Effect of the Wetting Front Detector (WFD) irrigation scheduling on yield and water productivity of Pepper in the Upper East Region of Ghana

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The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-in-development projects supported by the United States Agency for International Development (USAID) as part of the U.S. Government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING is creating 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.

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Contents

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Introduction

In Northern Ghana, farmers practice small-scale irrigation using simple equipment such as buckets and watering cans (Balana, et al., 2017; Giordano and de Fraiture, 2014; Namara et al., 2014; Drechsel et al., 2006). However, the productivity of irrigated agriculture in the region is generally low (Namara et al., 2010). The need for additional investments in agricultural water management technologies has gained enormous attention by the government of Ghana to enhance the productivity of irrigated agriculture in the country (MOFA, 2014; Namara et al., 2010). A strategic opportunity therefore exists to develop agricultural water management strategies with smallholder farmers to improve production and productivity (Antwi-Agyei et al, 2012; Giordano et al, 2012; de Fraiturea and Giordano, 2014).

The purpose of agricultural water management is to minimize losses of water (percolation, surface runoff and evaporation) and maximize transpiration, which is the beneficial loss of water due to its direct link to the dry matter production (Wei et al., 2015, Sharma et al., 2015). Use of appropriate water management tools such as a wetting front detector (WFD) can support more efficient water applications, reduce labor, improve productivity and increase farmers' income at the farm level (Adimassu et al., 2016; Schmitter et al., 2016; 2017 Kulkarni, 2011). Besides water management, soil nutrient management enhances productivity and water productivity of irrigated crops (Dunbabin et al., 2002; Ercoli et al., 1999). The wetting front detector is a mechanical easy-to use scheduling tool used for its effectiveness in water saving and productivity (Stirzaker, 2003; Stirzaker et al., 2009, 2017).

This study provides an opportunity for farmers to compare water use and agricultural productivity following the use of WFD against their standard practice and CROPWAT based scheduling. Pepper (*Capsicum annuum, L.*) was used as a test crop since it is a high value vegetable with various uses in the study areas (MOFA, 2014). The dried fruit is a spice used for *Shito* (traditional hot sauce in Ghana) making and seasoning (Dagnoko et al., 2013). Pepper is an important source of income, nutrition and medicine for resource poor households in urban, peri-urban and the rural areas of the country (Dagnoko et al., 2013; FAOSTAT, 2012; Namara et al., 2014). Almost every household in Ghana consumes pepper.

Materials and methods

Study areas

The study was conducted in Nyangua and Tekuru communities in the Upper East Region of Ghana for two years (2017/18 and 2018/19 irrigation season). The rainfall exhibits a unimodal pattern and mainly occurs between April/May and September/October with a peak in August. The average annual rainfall is 950 mm. Temperature ranges from 23 to 35oC with an average of 29oC. The topography of the area is relatively flat with slope less than 5°. The dominant land cover types in the study areas are open cultivated and savanna woodland (Kadyampakeni et al., 2017).

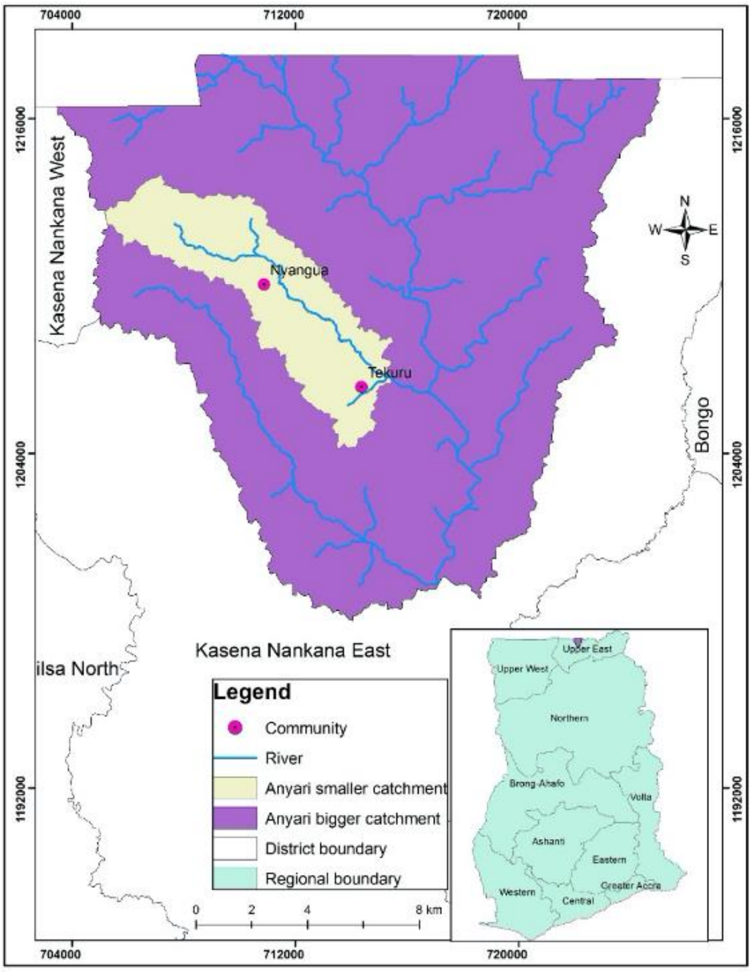


Figure 1. Location of study areas in the Upper East Region of Ghana

Soils in the area mainly consist of Lixisols (FAO-IIASA-ISRIC-ISS-CAS-JRC, 2012), which are dominated by sand (≥60%) followed by silt (> 25%) in both study areas (Table 1). In Nyngua, organic carbon content (%), total nitrogen (%), available phosphorus (mg/kg) and available potassium (mg/kg) of the soil were 0.8, 0.1, 10.3, and 9.4, respectively. Similarly, in Tekuru, organic carbon content, total nitrogen, available phosphorus and available potassium were 1.2, 0.1, 10.6, and 10.3, respectively. Generally, however, these values are extremely below the recommendation for optimum plant growth (McKenzie, 1998).

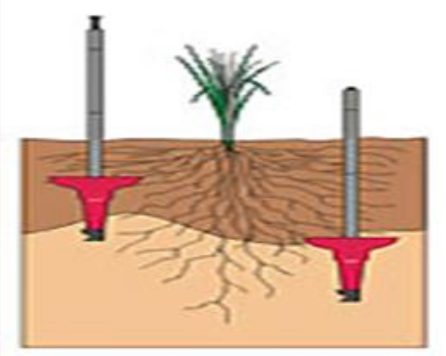
Table 1. Selected soil properties in the study areas at the soil surface (0-30 cm).

Soil properties		Nyangua (n=18)	Tekuru (n=18)
Particle size Distribution (%)			
	Sand	66.0	64.6
	Silt	25.6	26,5
	Clay	8.4	8.9
pH (H_2O, 1:1)		5.7	5.8
Organic C (%)		0.8	1.2
Total N (%)		0.1	0.1
Avail. P (mg/kg)		10.3	10.6
Avail. K (mg/kg)		9.4	10.3

Treatments and experimental design

The experiment was carried out in farmers' fields from November 2017 to March 2018 (year 1) and December 2018 to April 2019 (year 2). Pepper (Capsicum annuum) variety Scotch Bonnet, seeds were nursed on 29th September and transplanted on three farmers' fields on 11th November 2017 (year 1) and 7th December 2018 (year 2) at 5-6 true leaf stage. In this study, three irrigation-regimes and six soil-amendment treatments were tested (Table 2). The irrigation regimes included: i) Farmers' practices (FP) —the quantity and timing of daily irrigation water based on local knowledge and practices, ii) irrigation quantity was based on farmers decision using the WFD (as described in Box 1) whilst the timing was based on local knowledge and practices and iii) irrigation requirement using crop water requirement (IRCWR) which was computed using CROPWA (Allen et al., 1998).

