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Improving on-farm water management by introducing wetting-front detector tools to smallholder farms in Ethiopia

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Acronyms

BD	Bulk density
CEC	Cation exchange capacity
EC	Electrical conductivity
Fe^{2+}	Iron content
LIVES	Livestock and Irrigation Value Chain for Ethiopian Smallholders
P_{av}	Available phosphorus
RIS	Relative irrigation supply
TN	Total nitrogen
WFD	Wetting-front detector
WP	Water productivity

List of units

ha	Hectare
kg	kilogram
l	Litre
m	Metre
Mha	Millihectares
s	Second
t	Tonne

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Abstract

To ensure food security and support economic growth within the country, smallholder irrigation is developing fast in Ethiopia. However, the long-term sustainability of increased production may be irreparably damaged by inappropriate watering schedules. Over-irrigation in schemes has led to periodic water scarcity issues in large schemes and sodicity in the rift. This study investigated whether farmers' access to knowledge as to when and how much to irrigate would reduce over-irrigation without negatively affecting crop and water productivity, thereby leading to more sustainable on-farm water management. The study was conducted in Koga and Meki irrigation scheme. Farmers were trained on using the wetting-front detector, a low-tech mechanical scheduling instrument, and instructed on how irrigate approximately a 100 m² plot of land. Irrigation and crop performance was evaluated against control plots, having the same crop variety and management, but traditional irrigation practices. Reduction in applied irrigation volume due to the WFD differed within and between sites due to furrow length, soil texture and farmer experience. Although yield increases were highly variable between farmers due to differences in farm management and crop variety cultivated, the WFD had a positive effect on water productivity. Water productivity on average improved by 9% due to water savings through improved irrigation scheduling as well as yield increases between 13 and 17%. In some cases the volume of water saved could double the cropped area. The reduction of irrigation events, when using the WFD tool, led to labour saving (up to 11 working days per ha) and fuel saving (between USD 50 and 150 per ha). In both sites, farmers positively evaluated the scheduling tool, acknowledging that they learned to save water without negatively impacting crop productivity. The study showed that by providing access to when and how much to irrigate, farmers can positively adjust their on-farm water management resulting in more sustainable use of their natural resources.

1 Introduction

Demographic growth in the Nile Basin has resulted in accelerated pressure on natural resources to account for the increasing food and energy demand. This results in a rapidly increasing demand to put more land and fresh water for agricultural production. In Ethiopia, majority of agricultural land is under low input- low output rainfed agriculture, highly susceptible to rainfall variability both in magnitude as well as occurrence (Mekonen and Kebede 2011). Although the irrigable land is estimated between 1.5 to 4.3 mha with an average of 3.5 mha, only 5% (~200,000 ha) is under irrigation (Awulachew et al. 2007; Haile and Kasa 2015). From the irrigated land, the estimated irrigation consists out of 38% traditional, 20% modern communal, 4% modern private and 38% public schemes (Awulachew et al. 2007). Throughout the country, development of small-scale irrigation both in schemes, as well as the individual context, are being developed. Under the Water Sector Development program, it is aimed that in 2016 a total of 471,862 ha will be under irrigation (Ministry of Water Resources (2002) cited in Haile and Kasa 2015).

Sustainable development of irrigation within the country requires sound use of natural resources such as land and water. Efficient water use within irrigation practices covers the water source, water storage, conveying the water to the field and on-farm water management. For individual irrigators outside a scheme, the farmer is often responsible for all these aspects whereas in irrigation schemes farmers, depending on the operational structure, are mainly involved in water conveyance (together with water user associations) and on-farm management. However, in schemes one of the main challenges leading to inequitable distribution of water are water excess releases to compensate losses along the conveyance and delivery system (e.g. leakage, seepage losses) and in efficient on-farm water management practices. Agide et al. (2016) showed that the relative irrigation supply (RIS) (i.e. irrigation supply/crop water demand ratio) at scheme level for 10 schemes in Ethiopia ranged between 0.5 (i.e. under irrigation) to 5.0 (i.e. over irrigation) for the period January – May and between 0.8 and 7.0 for the period June to December. The surveyed schemes represented modern, semi-modern and traditional schemes[1]. In the main irrigation season (January–May) values of 1.9 and 2.9 were found for Koga and Meki, a modern and semi-modern scheme respectively. Differences of RIS values in head, mid and tail off takes decreased by 23% for Koga (i.e. 1.7, 1.4 and 1.3, respectively) showing that leakage and seepage losses were relative low whereas for Meki values decreased by 51% (i.e. 1.5, 1.2 and 0.7, respectively). On the other hand, the study found that for the modern irrigation schemes (e.g. Koga), 74% of the water excess is lost on-farm whereas for semi modern schemes (e.g. Meki) occurring water losses are mainly related within the conveyance and distribution systems. Although at landscape level these water losses in the scheme might lead to potential water gains downstream of the scheme, they negatively impact energy and labour costs associated with water distribution.

According to Haileslassie et al. (2016), who performed a diagnostic survey throughout Ethiopia, on-farm water management is relatively poor, resulting in low yield and water productivity. This was confirmed when looking at the field water supply at the different schemes where irrigation volume applied in Koga for wheat was 2.2 times higher than the volume required whereas in the case of Meki for onion the field delivery ratio was only 1.1 times higher (Agide et al. 2016). These water management practices resulted in an average water productivity[2] in Koga for wheat of

1 For more information on the definition of the various typologies reference is made to Agide, Z., Haileslassie, A., Sally, H., Erkossa, T., Schmitter, P., Langan, S., Hoekstra, D. 2016. Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia: Diversity and lessons across schemes, typologies and reaches. Working Paper under the Livestock and Irrigation Value Chain for Ethiopian Smallholders (LIVES) project, p. 41.

2 The reported water productivity values are based on the harvested yields which for wheat means dry grain weight and for tomato and onion fresh fruit respectively bulb weight.

0.10 kg m^{-3}, 1.4 kg m^{-3} for onion and 2.4 kg m^{-3} for tomato in Meki (Haileslassie et al. 2016). Comparing field delivery ratios for 10 irrigation schemes in Ethiopia, Koga ranked first and Meki fourth out of the four schemes where field water delivery exceeded the crop water demand whereas for the other 6 schemes the field water supply was below the water requirement pointing towards under irrigation (Agide et al. 2016).

However, crop productivity and overall farm performance is influenced by various factors (e.g. farmer irrigation experience, seed quality, seed and fertilizer access) in addition to timely and appropriate irrigation. In the study of Agide et al. (2016), farmers indicated that the main constraint for poor on-farm management was related to a lack of training on-farm irrigation practices for Koga followed by seed availability among others. On the other hand, in Meki, farmers ranked less developed market access and limited or non-transparent access to seeds as more important constraints and only ranked on-farm irrigation knowledge at number four as farmers are relatively more experienced in irrigation.

In both schemes farmers tend to over-irrigate as long as water is available assuming it increases their quality and quantity of production which results in water shortage and water conflicts in other parts of the schemes. Additionally in the case of motorized pumps (e.g. Meki) over-irrigation unnecessarily increases the cost of production. This is, in fact, only one side of the problem, in the long term over-irrigation have an environment impact on their land (e.g. salinity, increased water table) and may affect the sustainability of the scheme. Improving farmers' knowledge on on-farm water management, particularly on how much to irrigate and when to irrigate could reduce over-irrigation practices, reduce costs (in the case of pumping), improve the quality of the product and foster a more equitable water distribution within the scheme and throughout the dry season.

Therefore, this study investigates whether farmer access to irrigation scheduling advice improves crop and water productivity in two irrigation schemes, Koga and Meki. Both irrigation schemes were selected due to the difference in scheme typology, water access and farmers' irrigation experience. This study makes use of wetting-front detectors (WFD), a low tech mechanical scheduling instrument to guide irrigation scheduling (Stirzaker 2003) and evaluates it's suitability to improve water and crop productivity within the schemes for various crops. This report describes the preliminary results obtained in both schemes for the dry season of December 2014–April 2015 (Koga) and March 2015 to July 2015 (Meki), the first dry cropping season, as the experiment is still ongoing until June 2016.

