On-farm testing of wetting front detector as an irrigation scheduling tool in two communities in the upper east region of Ghana

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Through action research and development partnerships, Africa RISING will create opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment. http://africa-rising.net/

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Contents

Introduction

The overall aim of the Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program is to transform agricultural systems through sustainable intensification. The program seeks to identify and promote, through action research, sustainable agricultural technologies capable of creating opportunities for smallholder farm households to move out of hunger and poverty. The ultimate aim is to improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

Studies suggest that there are strong linkages between irrigation and poverty (Lankford et al. 2016; Hussain and Hanjira 2004; Rockström et al. 2002). These linkages are both direct (operate via localized and household-level effects) and indirect (operate via aggregate or sub-national and national level impacts).

Proper irrigation scheduling benefits the poor through higher production, higher yields, lower risk of crop failure, and higher and year-round farm and non-farm employment (Mdemu et al. 2009). Irrigation farmers in the Upper East Region of Ghana are under increasing pressure to manage water more prudently and more efficiently (Mdemu et al. 2009). This pressure is driven by water sharing requirements, product quality requirements, economic factors, demands on labor, and the desire to minimize the resource degradation and yield loss that can result from inefficient irrigation. However, the critical challenge of irrigation management approach is an accurate estimate of the amount of water applied to a field. In Ghana, the International Water Management Institute (IWMI) tested, at the farm level, the potential of the Wetting Front Detector (WFD) to improve crop and water productivity in dry season vegetable production by guiding farmers to schedule irrigation. Irrigation scheduling involves knowing when and how much to irrigate.

The twin questions of “when and how much to irrigate” is critical to the success of every dry season vegetable production venture, especially in areas such as the Upper East Region of Ghana where water is a critical limiting factor (Mdemu et al. 2009). Many techniques, such the use of tensiometers and neutron probes, already exist to monitor soil water status to determine when and how much water to apply. Nevertheless, the adoption of these technologies, especially by farmers in developing countries, is low due to the cost and complexity of these tools (Stirzaker et al. 2009; Stirzaker 2003). A WFD was developed at CSIRO in Australia in response to the low adoption of these existing irrigation tools (Stirzaker et al. 2017; Stirzaker 2003). It is a simple tool that helps to measure how deeply water has penetrated into the soil after an irrigation event. It is also useful for the monitoring of nutrient losses in soils (Stirzaker et al. 2004; Stirzaker 2003).

Brief Description of the Wetting Front Detector

The WFD comprises of a specially-shaped funnel, a filter, and a mechanical float mechanism (Fig.1). The funnel is buried in the soil within the root zone of the plants or crop. When the soil is irrigated, the funnel ‘captures’ some water from the wetting front as it goes past (Stirzaker 2003; 2009). The soil at the base becomes so wet that water seeps out of it, passes through a filter, and is collected in a reservoir. This water activates a float, which in turn pops up an indicator flag above the soil surface to indicate that the wetting front has passed a given depth (effective root zone) in the soil. There are no wires, electronics nor batteries for WFD to work. Studies show that WFD saved water (Kulkarni 2011), reduced labor and increased crop yield (Schmitter 2016). In addition, WFD helps you to "see" what is happening down in the root zone when the soil is irrigated.

