and started to decline until 63 DAP for all cropping systems. The profile water storage decreased in all cropping systems. During this vegetative period, the soil profile received rainfall events below 10 mm. There were no significant differences among cropping systems in the 0–300 mm layer. This top layer was characterized by variations in water content, possibly as a result of evaporation and root uptake. Similarly, the layers 300–600 and 600–900 mm showed no significant differences in water extraction patterns during this period. However, significant differences in soil water content were observed at 35 DAP in the 900–1200 mm layer. There intercrop recorded more water extraction than the SS and SC. There were significant differences in water uptake at DAP 56, 63, and 70 in the 1200–1500 mm layer. The SS used more water than the SC and the intercrop.

The SC had the least water consumption. The highest rainfall amount of 70 mm was received at flowering stage (after DAP 70). This resulted in the increase in soil profile water content. The increase was more pronounced in the 0–300 and 300–600 mm layers. There were more fluctuations of soil water content in the 0–300 and 300–600 mm layer compared to other layers. However, the 0–300 mm layer had marked fluctuations. There were no significant differences in water consumption in the 0–300 and 300–600 mm layers until DAS 119. At DAP 112 (grain filling stage) the intercrop extracted more water compared to other cropping systems in the 600–900 mm layer. Between DAP 56 and 119, the SS crop significantly extracted more water compared to the other cropping systems in the 1200–1500 mm layers. Total soil water extraction by SC was less compared to the other cropping systems but the differences were not statistically significant ($P < 0.05$) (**Figure 2**).

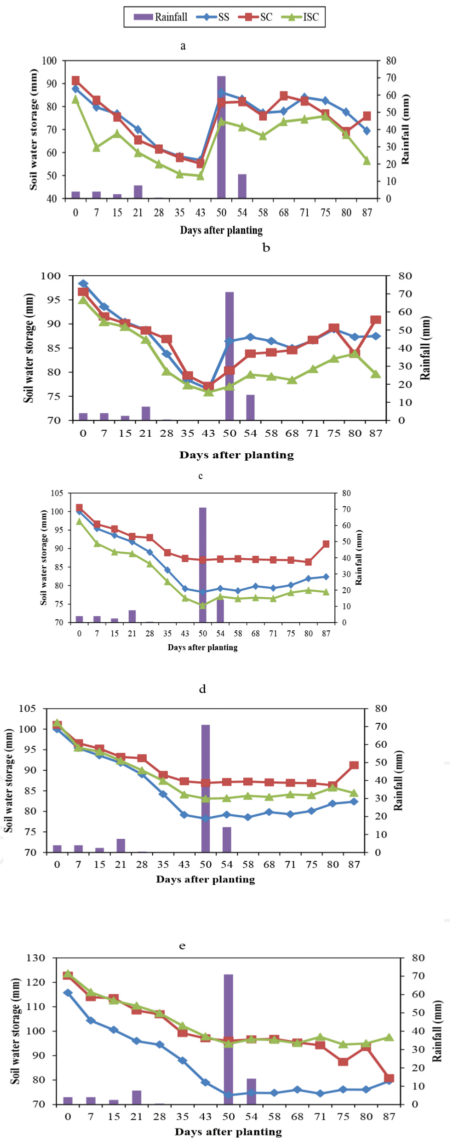

Figure 1. Soil water storage in various layers (a = 0–300; b = 300–600; c = 600–900; d = 900–1200; e = 1200–1500 mm) during the 2007/2008 for sole sunflower (SS), sole cowpea (SC), and sunflower × cowpea intercrop (ISC).

