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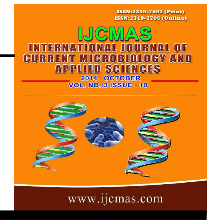

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Original Research Article

Monitoring of soil moisture regime and water use efficiency under maize – cowpea cropping system

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A B S T R A C T

Soil water is a critical component in agricultural production systems for optimization of grain yields. Soil water performs a number of important functions in soils. It is essential for mineral weathering and organic matter decay, chemical reactions that provide soluble nutrients in the plant-soil system. Water also serves as the medium in which nutrients move to plant roots. The retention of rain or irrigation water for direct plant use is another primary function of soil. Maize and cowpea were planted as sole crops and as intercrop before the soil moisture sensor of depths 30cm, 60cm and 90cm were installed on the nine plots. The design was a Randomized Complete Block Design (RCBD) and was replicated three times. The soil moisture was monitored during the growing seasons. The intercrop recorded the highest water use efficiency followed by the maize sole crop and lastly the cowpea sole crop. Since water does not settle in one horizon of the soil but moves further into the soil, much water was retained at the 60cm and 90cm depth than at the 30cm depth. This resulted in the increase of water usage at the 30cm and 60cm depth than at the 90cm.

Keywords

Intercropping, moisture, water use efficiency, water tension

Introduction

Rain-fed agriculture is central to the food production process in Sub-Saharan Africa (Cooper *et al.*, 2008). The majority of farmers heavily depend on rain-fed crop production systems (Boko *et al*., 2007), and lack the incentive to improve water use efficiency in agricultural production (Abbate *et al*., 2004) including the motivation to conserve water (Hsiao *et al*., 2007) during the crop growth period. In rain fed agricultural systems, soil water infiltration and storage in the root zone determine the overall availability and use efficiency of water in crop production (Hsiao *et al*., 2007). Improving agricultural production will depend on efficient capture, management and use of rainwater resources (Rockström *et al*., 2003). Therefore, planning agricultural systems that are efficient users of available water, as a pre-requisite for improving water productivity, requires a good understanding of crop water use vis-à-vis the water sources (water balance components) (Mulebeke et al, 2010). Mulebeke et al (2010) further explains that increasing crop water productivity and drought tolerance by genetic improvement and physiological regulation may be the means to achieve efficient and effective use of water. But high water productivity values carry little or no interest if they are not associated with high or acceptable yields (Ali and Talukder, 2008). Such association of high (or moderate) productivity values with high (or moderate) yields has important implications on the effective use of water.

Critchley and Siegert (1991) iterate that improved crop yields and water productivity can be accomplished in many ways explaining that one option is to maximize plant water availability in the root zone, which involves practices to capture surface run-off for *ex-situ* water harvesting and supplemental irrigation, redirect local run-off to the plant roots and maximize rainfall infiltration through *in-situ* water management, and by managing soil evaporation. Second, management can be targeted at maximizing the plant water-uptake capacity, which involves practices of crop and soil management to increase root water uptake.

Raising productivity, through adequate use of available natural resources e.g. light and nutrients is possible through intercropping provided demands for component crops are well understood (Midmore, 1993). According to Zhang *et al.* (2012) intercropping systems could promote the full use of cropland water by plant roots, increase the water storage in root zone, reduce the inter-row evaporation and control excessive transpiration, and create a special microclimate advantageous to the plant growth and development. Zhang *et al.* (2012) further states that intercropping systems could optimize source-sink relationship, provide a sound foundation for intensively utilizing resources temporally and spatially, and increase the crop yield per unit area greatly without increase of water consumption, so as to promote the crop water use efficiency effectively.

With this in view, this study sought to evaluate the sub-surface soil moisture regime and water use efficiency for maize – cowpea cropping system.

Maize (*Zea mays*) is one of the oldest food sources and is a fully domesticated plant (Smith 2001; Thobatsi, 2009). It is also an important staple crop and has contributed significantly in ensuring food security and the growth of Ghana's economy (Diao, 2010).