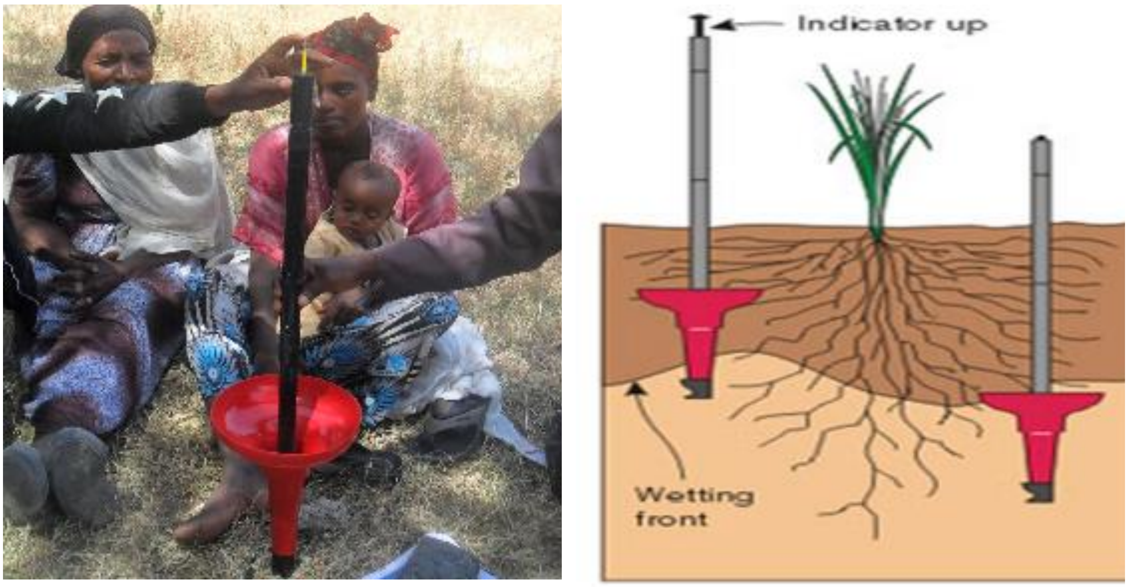

Figure 1. A Full Stop WFD. The funnel part is buried in the soil with the black tube protruding above the soil surface. When a wetting front reaches the detector, an indicator pops up.

Objective

The general objective of this research was to test at the farm-level whether the WFD can improve crop and water productivity by guiding the farmer on when and how much to irrigate. Moreover, the research assessed crop water productivity (CWP) of cowpea using WFD and farmers’ practices irrigation scheduling.

Methodology

Study area

The experiment was conducted in four Africa RISING demonstration plots located in two communities, Nyangua and Tekuru, in the Kasena Nankana East District of the Upper East Region. These communities lie approximately between latitude 11°10' and 10°3' North and longitude 10°1' West. Soils in the area mainly consist of Lixisols (FAO-IIASA-ISRIC-ISS-CAS-JRC 2012). These soils have high levels of iron concretions, low levels of organic matter; hence, susceptible to severe erosion. The average annual rainfall is 950 mm spread over a period of 65 days. The rainfall exhibits unimodal pattern and mainly occurs between April-May and September- October with peak in August. Temperature ranges from 23.0 to 35.2 ^{o}C with an average of 29.1 ^{o}C. The topography of the area is relatively flat with slope less than 5°. The dominant land cover in the watershed is open cultivated savanna woodland. The predominant land use is arable agriculture and widespread grazing of large numbers of livestock.

Choice of crop

Cowpea (*Vigna unguiculata* (L) Walp) was selected for this experiment because it is the second most important legume crop after groundnut, and an estimated 223,000 tons (t) was produced in 2012 (MOFA, 2013), mostly in the savannah zones. It is an important food legume and its use as a leafy vegetable serves as an inexpensive source of dietary protein for inhabitants of northern Ghana. Livestock also benefit from the protein content of the haulms. The crop also helps sustain soil fertility improvement in marginal lands by providing ground cover, suppressing weeds, and fixing soil nitrogen. Its ability to withstand drought, short growing period, and multi-purpose use make cowpea a very attractive crop for farmers in the savannah areas with low rainfall and less developed irrigation systems.

Experimental design

The on-farm experiments were implemented on four Africa RISING demonstration plots. Three of the demonstration plots (F1, F2, and F3) are located in Nyangua and the other one (F4) in Tekuru. Cowpea leaves, a delicacy in northern Ghana was the crop used for this experiment. The experimental design was a randomized complete block design (RCD) with four replicates of each treatment per location. The field layout is illustrated in Figure 2. The size of an experimental plot was 2.5 m × 5 m, with 0.5 m space between adjacent plots and 1 m space between replication. Three beds of dimensions 2.5 × 0.5 m were constructed on each of the plots.