2 Materials and methods

2.1 Site description of two irrigation schemes

The study was conducted in a modern (i.e. Koga) and semi-modern (i.e. Meki) irrigation scheme with different water distribution practices. In Koga, surface water is collected through a man-made reservoir, stored in night reservoirs and released gravitationally throughout the scheme whereas in Meki water is pumped from a main canal fed by lake Ziway. In the following sections a short climatic description is given for each of the sites (Table 1). For more information on the schemes reference is made to the LIVES diagnostic studies of irrigation schemes (Agide et al. 2016) and on-farm water management (Haileslassie et al. 2016).

Table 1: General climatic conditions at both sites. Data compiled from several sources and references therein.

Site	Annual precipitation (mm)*	Temperature (°C)*	Relative Humidity (%)*	Solar radiation (h d^{-1})*	Data source
Koga	1420	24.0	58	7.2	Mekonen and Kebede (2011), Eriksson (2013)
	(800-2200)	(8.9-30.1)	(43-75)	(4.4-9.9)	
Meki	729	19.7	66	N.A	AmbiWeb GmbH (2016), Getachew and Tesfaye (2015), Japan International Cooperation Agency (JICA) and Oromia Irrigation Development Authority (OIDA) (2002)
	(281-1131)	(8.9-27.0)	(60-70)	(6-10)	

* Data is presented as yearly averages with minimum–maximum values in brackets where available.

N.A = not available

2.1.1 Koga irrigation scheme, West Gojam

Koga reservoir (11°20´- 11°31´N; 37°02´ to 37°08´E; 1,880 -2,020 m a.s.l), commissioned in 2010 and with a volume of 83 mm^3, is one of the latest large scale irrigation schemes for smallholder farmers which, through its 1,750 ha reservoir, supplies irrigation to approximately 5,828 ha from a total of 7,000 ha in the dry season (Table 2) and more than 10,000 beneficiaries (Haileslassie et al. 2016).

The reservoir feeds twelve irrigation blocks between November and May. The command area has a total of twelve irrigation blocks and eleven night storage reservoirs (Figure 1). Each block has a secondary canal resulting in twelve lined secondary canals with a total length of 42 km. Secondary canals are fed by the main canal and night storage reservoirs and delivers water to the individual command areas via tertiary and quaternary canals. Management and operation of the dam, reservoir, main canal and secondary canals falls under the jurisdiction of the Abbay Basin Authority whereas the tertiary canals and drains, quaternary and field canals are managed by the Koga Irrigation Development Project. Water Users Associations are being established at the quaternary canal outlets within the various irrigation blocks to improve water allocation and decide the water rotation at the quaternary canal. Each quaternary canal has two outlets supplying 30 m^3 s^{-1} irrigating a maximum of 16 ha in total on a rotational basis of

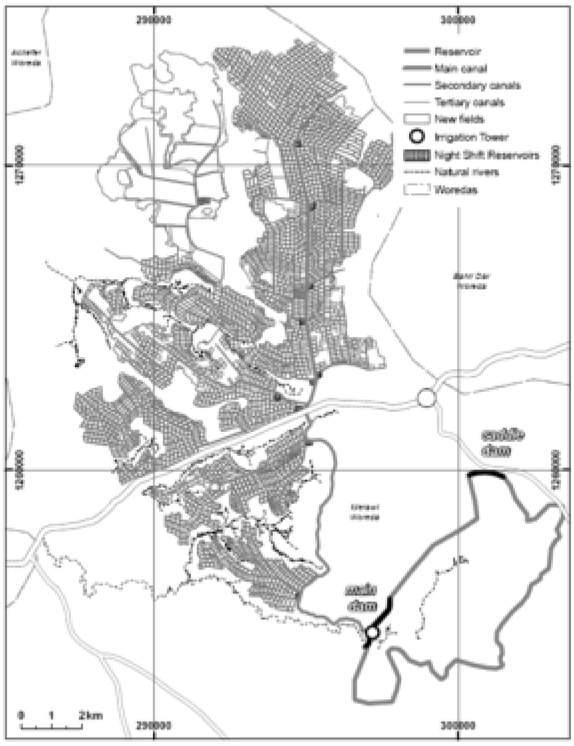
8–10 days (i.e. approximately 2 ha per day). The irrigation rotation at the quaternary canals is depending on the actual irrigated area within the season, the cultivated crop with a maximum of 2 ha per day.

Table 2: Overview of the various irrigation blocks in Koga irrigation scheme.

Irrigation block	Irrigation potential area (ha)	Currently irrigated area (ha)	Total participating farmers	Total male farmers	Total female farmers	Irrigation volume released annually (Mm3)	Night storage reservoir capacity (Mm^3)
Kudmi	373	368	715	657	58	3.97	20.01
Chihona	617	561	788	655	133	6.06	35.59
Ambomesk	812	676	1927	1834	93	7.30	40.18
Adibera	803	287	607	604	3	3.10	NA
Tagel wodefit	616	562	1338	1288	50	6.07	37.73
Inguti	393	385	824	793	31	4.16	19.20
Lasi	484	435	417	357	60	4.70	25.20
Bered	468	453	557	499	58	4.90	24.73
Anident	497	418	465	431	34	4.51	40.70
Amarit	290	203	353	330	23	2.20	-
Teleta	787	662	1097	1049	48	7.16	41.89
Tekel dib	864	821	1268	1132	136	8.87	44.61
Total	**7,004**	**5,828**	**10,356**	**9,629**	**727**	**63.00**	**329.82**

The irrigated area in the scheme starts with a low 700 ha in September to a maximum of 5,950 ha in December–February and decreases thereafter until June to a 4,500 ha (Agide et al. 2016). No water is released in the main rainy season (July–August). The average land holding size is 1.2 ha and furrow irrigation is common practice. During the irrigation season wheat *(Triticum aestivum*) is the main crop (60% of the cropping area) followed by potato (*Solanum tuberosum L.*) (15%), onion (*Allium cepa L.*) (15%) and maize (*Zea mays*) (10%) (Haileslassie et al. 2016). The main soil type (> 90%) in the command area is a Haplic Alisol while the remaining soils can be classified as Vertisols and Gleysols (Mekonen and Kebede 2011). The dominant soil texture within the scheme is silty clay.

Figure 1: Overview of the Koga irrigation scheme downstream of the reservoir (Source: Vigerske 2008 in Eguavoen and Tesfai 2012)



Meki irrigation scheme, East Shoa

Irrigation in East Shoa has high potential due to the abundance of surface as well as groundwater resources. The Awash River as well as Lake Ziway are largely used for irrigation aside from other activities such as livestock, fishery, recreation and tourism (Alemayehu 2013). Lake Ziway is fed by Meki and Katar rivers and provides water to the Bulbula river (Japan International Cooperation Agency (JICA) and Oromia Irrigation Development Authority (OIDA) 2002). The Meki scheme is fed by Lake Ziway and situated in Dugda district (08°07´N; 38°49´E; 1,880 - 1,650 m a.s.l) (Haileslassie et al. 2016) with a potential irrigable area of 3,000 ha with currently 700 beneficiaries (personal communication). However, due to the failure of the main pumps it is estimated that only 700 ha is under irrigation (Agide et al. 2016) and competition for water resources is moderate (Haileslassie et al. 2016). However, as water is scarce within the scheme many farmers use their private diesel pumps to extract water either from Meki River or shallow wells instead of the scheme. Within the scheme, water is released all year around through a primary canal from which, with privately owned diesel pumps plots are irrigated. The scheme provides enough water to irrigate 490 ha in November-December and March while in January-February and April to June the area reaches its maximum (i.e. 700 ha). In the rainy season (July-August) 600 ha is receiving supplementary irrigation and at the onset of the dry season (September-October) the area increases slightly to 630 ha.