Box 1: FullStop wetting front detector



The FullStop Wetting Front Detector (WFD) comprises of a specially shaped funnel, a filter and a mechanical float mechanism (Stirzaker, 2003). 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; Stirzaker et al., 2009).

As the soil moisture exceeds field capacity, water will gravitationally drain, passing through a filter and into 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, no electronics and no batteries for WFD to work. In addition, WFD helps the user to "see" what is happening in the root zone when the soil is irrigated.

As described in Table 2, Fortifer™, NPK (25:10:5) and Urea were the sources of soil-amendment treatments. Fortifer™ is a matured compost produced from dewatered faecal sludge (DFS) and sawdust or market waste. A brief description of Fortifer™ is given in Box 2. For the purpose of this research, granules (F_1) and powder (F_2) forms of fortifier were applied before transplanting while NPK was applied in different dosage depending on the treatments (F_3, F_4, F_5, F_6) two weeks after transplanting. Additionally, different dosages of foliar application of Urea was done four weeks after transplanting for treatments F_3, F_4, F_5, F_6 (Table 2). F1 and F2 are recommended rates of Fortifer™ (http://jekoraventures.com/greenproducts/fortifer-compost/). F_3 was the average rate applied by farmers in the study area, F_4 is ¼ of F_3, F_5 is 3/2 of F_3 and F_6 is twice of F_3.

Table 2. Description of treatments

Treatment	Description	
Irrigation treatments (Factor 1)		
WFD	Use of the FullStop Wetting Front Detector (WFD)	
IR_{CWR}	Irrigation requirement based on crop water requirement computation	
FP	Farmers' practice scheduling	
Fertilizer treatments (Factor 2)	**Description**	**Application rate (kg ha^{-1})**
F1	Fortifer granules 11 kg/plot = 5,500kg/ha	165N, 71.5P, 33K
F2	Fortifer powder 11 kg/plot = 5,500kg/ha	165N, 71.5P, 33K
F3	0.36 kg NPK + 0.18 kg Urea)/plot = (180kg NPK +90 kg Urea) /ha	86.4N, 18P, 9K
F4	(0.270kg NPK + 0.135kg Urea) /plot = (135kg NPK + 67.5 kg Urea) /ha	64.8N, 13.5P, 6.75K
F5	0.54kg NPK + 0.27kg Urea) /plot = 270kg NPK + 135 kg Urea + /ha	129.6N, 27P, 13.5K
F6	0.72kg NPK + 0.36kg Urea) /plot =360 kg NPK + 180 kg Urea/ha	172.8N, 36P,18K

Box 2: Fortifer^{TM} soil amendment

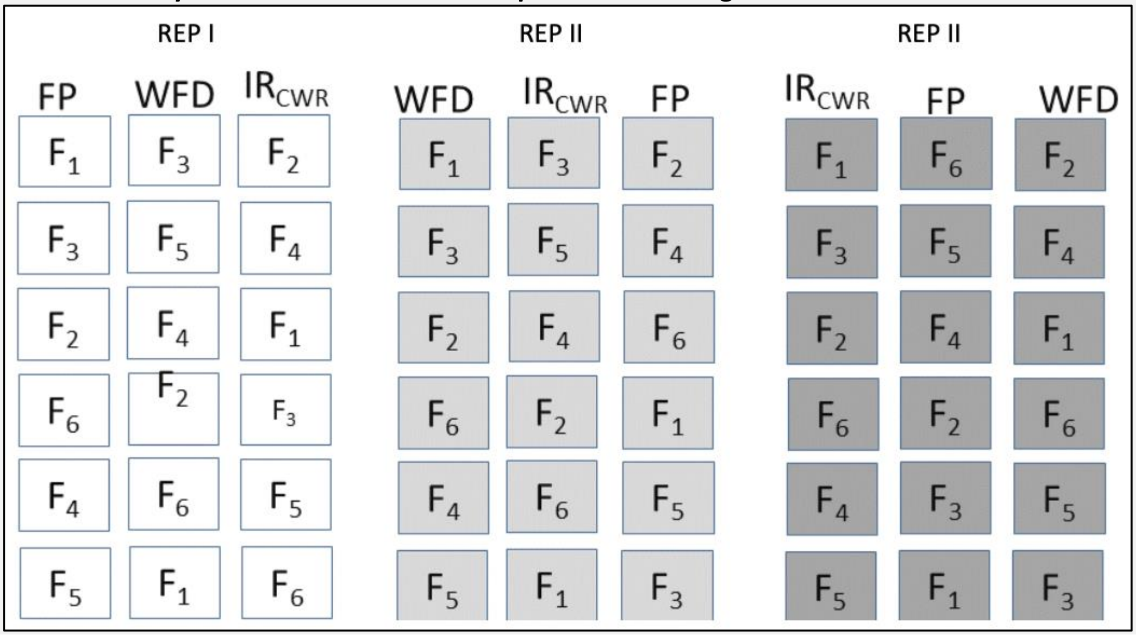
Fortifer^{TM} is a soil amendment certified by the Ministry of Food and Agriculture of Ghana. It is a matured compost produced from dewatered feacal sludge (DFS) and sawdust or market waste, and the nitrogen content enriched up to 3.0% (Adamtey et al., 2009). Being an organo-mineral, Fortifer^{TM} is rich in organic matter as well as micro-nutrients (Adamtey et al., 2009). This product was developed because of over a decade of research conducted by the International Water Management Institute (IWMI) and partners in Ghana.

Fortifer^{TM} is now being produced and marketed in Ghana through a public-private partnership arrangement between Jekora Ventures Ltd. and Tema Metropolitan Assembly (TMA). Fortifer is produced in three "particle sizes", i.e. granules, powder and pellets.

As shown in table 2, there were two factors in this study. The first factor is irrigation regime (FP, WFD, and IR_{CWR}) while the second factor was fertilizer levels (F_1, F_2, F_3, F_4, F_5, F_6). For this trial, split-plot design was chosen for water management reason. For practical expediency, it is desirable to assign irrigation regimes to the main plots to minimize water movement between adjacent plots and reduce border effects. There were two separate randomization processes in a split-plot design: one for the main plot and another for the subplot. In each replication, main-plot treatments (irrigation regimes) were first randomly assigned to the main plots followed by a random assignment of the subplot treatments (fertilizer levels) within each main plot (box 3). The treatments were replicated three times (farmers as replicates). The size of the sub-plots was 4 m x 5 m, with 1 m space between adjacent sub-plots. The 1 m spacing between sub-plots was needed for field operations such as cultivation, watering, weeding and harvesting. Row and plant distances were 0.7 m and 0.5 m, respectively. The land was tilled to a depth of 20 cm. WFDs were installed at a depth of 20 cm on the first beds of the WFD main plots to guide water application on the WFD plots. Pepper seedlings were planted on November 10, 2017 during the first year trial and

December 7, 2018 during the second year trial. Water was applied to the crops by an overhead application using watering cans, and fertilizers were applied by the side placement method.

Box 3: Field layout. See table 2 for a description of each irrigation and fertilizer treatment.



Determination of crop water requirement

Thirty-two years (1981-2012) of climatic data records (i.e. rainfall, temperature, relative humidity, sunshine hours and wind speed) were obtained from Navrongo weather station. The CROPWAT model (Ver.8) was used to determine reference crop evapotranspiration (ET_o) (Allen et al., 1998).

$$\lambda ET_0 = \frac{\Delta(R_n - G)\rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots eq\ 1$$

Where λ is heat of vaporization, R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and r_s and r_a are the (bulk) surface and aerodynamic resistances.

