Evaluation of suitable water lifting and on-farm water management technologies for the irrigation of vegetables and fodder in Lemo district, Ethiopia

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Abbreviations

ASF	Animal source foods
EC	Electrical Conductivity
FTC	Farmer Training Center
MP	Tractor mounted pump
OM	Organic Matter
OV	Oats-vetch
RW	Rope and Washer
TN	Total Nitrogen
WFD	Wetting Front Detector

Summary

Small scale irrigation (SSI) development could positively benefit the intensification of crop-livestock mixed farming systems in the Ethiopian highlands as it improves climate resilience in the rainy season through supplementary irrigation and provides off-season benefits as it enables production in the dry season. The intensification of production per land unit could on its turn positively impact household income, nutrition and ultimately livelihoods.

In sub-Saharan Africa information is scarcely available with regards to suitable water lifting and management technologies given a particular geographical location, socio economic conditions (market access, input availability and access, etc.). During the dry seasons of 2015 and 2016 IWMI piloted several water lifting (i.e. rope & washer, solar pump and tractor mounted pump with drip kits), and management technologies (i.e. wetting front detector) for sustainable intensification through irrigation in farming communities of Lemo (Jawe and Upper Gana village) together with 45 farmers to: i) evaluate the on-farm suitability of these technologies; ii) assess the effect of water lifting on the productivity of irrigated fodder and vegetables (i.e. carrot and cabbage) and iii) to assess potential increases in productivity through irrigation scheduling advice.

Depending on the water source and availability, the technologies led to a multi-crop and multi-use (agriculture, domestic and livestock) system. The irrigation of vegetables using solar pumps or service delivery of water in combination with drip showed great potential in Lemo. For cabbage the average profit obtained using solar based irrigation (16,703 USD) exceeded those made in the control (8,689 USD), rope and washer (7,758 USD) or service provision group (9,239 USD). For carrot the highest profit was obtained for the service provision of water (14,343 USD) followed by the control group (9,969 USD), rope and washer (9,890 USD) and solar pump (8,977 USD). The profitability of fresh fodder feed was found significantly lower (1,600-3,000 USD). Both technologies have their advantages and disadvantages. The irrigation labour when using solar was significantly lower compared to labour needed to deliver water, operate a rope and washer or a rope and bucket. However, the reduction of cost related to irrigation labour can be overshadowed by increased yields due to more efficient water application. For example, the carrot yield obtained in the drip system was 1.7 times the yield obtained in the solar group whereas for cabbage it was only 1.2 times higher. Hence, the higher net income for cabbage

when using solar pumps is mainly related to the absence of fuel costs and the reduction of labour. On the other hand, the higher carrot yield obtained in the drip compensated the fuel cost and the increased of irrigation labour. Hence, the distance of the water source to the plot strongly influenced profitability of the system as it increased labour to fetch water and fuel costs. Depending on the water source available and its distance to the farmland solar pumps or service delivery of water could be a solution for smallholder irrigation.

Irrespective of the technology used, the crop and water productivity showed a high variability among farmers. The irrigation water productivity in the rope and washer group for the control and WFD treatment were 3.83 kg m^{-3} and 4.36 kg m^{-3} for cabbage and 5.21 kg m^{-3} and 6.81 kg m^{-3} for carrot, respectively. The access to water management advice using simple tools such as the wetting front detector reduced yield variability and provide farmers with a higher profitability using the same water lifting technology. Profitability for cabbage and carrot increased by a factor 2 and 1.2 per unit of yield due to reduction in irrigation and labour. These results suggested that water management is an integral part when piloting water lifting technologies. It is crucial that water management is a component the irrigation 'package' offered to farmers when promoting irrigation and best-bet solutions aside from access and advice on best management agricultural practices.