Cowpea (*Vigna unguiculata*) is also an important staple food for millions of people in developing countries (Coetzee, 1995) especially in the semi-arid tropics covering Asia, Africa, southern Europe, Central and South America. Cowpea is a drought-tolerant and warm-weather crop with high protein content (22-24%) and can thrive in lower soil fertility conditions than many other crops (Coetzee, 1995). These properties and the presence of nodular bacteria specific to cowpea makes it suitable for cultivation in the hot, marginal cropping areas of Southern Africa as well as in the cooler, higher rainfall areas. Cowpea has the useful ability to fix atmospheric nitrogen through its root nodules. Cowpea variety selection is the key to the modification of cropping systems and is exceptionally suitable for intercropping (Singh et al, 2002).

Among the various combinations of cereals and legumes used by small-scale farmers, maize and cowpea is one of the most widely used. (Eaglesham et al.,1981; Ofori &

Stern,1986 and Mpangane et al, 2004).The principal reason for farmers to intercrop are flexibility, profit maximization, risk minimization against crop failure, soil conservation and maintenance, weed control and balanced nutrition (Shetty et al.,1995). Other advantages of intercropping include potential for increased profitability and low fixed costs for land as a result of a second crop in the same field. Time labour management and equipment are also better utilized (McCoy et al., 2001). According to Viljoen and Allemann (1996), some of intercropping advantages include: higher yield than sole crop yields, probably due to less intra-specific competition, greater yield stability, more efficient use of environmental resources, better weed control, provision of insurance against crop failure, improved quality by variety, also maize as a sole crop requires larger area to produce the same yield as maize in an intercropping system. Intercrops are believed to perform better than sole crops because of increased yield, preservation of moisture and shelter against pest attacks and even regarding the distribution of labour requirements and the provision of more balanced food supplies for humans (Vandermeer, 1992).

Water use by intercrops has mostly been studied in terms of water use efficiency (WUE). An intercrop of two crop species such as legumes and cereals may use water more efficiently than a monoculture of their species through exploring a larger total soil volume for water, especially if the component crops have different rooting patterns (Willey, 1979). Hulugalle & Lal (1986) reported that WUE in a maize/cowpea intercrop was higher than in sole crops when soil water was not limiting. However, under water limiting conditions, WUE in the crop compared to sole maize can be higher resulting in retarded growth and reduced yield. Work done by Sani et al (2011) showed that an intercrop of maize and sorghum utilized available resources more efficiently than their respective monocrops. Likewise, Kanton and Dennette (2004) recorded higher water use efficiencies in a maize/pea intercrop compared to sole maize cropping.

Materials and Methods

The study was conducted at the Council for Scientific and Industrial Research (CSIR) - Crops Research Institute at Fumesua, Kumasi. Maize was planted on 17th Oct 2012 and repeated for a second season on 14th Oct, 2013. Seeds were planted three seeds per hill at a spacing of 40 cm within rows and 80 cm between rows. Cowpea was also planted simultaneously at a plant spacing of 20 cm by 60 cm. Both crops were thinned to two plants per hill 10 days after sowing.

The experimental design was a randomized complete block design (RCBD) with three replications. With the aid of an auger, soil moisture sensors were installed on nine plots with each plot having sensors (replicated twice) at depths 30 cm, 60 cm and 90 cm culminating in six soil moisture sensors for each plot. However, one soil water monitoring device was used for the entire nine plots. The soil moisture tension data was taken from the field three times a week from depths of 30cm, 60cm and 90cm with the aid of the soil moisture meter during the growing season. Monitoring was done every three days for thirty five days.

Results and Discussion

Weather

The trend of weather during the period of the trial (Table 2 and 3) indicates adequate moisture for crop growth. However, rainfall amounts in both seasons were below the long term mean (1300mm) of the area. These were 1028.60mm and 1225.8mm for 2012 and 2013 respectively. Temperature, evaporation and relative humidity were also within the ranges necessary for adequate plant growth (Downes, 1972). This manifested in the good growth of both crops observed in both seasons during the study.

Supplementary irrigation

Irrigation plays an important role in plant growth. It is used to assist in the growing of agricultural crops, maintenance of landscapes and revegetation of disturbed soils in dry areas and during periods of inadequate rainfall (Toriman and Mokhtar, 2012). However in this study, irrigation was carried out to supplement the rainfall amount during the crops growing season. Each irrigation incident supplied an amount of 20mm for eight irrigated days amounting to 160mm of supplementary irrigation. Irrigation was done on the dates below.