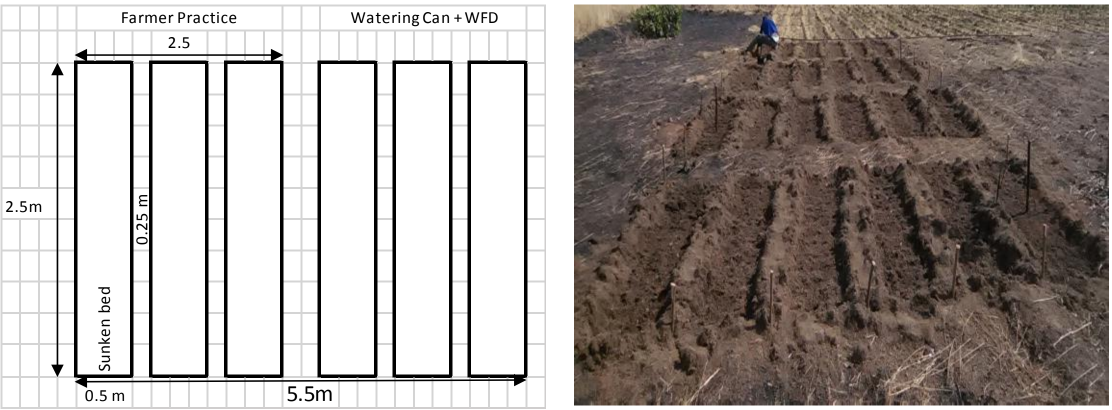

Figure 2 .Experimental field layout.

Soil characterization

Soil texture

Table 1 shows the physical characteristic of the soils in the four experimental sites. The soils in F1 and F2 are classified as sandy-loam with a clay content below 20%, and the soils in F3 and F4 are classified as sandy-clay-loam. Soil texture influences soil moisture content and evaporation rate; hence, it is a critical determinant of the rate and timing of irrigation. From the textural classes shown in Table 1, the rate of infiltration can be illustrated as F3<F4<F1<F2. Thus, the soils at F3 will be more prone to flooding and surface run-off compared to soils from the other sites because of the high clay content, which slows down infiltration of water during rainfall or irrigation (Kopec,1995). The implication of this is that, when scheduling irrigation water, the soils at F3 will need a slower flow rate to allow time for infiltration. Once this is achieved, it will take relatively more days before there will be a need for another water application (USDA 2008). The other soils, especially the soils at F2 (with sand content of over 66%), will require more frequent watering because the sandy soil have more interlayer spaces for percolation.

Table 1. Soil textural classes.

Sites	**Proportion of sand, silt and clay (%)**			**Textural classes (USDA)**
	Sand	**Silt**	**Clay**	
F1	56.85	24.16	18.99	Sandy-loam
F2	66.65	16.31	17.04	Sandy-loam
F3	54.12	22.31	23.52	Sandy-clay-loam
F4	64.94	14.88	20.21	Sandy-clay-loam

pH and electrical conductivity

Table 2 represents some chemical properties of the soils in the four experimental sites. The pH of the soil was determined in water (pH_w 1:1) and ranges between 5 and 6 in all four sites. The soils with pH below 6.0 (F2, F3, F4) are moderately acidic. Reduction in the use of ammonium fertilizers, addition of organic manure and plant residues are some management practices needed to increase the pH.

Electrical conductivity (EC) is an estimator of the amount of dissolved salts (TDS) in the soil. It influences infiltration rates during rainfall or irrigation. The EC of soils from the four sites ranges between 0.14–0.25 dS/m; therefore are non-saline. These are good for irrigation (FAO, 2006).

Soil fertility

The total nitrogen of the soils from all the four sites is less than 1%. This is too low to support crop growth and development. According to McKenzie (1998), total nitrogen content of < 1.5% is too low for all crop requirement. Therefore, external supply of nitrogen, either in the form of organic or inorganic fertilizers is required to meet crop nitrogen requirements for growth and development.