Introduction

Over 85% of Ethiopia's population (i.e. 81 million) and 75 % of the livestock (Leta and Mesele, 2014) live in the Ethiopian highlands which covers approximately 76.3 million ha (45 % of the total land area) (Dejene, 2003). Recent studies have shown the vulnerability of these highlands towards changing rainfall regimes resulting in low agricultural productivity in the rainy season negatively impacting the country's agricultural GDP (Sandstrom and Juhola, 2017; Suryabhagavan, 2017). This is not surprising as the vast majority of these highlands is under rainfed agriculture whereas only 1.3% is under smallholder irrigation (Sheahan and Barrett, 2017). Estimates in 2005-2006 showed that irrigation only contributes to 4.5% of the agricultural GDP (Hagos *et al.*, 2009). Therefore, the Ethiopian Government through the Agricultural Growth Program (AGP) continues to invest heavily in small and large scale irrigation within the country. Recently, the Agricultural Transformation Agency (ATA) estimated the suitable irrigable land in Ethiopia at 11million ha[1] of which 48% could be irrigated using groundwater (Agricultural Transformation Agency (ATA), 2016).

Irrigation is one of the coping mechanisms for agriculture under a changing climate aside from the use of different crops or crop varieties, planting trees, soil conservation, and changing planting dates (Bryan *et al.*, 2009; Alemayehu and Bewket, 2017). However, in a recent study by Alemayehu and Bewket (2017) the proportion of households entering small scale irrigation remains still low (i.e. 10%) compared to alternative rainfed cropping strategies such as changing planting dates. The same study also revealed that unproductive rainfed periods result in farmers selling a substantial amount of their livestock. The intensification of the crop-livestock system is under enormous pressure as arable land holdings per capita decreases and natural resources become scarcer. Furthermore, water scarcity during the main rainy season as well as off-season strongly influences the sustainable productivity of these systems (Amede *et al.*, 2014). Small scale irrigation, using available surface water and ground water resources, could decrease household vulnerability to climate shocks and improve livelihoods (Giordano and de Fraiture, 2014).

Understanding suitability and adoption of suitable irrigation technologies for smallholder farmers remains challenging in Sub-Saharan Africa (SSA) (Namara *et al.*, 2014). Often studies on water

[1] The estimation takes into account water efficient application methods such as drip and pressurized systems that would allow irrigation on sloped land.

lifting technologies are conducted in controlled environments, at different scales, focus on specific location/regions, fail to specify whether technologies were given to farmers/owned by farmers or taken up on credit whilst using different evaluating factors, complicating the technical and socio-economic comparison between technologies (Kamwamba-Mtethiwa *et al.*, 2016). Hence, little information is available on suitable technologies given a particular geographical location, socio economic conditions (market access, input availability and access, etc.). For example, manual water lifting devices (i.e. rope and washer, treadle pumps) were found to have a positive performance on food security, poverty reduction and crop revenue in Zimbabwe, Kenya and Ghana however their labour intensiveness hampers potential adoption in some African countries like Malawi (Kamwamba-Mtethiwa *et al.*, 2016 and references therein). When using crop yield and profit indicators, motorized pump studies do report a positive impact on household consumption amongst other socio-economic factors (e.g. Nigeria, Mali, Mauritania, Niger, Ethiopia) whereas when factors such as labour, energy and water consumption are used motorized pumps a rather negatively evaluated (e.g. Mauretania, Nigeria, Kenya, South Africa, Ethiopia, Mali) (Kamwamba-Mtethiwa *et al.*, 2016 and references therein). Solar pumps are in growing demand in Asia (e.g. Bangladesh and India) but a relative new technology for SSA and available literature on success rates is limited (Burney *et al.*, 2010; Burney and Naylor, 2012). The studies evaluated a positive effect of solar powered drip on household nutrition and food security for households (mainly women) below the poverty line (i.e 1.25 USD day^{-1} in the study). Number of available studies investigating the full technical as well as the socio-economic benefits are rare and their potential in improving livelihood of poor households need some further investigation.