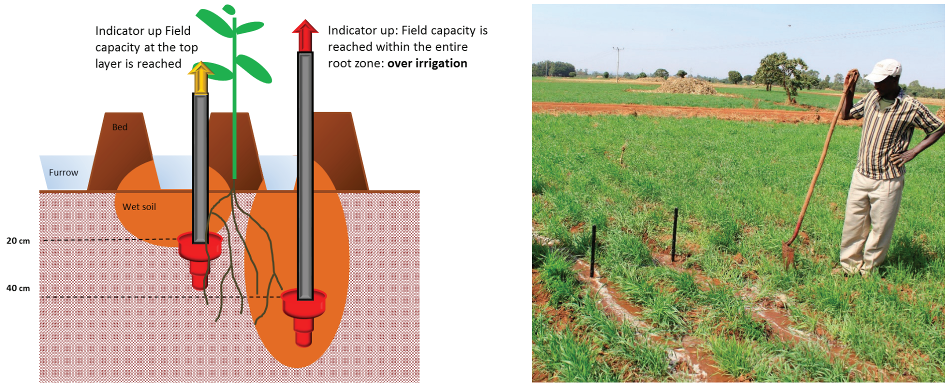
The average land holding size is 2 ha and irrigated using furrows. Overall farmers in this area are more experienced compared to Koga, furrows well prepared and maintained, have on average a fixed length of 5m for all irrigated vegetable crops. During the irrigation season, the areal coverage of cabbage (*Brassica oleracea*), maize (*Zea mays*) and onion (*Allium cepa L.*) is each 30% of the total irrigated area (i.e. 700 ha) whereas tomato (*Solanum lycopersicum*) only covers 10% (Haileslassie et al. 2016). There are four main soil types within Dugda district: Pelli-Calcic Vertisols (hilly areas), Vitric Andosols (rift valley floors), Gleyic-Mollic Fluvisols (lake shore of Lake Ziway) and Mollic Solonetz (bottomlands and depressions within the flood plains). Especially the latter one is common in Meki irrigation scheme (Japan International Cooperation Agency (JICA) and Oromia Irrigation Development Authority (OIDA) 2002). Soil texture ranges from sandy, sandy loam to clayey loam and in some cases salinity is an issue (Agide et al. 2016).

2.2 Wetting-front detectors as an irrigation scheduling tool

Wetting-front detectors[3] are mechanical devices which, depending on the soil type, irrigation method and quantity, are installed in pairs at a specific depth below the soil surface (Stirzaker 2003; Stirzaker et al. 2004). When field capacity is reached and soils gravitationally start draining, the water is collected within the reservoir below the funnel. Depending on the amount of water collected in the reservoir (i.e. suction > 3kPa) the float will be activated. Each pair consists out of a yellow and a red indicator. For furrow irrigation, the yellow indicator was installed around 20 cm whereas the red indicator was installed around 40 cm below the soil surface (Figure 2). More detailed information on the functioning and installation can be found in Stirzaker et al. (2004). Farmers were trained on how to use the irrigation tool and instructed to start irrigation one day after the yellow indicator (shallow detector) stayed down and stop when the shallow detector responded.

3 The wetting-front detectors were invented by Richard Stirzaker at Commonwealth Scientific and Industrial Research Organisation and produced in South Africa by Agriplas.

Figure 2: Installation of the wetting-front detector according to Stirzaker et al. (2004) (left) with a wheat farmer within the Koga irrigation scheme (right).



2.3 Experimental design and data collection

During the dry season (December 2014–April 2015), farmers growing wheat and potato were selected within the Ambomesk irrigation block of Koga irrigation scheme. Due to differences in cropping periods the experiment in Meki was conducted from March to June 2015 with farmers growing tomato, cabbage and green pepper. In both sites, each farmer used 100 m² for the wetting front indicator experiment, while the remaining field was taken as a control. A small plot was chosen for the WFD treatment to test the device and reduce potential risks for the farmer. In the 100 m² experimental plot a pair of wetting-front detectors were installed partially in the bed and partially in the furrow (Figure 2) at approximately 2 m from the furrow end for long furrows (i.e. 7–30 m) (Koga) and 1 m from the furrow length for short furrows (i.e. 4–6 m) (Meki). Furrow irrigation in the control fields was performed according to the overall scheme management (approximately every 8–10 days) in Koga whereas in Meki farmers pumped water whenever they redeemed necessary (Table 4). The duration of the irrigation in the control treatment for both sites was dependent on farmers' experience. At farmer level, both irrigation treatments had the same crop variety, same fertilizer dosage and were planted at the same time. As the farmers already planted their crop before the start of the experiment, farmers with approximately the same date of planting were selected. As a result furrows were not uniform in length.

Recording books were distributed to each of the participating farmers in which they could record when and how long irrigation took place, how much and which fertilizer was used for both water management treatments (i.e. control and WFD). Irrigation amounts were obtained by multiplying the irrigation duration with the calibrated the discharge entering the field. Discharge calibrations were performed for the various water sources: gravitational irrigation (Koga) as well as motorized pump in function of the water source as heads will be different (Table 3).

Table 3: Average discharge values with standard deviation obtained for the various water sources.

	Reservoir	Lake	Groundwater well	River
Location	Koga	Meki	Meki	Meki
Distribution	Gravitational	Pumping	Pumping	Pumping
Number of observations	6	3	5*	2*
Average discharge to the field ($m^3\ s^{-1}$)	0.0230 ± 0.0036	0.0066 ± 0.0027	0.0041 ± 0.0007	0.0101 ± 0.0001

* One farmer pumps from the groundwater as well as from the river depending on availability resulting in two calibrations.

Soil samples were taken in all plots during the cropping season to obtain a general overview of the soil fertility. Samples were analysed on field capacity (FC), wilting point (WP), pH, total Nitrogen (TN) (%), available phosphorus (P_{av}) (mg kg^{-1}), cation exchange capacity (meq 100 mg^{-1}), iron content (Fe^{2+}) (mg kg^{-1}). Analysis was performed according to standardized procedures at Amhara Design and Supervision Works Enterprise for Koga and by Water Works Design and Supervision Enterprise Laboratory in the case of Meki.

Table 4: Overview of the experimental design and associated data collection for Koga and Meki.

	Wheat	Potato	Cabbage	Tomato	Pepper
Location	Koga	Koga	Meki	Meki	Meki
Number of farmers	9	9	3	3	3
Cropping Period	Dec. 2014–Apr. 2015	Dec. 2014–Apr. 2015	Mar.–Jun. 2015	Mar.–Jun. 2015	Mar.–Jun. 2015
Planting date	18/12/14–01/01/15	24/12/14–08/02/15	10/03/15–01/04/15	24/03/15–01/04/15	23/03/15–01/04/15
Water source	Surface reservoir	Surface reservoir	Surface water–lake (1), Surface water-river (1), groundwater (1)	Surface water–lake (1), Surface water-river + groundwater (1), groundwater (1)	Surface water–lake (1), groundwater (2)
Distribution	Gravitational	Gravitational	Pumping	Pumping	Pumping
Irrigation interval	*WFD*: One day after the yellow flag popped down *Control*: 8–10 days	*WFD*: One day after the yellow flag popped down *Control*: 8–10 days	*WFD*: One day after the yellow flag popped down *Control*: Farmers' knowledge	*WFD*: One day after the yellow flag popped down *Control*: Farmers' knowledge	*WFD*: One day after the yellow flag popped down *Control*: Farmers' knowledge
Irrigation quantity	*WFD*: Stop when yellow flag pops up *Control*: Farmers' knowledge	*WFD*: Stop when yellow flag pops up *Control*: Farmers' knowledge	*WFD*: Stop when yellow flag pops up *Control*: Farmers' knowledge	*WFD*: Stop when yellow flag pops up *Control*: Farmers' knowledge	*WFD*: Stop when yellow flag pops up *Control*: Farmers' knowledge
Furrow length (m)*	7–23 (14 ± 5)	11–30 (17 ± 4)	4–5 (5 ± 0.5)	5–6 (5 ± 0.4)	5–6 (5 ± 0.5)
Harvest (plant, bed and full field measurements)	Yield Straw biomass (Harvest index)	Yield Number of tubers per plant	Yield, Head diameter, number of leaves	Yield Number of fruits per plant	Yield Number of fruits per plant
Harvest sample laboratory analysis	TN moisture content	TN moisture content	TN moisture content	TN moisture content	TN moisture content

* Average furrow length with standard deviation is given in brackets

** One farmer pumps from the groundwater as well as from the Meki river, depending on availability, four farmers use solely groundwater, three farmers pump from the lake and one farmer uses the Meki river.