The crop water requirement (ETc) was then determined using eq.3 (Allen et al., 1998).

$$CWR = ETc = \mathrm{ETo} * \mathrm{Kc} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq.2$$

Where, CWR: Crop water requirement, ETc: Crop evapotranspiration (mm/day), ETo: Reference crop evapotranspiration (mm/day) and Kc: Crop coefficient. The Kc Values vary across the growing stages of pepper. Accordingly, 0.6, 0.9, 1.05 and 0.7 are the Kc values for initial, development, mid and late stages of pepper, respectively. The corresponding length of growing period are 30, 35, 40- and 20-days Allen et al., 1998).

Since irrigation is the sole source of water supply for the plant during the dry season in the study area, the irrigation requirement (IR_{CWR}) is greater than the crop water requirement to allow for inefficiencies in the irrigation system. Then CWR based irrigation requirement

(IR_{CWR}) was calculated using a typical irrigation efficiency (IE) value of 70% (Wu and Gitilin, 1975) (eq. 3).

$$IR_{CWR} = \frac{CWR}{IE} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3$$

Once the IR_{CWR} was calculated, the irrigation depth was converted into volumetric (liter) irrigation requirement. Farmers were instructed to apply IR_{CWR} using known volumetric measurement such as Geri can. Farmers also recorded the volume of water applied every day for WFD and FP in each sub-plot. The irrigation interval across all irrigation regimes was once in a day (usually in the evening).

Determination of water productivity

Water productivity (WP) was calculated using equation (eq. 4) (Howell, 2001; Karam et al., 2009; Bos, 1980, 1985).

$$WP = \frac{Y}{I} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . eq. 4$$

Where y is yield and I is irrigation water applied. WP, Y and I are expressed in kg m^{-3}, kg and m^{-3}, respectively.

Estimating sustainable intensification indicators

Field/plot scale data were used to estimate specific sustainability intensification indicators across the five domains, including productivity, economic, environment, human and social (Table 3). We used collected data from the pepper experiment to estimate the SI indicators and metrics as shown in Table 5. Sustainable Intensification Assessment Framework (SIAF) guide was used to select the indicators and matrices (Musumba et al., 2017).

The five domains were represented by various indicators using primary and secondary data sources. *i) Productivity domain:* Yield of pepper and input use efficiency were selected to represent productivity domain. Yield data (kg/ha) and input use efficiency including pepper yield per quantity of water applied (kg/m3) as well as pepper yield per quantity of nutrient applied were also generated from the experimental plots. ii) *Economic domain*: Input use intensity was selected as an indicator. This indicator consists of intensity of water (m^3/ha) and nutrient (kg/ha N, kg/ha P and kg/ha) used to grow pepper under different treatments. iii) Environment domain: Soil carbon and soil nutrient levels (N, P, and K) after harvest were used to explain environment domains. The soil analysis was done at the Soil Research Institute (SRI) in Accra. Total soil carbon (0-30 cm soil depth) was calculated based on the organic carbon content (%) and the average bulk density estimated from soil texture and organic matter in the SPAW model (Saxton and Rawls, 2006). iv) *Human condition domain*: Nutrition consisting of protein production and micronutrient was selected to estimate human condition domain. This indicator was derived from yield data from the experiment and nutritive value of pepper from secondary sources (Zou et al 2015). v) *Social domain* was represented by the yield and income of male and female farmers. However, selecting social domain indicators was a bit challenging as the number of male and female farmers were small as only one female was involved in the experiment.

Scores (values) for each individual indicator were standardized using eq. 5 and integrated (if more than one indicator per domain were used). Then radar charts were produced for irrigation regimes and fertilizer level treatments. This framework does not take into account weight across the indicators and domains.

$$\text{Standardized score} = \frac{(Score_{mean} - Score_{minimum})}{(Score_{maximum} - Score_{minimum})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (eq. 5)$$

Table 3. Indicators and matrices used to represent the five SI domains

SI domain	Indicator	Field/plot level metrics	Measurement method
Productivity	Yield	Kg/ha	Yield recorded
	Input use efficiency	-Kg of pepper per m^3 of water applied -Kg of pepper per kg of nutrient (N, P, K) applied	Measured from the field trial
Economics	Input use intensity	m^3/ha of water applied, kg/ha of N, P and K applied.	Measured from the field trial
Environment	Soil carbon	Total carbon (t/ha) at 30 cm	Soil test at SARI
	Soil nutrient level	-Total N after harvest -Available P after harvest -Exchangeable K after harvest	Soil test at SARI
Human	Nutrition	-Protein production (g/ha) -Micronutrient (Zn, Mg, Fe) (g/ha)	Estimated from pepper yield (kg/ha) and secondary data (nutrient content of pepper)
Social	Equity	-Yield of female and male farmers -Income of female and male farmers	Measurement of output (yield) and inputs

Data collection and analysis

Irrigation water was recorded daily for each treatment. Pepper yields per sub-plot were recorded from each treatment containing 30 plants per sub-plot. Fresh fruits were harvested three times during the first growing season (Year 1) and four times during the second growing season (year 2). Fresh fruit weight was recorded during harvesting. Analysis of variance (ANoVA) was performed using SPSS (Ver. 21) software. Selected parameters such as yield and water productivity were analyzed with standard split-plot analysis of variance technique (Factorial ANoVA) to test the effects of watering regimes, fertilizer treatments and their interactions (Field, 2005). Since the number of harvests and yield were different between the two years, the analysis was conducted separately for year 1 and year 2. Means were separated using least significant difference (LSD) at 0.05 (Snedecor and Cochran, 1980). All data were tested for homogeneity and normality test before subjecting to ANoVA (Field, 2005). Graphs were plotted using Microsoft Excel.

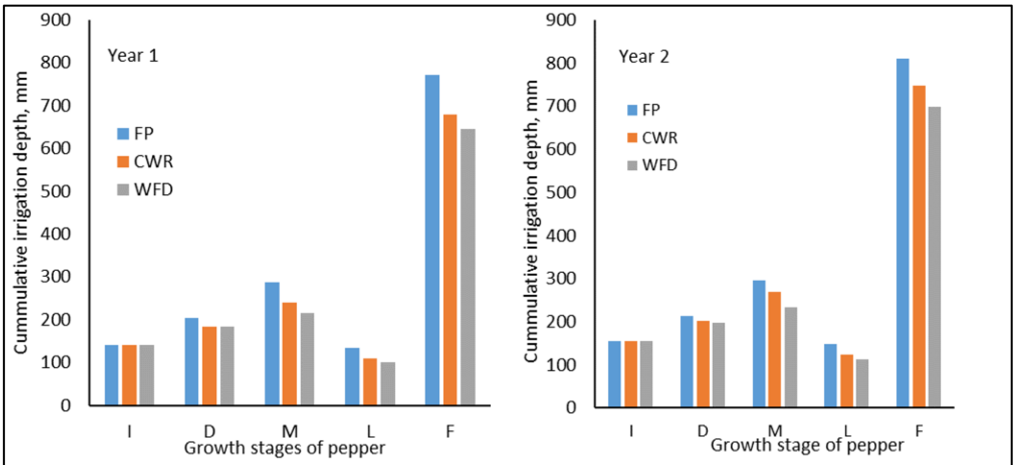
Results and discussion

Effect of wetting front detector (WFD) on irrigation water

Figure 2 presents the cumulative irrigation water applied to grow pepper using WFD, IR_{CWR} and FP in the year 1 (2017/18 growing season) and year 2 (2018/19 growing season). During 2017-2018, 644, 680- and 771-mm irrigation water was applied to grow pepper using WFD, IR_{CWR} and FP, respectively. Compared with FP, 127 mm of water was saved on farmers' fields by scheduling irrigation with WFD. Similarly, during 2018-2019, 698, 747- and 810-mm irrigation water was applied to grow pepper using WFD, IR_{CWR} and FP, respectively. The difference in the irrigation depth between year 1 and year 2 was mainly due to the difference in planting dates. Compared with FP, 112 mm of water was saved on farmers' fields by scheduling irrigation with WFD. The result in both years shows that when farmers used the WFD, they saved 16% of irrigation water compared level too their standard practices (FP) (Figure 2). However, the reduction in on-farm water application does not necessarily translate into water saving at scale beyond the farm as the volume of water saved could be used by farmers to expand the cultivated area under irrigation.