Rapid expansion and promotion of irrigation within SSA calls for associated water management recommendations and guidelines to accompany the promotion of small scale irrigation and avoid sub-optimal agricultural performance and negative environmental effects (Namara *et al.*, 2010). This particular study evaluated the agronomic performance using various water lifting and on-farm water management technologies, which was part of an integrated study on technology feasibility[2]. Within the high value crops and irrigated fodder protocols, ICRAF and ILRI have implemented high value crops (avocado, apple) and fodder (oats-vetch) in various Africa Rising sites. In collaboration

[2] which included gender insights on technology preference and performance, as well as the socio-economic feasibility of those technologies. Nigussie, L., Lefore, N., Schmitter, P. and Nicol, A. , 2017. Gender and water technologies: Water lifting for irrigation and multiple purposes in Ethiopia. Nairobi, Kenya: ILRI.

with ICRAF and ILRI, IWMI has identified water lifting and scheduling technologies suitable for irrigated crop production as function of the available water source. In many of the sites farmers are involved in multiple protocols increasing the stress on available water resources. Lemo woreda is one of the implementation sites were potential irrigable land is underutilized due to a scarcity of surface water despite a potential of shallow groundwater. The site is a taking as a test case for comparing various water lifting technologies and their effect on the production of vegetables, fruit trees and irrigated fodder. IWMI has partnered with ILRI, ICRAF and CIMMYT in Lemo to: i) evaluate the suitability (i.e. labour, discharge, production) of various water lifting technologies (i.e. rope & washer, solar pump and service provision through tractor mounted pump with drip kits), ii) assess the effect of water lifting on the productivity and profitability of irrigated fodder and vegetables and iii) to assess potential increases in productivity through irrigation scheduling advice in two villages Upper Gana and Jawe in Lemo Woreda.

Materials and Methods

Site description

The Lemo Gilgel Gibe is a sub-basin of Omo Gibe basin, one of the twelve basins of Ethiopia, located in the southern nation's nationalities people region which is situated in the tep sub-humid mid higlands. Lemo Gilgel Gibe sub basin is found between 7° 25'55" and 7° 37'41" latitude and 37°37'55" and 37°52'48" longitude. The Upper Gana and Jawe micro watersheds are two out of 26 micro watersheds found in the Lemo Gilgel gibe sub-basin. The Upper Gana micro watershed, named after the village, having an area of about 1946 ha is located between 7°31'55" and 7° 33'54" latitude and 37°40'48" and 37°45'58" longitude and 2061 m -2559 m a.s.l. The other one is Jawe micro watershed, also named after the village, having an area of about 1024 ha of land. Jawe micro watershed is located between 7°30'54" and 7°25'55" latitude and 37°45'29" and 37°49'12" longitudes with an elevation ranging between 1900 – 2700 m a.s.l. The Upper Gana and the Jawe micro watersheds approximately cover together about an area of 2,971 hectare of land and are about 7.2 % of the total area of the sub Lemo Gilgel Gibe sub basin.

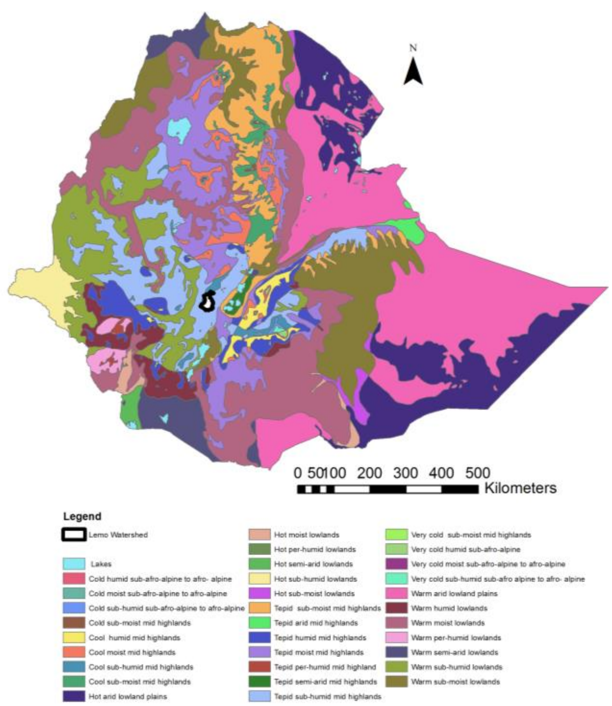

Figure 1: Situation of Lemo watershed within identified agro-ecological zones of Ethiopia (Ethiopian Institute for Agricultural Research, 2017).