During harvest, measurements were taken at plant, bed and full field level depending on the characteristics of the produce (Table 3). For vegetables, the harvested produce was divided into marketable and non-marketable yields to evaluate the effect of irrigation on the marketability of the product. Farmers were asked blindly which produce they preferred and to provide a reason. This would provide information on produce preference linked to a specific water management treatment. Subsets of harvested samples send to the Food laboratory at Bahir Dar University for Koga and Supervision Enterprise Laboratory for Meki to estimate the moisture content and the TN content.

Water productivity (WP) was calculated according to:

$$\text{WP}\ (\text{kg m}^{-3}) = \frac{\text{Yield}\ (\text{kg ha}^{-1})}{\text{Irrigation}\ (\text{m}^3\ \text{ha}^{-1})}$$

where yield refers to the dry matter yield per hectare and irrigation to the total irrigation volume applied per hectare during the cropping season.

Descriptive statistics were obtained using the univariate procedure in SAS v9.2. Firstly the spatial variability of the initial soil parameters prior to the field experiments was investigated both within the site (i.e. between the various crop) and between sites (i.e. Koga and Meki). This allowed for an indication whether a) the WFD would behave differently and b) whether soil fertility was suitable for the specific crops.

As field capacity and soil texture influence the movement of the wetting front (Stirzaker et al. 2004), irrigation treatments within each of the cropping system was evaluated as a nested design for each of the sites separately. The effect of irrigation treatment on irrigation practices during the season was assessed by evaluating whether irrigation interval, time to irrigate a furrow and total irrigation depth differed significantly. Similar analysis was conducted for the effect of irrigation treatment on crop yield at plant, bed and field level. All analysis was performed using Proc MIXED in SAS v9.2, one model consisted out of site (i.e. Koga or Meki), the five crops (i.e. potato, wheat, cabbage, pepper, tomato) while the other contained the irrigation treatment (WFD or farmers practice) and the five crops as fixed effects. For the harvest analysis, plant density was added as a random factor. For each response variable variance consistency and normal distribution of the residuals was evaluated. In case the variance of the residuals was not consistent and not normally, distributed data was transformed prior to the analysis. Correlation analysis between all variables at field level using the Proc CORR statement in SAS v9.2 and Pearson correlation was computed after transformation of variables where necessary.

3 Results and discussion

3.1 Soil type and nutrient status

Between the two sites, Koga and Meki a significant difference was found in CEC, Sand, Silt, TN, Pav., Fe and pH at a significance level of $p<0.0001$ and for field capacity at $p=0.05$ (Table 5). As both texture (i.e. sand and silt) as well as field capacity significantly differed ($p=0.05$) between Koga and Meki, one could expect a difference in WFD performance as the movement of the wetting front is highly influenced by soil structure and texture (Stirzaker et al. 2004). Secondly, the soil parameters did not differ significantly between the various crops within the same site. This will allow to compare WFD response between the various crops within the same site.

Table 5: Overview of the soil characteristics for each of the crop. Different letter superscripts within the row point towards a significant difference between the sites at p = 0.05-level

	Koga		Meki		
	Wheat	Potato	Cabbage	Tomato	Pepper
Number of observations	7	9	6	6	6
Field capacity (%)	30.8 ± 1.8^{a}	32.1 ± 2.3^{a}	31.1 ± 8.7^{b}	36.5 ± 6.9^{b}	35.6 ± 5.9^{b}
Wilting point (%)	18.8 ± 1.1^{a}	19.4 ± 1.0^{a}	17.0 ± 7.0^{a}	17.45 ± 5.1^{a}	20.9 ± 7.8^{a}
CEC (cmol kg^{-1})	19.7 ± 2.9^{a}	20.8 ± 1.8^{a}	45.0 ± 14.0^{b}	40.7 ± 7.8^{b}	40.6 ± 9.1^{b}
Texture – Sand (%)	19.4 ± 4.9^{a}	24.0 ± 7.3^{a}	49.0 ± 26.7^{b}	39.7 ± 19.7^{b}	40.0 ± 27.1^{b}
Silt (%)	57.4 ± 5.2^{a}	50.0 ± 10.1^{a}	29.3 ± 10.2^{b}	34.7 ± 10.5^{b}	36.0 ± 13.2^{b}
Clay (%)	23.1 ± 1.5^{a}	26.0 ± 4.9^{a}	21.3 ± 16.6^{a}	25.3 ± 16.6^{a}	24.0 ± 14.0^{a}
Electrical conductivity (mS cm^{-1})	N.A.	N.A.	0.7 ± 0.10^{b}	0.84 ± 0.03^{b}	0.92 ± 0.03^{b}
Total nitrogen (%)	0.22 ± 0.03^{a}	0.22 ± 0.04^{a}	0.09 ± 0.02^{b}	0.10 ± 0.02^{b}	0.10 ± 0.03^{b}
Available phosphorus (ppm)	$12.7 \pm 2.6^{*a}$	15.4 ± 2.9^{a}	38.0 ± 12.5^{b}	46.07 ± 8.6^{b}	46.2 ± 9.1^{b}
Iron content	15.0 ± 1.4^{a}	14.8 ± 2.6^{a}	3.57 ± 0.25^{b}	5.23 ± 2.6^{b}	4.6 ± 1.8^{b}
Bulk density (g cm^{-3})	0.88 ± 0.04^{a}	0.91 ± 0.02^{a}	N.A.	N.A.	N.A.
pH (H_2O)	4.81 ± 0.09^{a}	5.18 ± 0.39^{a}	7.68 ± 1.0^{b}	8.40 ± 0.47^{b}	8.13 ± 0.61^{b}

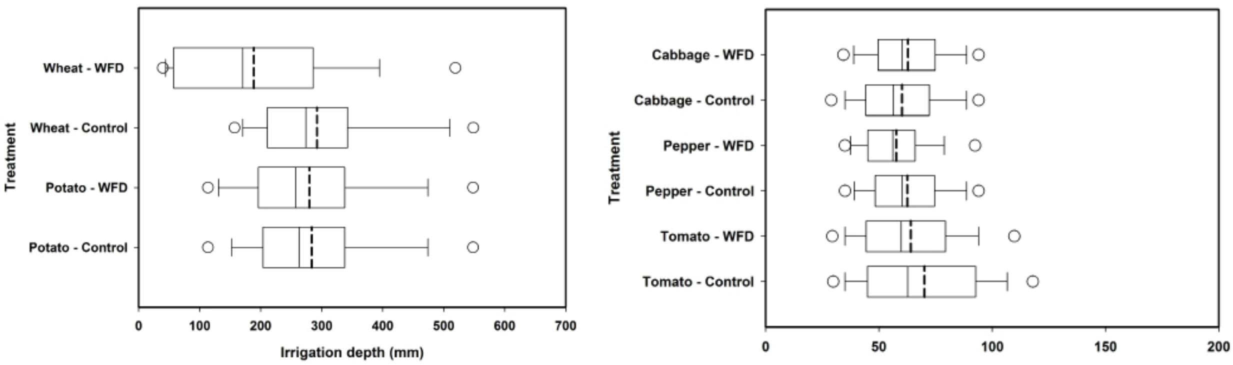
* Total sample size for phosphor analysis is 6 for the wheat farmers instead of 7.

In Meki the EC might cause a slight yield reduction however, the EC values of the soils did not exceed the threshold values reported for the various crops in the FAO 56 Irrigation and Drainage paper (Allen et al. 1998). Available phosphorus ranged from low in Koga to medium in Meki. Total N was relatively low in both sites whereas Fe^{2+} was followed the opposite trend as the soils in Koga are more weathered and acidic. The difference in soil chemical properties, between the sites as well as between the various fields within one site, together with differences in fertilizer application will further influence plant and root development and therefore water uptake resulting in potential differences of crop performance response to the WFD.