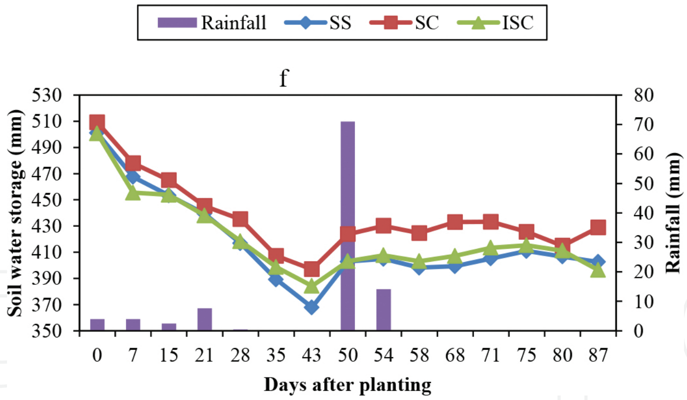

Figure 2. Soil water storage in total soil profile (f = 0–1500 mm) during the 2007/2008 for sole sunflower (SS), sole cowpea (SC) and sunflower × cowpea intercrop (ISC).

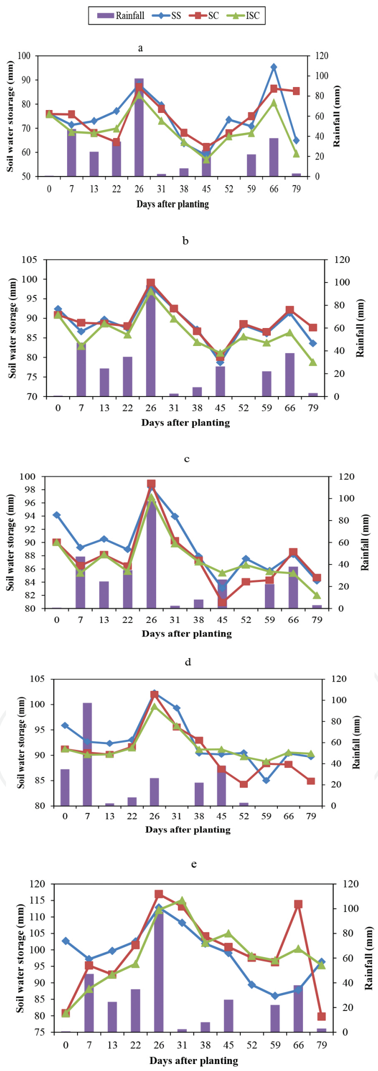

Figure 3. Soil water storage in various layers (a = 0–300; b = 300–600; c = 600–900; d = 900–1200; e = 1200–1500 mm) during the 2008/2009 for sole sunflower (SS), sole cowpea (SC), and sunflower × cowpea intercrop (ISC).

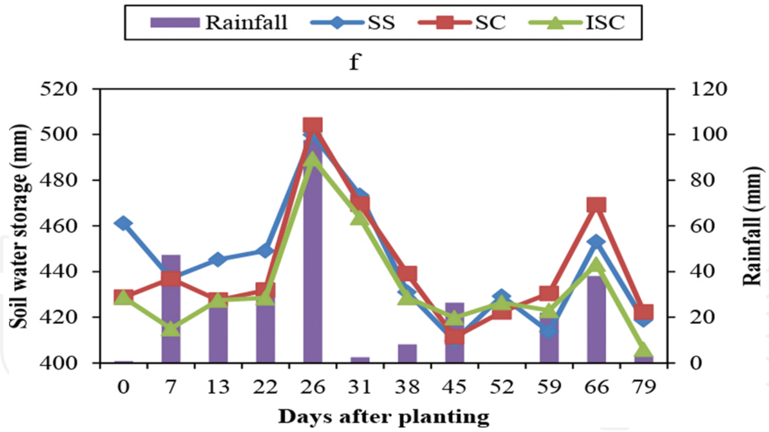

Figure 4. Soil water storage in total soil profile (f = 0–1500 mm) during the 2008/2009 for sole sunflower (SS), sole cowpea (SC), and sunflower × cowpea intercrop (ISC).