The mean daily maximum temperature ranges from 20.1 C^{o} to 25.3 C^{o}, mean daily minimum temperature ranges from 8.5C^{o} to 12 C^{o}, mean annual rainfall in the area about 1161 mm and the maximum mean monthly rainfall of 180 mm occurs in July (2005-2014, source: National Meteorological Agency, Hossaena station). The rainfall, calculated potential evapotranspiration for 2014 – 2016 and cropping seasons during the study is given in Figure 2.

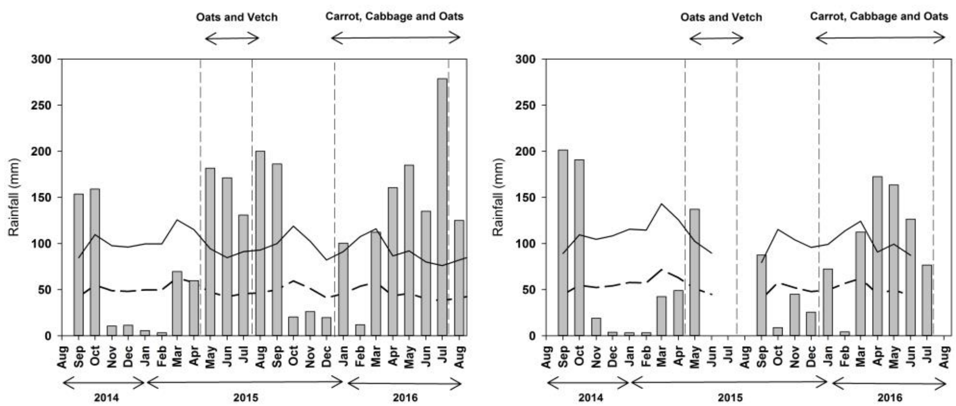

Figure 2: Monthly rainfall distribution (mm, vertical bars), 100% monthly ET_o and 50% of the monthly total potential evapotranspiration ($0.5ET_o$, mm, dashed line) according to FAO guideline (1985) for Upper Gana (left) and Jawe (right), indicating dry periods where rainfall is below the $0.5ET_o$ line (top). Dashed vertical lines indicate the supplementary irrigated cropping season for oats-vetch in 2015 and cabbage, carrot and oats in 2016. Data for June and July in 2015 is missing.

The major rainfed crops produced in the area are enset, wheat, barley, faba bean, teff and potato during the rainy season and irrigated tomato, potato, cabbage, beet root during the dry season. Main livestock feed are crop residues, enset leaves and naturally occurring grass. Soil range from red loamy clay at the hill slopes in eroded fields to dark brownish black fertile soils in the valley bottoms(Kuria *et al.*, 2014).

Implementation of water lifting and water management technologies

At the initial stage of the project, a focus group discussion was held in both Jawe and Upper Gana to explore potential and suitable water lifting technologies. Different water lifting devices were proposed to improve water abstraction from groundwater wells and reduce labour during irrigation while the scheduling devices aim at guiding the farmer when and how much to irrigate. The main purpose of the interventions was to support and optimize irrigation activities in the dry season for high value trees (avocado), vegetables (cabbage and carrot), and irrigated fodder (oats, oats-vetch intercropped). However, given the bi-modal rainfall in the area irrigation in the dry season mainly constitutes out of supplementary irrigation at the onset of the cropping season (January-March) depending on the rainfall distribution. The following technologies together with their costing were presented to the community: treadle pumps, pulley, rope and washer, solar pumps, tractor mounted pumps[3] for the water lifting technologies, and wetting front detectors (WFD) for on-farm water management. The tractor mounted pump supplied water to households, who had limited water access, by filling drip tanks, enabling irrigation of vegetables. The treadle pumps and pulley had no or little traction in the community and were excluded in this study.