3.2 Changes in irrigation timing and quantity

The wetting-front detectors were installed, a few days in the case of Meki and a few weeks after planting in Koga. This allows only for a partial irrigation evaluation in Koga. For the various crops, the irrigation depth applied per event varied strongly between farmers and events (Figure 3). This was confirmed by the coefficient of variation which, for each treatment and crop, ranged between 31 and 48% (data not shown). Standard deviation of the irrigation depth within the WFD treatment was, aside for the plots with cabbage cultivation, much lower compared to those obtained in the control plots (Table 6, Appendix 1).

Figure 3: Irrigation depth (mm) applied per event in the control and WFD plots for wheat and potato in Koga (left) and vegetables in Meki (right). Crossbars, boxes and whiskers represent the median, quartile range (5th and 95th percentile) and range, respectively. The dashed line represents the mean.



When comparing the difference of the irrigation parameters between the various crops within one site (Model 1 in Table 7), results showed that the crops did influence the irrigation interval, time to irrigate a furrow and irrigation depth but did not influence the number of irrigation events.

Table 6: Irrigation characteristics for the various fields after the wetting-front detector was installed with Cont. (i.e. control) and WFD referring to farmer and WFD based scheduling, respectively.

Crop	Irrigation events		Irrigation interval (days)		Irrigation furrow (min)		Irrigation depth (mm)*		Reduction irrigation depth (%)
	Cont.	WFD	Cont.	WFD	Cont.	WFD	Cont.	WFD	
Potato	6 ± 2	4 ± 1	12 ± 2	16 ± 2	600 ± 240	420 ± 60	1897 ± 735	1188 ± 358	34 ± 16
Wheat	6 ± 1	4 ± 1	12 ± 1	17 ± 5	480 ± 120	480 ± 120	1639 ± 913	1043 ± 522	44 ± 21
Tomato	18 ± 6	14 ± 6	4 ± 1	6 ± 1	74 ± 22	69 ± 15	1483 ± 1032	1086 ± 602	21 ± 35
Pepper	17 ± 1	11 ± 1	5 ± 1	7 ± 1	60 ± 13	55 ± 14	1140 ± 502	712 ± 323	38 ± 5
Cabbage	13 ± 3	12 ± 2	5 ± 1	6 ± 1	70 ± 16	70 ± 12	638 ± 93	597 ± 91	5 ± 21

* Irrigation depth for the period after the wetting-front detector was installed.

Table 7: Evaluation of the difference in sites with its various crops (Model 1) as well as the water management with the various crops (Model 2) on the number of irrigation events, the irrigation interval, the time to irrigate a furrow, the irrigation depth applied throughout the season and the reduction in irrigation depth obtained.

Parameter**	df	Irrigation events	Irrigation interval (days)	Irrigation furrow (min)	Irrigation depth (mm)*	Reduction irrigation depth (%)
Model 1						
Site	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Crop (site)	3	n.s.	0.01	<0.0001	<0.0001	n.s.
Model 2						
Treatment	3	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment (crop)	5	0.05	<0.0001	<0.0001	n.s.	n.a.

* Irrigation depth for the period after the wetting-front detector was installed.

**Treatment refers to the WFD or the control irrigation treatment. Data was transformed; square root was taken for the irrigation interval and number of irrigation events; time to irrigate a furrow as well as irrigation depth were log normal transformed. The abbreviation n.s. = not significant.

Aside from the fixed schedule of both potato and wheat in Koga irrigation scheme, the number of irrigation events in Koga were relatively small as many of the potato and wheat fields were already in the vegetative growth stage when the irrigation experiment started. Furthermore, irrigation of vegetables does require more frequent irrigation compared to wheat and potato resulting in a larger number of events even if potato and wheat would have been monitored at the onset of the season. The difference in the time to irrigate a furrow, both between sites as well within the sites, can be explained by the length of the furrow (which is very different between both sites), soil texture, climatic conditions (i.e. potential evapotranspiration) as well as the crop choice and their respective root zone. The crop selection influences the length of the furrow. Vegetables like onion, pepper, tomato and cabbage having relative short furrows (± 5 m) compared to wheat and potato (± 15 m). The difference in crops grown results in a difference in effective root zone and therefore the amount of water redrawn in the top 20 cm (shallow detector) and 40 cm (deep detector). It is known that the first 25% of the root zone extracts 40% of the water, 25–50 % extracts 30%, 50–75 % extracts 20 % and the remaining 75–100 % extracts the last 10 % (Allen et al. 1998) .

Irrespective of the site and therefore the soil condition, the evaluation of the effect of the WFD within each of the fields for all crops showed that irrigation following the WFD indicator influenced positively the number of irrigation events, the irrigation interval and time to irrigate a furrow as well as total irrigation depth applied within the season (Model 2 in Table 7). For each crop experiment, the tool decreased the time used to irrigate a furrow, decreased the number of events and increased the irrigation interval. However, the variability of total irrigation depth in both treatments resulted in no significant difference between both treatments for each crop experiment.

A total volume of 26,025 m^3 was saved during the partially monitored season for potato and wheat on a total cropping area of 2.0 ha while in Meki 2,338 m^3 of water was saved on 1.8 ha. The irrigation depth applied during the monitoring period (i.e. before the wetting-front detectors were installed) frequently exceeded the crop water demand of both potato and wheat in this area which is approximately 478 mm (wheat) and 403 mm (potato) given the local climatic conditions. Assuming a 50% irrigation efficiency for the local furrow practice, this would lead to a gross irrigation requirement of 717 mm and 604.5 mm, respectively. Using the gross application rates of potato and wheat it would results in an additional cropping area of 3.6 ha for wheat or 4.3 ha for potato which is 1.8 to 2.1 times the total area of the full cropping experiment in Koga (i.e. 2 ha). The total irrigation reduction varied at field level between 12 and 64% and differed significantly between sites but not between the crops within a site (Model 1 in Table 6). Similar trends observed for all crops within one site which can be related to the installation depth of the WFD (i.e the same for each crop). Differences between sites could be related to the difference in soil physical properties and furrow length between Koga and Meki (see Section 3.1) as field capacity, silt and sand fraction showed significant differences between both sites. This might influence the movement of the wetting front (Stirzaker et al. 2004). However, it could also be related to the fact that farmers are more experienced in Meki and less improvement is possible with the WFD for furrow irrigation or that challenges existed in applying the wetting-front detector correctly. The challenge of applying the WFD was illustrated by farmers M07 and M08 who applied more water compared to their colleagues when cropping tomato and cabbage, respectively.

3.3 Influence of soil properties and furrow length on WFD performance

To further understand whether soil physico-chemical properties and furrow length influenced the reduction in irrigation depth achieved when using the WFD, correlation analysis was performed (Table 8). No correlation was found between the furrow length and the reduction of irrigation depth solely (Figure 4).

Figure 4: Reduction of irrigation depth (%) in function of the furrow length (m) for potato (black circles), wheat (open circles) and cabbage-tomato-pepper (black triangles).

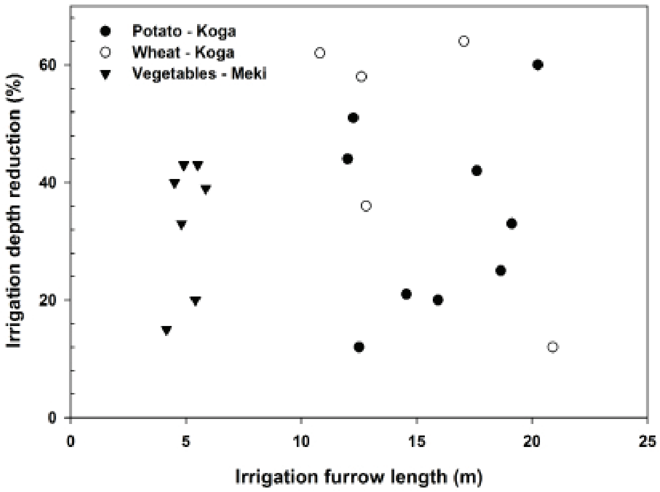


Table 8: Pearson correlation coefficients between field characteristics (i.e. furrow length), irrigation depth applied, irrigation reduction obtained using WFD and soil physio-chemical properties (i.e; field capacity, wilting point, sand and silt fraction, total nitrogen content. *,**,*** refer to 0.5, 0.01 and <0.0001 p-levels respectively while N refers to the number of observations