Compared to the 2007/2008, the rainfall during 2008/2009 (405 mm) was well distributed. **Figure 3** shows soil water content in various layers for the 2008/2009 growing season. The 0–300 mm layer showed huge variations in soil water content which increased soon after rainfall. The SS extracted significantly less soil water from the 0 to 300 mm layer compared to the other cropping systems at DAP 22. Thereafter, there was no systematic water extraction pattern recorded in the period DAP 66–79. By the end of this period the intercrop had the highest extraction followed by SC and the lowest SS ($P < 0.001$). Cropping system water extraction pattern in the 0–300 mm layer was similar to 300–600, 600–900, and 900–1200 mm layers. There was no clear water extraction pattern in the 1200–1500 mm layer by all cropping systems. Similarly, no systematic soil water extraction was observed in the whole profile from the beginning to the end of the 2008/2009 growing season (**Figure 4**).

3.2. Productivity of cropping systems

The yield of sole and intercrop sunflower increased during season 2008/2009 compared to 2007/2008 while the yield of SC and its intercrop decreased in the same period (**Table 1**). The yield of each crop species was not significantly different during 2007/2008 season. However, a statistical difference of yield was observed in both crop species during 2008/2009.

The intercrop was more productive than the sole crops ($LER_T > 1$) (**Table 2**). The highest sunflower yield loss of nearly 50% was recorded during 2007/2008 season, while 31% yield loss in cowpea was recorded during 2008/2009 season. The cowpea was a better competitor for resources in 2007/2008 season ($LER_C = 0.86$) but the sunflower exhibited higher competitive ability than cowpea during 2008/2009 season ($LER_S = 0.80$).

3.3. Water use and water use efficiency

Water use by all cropping systems was higher during 2008/2009 compared to 2007/2008 (**Table 3**). There was no statistical difference in water consumption between the cropping systems during 2007/2008 season. However, water consumption by SS was statistical greater than SC and the intercrop during 2008/2009 season. Water use efficiency by the SS and inter-

http://dx.doi.org/10.5772/62764

crop increased during 2007/2008 compared to 2008/2009. The WUE by the cowpea decreased by nearly 50% during 2008/2009 compared to 2007/2008. WUE by SS was significantly higher compared to the other cropping systems during 2007/2008 season. During 2008/2009, WUE by all cropping systems was significantly different from each other. The SS had the highest WUE then the intercrop and SC in that order (**Table 4**).

Cropping system	Yield (kg ha^{-1})	
	2007/2008	2008/2009
Sole sunflower	1135	1203
Sole cowpea	256	137
Intercrop sunflower	584	960
Intercrop cowpea	221	95

Table 1. Mean grain yield for different cropping systems during the 2007/2008 and 2008/2009 seasons.

LER	Growing season	
	2007/2008	2008/2009
LER_S	0.51	0.80
LER_C	0.86	0.69
LER_T	1.37	1.49

Table 2. LER during 2007/2008 and 2008/2009 seasons.

Cropping system	Water use (mm)	
	2007/2008	2008/2009
Sole sunflower	475.5	455.4
Sole cowpea	401.8	406.6
Intercrop	415.5	433.7

Table 3. Water use (WU) of crops in different cropping systems during the 2007/2008 and 2008/2009 seasons.

Cropping system	WUE (kg ha^{-1} mm^{-1})	
	2007/2008	2008/2009
Sole sunflower	2.40	3.53
Sole cowpea	0.62	0.34
Intercrop	1.94	2.51

Table 4. Water use efficiency (WUE) of crops in different cropping systems during the 2007/2008 and 2008/2009 seasons.

4. Discussion

Low rainfall during 2007/2008 season resulted in continuous decline of soil profile water content until DAP 63. This happened during the vegetative period when the crops needed water for development. High amount of rainfall received during 2008/2008 season could be attributed to better performance especially of sunflower crop species during this season compared to the previous one. However, there were no significant differences in total profile water extraction all by all cropping systems during the two seasons.