Soil moisture tension

Soil water tension is related to *water potential*. This is not water content but the potential of the soil to provide water to the plants. As the soil dries and soil water tension increases, the water potential decreases (Hensley and Deputy, 1999) meaning that as the soil water content increases due to additions from rainfall or irrigation, the soil-water tension decreases and soil water potential increases.

It is shown in Fig 1 that, at the 30 cm depth for sole maize, sole cowpea and the intercrop that there was an adequate use of water for all the crops. The amount of water retained at the 30 cm soil depth for all the crops is low as compared to the other depths. It is also shown in fig 2 that at the 60 cm depth there was enough moisture for the sole maize and sole cowpea crops. However, the 90 cm soil depth (fig 3) recorded the highest water retention.

From figure 4, there was enough moisture in the soil at all the three identified depths. From the sole cowpea graph of figure 5, it is clearly shown that the soil was adequately wet for both 60 cm and 90 cm depth. However, the water tension in the 30 cm depth quite high, indicating a higher pressure for extraction by plants. It can therefore be said that water use for this particular plot was quite high. From figure 6, water use at the 30 cm and the 60 cm depth was high due to the competing nature of the two intercrops. However, since most of the root of both crops were within the first two depths, water use at these depths was quite high, leaving the 90cm depth saturated.

Water use and water use efficiency

Water-use (mm) = (soil water at sowing – soil water at maturity) + in-crop rain + supplementary irrigation. This was the method employed by French & Schultz, who deliberately chose sites that were not prone to run-off, drainage or lateral water movement so. For this experiment runoff and drainage was assumed negligible and was not measured. Water-use efficiency (WUE) is simply grain yield (kg/ha) divided by water-use:

WUE (kg/ha.mm) = grain yield/water-use

The final values of WUE (Table 5), derived as described by CSIRO in its WUE-Benchmarking guide (Hunt and Kirkegaard, 2012) shows the various water use and corresponding use efficiencies of the various cropping systems.

The sole maize cropping had a WUE of 10.35 kg/ha mm and 7.64 kg/ha mm for 2012 and 2013 respectively. The sole cowpea cropping had a WUE of 3.69 kg/ha mm and 4.06 kg/ha for 2012 and 2013 respectively. The maize cowpea intercrop had a WUE of 12.72 kg/ha mm and 13.24 kg/ha mm for 2012 and 2013 respectively. A percentage difference of 22.9 and 73.3 was observed for the WUEs of the maize cowpea intercrop and its respective sole maize inetrcrop. There was no significant difference between the two growing seasons indicating similar conditions for growth. However, there were significant differences (at $p>0.05$) between the maize cowpea intercrop and its corresponding sole crops.

It is also shown that at the 60 cm depth there was enough moisture for the sole maize and sole cowpea crops. But the intercrop at the 60 cm depth recorded the highest water use which can be attributed to the competitive nature of the rooting system between the two crops at that depth. However, the 90 cm soil depth recorded the highest water retention. Also since water does not settle in one horizon of the soil but moves further into the soil, we expect much water to be at the 60 cm and 90 cm depth than at the 30 cm depth. This resulted in the increase of water usage at the 30 cm. This study has clearly demonstrated that intercrops of maize and cowpea had greater water use efficiencies than their component crops. It can therefore be said that the intercrop has the highest water use efficiency followed by the maize sole crop and lastly the cowpea sole crop. i.e. cowpea sole crop > maize sole crop > intercrop.

In both seasons, the water use by intercrops and the sole crops were very similar. Water use by various intercrops, in tropical conditions, has been found to be similar to their sole counterparts but intercrops used the water more efficiently (Natarajan and Willey, 1980; Hulugalle and Lal, 1986; Ong *et al.*, 1996). The results from this discussion also agree with the studies conducted by Ofori and Stern, 1987.