	Furrow length	Irrigation depth	Irrigation reduction	Field capacity	Wilting point	Sand	Silt	Total nitrogen	Available phosphorus
Koga									
N	32	32	28	32	32	32	32	32	28
Furrow length	1	-0.041	-0.120	0.432*	0.268	0.240	-0.179	0.257	-0.056
Irrigation depth		1	0.210	-0.202	0.028	-0.284	0.288	0.047	0.230
Irrigation reduction			1	0.417*	0.376*	-0.143	0.262	-0.030	-0.320
Field capacity				1	0.666***	0.691***	-0.572**	0.249	0.081
Wilting point					1	0.487**	-0.349	0.204	0.404
Sand						1	-0.914***	0.294	0.211
Silt							1	-0.357*	-0.220
Total nitrogen								1	-0.067
Available phosphorus									1
Meki									
N	18	18	18	18	18	18	18	18	18
Furrow length	1	0.401	0.195	-0.083	-0.054	-0.004	0.001	0.045	-0.390
Irrigation depth		1	0.161	-0.419	-0.220	0.367	-0.255	0.039	-0.158
Irrigation reduction			1	-0.421	0.538*	0.499*	-0.516*	-0.512*	-0.599**
Field capacity				1	0.750**	-0.949***	0.776**	0.671**	0.775**
Wilting point					1	-0.917***	0.787**	0.667**	0.633**
Sand						1	-0.886***	-0.795***	-0.726**
Silt							1	0.932***	0.639**
Total nitrogen								1	0.695**
Available phosphorus									1

Correlation analysis showed that for Koga a positive correlation was found between reductions in irrigation depth and field capacity (R^2=0.417) as well as wilting point (R^2=0.376).This can be explained by the functioning of the WFD as the indicator switch is activated when soil moisture around field capacity is reached (Tesema et al. 2016). For Meki no correlation was found with field capacity whereas irrigation reduction was positively correlated with the wilting point of the soil (R^2=0.538). Correlation results for Meki might be influenced due to the limited number of samples and the weak correlation. Additionally it was positively correlated with sand (R^2=0.499) and negatively correlated to soil physio-chemical properties such as silt fraction (R^2=-0.516), total nitrogen (R^2=-0.512) and available phosphorus (R^2=-0.599) content (Table 7).

Despite the small sample size, the results further support the results from section 3.2, indicating that irrigation depth reductions obtained through the use of WFD were influenced by both soil physical (i.e. texture and field capacity) as well as soil chemical properties. The latter influences crop performance and hence root zone development influencing water uptake and movement of the wetting front. Low nutrient concentrations might result in shallow root zone development, resulting in less water consumption at a specific irrigation depth and, therefore, a more rapid response of the WFD, leading to larger reductions compared to the control treatment.

3.4 Effect of irrigation scheduling on crop and water productivity

Effect on crop productivity

Comparison of yield parameters at plant, bed and field level showed a high variability between the control and WFD plots for the various crops (Table 9 and Appendix 2). Large variability between the various farmers was partly influenced by the difference in crop variety and fertilizer application. For example, a tomato farmer (M07) using a hybrid variety harvested up to 17 times more compared to the other two farmers using a local variety. For potato, tomato and pepper the number of produce per plant in the WFD plots was significantly higher compared to the number obtained in the control plots. Scheduling irrigation had a positive effect on the yield per plant for all four crops (i.e. potato, tomato, pepper and cabbage (Table 10). This suggests that the average fruit or tuber weight increased in the fields scheduled by the WFD.

Table 9: Harvest characteristics at plant, bed and total field level measured in the control (i.e. Cont., farmers practice) and WFD plot. The number of observations per farmer for each treatment are at plant, bed and total level were 9, 3 and 1, respectively

Crop	Number of produce per plant		Yield per plant (kg)		Yield per bed (kg 100m^2)		Yield field (t ha^{-1})		Yield increase (%)
	Cont.	WFD	Cont.	WFD	Cont.	WFD	Cont.	WFD	
Potato	17 ± 6	17 ± 6	1.1 ± 0.5	1.1 ± 0.5	390 ± 264	398 ± 228	21.9 ± 12.3	25.3 ± 10.2	17 ± 21
Wheat	n.a	n.a	n.a	n.a	44 ± 14	46 ± 25	2.6 ± 0.8	2.6 ± 0.9	-3 ± 13
Tomato	88 ± 65	149 ± 115	6.7 ± 5.5	10.5 ± 7.8	367 ± 269	579 ± 468	22.1 ± 17.6	25.4 ± 19.5	14 ± 3
Pepper	109 ± 32	150 ± 27	5.4 ± 7.0	5.8 ± 3.9	571 ± 270	723 ± 345	18.8 ± 5.6	22.4 ± 8.0	14 ± 8
Cabbage	n.a	n.a	2.6 ± 0.5	2.8 ± 0.6	515 ± 282	508.4 ± 201	69 ± 22.3	79.7 ± 25.8	13 ± 8

Table 10: Effect of water management (treatment) on yield performance parameters

Parameter**	df	Number of produce per plant	Yield per plant (kg)	Yield per bed (kg 100m^2)	Yield field (t ha-1)	Yield increase (%)
Treatment	3	<0.0001	n.s.	<0.0001	<0.0001	n.s.
Treatment (crop)	5	<0.0001	0.01	0.04	0.01	n.a.

Data was transformed; number of produce, yield per plant, yield per bed and yield per field were log normal transformed. The abbreviations n.s. = not significant, and n.a.= not applicable. Farmer M07 was deleted during the analysis.

The influence of the size of cabbage was assessed to evaluate whether the size and weight of the produce might have been affected by the irrigation treatment. Measurements were only taken at field level. For cabbage the wetting-front detector did positively influence the number of leaves (i.e.: Control: 22 leaves; WFD: 27 leaves) and head diameter (i.e.: Control: 19 cm; WFD: 21 cm) ($p=0.05$). Comparison of the harvest indices for wheat showed that a positive influence of the WFD (i.e: control = 0.43 and WFD = 0.45) ($p<0.0001$). Differences in crop size might be related to the effect of the irrigation treatment given that no significant differences were observed in plant density, crop management or fertilizer application between the control and the WFD for the same farmer. At bed and field level similar observations were found compared to the plant level measurements, showing that the data are relatively consistent and that information to irrigation scheduling influences the yield. Overall variability remained high between the various farmers within the same treatment as well as between treatments causing negative yield reductions in some cases.

This might be related to water management and associated nutrient uptake depending on the applied fertilizer amount. Sub-samples of both treatments for each field were analysed on total nitrogen (Table 11) as changes in nitrogen content might affect protein content (e.g. wheat), starch content (e.g. potato) and appearance of tomato, cabbage and pepper. Results indicated a slightly lower nitrogen value for the produces from the WFD treatment however a pairwise comparison did not show a significant difference between both irrigation treatments.

Table 11: Average total nitrogen content for each produce and each irrigation treatment (i.e. control and WFD). Difference in letter superscripts shows significance of difference between both irrigation treatments at a 0.05 p level

	Total nitrogen content in the produce (%)	
	Control	WFD
Potato*	0.32 ± 0.03 [a]	0.31 ± 0.04 [a]
Wheat*	1.98 ± 0.12 [a]	1.92 ± 0.18 [a]
Tomato	3.74 ± 0.91 [a]	3.04 ± 0.28 [a]
Pepper	2.80 ± 0.43 [a]	2.55 ± 0.19 [a]
Cabbage	3.18 ± 0.60 [a]	3.42 ± 0.57 [a]

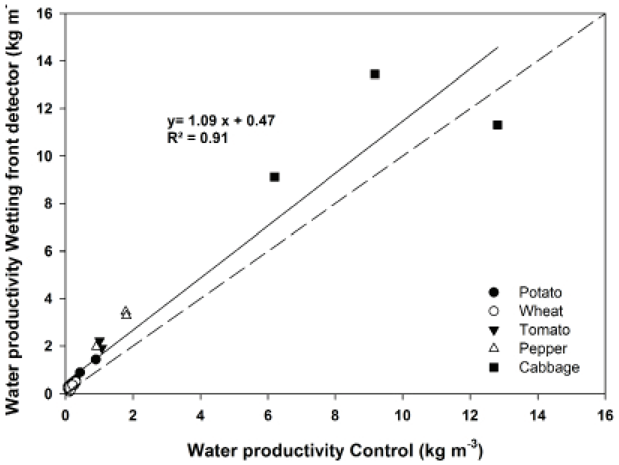
* Results are based on 3 bed samples per field for potato and wheat whereas for tomato, pepper and cabbage only one sample per field was taken

When farmers were asked about their harvest product preference, the majority of farmers choose the wheat, tomato, cabbage and pepper from the WFD plots. The main reasons were the homogenous grain filling, in the case of wheat, bigger and shinier fruits, in the case of tomato and pepper and larger heads in the case of cabbage. Only one cabbage farmer selected the control produce as he mentioned that on the market consumers prefer smaller heads. Further research is needed about the significance of this semi-qualitative evaluation on the harvest product.