The reduction of irrigation water, when using the WFD, led to 16% labour saving to irrigate pepper as compared to FP, since the water application method used was a manual application with watering cans. A similar result was reported in an earlier study carried out in the same area, where WFD saved 14% of irrigation water compared with FP to grow cowpea (Adimassu et al., 2016). Another recent study reported that WFD saved 11 person days per hectare to irrigate different cereals and vegetables in Ethiopia (Schmitter et al., 2016). A similar study by Tamasgen (2016) using pepper and onion as the test crops, resulted in a 16% decrease irrigation water in the WFD treatment compared to farmer practice. However, the water saved was 19% and 21% lower than water saved through the use CROPWAT in onion and pepper production, respectively (Tamasgen, 2016). Tesema et al. (2016) also found that water applied in the WFD plots was 24% lower than the water applied using TDR (Time-Domain Reflectometer).

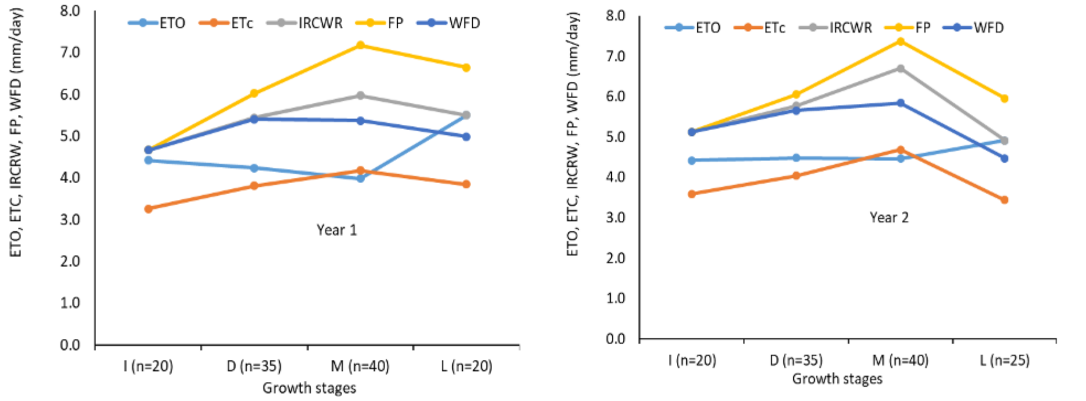
Figure 2 also depicts the cumulative irrigation depth (mm) applied in the growth stages of pepper using WFD, IR_{CWR} and FP. As shown in the figure, about 140 mm and 154 mm of water was applied during the initial stage of pepper across all treatments in year 1 and year 2, respectively. On average, over 60% of the irrigation depth were applied in the crop development and mid stages in both years (Figure 2). This can be explained in two ways. First, the crop co-efficient (K_c) values of pepper are the highest in the crop development (K_c = 0.90) and mid (Kc = 1.05) stages of pepper as compared to initial (K_c = 0.60) and late (K_c = 0.70) growth stages (Allen et al., 1998). Second, the growing periods are longer in the crop development (35 days) and mid (40 days) growth stages as compared to initial (30 days) and late (20 days) growth stages (Allen et al., 1998).



I: initial, **D:** development, **M:** mid, **L:** late, **F:** full period) using a wetting front detector (**WFD**), irrigation requirement based on ETC (**IR_{CWR}**) and Farmers' practice (**FP**).

Figure 2. Cumulative irrigation depth (mm) applied in the growth stages of pepper.

Figure 3 compares Reference Evapotranspiration (ET_0), Crop Water Requirement (ET_c) irrigation using a wetting front detector (WFD), irrigation requirement based on ETC (IR_{CWR}) and Farmers' practice (FP). As shown in the figure, the daily irrigation depth using FP was higher than IR_{CWR} and WFD mainly during development, mid and late stages. Similarly, the irrigation depth using WFD is lower than the irrigation requirement (IR_{CWR}) and FP. During the initial growth stage, an average of 4.7 mm/day water was applied across irrigation regimes treatments in year 1. Similarly, in year 2, an average of 5.1 mm/day water was applied across irrigation regimes treatments (Figure 3). During the development stage, a daily average of 5.4 mm/day (in year 1) and 5.8 mm/day (in year 2) was applied to plots with IR_{CWR} treatments. Similarly, a daily average of 5.4 and 5.7 mm/day was applied to plots with WFD while farmers applied almost the same quantity (6.0 mm/day) of irrigation water in year 1 and year 2. In year 1, during the mid-stage, average irrigation depths of 6.7 mm/day and 5.9 mm/day was applied to plots with IR_{CWR} and WFD, respectively. Similarly, during the late stage, average irrigation depths of 5.5 mm/day and 5.0 mm/day was applied to plots with IR_{CWR} and WFD, respectively in year 1. Farmers applied 7.2 mm/day (in year 1) and 7.4 mm/day (in year 2) during mid and late growth stages. Generally, this study shows that the saving in water application was concentrated mainly in the mid-crop development stage.



I: initial, **D:** development, **M:** mid, **L:** late using a wetting front detector (**WFD**), irrigation requirement based on CWR based irrigation depth (**IR_{CWR}**) and Farmers' practice (**FP**). **ET_o** and **ET_C** are reference evapotranspiration and crop water requirement, respectively. The growing length of the late stage in year 2 was 25 days instead of 20 days. This is mainly due to one more harvest against the year 1 harvest.

Figure 3. Irrigation depth (mm/day) of ETo, ETC, IRCWR, FP and WFD in the growth stages of pepper[1].

Effect of irrigation regimes and fertilizer treatments on pepper yield

In year 1, the average fresh fruit yields of pepper irrigated through IR_{CWR}, FP, and WFD were 5.4, 5.6 and 4.4 t ha^{-1}, respectively. In year 2, average fresh fruit yields of pepper irrigated through IR_{CWR}, FP, and WFD were 6.6, 6.8 and 5.4 t ha^{-1}, respectively. The fresh yield of pepper in year 2 is higher than in the year 1 across all irrigation regimes. Although the yield appears correlated with increasing amounts of irrigation, the fresh yield of pepper under different irrigation regimes were not significantly different. In both years, fresh yield of pepper was the highest under the FP irrigation regime (Figure 4). Generally, however, the yield is highly variable (annex I) and average yield of pepper in the study area is below the national average (10 t ha^{-1}) for the country (MoFA, 2013). As shown in figure 4, fresh yield of pepper was not significantly ($p=0.575$) affected by the irrigation regime. In year 1, plots with WFD had 23% and 27% lower fresh fruit yield of pepper compared with plots with IR_{CWR} and FP, respectively. Similarly, in year 2, plots with WFD had 18% and 21% lower fresh fruit yield of pepper compared with plots with IR_{CWR} and FP, respectively. In both years, the irrigation depth using WFD is lower than the irrigation depth using IR_{CWR}. This implies that irrigation using WFD was under moisture stress and affected the yield of pepper to a certain extent. This might be because of the fact that the field capacity of the sandy loam soil is low to support the irrigation requirement of the crop for 24 hrs irrigation interval. This is observed in Figure 3 where the daily irrigation depth applied using WFD was lower than the irrigation requirement (IR_{CWR}) of pepper.   In general, low water holding capacity of sandy loam soil coupled with a hotter weather in the study area suggests the need to irrigate pepper twice a day using the WFD. As shown in Figure 4, although a relatively higher irrigation water was applied using FP irrigation regime, it produced a relatively higher yield compared with WFD and IR_{CWR}. This implies that farmers are not over irrigating their plots in the context of the study areas with hot weather and poor soil condition.