Table.1 Soil analysis of the experimental field for the various physico-chemical properties

LABELS	Soil depth	pH 1:1 H_2O	% Carbon	% Total Nitrogen	% organic matter	Exchangeable cations				% base Saturation	Available - brays		Texture
						Ca	Mg	K	Na		P Ppm	K Ppm	
AT PLANTING	0 - 30	5.12	0.37	0.03	0.64	2.40	0.53	0.07	0.03	80.16	68.80	28.39	Sandy loam
	30 – 60	5.31	0.31	0.02	0.53	1.07	0.27	0.06	0.03	64.13	16.26	25.36	Sandy Loam
	60 - 90	5.27	0.42	0.09	0.72	1.87	0.53	0.10	0.04	72.78	42.65	39.67	Sandy loam
AT HARVEST	0 - 30	5.34	0.82	0.07	0.81	2.14	0.53	0.08	0.03	82.25	179.41	32.87	Sandy loam
	30 - 60	5.18	0.37	0.08	0.73	4.81	1.87	0.18	0.05	97.88	9.59	72.38	Sandy loam
	60 - 90	5.11	0.87	0.08	0.80	1.87	0.53	0.12	0.04	75.07	18.66	47.38	Sandy loam

Table.2 Weather data for 2012

Month	Rain	Minimum Temperature, °C	Maximum Temperature, °C	Humidity, %	Solar radiation, w/m2	Wind, m/s
January	9	19.68	33.89	61.02	313.36	0.64
February	17.8	21.89	33.96	70.00	332.06	0.99
March	82.4	22.74	33.89	76.77	369.48	0.94
April	152.6	22.47	32.63	83.25	351.14	3.98
May	170.4	22.17	31.58	85.29	315.14	0.87
June	204	21.96	29.65	89.52	263.60	0.92
July	43.6	21.67	28.45	89.12	233.90	0.94
August	4.6	21.28	28.42	86.74	195.37	1.14
September	46.6	21.95	30.73	86.44	244.02	0.80
October	215.2	21.78	31.86	88.42	307.24	0.59
November	41.6	22.20552	32.68216	85.13548	321.9	0.649677
December	40.8	21.42394	32.55471	80.09677	321.4451613	0.585806

Table.3 Weather data for 2013

Month	Rain	Minimum Temperature, °C	Maximum Temperature, °C	Humidity, %	Solar radiation, w/m^2	Wind, m/s
January	3	19.99	35.08	56.63	313.70	0.67
February	55	22.22	35.82	64.56	330.14	0.90
March	103.6	22.71	33.64	81.51	367.74	0.95
April	71.4	22.56	34.02	80.78	381.44	0.93
May	183.2	22.32	32.73	83.76	343.41	0.81
June	111.8	22.15	30.60	87.82	289.25	0.85
July	153	21.46	28.51	91.12	225.28	0.90
August	7.4	21.18	27.82	89.13	202.84	1.00
September	255.4	21.69	30.14	90.09	257.57	0.81
October	171.4	21.63	31.24	89.13	303.16	0.63
November	104.8	21.97	32.40	87.64	309.63	0.66
December	5.8	20.11	32.27	74.68	283.63	0.58

Table.4 Dates on which supplementary irrigation was done.

2012	2013
1st November	17th October
9th November	25th October
12th November	31st October
13th November	8th November
14th November	15th November
20th November	27th November
22nd November	9th December
28th November	17 December