Phosphorus is an essential plant nutrient required for protein synthesis and plant growth. It is also an energy source (ATP) for microbes during mineralization and release of soil organic carbon and total nitrogen in the soil. The available phosphorus in the soils ranges between 7.0 and 16.5 mg/kg. Crop production on the four experimental plots may gradually deplete the available phosphorus in the absence of phosphorus fertilizer application.

Cation Exchange Capacity

Cation exchange capacity (CEC) is a measure of soil fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination. It is the maximum quantity of exchangeable cations that a soil can hold at a given pH. According to the FAO (2006), CEC values > 10 CEC cmol/kg^{-1}are classified as high. Leaching of nutrients is high in soils with low CEC such as F4. When applying inorganic fertilizers to low CEC soils, the application must be spread over time (Ketterings et al. 2007) to help reduce leaching of nutrients into groundwater. Soils with low CEC will also require low but frequent watering. Soils with high CEC such as F1, F2, and F3 have low infiltration rates. When applying inorganic fertilizers to high CEC soils, the fertilizer must be incorporated into the soil to reduce surface run-off losses due to the low infiltration rate (Cornell University 2007).

Table 2. Soil chemical properties.

Sites	pHw (1:1)	EC (dS/m)	TN (%)	AP (mg/kg)	K (coml/kg)	CEC (coml/kg)
F1	6.14	0.26	0.055	16.02	0.19	15.39
F2	4.94	0.18	0.047	7.00	0.14	16.11
F3	5.62	0.19	0.051	12.04	0.18	21.42
F4	5.65	0.15	0.038	16.51	0.20	9.77
FAO	6.0-8.0					>10

Water quality characterization

Table 3 shows the indicators of irrigation water quality in the four experimental sites. The pH values from the four sites ranged from 6.9 to 7.5; hence are within the FAO acceptable range of 6.0 to 8.0 (Ayers and Westcot 1994). The EC gives a measure of salinity potential of the irrigation water. None of the water samples exceed the salinity levels at which crops are affected (>700 µS/cm; Abrol et al. 1988). Other hydro-chemical parameters such as sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) are all within the water quality guidelines for irrigation use (Ayers and Westcot 1994). The fluoride (F^-) concentrations ranges between 0.15 and 0.91 mg/l; hence, within the acceptable limits of 1.0 mg L^{-1} (Ayers and Westcot 1994) though the value for F2 was high. Average concentrations for iron (Fe^{2+}) and aluminium (Al^{3+}) were also within the acceptable range of < 5 mg/L.

Table 3. Water quality.

Site	pH	Cond.	K^+	Na^+	Ca^{2+}	Mg^{2+}	F^-	Fe^{2+}	Al^{3+}
	pH Units	uS/cm	mg L						

Site	pH	Cond.	K^+	Na^+	Ca^{2+}	Mg^{2+}	F^-	Fe^{2+}	Al^{3+}
F1	7.12	374.50	2.90	36.50	33.70	14.05	0.15	0.90	0.11
F2	7.01	290.50	3.30	40.50	29.70	8.25	0.22	0.93	0.65
F3	7.15	297.50	2.90	37.00	24.85	9.70	0.91	1.60	1.42
F4	7.55	561.00	3.47	41.00	27.97	42.20	0.29	2.17	0.10
FAO	6 – 8**	> 700*	0-2	920	400	60	1.0	5.0	5.0

*Abrol et al. 1988; **Ayers and Westcot 1994

Land preparation and farm management

The land was tilled by ploughing & harrowing to a depth of 20 cm. WFDs were installed at a depth of 15 cm on the first beds on the sub-plots with treatment “A” to guide water application. WFD was not installed on the second treatment ‘’B.’’ Three rows of cowpea (Songotra- IT97K-499-35) were planted per bed at a spacing of 15 cm × 15 cm giving a plant population of 48 plants per bed. Two seeds were planted per hole. Water was supplied to the crops by overhead application using watering cans. All other crop management and weed and pest control followed recommendations from the Savanna Agricultural Research Institute (SARI 2012).