[1] The growing length of the late stage in year 2 was 25 days instead of 20 days. This is mainly due to one more harvest against the year 1 harvest.

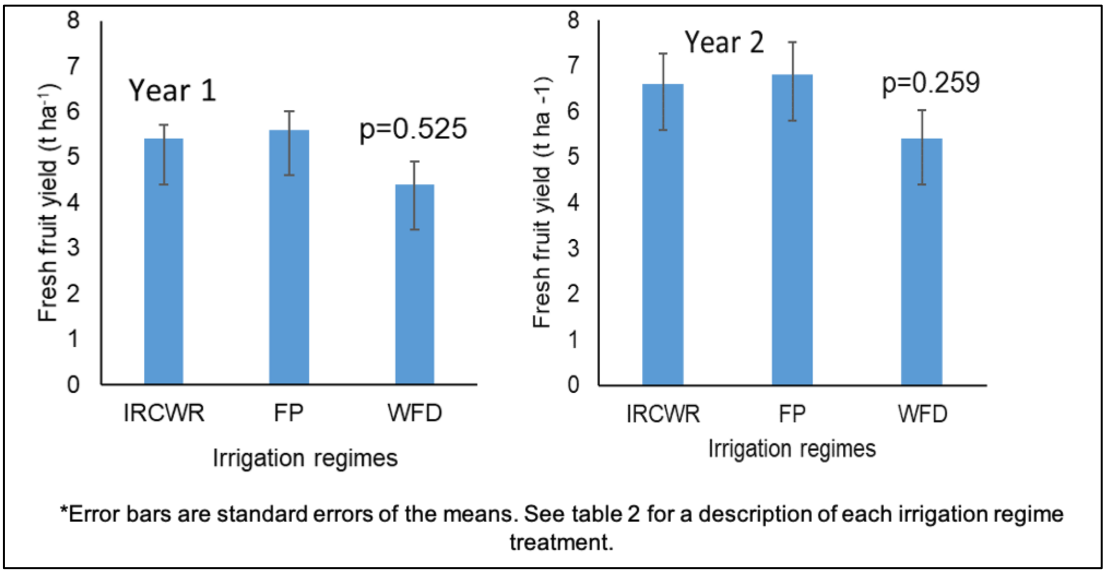


Figure 4. Response of fresh fruit yield of pepper to irrigation regimes in year 1 and year 2.

The fresh fruit yield of pepper was significantly ($p=0.034$) influenced by fertilizer treatment in both years (Figure 5). As shown in the figure, plots with F1 (Fortifer granules) and F2 (Fortifer compost) had highest fresh fruit yield compared with other fertilizer treatments. The highest fresh fruit yield of pepper in year 1 (7.2 t ha^{-1}) and year 2 (8.6 t ha^{-1}) was recorded from F1 fertilizer while the lowest yield was recoded from F4 fertilizer treatment.

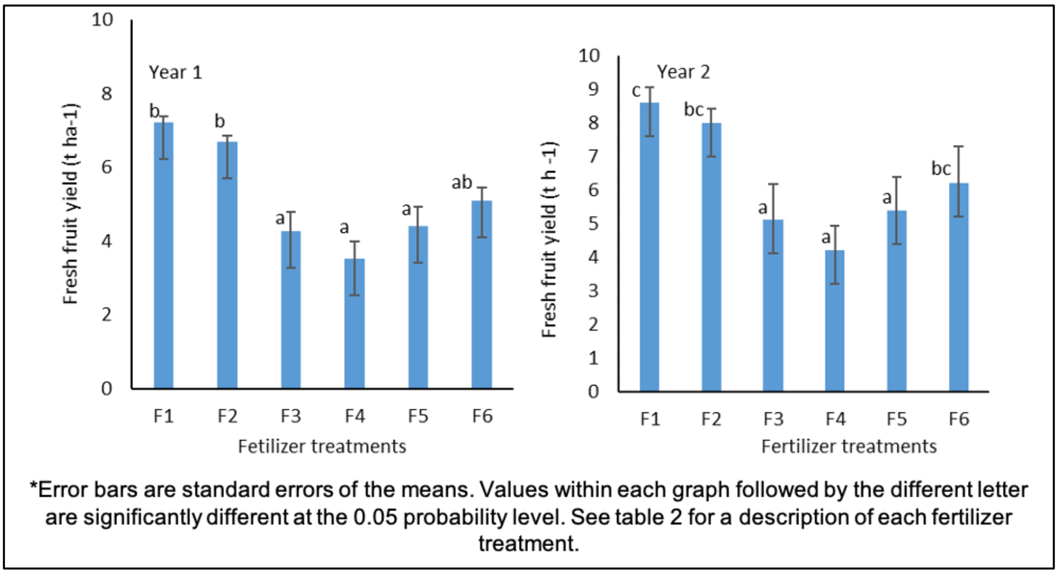


Figure 5. Response of fresh fruit yield of pepper to fertilizer treatments in year 1 and year 2.

Table 4 portrays the interaction effects of irrigation water and fertilizer on fresh yield of pepper. As shown in the table, fresh fruit yield was not significantly affected by irrigation regime and fertilizer interaction in both years. In year 1, the highest fresh fruit yield (8.4 t ha^{-1}) of pepper was recorded from F1 fertilizer combined with the FP irrigation regime. Similarly, in year 2, the highest fresh fruit yield (9.98 t ha^{-1}) of pepper was recorded from F1 fertilizer combined with the FP irrigation regime. The lowest fresh fruit yield of pepper was recorded from the interaction of F4 fertilizer and the WFD irrigation regime during year 1 and year 2 growing season.

Table 4. Response of fresh fruit yield of pepper to irrigation-fertilizer interaction.

Irrigation regimes	Fertilizer treatments	Yield of pepper (Mean±SEM)	
		Year 1	Year 2
IR_{CWR}	F1	6.80±0.40	8.27±0.86
	F2	7.40±0.20	8.77±0.34
	F3	5.00±0.90	5.96±2.03
	F4	3.40±0.70	4.10±1.66
	F5	4.60±0.90	5.52±1.55
	F6	5.80±0.70	6.94±2.27
FP	F1	8.40±0.00	9.98±0.10
	F2	6.60±0.20	7.96±0.40
	F3	4.60±0.90	5.53±2.50
	F4	4.20±0.90	4.95±1.41
	F5	5.20±1.00	6.32±2.17
	F6	5.00±0.70	6.14±2.22
WFD	F1	6.40±0.30	7.64±0.53
	F2	6.00±0.50	7.25±1.19
	F3	3.20±0.80	3.90±1.43
	F4	3.00±0.80	3.64±1.19
	F5	3.60±0.60	4.32±1.89
	F6	4.60±0.50	5.49±1.93
	P value	0.520	0.891

*Error bars are standard errors of the means. See table 2 for a description of each irrigation and fertilizer treatment.

Effects of irrigation regimes and fertilizer treatments on water productivity

Water productivity (kg m^{-3}) at fresh fruit-yield basis (WP) is presented in Figure 6. In year 1, the average WP at fresh yield basis were 0.80, 0.73 and 0.68, kg m^{-3} for IR_{CWR}, FP, and WFD, respectively (Figure 6). Similarly, in year 2, the average WP at fresh yield basis were 0.74, 0.70, and 0.69 kg m^{-3} IR_{CWR}, FP, and WFD, respectively.