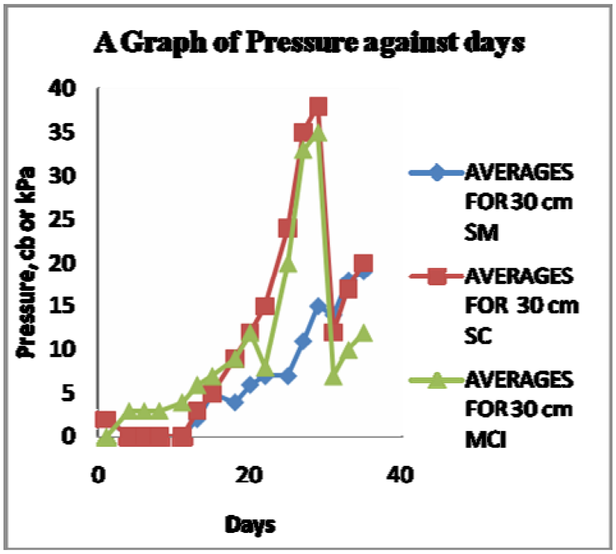


Fig 1 Average moisture tension at 30 cm depth

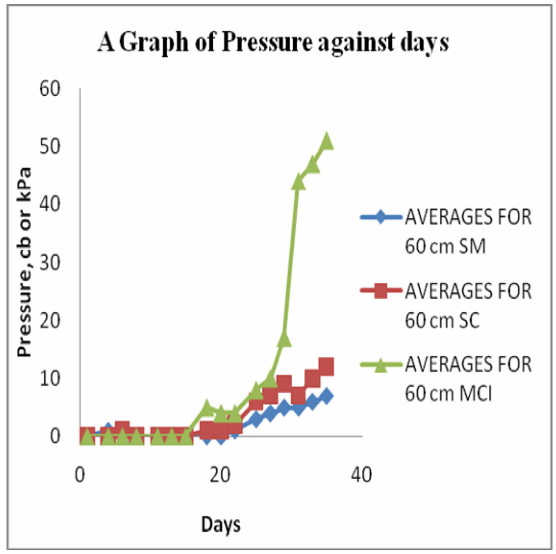


Fig 2 Average moisture tension at 60 cm depth

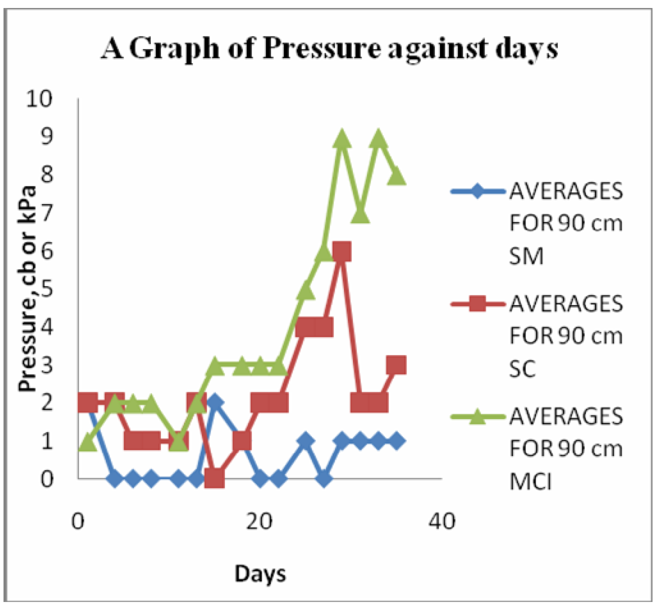


Fig 3 Average moisture tension at 90 cm depth

SM = Sole maize
SC = Sole cowpea