Water lifting and application technologies

Within the project, farmers decided to take up credit for one of the manual or motorized technologies with the exception of the tractor mounted pump (see figure 3)

Figure 3: The various technologies implemented under Africa RISING: Top left drip kit, top right service provider with tractor mounted pump, bottom left solar pump and bottom right a rope and washer (photo credit: Dale Pulker).

The tractor mounted pump and its feasibility to deliver water for irrigation was being tested in this study and hence not offered to the farmers as a feasible technology (Figure 3). In the case of the

[3] Tractor mounted pump is part of the service provision of the small mechanization protocol led by CIMMYT. Water is delivered to drip kits by a service provider using the tractor mounted pump, transporting water via a trailer.

service provision water was delivered to drip kits that were able to store water at a given time and provide flexibility to the farmer on when he wanted to irrigate.

Table 1: Overview of the different technologies implemented under Africa RISING.

Technology	Jawe	Upper Gana	Total number of farmers
Rope and washer	15	11	26
Solar	1	3	4
Drip and tractor mounted pump	3	3	6
No technology	5	6	11

In total 26 farmers have taken up credit (15 farmers from Jawe and 11 farmers from Gana) for a rope and washer, four farmers for solar pump (1 farmer from Jawe and 3 farmers from Gana). For the service provision group, 6 drip kits were distributed to farmers (3 farmers from Jawe and 3 farmers from Gana) and one multipurpose tractor (with a mounted pump) per village (Table 1). The iDE drip kits consisted out of two 215 L tankers which were installed approximately 1.5 m above the ground. Each tanker supplied water to 50 m^2 of carrot and cabbage. The drip lines were 10 m long. Emitter spacing changed due to crop spacing. For cabbage emitter spacing was 30 cm whereas for carrot it was 15 cm along the drip line. A control group of 11 farmers (5 in Jawe and 6 in Upper Gana), who had no water lifting technology, were selected who agreed to grow the same crops as the other groups (Table 1). Water was applied using a watering can in combination with the rope and washer and by using a hose in case of the solar pump.

Water management using wetting front detectors

Optimal application of irrigation requires the right amount of water at the right time which can be challenging. The amount of water applied often depends on overall water availability, knowledge or experience on the plant available soil moisture and crop water requirement as well as climatic variations within the irrigation season and cost/labour/energy involved in irrigation. There are several measuring and estimation tools available (e.g. time domain reflectometer, tensiometer (soil moisture profiler, and ICT) alongside farmers own knowledge and experience to govern irrigation scheduling. However many of these approaches for irrigation scheduling are still too complex or too expensive for small scale farmers. Under Africa RISING the objective was to provide farmers with tools /options for sustainable intensification of smallholder irrigation. Wetting front detectors[4]

[4] The wetting front detectors were invented by Richard Stirzaker at CSIRO and produced in South Africa by Agriplas.

were tested, to increase productive use of water whilst aiming to income per unit water applied. The tool guided irrigators in how much water to apply and when new crops are introduced under the project. The detectors are mechanical devices which, depending on the soil type, irrigation method and crop type are installed in pairs at a specific depth below the soil surface (Stirzaker, 2003; Stirzaker *et al.*, 2004) (Figure 4).

Figure 4: Installation of the wetting front detector according to Stirzaker et al. (2004) (left) with a fodder farmer in Lemo and within the farmer trainings center (right).

Each pair consists out of a yellow (i. e. shallow detector) and a red (i.e. deeper detector) indicator. The shallow detector is installed at 50 % of the effective (or 1/3rd of the total) root zone whereas the deeper detector is installed 2/3rd of the total root zone. Given the difference in effective root zone the shallow and deeper detector were installed at different depths for the various crops. When field capacity is reached during irrigation, drainage water is collected within the buried reservoir. Depending on the amount of water collected in the reservoir (i.e. suction > 3kPa), the float will be activated. More detailed information on the functioning and installation can be found in Stirzaker *et al.* (2004). Farmers were trained to optimize their irrigation application so that the shallow detector would respond after irrigation without too frequently activating than the deeper detector. To guide farmers with their irrigation in the WFD treatment, the shallow WFD was installed at a depth of 20 cm whereas the deep WFD was installed at 40 cm.