Effect of irrigation scheduling on water productivity

Water productivity values for the various produce ranged between 0.08 and 1.43 kg m^{-3} (potato); 0.08 and 0.49 kg m^{-3} (wheat); 1.01 and 20.88 kg m^{-3} (tomato); 0.91 and 3.45 kg m^{-3} (pepper) and 6.19 and 13.44 kg m^{-3} (cabbage). The high water productivity value of 20.88 kg m^{-3} for the hybrid tomato variety of tomato used by Farmer M07 and was considered an outlier compared to the local varieties (Figure 5). Removal of M07 reduced the range of tomato water productivity between 1.01 and 2.22 kg m^{-3}.

Figure 5: Calculated water productivity values for both irrigation treatments (i.e. control = farmers practice and Wetting-front detector = irrigation tool. Slope coefficients of the regression is significant while the intercept is not significant at a 0.05 p-level. Farmer M07 was considered as an outlier and removed.



Combining the obtained water productivity values for the various crops showed a strong correlation between both irrigation treatments 0.91 (Figure 5). Overall the water productivity in the WFD plots was slightly higher (i.e. 9 %) compared to the farmers practice despite the large variability obtained in water productivity values for the various crops (i.e. large range of WP values mentioned per crop). To obtain a statistical mixed linear regression model the length of the furrow as well as the silt fraction were included as a random factor. The model showed that for each crop there was a significant increase on water productivity when the irrigation scheduling tool was used ($p<0.0001$) (aside from the tomato due to limited number of observations (N=2)). These results support the earlier suggestion of soil texture as well as furrow length influencing the amount of irrigation reduction in the WFD treatment and therefore affecting water productivity gains for the various crops.

3.5 Reducing labour- and improving water-use dialogue between farmers and water user associations (Koga case)

A WFD evaluation meeting was organized on 17 April 2015 in Koga irrigation scheme with all the participating farmers. Farmers involved in field trials were asked to reassess their normal irrigation water use practices based against one season of using the wetting front. The comparison took place at the level of labour and time taken to irrigate the field, crop performance and harvested product. One of the responses was that the rush to have more and more water for irrigation may not be necessarily worthwhile. Some farmers responded that they have spent less time for irrigation when they used the wetting-front detector and also mentioned the positive effect it has on the irrigation interval (Figure 6).

Figure 6: Participating farmers discussing the optimal use of the WFD for potato in Koga.

Comparison of the amount of irrigation events for the period that the WFD was installed showed that potato farmers saved between 0 and 4 irrigation events, while wheat farmers saved between 2 or 3 irrigation events. Using the average irrigation time they spend approximately on the field using their own irrigation experience (i.e. 30 min) would result in a maximum saving of 2 hours for potato and 1.5 hours for wheat on an average plot size of from 100 m^2. A rough estimation for one hectare would yield an average saving of 165 h or 22 days. This would be cumulative estimates for various farmers together as the number of irrigation days per season is influenced by the scheme rotation which is, on an average cropping season of 4 months and an interval of 10 days, only 12 days a season.

Farmers indicated that before using the WFD, they would often insist on irrigating frequently, thereby causing water shortages and leading to conflicts over water. This observation is supported by the positive results obtained in the field on irrigation reduction. Based on rough estimates, the water saved could support a full cropping season of wheat or potato for a total of 3.6 ha or 4.3 ha, respectively.

Preliminary interviews and discussions conducted with field trial participants in the Koga irrigation scheme highlighted the potential contribution of the WFD in managing conflicts due to competition over water. They reported that water conflicts have been avoided while using the WFD. Further detailed research is currently being conducted in the second season to examine the potential of the tool in reducing conflict between farmers, as well as with water-user associations along with farmers' adoption of the technology.

3.6 Reducing fuel costs (case of Meki)

The case of Meki is very different from Koga. Farmers do not depend on a scheme rotation but use their private pumps to extract water from the scheme or in absence of the scheme use the lake or groundwater wells. The lake has resided significantly in recent years according to the farmers. Saving water will not only support a larger irrigable area and reduce potential water conflicts in schemes, but will also enhance ecological flows. One of the many direct and indirect benefits of saving water is related to pumping, as less water will result in lower pumping cost, increasing the the life of the pump and reducing maintenance or repair costs. Based on the obtained preliminary results 2,338 m^3 was saved. Depending on the head, the estimated pumping discharges were 0.0041 m^3 s^{-1} for groundwater extraction, 0.0066 m^3 s-1 when pumping from the lake and 0.0101 m^3 s^{-1} if water was extracted from the river. This would result in a pump saving of 64 hours (river), 98 h (lake) and 158 h (groundwater) for 1.8 ha. Assuming an average fuel consumption of 3 litres per pump for 2 ha would result in reduced consumption of 96, 147 and 238 litres or an economic gain[4] of USD 113, 174 and 280, respectively.

4 Assuming an average fuel price of ETB17 birr or USD 0.85.

4 Conclusions and future work

The study assessed whether the use of a simple irrigation tool can assist farmers in saving water, while improving water and crop productivity. In total, 27 farmers participated in this first season. They cultivated and irrigated approximately 100 m² using traditional irrigation practices, whilst on an equal area they used the wetting-front detector tool. The following main preliminary results were obtained in the first season:

- *Water saving*: Reduction in irrigation depth varied significantly between Meki and Koga. Results indicate that differences could be related to the furrow length, soil texture and farmer experience. Some farmers faced more challenges in understanding and using the detector more efficiently compared to others. In Koga, the volume of water saved could increase the area currently cropped almost twofold. On the other hand the volume of water saved in Meki had a positive economic benefit ranging from USD 100 to 300 for a total of 1.8 ha depending on the water source.
- *Crop performance and water productivity*: Yield increases were positively influenced by the reduction in water consumption but no influence on nutrient uptake was found. On average, the produce was larger, more in number and heavier compared to those cultivated under traditional irrigation practices and farmers preferred the produce obtained from the wetting-front detector plots above those in the control plots. Although yield increases were highly variable between farmers depending on their farm management, crop variety cultivated and irrigation depth reduced, the scheduling tool had a clear positive effect on water productivity.
- *Water dialogue and economic benefits for farmers*: In both sites farmers positively evaluated the scheduling tool. In Koga, farmers reflected on their traditional practices and acknowledged that they learned to save water without negatively impacting yield. Although there was an effect of labour saving, so far it has not been identified by the farmers as a main effect as they highlighted the experience of less water conflicts in that particular period. In Meki, on the other hand, the reduction in volume resulted in decrease of fuel costs and therefore a monetary economic gain.

Based on these preliminary results, further research is currently being conducted.