Water extraction patterns were almost similar for all cropping systems in the 0–300 and 300–600 mm layers during season 2007/2008. The intercrop extracted slightly higher soil water than other cropping systems throughout the rest of the season. An almost similar trend was observed during 2008/2009 season in all cropping systems in the same soil layers. However, extraction patterns by all cropping systems in the 0–300 and 300–600 mm layers were statistically non- significant. The intercrop did not extract greater moisture as expected. Similar findings were reported in maize-bean intercrop [19]. Similar moisture extraction was observed in the 600–900 mm layer (**Figure 1**). However, water extraction by the intercrop was significant at 112 DAP during 2007/2008.

In the lower profile soil layers (900–1200 and 1200–1500 mm for 2007/2008), the sunflower extracted significantly more soil water compared to other cropping systems after 56 and 66 DAP during 2007/2008 and 2008/2009, respectively. This was not unexpected. The sunflower crop has a deeper and extensive rooting system that is able to exploit water from deeper soil layers [20]. Despite the differences in tillage systems, our results are analogous to those of [20] who demonstrated that the average soil profile water content at harvest under sunflower was lower (77 mm) than that under cowpea (158 mm) in no-till (NT) and stubble mulch tillage in a clay loam soil.

Good rainfall conditions were attributed to the higher sole and intercrop sunflower yield during 2008/2009 compared to 2007/2008 (**Table 1**). Significant difference in yield between the sole and intercrop sunflower was observed during 2008/2009 season. Similar results were reported in other cropping systems. Higher sunflower yield in sole crop compared to its mixture with soybean were reported [21]. Differences in yield in the sole and intercropped sunflower were attributed to competition for resources such as nutrients and moisture. Higher productivity of SS over its intercrop in the current study was attributed to lower population in the intercrop. The results could also suggest intense competition between crop species in the crop mixture. It was reported that some cowpea genotypes can suppress the growth of sunflower [22]. In contrast, the grain yield of cowpea showed no statistical difference due to cropping system probably because cowpea was able to out-compete sunflower in acquiring nutrients and other resources. However, cowpea was a better competitor than sunflower during 2007/2008 season as indicated by the LER_C (**Table 2**). Overall, the values of LER during the two seasons were >1, indicating that the intercrop was more productive than the pure stands of sunflower and cowpea as earlier reported in other intercrops [18].

The observed greater WU in SS compared to the cowpea and intercrops was attributed to the relatively higher WU of sunflower compared to the cowpea as previously reported [23]. When the two crops were combined in an intercrop their combined WU became higher than the SC. Similar findings have been reported [23]. The SS exhibited greater WUE than other cropping systems. The intercrop was second followed by the SC. Conflicting results on WU and WUE of crop mixtures have been reported by other researchers. It was reported that WUE of maize-bean intercropping were equal or higher than maize sole crops, and higher than bean sole cropping [24]. In Nigeria, [25] reported that intercropping cowpea with millet did not increase WUE over the sole millet. Results in the current study indicated that under high rainfall conditions WUE by cowpea was significantly reduced. This could mean that the cowpea crop was better able to utilize limited soil moisture, thus making it an ideal crop in water scarce environments such as those prevailing at the study site.

5. Conclusion

Soil water extraction patterns could be related to seasonal rainfall conditions and cropping systems. Soil moisture extraction patterns by layers showed no significant differences in all cropping systems in the 0–300, 300–600, and 600–900 mm during 2007/2008 and 2008/2009 seasons. SS significantly extracted more soil water than SC and the intercrop from the 1200 to 1500 mm layer after 56 DAP during 2007/2008 season. Overall, the whole profile did not show statistical difference in moisture depletion by crops and their combinations during the two seasons. Intercropping of sunflower resulted in grain yield reduction of sunflower of 50% and 30% of cowpea during 2007/2008 and 2008/2009, respectively. LER > 1 meant that intercropping was advantageous in the utilization of environmental resources. Generally, WU and WUE by SS were significantly greater than other cropping systems during the second cropping season (2008/2009). The SC had the lowest WU and WUE.

Acknowledgements

This study was supported by International Foundation for Science (Sweden) Grant No. C/3918-1. We appreciate the field assistance offered by Mrs. Memory Mzezewa.

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