Given the limited number of drip and solar pumps the implementation of WFD was only possible with the rope and washer farmers (Table 1 and Table 3). To assess the impact of water and crop productivity of the WFD treatment, a group of farmers, owning a rope and washer pump and irrigated according to their own traditional practice, was used for comparison (more details are described in section below and Table 3).

Experimental design

In 2015, the only crop tested and irrigated under this project was oats-vetch. Farmers who invested in a water lifting technology and willing to grow oats-vetch were selected. In 2016 farmers requested to grow carrot and cabbage aside from fodder, hence both crops were added to the assessment. Additionally, oats aside from oats-vetch was added as a fodder option. Depending on water availability, farmers chose which crops they cultivated during the dry season (Table 2). The land size per crop varied between 50 and 100m² for each farmer.

Table 2: Number of farmers and their respective technologies for vegetables and fodder in both villages by 2015 and 2016. The number of farmers for oats-vetch in 2015 are the total number of farmers participating in 2015.

Technology	Control	FTC	RW	Solar	Tractor mounted pump with drip
Water source	SW & GW	DW	GW	GW	SW
Jawe					
Oats-vetch (2015)	-	-	*12*	-	-
Cabbage (2016)	*4*	*6*	*7*	*1*	*3*
Carrot (2016)	*4*	*6*	*7*	*1*	*3*
Oats (2016)	-	*6*	*6*	*1*	-
Oats-vetch (2016)	-	-	*6*	*1*	-
Total number of farmers in 2016	*4*	*6*	*9*	*1*	*3*
Upper Gana					
Oats-vetch (2015)	-	-	*8*	-	-
Cabbage (2016)	*4*	-	*7*	*2*	*3*
Carrot (2016)	*4*	-	*7*	*3*	*3*
Oats (2016)	-	-	*6*	*2*	-
Oats-vetch (2016)	-	-	*6*	-	-
Total number of farmers in 2016	*8*	-	*8*	*3*	*3*

In the first year (2015) farmers, using a RW, irrigated oats-vetch using WFD whereas in 2016 farmers were selected who were willing to cultivate both fodder and vegetables. Farmers cultivating cabbage, carrot and fodder (oats, oats-vetch) were given a WFD for each crop so that the amount of water used could be evaluated for various crops under similar crop management. Due to the limited availability of WFD, the WFD was installed in the oats plot and provided irrigation advice for the oats-vetch plot (as the installation depth was the same) (Table 3).

Table 3: Application of WFD for vegetables and fodder in plots irrigated by a RW in both villages by 2015 and 2016.

		2015			2016		
Kebele	Crop type	Area (m^2)	WFD	Farmers' practice	Area (m^2)	WFD	Farmers' practice
Jawe	Cabbage	-	-	-	50	3	4
	Carrot	-	-	-	50	3	4
	Oats	-	-	-	50	-	6
	Oats &Vetch	100	5	7	50	-	6
Upper Gana	Cabbage	-	-	-	50	3	4
	Carrot	-	-	-	50	3	4
	Oats	-	-	-	50	3	3
	Oats-vetch	100	2	6	50	-	3

Aside from irrigation management, crop management plays an important role on crop performance. This is likely to vary greatly between farmers even if the same amount of fertilizer is applied. Furthermore, there is only a limited number of the WFD per crop. Hence, the experiment on WFD is repeated at FTC in a controlled environment for carrot, cabbage, and oats. The design followed a complete randomized block design with three replications for each crop and two irrigation treatments (i.e. Farmers practice and WFD treatments). The plot size of each crop was 20 m^2 (4 m * 5 m) and the treatments were distributed randomly within each of the 3 blocks (6 plots were found in one block).

Planting of high value crops

Seeding and transplanting was done at similar times for the various technologies with the exception of the drip and control farmers (Table 4). Cabbage seedlings were prepared using one nursery in each village whilst carrot, oats and oats-vetch were directly seeded in farmers plots. Given the delays in the drip equipment a second nursery was prepared solely for the tractor mounted pump with drip farmers. The seeding rate for cabbage was 1 kg per bed area of 10 m^2. The cabbage seedlings were transplanted in rows with a 30 cm spacing between plants and 50 cm spacing between rows.