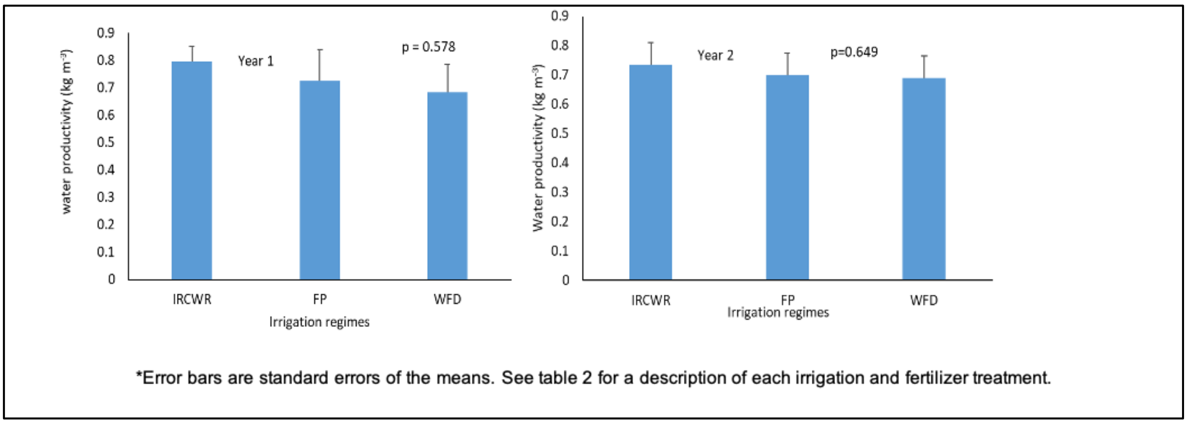


Figure 6. Irrigation regime effects on water productivity of pepper.

This result shows, however, that water productivity (WP) of pepper was not significantly (p=0.578) affected by irrigation regimes (Figure 6). The result is consistent with earlier findings in Ethiopia by Tesema et al (2016) that water productivity in the WFD treatment did not differ significantly from the WP in the TDR treatment. Contrary to our findings, studies in Ethiopia show that use of WFD improved water productivity. For example, Schmitter et al.

(2017) reported that by using WFD, farmers improved their water productivity by about 9% with a corresponding labour savings of up to about 11 working days per ha. In addition, Temasgen (2016) also reported that WP of pepper in the WFD treatment (0.31 kg m^{-3}) was significantly higher than WP (0.15 kg m^{-3}) in the FP treatment.

As shown in Figure 7, WP of pepper was significantly (p=0.04) influenced by fertilizer treatments. Accordingly, the WP of pepper using F1 and F2 fertilizer treatments were significantly higher than WP of pepper using other fertilizer treatments. For example, in year 1, WP of pepper using F1 was 68%, 103%, 63% and 42% higher compared to WP of pepper using F3, F4, F5, and F6, respectively (see Figure 7). Similarly, in year 2, WP of pepper using F1 was 69%, 43%, 62% and 40% higher compared to WP of pepper using F3, F4, F5, and F6, respectively.

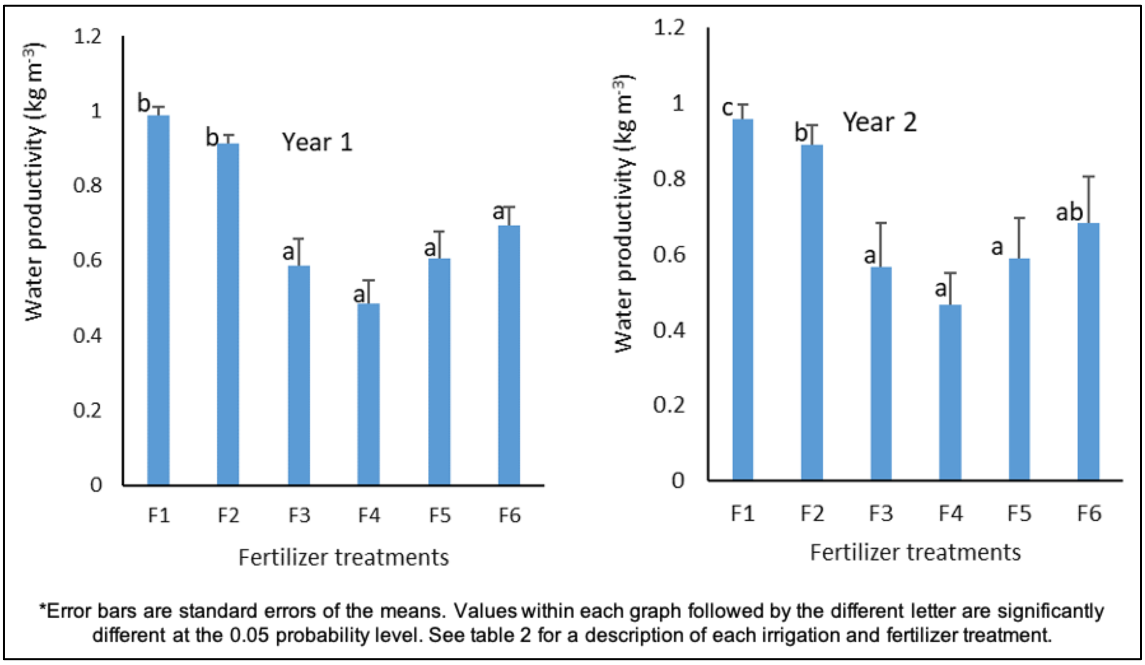


Figure 7. Fertilizer effects on water productivity of pepper.

Table 5 shows the interaction effects of irrigation water and fertilizer on WP of pepper. In general, however, water productivity (WP) of pepper was not significantly influenced by the interaction between irrigation regimes and fertilizer treatments for both years (Table 5). Although there was no significant difference, the WP varied across irrigation and fertilizer treatment interactions. For example, in year 1, the highest WP (1.25 kg m^{-3}) of pepper was recorded from plots with F1 fertilizer treatment and WFD irrigation. The lowest WP (0.36 kg m^{-3}) of pepper was recorded from plots with F4 and FP (Table 5). In year 2, the highest WP (1.04kg m^{-3}) of pepper was recorded from plots with F1 and FP.

Table 5. Irrigation water and fertilizer interaction effects on water productivity of pepper.

Irrigation regimes	Fertilizer treatments	Water productivity of pepper (Mean±SEM)	
		Year 1	**Year 2**
IR_{CWR}	F1	0.93±0.04	0.91±0.10
	F2	1.04±0.04	0.99±0.04
	F3	0.70±0.12	0.67±0.23
	F4	0.47±0.11	0.45±0.19
	F5	0.63±0.12	0.61±0.18
	F6	0.79±0.09	0.77±0.25
FP	F1	0.79±0.04	1.04±0.01
	F2	0.73±0.04	0.82±0.04
	F3	0.57±0.12	0.57±0.26
	F4	0.36±0.11	0.52±0.15
	F5	0.43±0.12	0.64±0.22
	F6	0.57±0.09	0.62±0.22
WFD	F1	1.24±0.04	0.92±0.07
	F2	0.96±0.04	0.86±0.14
	F3	0.68±0.12	0.46±0.17
	F4	0.63±0.11	0.43±0.14
	F5	0.75±0.12	0.51±0.22
	F6	0.72±0.09	0.66±0.23
	P value	0.891	0.998

*See table 2 for a description of each irrigation regime and fertilizer treatment.