Treatments

The two treatments tested were:

1. Irrigation water application using the same buckets used for drawing water from the wells and scheduling using farmers’ judgement (FP).
2. Irrigation water application using watering cans and scheduling using WFD (WF).

Data collection

Amount and frequency of water application to the experimental plots were recorded throughout the growing period. Leaf vegetable yield data were collected at a 10-day interval upon initiation of leaf harvesting. Harvesting was done on the 25th, 35th, 45th, and 55th day after planting. The total leaf vegetable weight for each treatment was obtained by summing up the fresh leaf weights obtained for the given treatment at different leaf harvesting dates and expressed in kilograms per hectare (g/m^2).

Data analysis

Descriptive statistics and graphs were used to summarize and present the data. Moreover, independent pair t-test was used to compare means between the two treatments. CWP was computed as the ratio of biomass yield of cowpea to water consumed during the growing period (Molden et al. 2010).

Results and observations

Effect of watering can and WFD scheduling on biomass yield of cowpea

Table 4 presents the biomass yield of cowpea using WFD and FP. Generally, the plots with watering can and WFD scheduling (WF) increased biomass yield by 8%, 19%, 12%, and 9% in F1, F2, F3, and F4, respectively. Although the differences were statistically insignificant, the fresh leave yield of cowpea on WF plots were higher compared to FP (Table 4). The average fresh leave yield from the WF plots (303 g/m^2) was higher compared to FP (271 g/m2). Lower fresh leave yield from farms using farmers' practices might be associated with waterlogging of cowpea plant.

Table 4. Biomass yield ± standard deviation of cowpea (g/m^2) using WF and FP in the Upper East Region of Ghana.

	F1	**F2**	**F3**	**F4**	**Average**
WF	352.0±19.71	303.3±111.3	274.7±55.51	280.7±172.9	302.7±100.7
FP	326.0±37.86	254.0 ±141.8	244.7±66.55	258.0±135.3	270.7±99.9
t-statistics	–1.21	0.547	–0.692	0.206	–0.903
p-value (2-tail)	0.269	0.604	0.515	0.843	0.374
Relative effect of WF (%)	7.39	16.25	10.92	8.09	10.57

*F1, F2, F3, and F4 represent farm 1, 2, 3, and 4, respectively. WF denotes irrigation water application using watering cans and scheduling using WFD; FP denotes irrigation water application using buckets and scheduling using farmers' judgement.

Effect of watering can and WFD scheduling on irrigation water applied/requirement

Table 5 shows the irrigation water applied using WF and FP. As shown in the table, 273 (F3) and 410 (F4) mm water was required to grow cowpea using FP. Similarly, 205 (F3) and 349 (F4) mm was used to grow cowpea using WF. On the average, 302 mm and 346 mm water was applied over a period of 55 days using WF and FP, respectively. This implies that WF saved 14% of irrigation water compared to FP (Table 5). This indicates that WF saves 14% of labor requirement to irrigate as compared to FP.

Table 5. Total irrigation water applied/requirement (mm) ± standard deviation for cowpea using WF and FP in the Upper East Region of Ghana.

	F1	**F2**	**F3**	**F4**	**Average**
WF	308.0±0.0	349.1	205.3±0.00	349.7±0.00	302.9±60.9
FP	349.1±0.0	349.1	273.1±0.00	410.6±0.00	345.5±50.4
t-statistics	8.60	0.00	10.10	9.6	2.16
p-value (2-tail)	0.000	1.00	0.000	0.00	0.039
Relative effect of WF (%)	–13.34	0.00	–33.02	–17.41	–14.06

* F1, F2, F3, and F4 represent farm 1, 2, 3, and 4, respectively. WF denotes irrigation water application using watering cans and scheduling using WFD; FP denotes irrigation water application using buckets and scheduling using farmers' judgement.

The t-test shows that daily irrigation water (mm/day) was significantly lower in WF compared to h FP (Fig. 3) except F2. Over 55 days, the average daily irrigation water for cowpea was 5.5 mm/day and 6.3 mm/day using WF and FP, respectively. However, the daily irrigation water applied varied across the sites, application, and scheduling methods (WFD and FP). Accordingly, the lowest irrigation water applied (3.7mm/day) using WF was recorded in F3 and the highest (6.4 mm/day) in F4. Similarly, the lowest irrigation water applied (5 mm/day) using WF was recorded in F3 and the highest (7.5 mm/day) in F4 (Fig. 3).