MCI = Maize cowpea

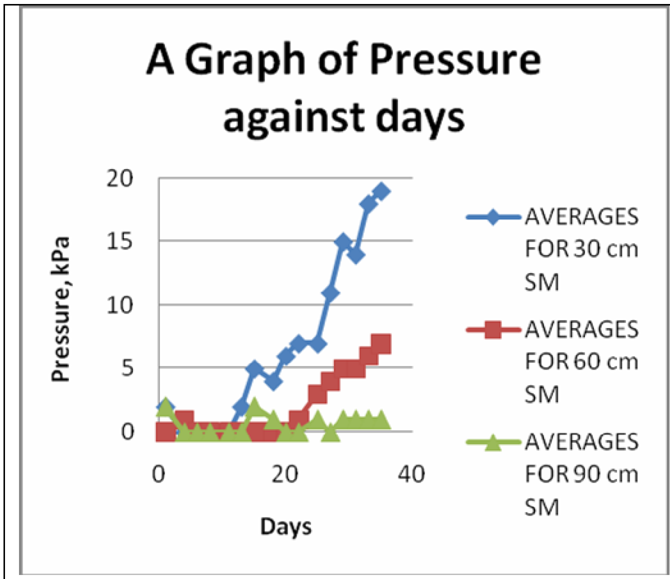


Fig 4 Moisture tension for sole maize

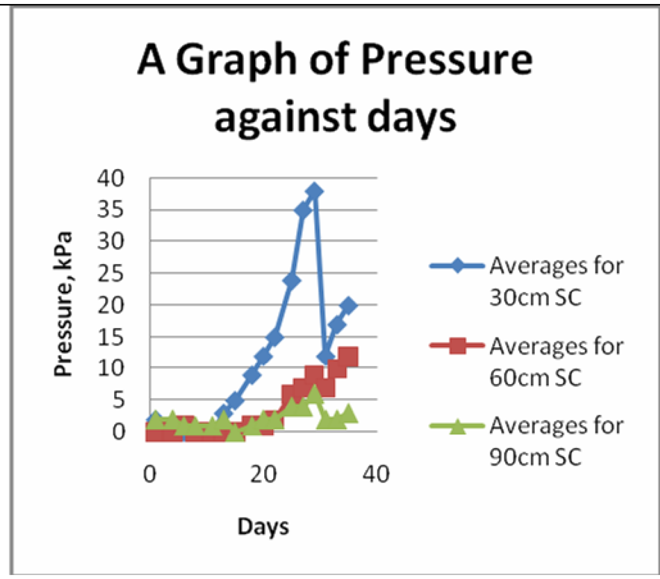


Fig 5 Moisture tension for sole cowpea

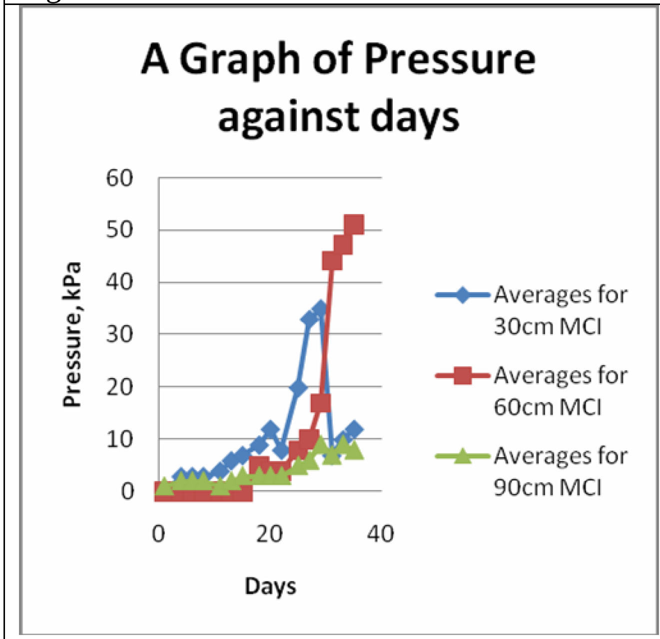


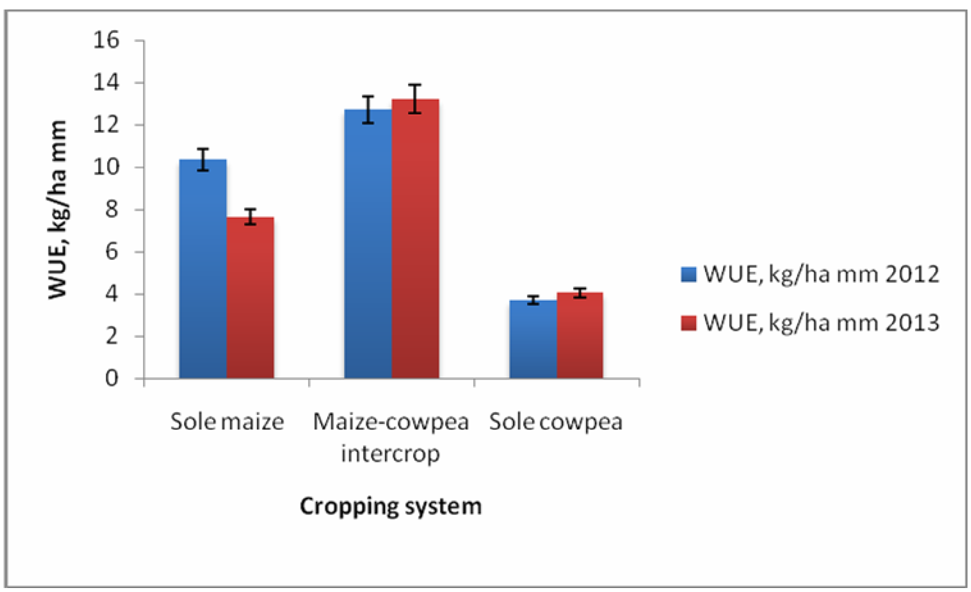
Fig 6 Moisture tension for maize cowpea intercrop