Sustainable Intensification Indicators

This section presents a case study on the sustainability intensification indicators of irrigation regime and fertilizer treatments. Field/plot scale data were used to estimate specific sustainability intensification indicators across the five domains, including productivity, economic, environment, human and social condition. The standardized values of SI indicators across the five domains for the three irrigation regimes (IR_{CWR}, FP and WFD) are presented in Figure 8. The result shows that the use of IR_{CWR} and FP irrigation regime had higher scores in the productivity and human domains compared to the WFD irrigation regime. All irrigation regimes had similar scores for the economic and environmental domain. This means input use intensity of pepper did not respond to irrigation regimes because the amount used was determined by the experiment and not by the irrigation method. Again, it suggests that the content of soil carbon, nitrogen, phosphorus and potassium after harvest were not different across the irrigation domains.

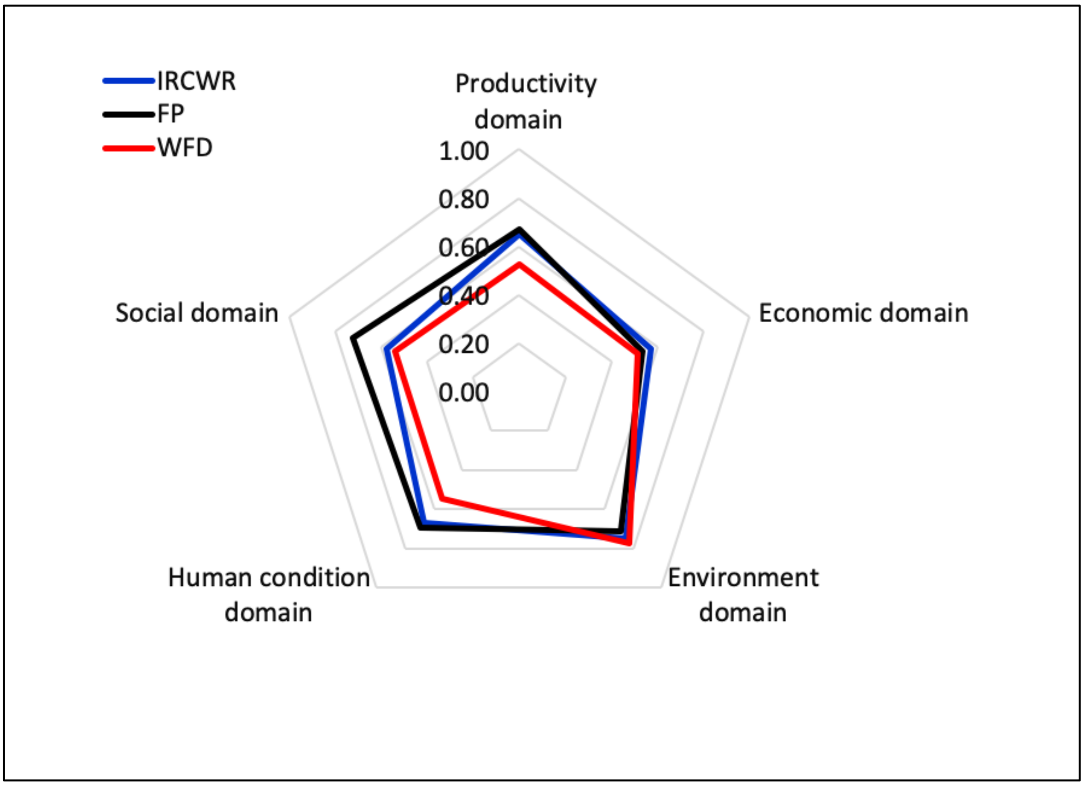


Figure 8. Comparison of watering regimes (IRCWR, FP and WFD) across various sustainable intensification domains. See table 2 for a description of each irrigation and fertilizer treatment.

The standardized values of SI indicators across the five domains for the six fertilizer options (F1, F2, F3, F4, F5 and F6) are presented in Figure 9. The result shows that the use of F1 and F2 Fertilizer options (Organo-mineral Fortifer^{TM} products) had the highest scores for all domains except economic domain (input use intensity). The use of lower rate of NPK in F4 had the lowest score in productivity, human and social domains. The highest scores in F1 and F2 across most SI domains suggests that the use of Fortifer products, both in the form of compost and granular, is suitable for pepper production in the study area.

For a given technology option, there are tradeoffs and/or synergies among the SI domains and indicators. Hence, it is crucial to establish thresholds (acceptable limits) for a recommendation about a given technology option based on SIAF criteria. This also requires establishment of relative weights across indicators and domains. Selection of indicators under each domain is also an important element to be considered in the SIAF exercise. In this exercise, most of the indicators are interrelated. For example, yield data was used to explain primarily productivity domain. However, it was also indirectly used to explain economic, social and human condition domains. Hence, the scores of these domains followed the trend of productivity domain. This suggests the need to determine independent indicators and corresponding data collection protocols prior to the study for SIAF analysis. In this study, the data collected had the primary purposes to assess differences in pepper yield as influenced by irrigation and fertilizer management strategies and where used additionally for the SIAF analysis.

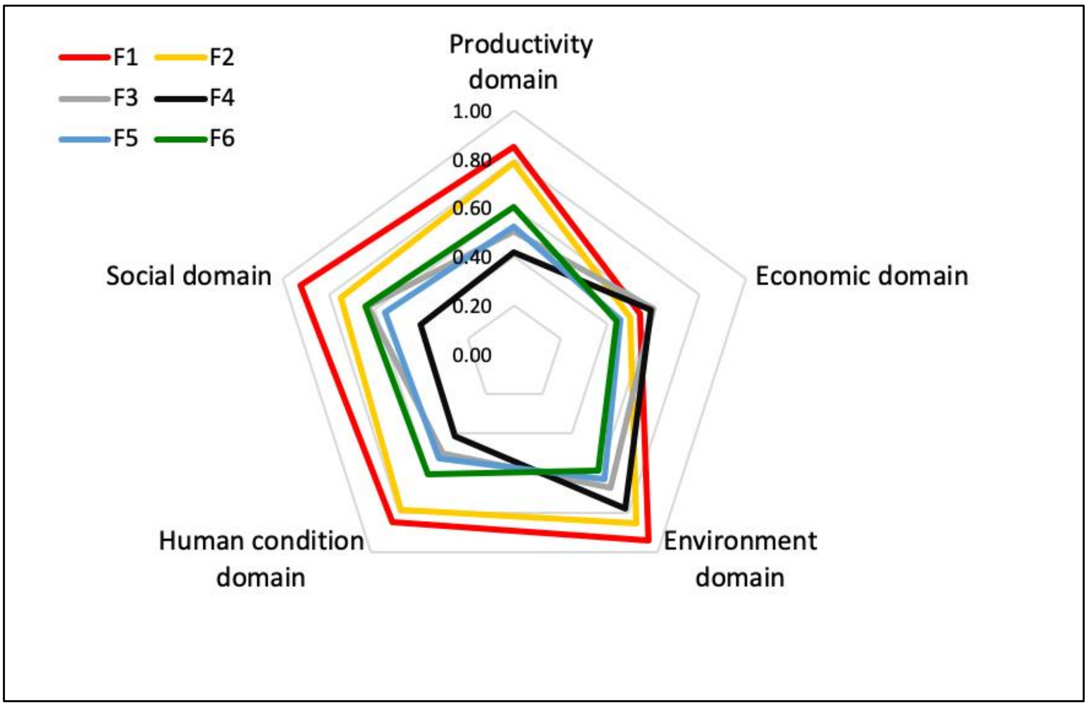


Figure 9. Comparison of fertilizer treatments (F1, F2, F3, F4, F5 and F6) across various sustainable intensification domains. See table 2 for a description of each irrigation and fertilizer treatment.