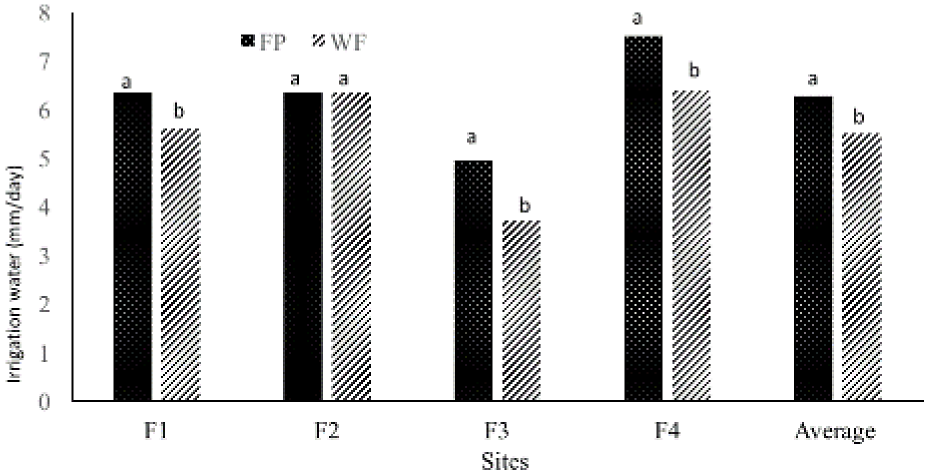

Figure 3. Daily irrigation water applied/required (mm/day) for cowpea in the Upper East Region of Ghana.

* Different letters in each site (F1, F2, F3, F4) are significantly different at *P* < 0.05; F1, F2, F3, and F4 represent farm 1, 2, 3, and 4, respectively; WF denotes irrigation water application using watering cans and scheduling using WFD, and FP denotes irrigation water application using buckets and scheduling using farmers' judgement.

Effect of watering can and WFD scheduling on crop water productivity

CWP, as defined by most authors, is the ratio of crop yield to water consumed, applied, or evaporated in the process of growing a crop (Molden et al. 2010; Zwart et al. 2004). The average CWP for cowpea using watering can application and WFD scheduling was 10.4 kg/mm/ha (≈1.04 kg/m^3) (Table 6). Similarly, the average CWR for cowpea using FP application and scheduling was 7.96 kg/mm/ha (≈0.796 kg/m^3). This difference in CWR between WF and FP is statistically significant (Table 3). However, the results vary across farms. The highest CWR for cowpea (13.37 kg/mm/h) using WF was recorded in F3 and the lowest (8.09 kg/mm/ha) in F4 (Table 6). Using FP, the highest CWR for cowpea was 9.3 kg/mm/ha and the lowest was 6.28 kg/mm/ha.

Figure 4 depicts the relationship between fresh cowpea leaves production and water applied. On the average, 3029 m3/ha water was required to produce 3.03 t/ha of fresh cowpea leaves using WF. However, 3455 m3/ha of water was applied to produce 2.71 t/ha of fresh cowpea leaves using FP (Fig. 4).

Table 6. CWP (kg/mm/ha) ± standard deviation of cowpea using WFD and FP in the Upper East Region of Ghana.

	F1	**F2**	**F3**	**F4**	**Average**
WF	11.14±0.64	8.7	13.37±	8.09±4.95	10.38±3.65
FP	9.3±1.08	7.2	8.95±	6.28±3.29	7.96±2.92
t-statistics	–3.32	0.547	–2.43	–0.59	–2.07
p-value (2-tail)	0.016	0.604	0.051	0.576	0.048
Relative effect of WF (%)	16.52	17.24	33.06	22.37	23.31

* F1, F2, F3, and F4 represent farm 1, 2, 3 and 4, respectively. WF denotes irrigation water application using watering cans and scheduling using WFD; FP denotes irrigation water application using buckets and scheduling using farmers' judgement.