Table.5 Water use and water use efficiency of the various cropping systems

		Sole maize		Maize-cowpea intercrop		Sole cowpea	
		Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Total available water at planting, mm		26	30	26	30	26	30
Total soil water at maturity, mm		12	14	8	6	18	16
Growing season rain, mm		297.60	282.00	297.60	282.00	297.60	282.00
Supplementary irrigation, mm		160 .00	160.00	160.00	160.00	160.00	160.00
Water use, mm		471.60	458.00	475.60	466.00	465.60	456.00
Grain yield @ 12%moisture content, kg/ha	Cowpea	N/A	N/A	1600	1350	1720	1850
	Maize	4880	3500	4450	4820	N/A	N/A
	Cowpea + maize	4880	3500	6050	6170	1720	1850
WUE, kg/ha mm		10.35	7.64	12.72	13.24	3.69	4.06

N/A = Not applicable

Fig.7 Water use efficiency of the various cropping system for the two growing seasons



References

Ali M. H. And Talukder M. S. U. 2008. Increassing water productivity in crop production- A synthesis. Agricultural water management 95(11):1201-1213 http://ideas.repec.org/s/eee/agiwat.html.

Azam-Ali S. N. and Squire G. R. 2002. Principles of Tropical Agronomy. CABI

Azam-Ali, S.N., Matthews, R.B., Williams, J.H and Peacock, J.M, 1990. Light use, water uptake and performance of individual components of sorghum/groundnut intercrop. *Exp.Agric*.26, 413-427

B.M. Sani , N.M. Danmowa,Y.A. Sani and 1M.M. Jaliya (2012) Growth, Yield and Water Use Efficiency of Maize-Sorghum Intercrop at Samaru, Northern Guinea Savannah, Nigeria Nigerian Journal of Basic and Applied Science (2011), 19 (2): 253-259.

Boko M, Niang I, Nyong A, Vogel C, Githeko A, Medany M, Osman-Elasha B, Tabo R and Yanda P. 2007. Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry M L, Canziani O F, Palutikof J P, van der Linden P J and Hanson C E (eds). Cambridge University Press. Cambridge UK. pp. 433 – 467.

Coetzee, J.J., 1995.Cowpeas: A traditional Crop in Africa. Africa Crops info 1995 leaflet. ARC, Pretoria.

Cooper, P J M and Dimes, J and Rao, K P C and Shapiro, B and Shiferaw, B and Twomlow, S J and Verchot, L P and Cooper, P. 2008 *Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?* Agriculture, Ecosystems & Environment, 126 (1/2). pp. 24-35.

Critchley W and Siegert K. 1991 "A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production." 17/1991. *FAO Corporate Document Repository*. http://www.fao.org/docrep/U3160E/u3160e00.htm#Contents.

Hensley D and Deputy J. 1999. Using Tensiometers for measuring soil water and scheduling irrigation. CTAHR Cooperative Extension Service, Landscape L-10 http://www.ctahr.hawaii.edu/publications

Diao X. 2010. Economic importance of Agriculture for sustainable development and poverty reduction: Findings from a case study of Ghana. Global forum on Agriculture 29-30 November 2010 Policies for Agricultural development, poverty reduction and food security OECD

Downes, R.W. (1972). Effect of temperature on the phenology and grain yield of sorghum. Australian Journal Agricultural Research 23: 585-594

Eaglesham, A.R.J., Ayanaba, A., Rango Rao, V and Eskew, D.L., 1981. Improving the nitrogen nutrition of maize by intercropping with cowpea. Soil. Biol, Biochem. 13, 169 -171.

Hsiao, T.C., Steduto, P. and Fereres, E. 2007. A systematic and quantitative approach to improve water use efficiency in agriculture. *Irrigation Science* 25:209-231.

Hulugalle, N.R and Lal, R., 1986. Soil

water balance in intercropped maize and cowpea grown in a typical hydromophic soil Western Nigeria. *Agron.* J. 77, 86-90

Hunt J and Kirkegaard J. 2012. A guide to consistent and meaningful benchmarking of yield and reporting of water-use efficiency. Sustainable Agriculture. http://www.csiro.au

Kanton R. A. L. and M. D. Dennett (2004) Water Uptake and use by Morphologically Contrasting Maize/Pea Cultivars in Sole and Intercrops in Temperate Conditions. Expl Agric. 40, pp. 201–214 C _ 2004 Cambridge University Press United Kingdom

McCoy, S., Vyn, T., Kline, A., West, T. And Christmas, E., 2001. Management considerations for relay intercropping: II. Soybean. Agronomy Guide. AY-136. Purdue University Cooperative Extension service.