Conclusion

Although pepper yield was not significant difference under the three irrigation regimes, farmers' irrigation practice produced a relatively higher yield as compared to the WFD and IR_{CWR}. The study showed that WFD saved significant irrigation water on farmers' fields to grow pepper. However, given the hot weather coupled with low soil fertility and poor water holding capacity of the soil, water saving using WFD resulted in reduction of pepper yield in this case study. Results suggest that based on the poor water holding capacity and the installation depth of the WFD the daily replenishment of the soil moisture might have been too shallow. This resuted in soil moisture values dropping below the maximum allowable deficit in the root zone which inturn leads to a decline of pepper yield. The study showed that application of higher rates of NPK fertilizer from the Fortifer™ increases fruit yield and water productivity of pepper. The study results also suggest that in combination, irrigation and fertilizer use can support strategies to improve the productivity of small-scale irrigation in Northern Ghana. The preliminary result from SIAF exercise shows that Fortifer products as soil amendment are suitable for SI of pepper production in the study areas. Although outside the scope of the study, the research also revealed key areas to support the effective use and uptake of promising agricultural water management interventions, namely capacity building and awareness creation for a wider audience.

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Appendices

Appendix I. Variability of pepper yield across water and fertilizer treatments

		Year 1						Year 2				
		N	**Mean**	**SD**	**Min**	**Max**	**CV%**	**Mean**	**SD**	**Min**	**Max**	**CV%**
Main plot effect	IR_{CWR}	18	5.48	2.44	0.6	8.85	44.5	6.59	2.85	0.85	10.63	43.2
	FP	18	5.67	2.59	0.86	8.59	45.7	6.81	3.07	1.03	10.1	45.0
	WFD	18	4.45	2.27	0.88	7.73	50.9	5.38	2.65	1.06	9.43	49.4
Sub-plot effect	F1	9	7.22	1.27	5.64	8.59	17.59	8.63	1.37	7.04	10.1	15.83
	F2	9	6.68	1.15	4.44	8.06	17.16	8.00	1.30	5.33	9.43	16.31
	F3	9	4.27	2.75	0.86	8.42	64.42	5.13	3.20	1.03	9.77	62.31
	F4	9	3.53	1.98	0.6	6.33	56.15	4.23	2.22	0.85	6.98	52.57
	F5	9	4.41	2.47	0.88	7.13	55.98	5.39	2.96	1.06	8.56	54.88
	F6	9	5.09	2.71	1.35	8.85	53.23	6.19	3.28	1.71	10.63	52.96
IR_{CWR}	F1	3	6.73	1.41	5.64	8.32	20.92	8.27	1.48	7.35	9.98	17.92
	F2	3	7.48	0.62	6.82	8.06	8.34	8.77	0.59	8.18	9.36	6.73
	F3	3	5.06	3.09	2.35	8.42	61.06	5.96	3.52	2.82	9.77	59.16
	F4	3	3.38	2.45	0.6	5.23	72.52	4.10	2.87	0.85	6.28	69.97
	F5	3	4.54	2.34	1.83	5.92	51.67	5.52	2.68	2.43	7.1	48.48
	F6	3	5.71	3.26	2.34	8.85	57.11	6.94	3.93	2.81	10.63	56.63
FP	F1	3	8.48	0.10	8.42	8.59	1.12	9.98	0.17	9.79	10.1	1.67
	F2	3	6.57	0.69	5.78	7.03	10.46	7.96	0.69	7.17	8.44	8.69
	F3	3	4.61	3.61	0.86	8.06	78.34	5.53	4.33	1.03	9.67	78.36
	F4	3	4.29	2.26	1.87	6.33	52.52	4.95	2.44	2.24	6.98	49.34
	F5	3	5.14	3.15	1.35	6.8	61.26	6.32	3.76	1.98	8.56	59.47
	F6	3	4.90	3.08	0.86	8.59	62.81	6.14	3.84	1.71	8.57	62.58
WFD	F1	3	6.45	0.91	5.87	7.75	14.12	7.64	0.93	7.04	8.71	12.12
	F2	3	6.00	1.65	4.44	7.73	27.53	7.25	2.06	5.33	9.43	28.42
	F3	3	3.14	2.15	0.89	5.18	68.61	3.90	2.48	1.37	6.33	63.58
	F4	3	2.92	1.78	1.51	4.92	60.96	3.64	2.07	2.13	6	56.77
	F5	3	3.56	2.67	0.88	6.21	74.80	4.32	3.27	1.06	7.59	75.52
	F6	3	4.65	2.88	1.45	7.04	61.97	5.49	3.35	1.74	8.18	60.99

Appendix II. Variability of water productivity of pepper across water and fertilizer treatments.

			Year 1					Year 2				
			Mean	SD	Min	Max	CV%	Mean	SD	Min	Max	CV%
Main plot effect	IR_{CWR}	18	0.85	0.38	0.09	1.37	44.54	0.73	0.32	0.09	1.19	43.86
	FP	18	0.73	0.34	0.11	1.11	45.67	0.70	0.32	0.11	1.05	45.29
	WFD	18	0.66	0.33	0.13	1.14	50.92	0.64	0.32	0.13	1.12	50.15
Sub-plot effect	F1	9	1.03	0.14	0.86	1.29	14.00	0.96	0.12	0.79	1.11	12.90
	F2	9	0.97	0.20	0.65	1.25	20.94	0.89	0.15	0.64	1.12	17.26
	F3	9	0.61	0.40	0.11	1.31	64.49	0.57	0.35	0.11	1.11	61.68
	F4	9	0.50	0.28	0.09	0.82	55.45	0.47	0.25	0.09	0.75	52.99
	F5	9	0.63	0.35	0.13	0.92	54.84	0.59	0.32	0.13	0.9	54.11
	F6	9	0.74	0.40	0.18	1.37	54.75	0.68	0.36	0.17	1.19	53.05
	F1	3	1.05	0.22	0.88	1.29	20.93	0.91	0.18	0.79	1.11	19.37
IR_{CWR}	F2	3	1.16	0.10	1.06	1.25	8.34	0.99	0.07	0.91	1.06	7.52
	F3	3	0.79	0.48	0.36	1.31	61.06	0.67	0.40	0.31	1.11	60.11
	F4	3	0.52	0.38	0.09	0.81	72.52	0.45	0.32	0.09	0.7	71.33
	F5	3	0.70	0.36	0.28	0.92	51.67	0.61	0.31	0.26	0.79	50.03
	F6	3	0.89	0.51	0.36	1.37	57.11	0.77	0.44	0.31	1.19	56.90
FP	F1	3	1.10	0.01	1.09	1.11	1.12	1.04	0.01	1.02	1.05	1.09
	F2	3	0.85	0.09	0.75	0.91	10.46	0.82	0.08	0.73	0.87	9.54
	F3	3	0.60	0.47	0.11	1.05	78.34	0.57	0.45	0.11	1	78.35
	F4	3	0.56	0.29	0.24	0.82	52.52	0.52	0.26	0.23	0.75	50.87
	F5	3	0.67	0.41	0.2	0.92	61.25	0.64	0.39	0.2	0.88	60.33
	F6	3	0.64	0.40	0.18	0.88	62.80	0.62	0.39	0.17	0.86	62.65
WFD	F1	3	0.95	0.13	0.86	1.1	14.12	0.92	0.12	0.84	1.06	13.13
	F2	3	0.88	0.24	0.65	1.14	27.53	0.86	0.24	0.64	1.12	27.96
	F3	3	0.46	0.32	0.13	0.76	68.62	0.46	0.30	0.14	0.75	66.19
	F4	3	0.43	0.26	0.22	0.72	60.95	0.43	0.25	0.23	0.71	58.85
	F5	3	0.52	0.39	0.13	0.91	74.80	0.51	0.39	0.13	0.9	75.21
	F6	3	0.68	0.42	0.21	1.04	61.97	0.66	0.41	0.21	0.99	61.49