Figure 4 presents the relationship between fresh cowpea leave yield (t/ha) and applied water (m^3/ha) in four communities. As shown in the figure, the crop water requirement of cowpea with WF was higher as compared to FP in all the communities.

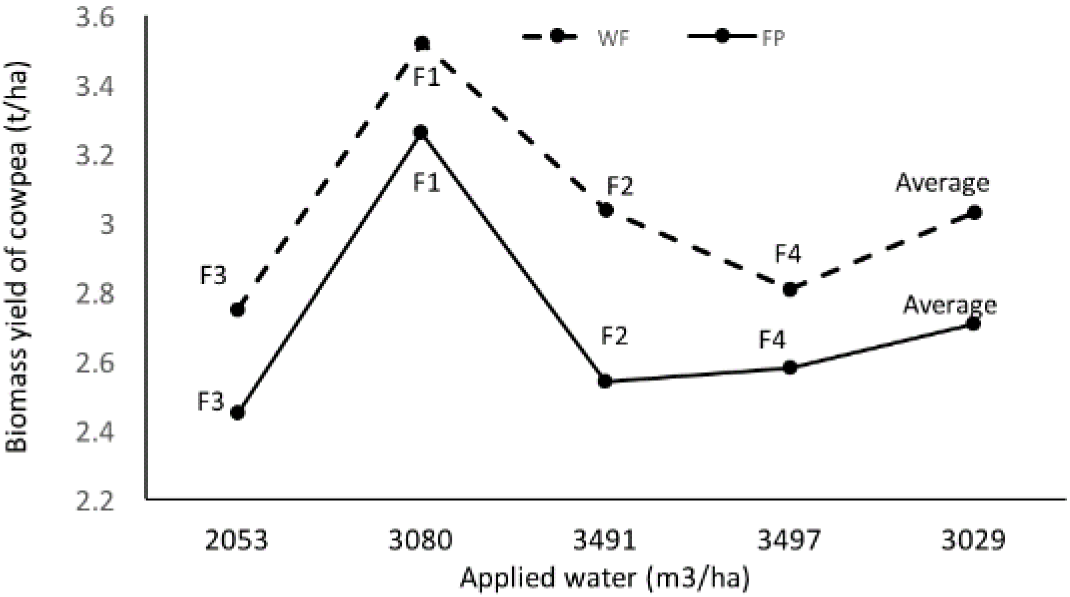

Figure 4. Relationship between fresh cowpea leave production (t/ha) and applied water (m3/ha) in the Upper East Region of Ghana.

* F1, F2, F3, and F4 represent farm 1, 2, 3, and 4, respectively. WF denotes irrigation water application using watering cans and scheduling using WFD; FP denotes irrigation water application using buckets and scheduling using farmers' judgement.

Challenges

The experiment went well as planned. One limitation of using the WFD as an irrigation scheduling tool is the inability of the farmer to be on the farm at all times. Normally, water should be applied when the flag drops down but this is not possible when the farmer is not available to do it (e.g., at night). Thus, there is always a time lag between when the flag drops down (when there is not enough water in the soil) and when the farmer can practically apply water. A way to resolve this challenge is an automation of the water application. Moreover, considerable amount of knowledge is required to correctly choose the placement depth for each crop types.

Conclusions

Though the WFD did not resolve the question of accuracy in irrigation scheduling, the yield difference and CWP between the WF plots and FP plots will help the farmer to understand that it is worth applying water uniformly over beds. Lower irrigation water requirement of cowpea using WFD implies that WFD saves water and labor for irrigation.

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Appendix

Activities and dates

Date	Activity
22-24/ 01 /2017	Land preparation
25 / 01 / 2017	Planting
17 / 02 / 2017	Harvesting 1
28 / 02 / 2017	Harvesting 2
10 / 03 / 2017	Harvesting 3
22 / 03 / 2017	Harvesting 4