Midmore, D.J., 1993.Agronomic modification of resource use and intercrop productivity. Field Crops Resource. 34:357-380.

Mpangane, P.N.Z., Ayisi, K.K., Mishiyi, M.G. and Whitebread, A., 2004. Grain Yield of Maize Grown in Sole and Binary Cultures with Cowpea and Lablab in the Limpopo Province of South Africa. Tropical legumes for sustainable farming systems in Southern Africa and Australia. Edited by Whitebread, A.M., and Pengelly, B.C. ACIAR Proceedings No. 115

Mulebeke R. Kironchi G. And Tenywa M. M. 2010 Enhancing water use efficiency of cassave and sorghum based cropping systems in drylands. Second RUFUROM biennial meeting, 20-24 September, 2010, Entebbe, Uganda. http://news.mak.ac.ug/documents/RUFORUM/Mulebeke.pdf

Natarajan, M and Willey, R W 1980. *Sorghum-pigeonpea intercropping and the effects of plant population density. 2. Resource use.* The Journal of Agricultural Science, 95 (1). pp. 59-65. ISSN 1916-9752

Ofori, F. and Stern, W.R, 1986. Maize/Cowpea intercrop: Effect of nitrogen fertilizer on productivity and efficiency. *Field Crop Research.* 14, 247-261.

Ofori, F. and Stern, W.R, 1987. Cereal – legume intercropping systems.Adv.Agron.41, 41-90

Ong, C.K., Black, C.R., Marshall, F.M., Corlett, J.E., 1996. Principles of resource capture and utilisation of light and water. In: Ong, C.K., Huxley, P.A. _Eds.., Tree–crop Interactions— a Physiological Approach. CAB International.

Rockström, J., Barron, J. and Fox, P. 2003. Water productivity in rain-fed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agroecosystems. In: Kijne, J.W., Barker, R. and Molden, D. (Eds.). Water productivity in agriculture: Limits and opportunities for improvement. CAB International. pp. 145- 159.

Shetty, S.V.R., Ntare, B.R., Bationo, A and Renard, C., 1995. Miller and cowpea in mixed farming of Sahel. A review of strategies for increased productivity and sustainability. Pages 293 – 304 in Livestock and sustainable nutrient cycling in mixed farming systems of Sub-Saharan African, edited by J.M Powell, S. Fernandez Revira, T. O. Williams, and C. Renard. Proceedings International Conference, ILCA, Addis Ababa, Ethiopia.

Singh, B.B., Ehlers, J.D., Sharma, B. And Fereire Filho, F.R., 2002. Recent progress in cowpea breeding. Pages 22 – 40 in Challenges and opportunities for enhancing sustainable cowpea production, edited by C.A Fatokun, S.A. Tarawali, B.B, Singh, P.M. Kormawa., and M. Tamo. IITA, Ibadan, Nigeria

Smith B D 2001. Documenting Plant Domestication: The Consilience of Biological and archeological approaches. PNAS vol 98(4) 1325-1326

Thobatsi T. 2009. Growth and yield responses of maize (Zea mays L.) and cowpea (Vigna vinguiculata L.) in an intercropping system. MSc thesis at the University of Pretoria

Toriman M. E and M. Mokhtar (2012). Irrigation: Types, Sources and Problems in Malaysia, Irrigation Systems and Practices in Challenging Environments, Dr. Teang Shui Lee (Ed.), ISBN: 978-953-51-0420-9.

Vandermeer, J., 1989. The Ecology of intercropping. University of Cambridge, Cambridge.

Viljoen, J. and Allemann, J., 1996. Cowpea and maize intercropping. Pages 16-24 in Training course. Cowpeas. Vegetable and Ornamental Plant Institute, Agricultural Reseacrh Council, Roodeplaat

Willey, R.W., 1979. Intercropping-its importance and research needs. Part 1: Competition and yield advantages. Field Crop Abstract. 32, 1-10

Zhang F. Y, Wu P. T., Zhao X. N. and Cheng XF (2012). Water-saving mechanisms of intercropping system in improving cropland water use efficiency.