- Under well-planned and careful implementation, the results suggest that WFD can reduce irrigation events, the total amount of water applied and the associated labour costs without affecting the total yield when compared with the current farmer practices. One of the major challenges that emerged from this study is the applicability of this tool to assist equitable distribution of irrigation water by the water user association in Koga. Furthermore, the upscaling of the tool will not have a linear effect. Therefore, research is currently being conducted on full farmer fields with water-user associations and farmers to evaluate how much water can be saved, and the effects on crop yield. Additionally, focus group discussions with farmers, as well as water-user associations, are planned before and after the season to evaluate the effect of the scheduling tool on the water dialogue and the potential reduction of water-related conflicts leading to equitable distribution.
- The effect of water saving on nutrient uptake and, therefore, yield could not fully be assessed and a study exploring the main yield limiting factors is needed. In this regard IWMI-LIVES planned demonstration of WFD with greater numbers of farmers including fertilizer trials as a split plot design to see optimum water, fertilizer and variety interactions. The study is currently being conducted in Koga.

The economic benefit pump farmers in Meki would derive from the use of the wetting-front detector is promising. However, a larger representative group of farmers is needed to confirm the preliminary findings obtained in Meki. Additionally, the water source has a potential effect on soil sodicity which might be aggravated by using the wetting-front detectors as salts are more likely to concentrate in the root zone. As such, a comparison study needs to be done for the same vegetables between groundwater and lake users.

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Annex 1: Farm level overview of irrigation results

Detailed irrigation characteristics for the various fields after the wetting-front detector was installed with Cont. (i.e. control) and WFD referring to farmer and WFD based scheduling, respectively. Data was used to evaluate difference between the sites as well as within the irrigation treatment.

		Irrigation events		Irrigation interval (days)		Irrigation furrow (sec)		Irrigation depth (mm)*		Reduction irrigation depth (%)
Crop	Field	Cont.	WFD	Cont.	WFD	Cont.	WFD	Cont.	WFD	
Potato	K01	5	3	10	17	420	420	1248	1093	12
	K03	5	4	11	14	480	420	1264	950	25
	K06	8	5	10	18	420	420	1968	1571	20
	K10	5	5	13	14	900	480	2858	1645	42
	K11	5	3	13	17	600	540	1433	1137	21
	K12	5	4	14	16	1080	540	2718	1088	60
	K16	6	5	13	15	660	480	2889	1608	44
	K17	6	5	10	14	660	420	1560	1045	33
	K18	9	5	10	21	360	300	1136	559	51
	Mean	**6**	**4**	**12**	**16**	**600**	**420**	**1897**	**1188**	**34**
	SD	**2**	**1**	**2**	**2**	**240**	**60**	**735**	**358**	**16**
Wheat	K02	6	4	9	14	420	360	1209	793	34
	K05	5	3	11	16	480	480	1200	767	36
	K07	8	5	12	18	600	540	3208	1339	58
	K08	6	3	12	28	420	480	1048	924	12
	K13	7	5	13	15	660	420	2693	1011	62
	K14	7	4	12	15	300	300	1157	420	64
	Mean	**6**	**4**	**12**	**17**	**480**	**480**	**1639**	**1043**	**44**
	SD	**1**	**1**	**1**	**5**	**120**	**120**	**913**	**522**	**21**
Tomato	M01	24	15	4	6	83	80	2661	1595	40
	M04	12	8	4	6	89	76	741	421	43
	M07	18	20	6	5	48	52	1047	1243	-19
	Mean	**18**	**14**	**4**	**6**	**74**	**69**	**1483**	**1086**	**21**
	SD	**6**	**6**	**1**	**1**	**22**	**15**	**1032**	**602**	**35**
Pepper	M03	17	12	5	7	57	49	1647	1008	39
	M05	17	12	4	6	75	72	1131	761	33
	M09	16	10	6	7	49	45	643	368	43
	Mean	**17**	**11**	**5**	**7**	**60**	**55**	**1140**	**712**	**38**
	SD	**1**	**1**	**1**	**1**	**13**	**14**	**502**	**323**	**5**
Cabbage	M02	16	13	4	7	54	58	592	505	15
	M06	14	14	4	6	86	69	744	597	20
	M08	10	10	5	5	70	83	577	688	-19
	Mean	**13**	**12**	**5**	**6**	**70**	**70**	**638**	**597**	**5**
	SD	**3**	**2**	**1**	**1**	**16**	**12**	**93**	**91**	**21**

* Irrigation depth for the period after the wetting-front detector was installed.

Annex 2: Farm level overview of crop productivity

Detailed harvested yields at plant, bed and total field level measured in the Cont. (i.e. control farmers practice) and WFD plot. The number of observations per farmer are at plant, bed and total level were 9, 3 and 1, respectively (see section 3.4.).

		Number of produce per plant		Yield per plant (kg)		Yield per bed (kg 100m²)		Yield field (t ha-1)		Yield increase (%)
Crop	Field	Cont.	WFD	Cont.	WFD	Cont.	WFD	Cont.	WFD	
Potato	K01	17	13	1.1	1.0	284.1	200.6	17.6	21.0	16
	K03	19	18	1.1	1.3	494.4	539.3	25.0	37.6	33
	K06	21	24	1.8	1.7	426.1	496.9	23.5	26.5	11
	K10	15	12	1.2	1.2	225.9	281.6	21.0	27.5	24
	K11	17	21	0.8	0.9	136.8	250.6	8.4	13.5	38
	K12	14	17	0.7	0.7	176.6	133.0	9.5	15.4	38
	K16	15	16	1.4	1.3	646.1	650.6	38.3	39.1	2
	K17	16	15	0.9	0.9	180.1	220.3	11.1	13.2	17
	K18	15	16	1.0	1.2	937.2	802.8	43.2	34.1	-27
	Mean	**17**	**17**	**1.1**	**1.1**	**389.7**	**397.3**	**21.9**	**25.3**	**17**
	SD	**6**	**6**	**0.5**	**0.5**	**263.5**	**228.2**	**12.3**	**10.2**	**21**
Wheat	K04	n.a	n.a	n.a	n.a	47.7	32.3	2.5	2.4	-3
	K05	n.a	n.a	n.a	n.a	52.3	56.5	3.9	4.2	6
	K07	n.a	n.a	n.a	n.a	61.5	67.7	2.8	3.0	5
	K08	n.a	n.a	n.a	n.a	18.6	20.3	1.7	1.5	-13
	K09	n.a	n.a	n.a	n.a	-	30.2	-	2.2	-
	K13	n.a	n.a	n.a	n.a	41.7	85.9	2.5	2.9	12
	K14	n.a	n.a	n.a	n.a	34.0	29.3	2.2	1.7	-27
	Mean	**n.a**	**n.a**	**n.a**	**n.a**	**44.1**	**46.1**	**2.6**	**2.6**	**-3**
	SD	**n.a**	**n.a**	**n.a**	**n.a**	**14.4**	**24.7**	**0.8**	**0.9**	**13**
Tomato	M01	148	257	11.6	18.0	605.9	1001.7	34.6	39.2	12
	M04	27	42	1.8	3.0	129.5	155.9	9.6	11.6	17
	M07	130	142	23.1	27.3	2225.0	2496.5	279.3	282.5	1
	Mean	**102**	**147**	**12.1**	**16.1**	**986.8**	**1218.0**	**107.8**	**111.1**	**10**
	SD	**57**	**93**	**9.2**	**10.2**	**953.0**	**1028.2**	**149.0**	**149.1**	**8**
Pepper	M03	73	127	2.8	4.5	432.0	552.1	18.4	23.0	20
	M05	123	173	11.8	10.9	916.9	1171.5	24.6	30.1	18
	M09	129	149	1.7	2.1	362.5	445.6	13.5	14.2	5
	Mean	**109**	**150**	**5.4**	**5.8**	**570.5**	**723.1**	**18.8**	**22.4**	**14**
	SD	**32**	**27**	**7.0**	**3.9**	**269.6**	**345.4**	**5.6**	**8.0**	**8**
Cabbage	M02	n.a	n.a	2.4	2.5	349.1	410.3	44.5	50.0	11
	M06	n.a	n.a	2.8	2.8	310.3	343.8	74.3	94.8	22
	M08	n.a	n.a	2.6	3.2	886.3	771.1	88.6	94.5	6
	Mean	**n.a**	**n.a**	**2.6**	**2.8**	**515.2**	**508.4**	**69.1**	**79.7**	**13**
	SD	**n.a**	**n.a**	**0.5**	**0.6**	**282.3**	**200.8**	**22.5**	**25.8**	**8**

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