Carrot was seeded in beds with 1 meter width and 10 m length with a 50 cm spacing between beds with a seeding rate of 26 kg ha^{-1}. The oats-vetch was dribble seeded[5] in a mix of 90 kg ha^{-1} oats and 30 kg ha^{-1} vetch while oats was seeded at a rate of 100 kg ha^{-1}in the oats plots. The 100m^2 plot of fodder was planted with oats-vetch in 2015 and harvested only ones (i.e. single cut) whereas in 2016 the 100m^2 was divided into four treatments: oats single cut (oats SC), oats multiple cut (oats MC), oats-vetch single cut (oats-vetch SC) and multiple cut (oats-vetch MC). The multiple cut treatment contained 3 cuts of fodder during the growing period at an interval of 45 days.

Table 4: Type of crops grown and their respective (trans)planting dates and length of growth period as well as N and P applied (kg ha^{-1}).

Technology	Type of crop	Date of sowing/transplanting	Fertilizer applied (kg ha^{-1})		length of growing period
			N	P	
Solar Pump	Cabbage	20/01/2016-26/01/2016	100	138	111-133
	Carrot	20/01/2016-26/01/2016	75	104	142-167
	Oats SC[1]	10/01/2016-20/01/2016	18	46	118-121
	Oats MC[1]	10/01/2016-20/01/2016	18	46	161-171
	Oats-vetch SC[1]	10/01/2016-20/01/2016	18	46	120-130
	Oats-vetch MC[1]	10/01/2016-20/01/2016	18	46	161-171
Drip	Cabbage	13/02/2016-10/03/2016	100	138	86-121
	Carrot	13/02/2016-10/03/2016	75	104	121-136
Rope and washer	Cabbage	01/01/2016-03/01/2016	100	138	103-135
	Carrot	14/01/2016-30/01/2016	75	104	116-166
	Oats SC[1]	10/01/2016-23/01/2016	18	46	117-121
	Oats MC[1]	10/01/2016-23/01/2016	18	46	144-161
	Oats-vetch SC[1]	05/04/2015-12/05/2015	18	46	52-75
	Oats-vetch SC[1]	10/01/2016-23/01/2016	18	46	117-130
	Oats-vetch MC[1]	10/01/2016-23/01/2016			158-168
FTC	Cabbage	15/01/2016	35	48	124-124
	Carrot	15/01/2016	33	104	161-161
	Oats SC[1]	15/01/2016	18	46	131-131
Control	Cabbage	13/02/2016-10/03/2016	100	138	105-149
	Carrot	13/02/2016-10/03/2016	75	104	117-163

[1] SC refers to one cut while MC refers to multiple cut (i.e. total of three cuts during the cropping season)

The recommendation of ILRI, for the fodder species, and agronomic extension service of the woreda, for carrot and cabbage, were followed with regards to fertilizer quantity and application

[5] The normal seedling rate for oats-vetch mixed cropping is 75 kg ha^{-1} oats and 25 kg ha^{-1} vetch per hectare. However, to compensate for possible losses due to poor germination seeding rate was raised by ILRI. The seed rate for oats-vetch was the same for both years (2015 and 2016).

time. Fertilizer was applied during the seeding of oats-vetch, oats and carrots and 11-15 days after transplanting of cabbage. The amount of fertilizer applied for each technology was the same for a specific crop and land size. According to the recommendation, the amount of DAP and urea for cabbage was 300 kg $ha^{-1}$and 100 kg ha^{-1}; for carrot 225 kg $ha^{-1}$and 75 kg ha^{-1}; oats-vetch and oats was 100 kg $ha^{-1}$and 0 kg ha^{-1}, respectively.

Water used during nursery preparation

On 11th and 14th of October 2015 respectively two nursery beds were prepared to supply cabbage seedlings to the rope and washer, solar and FTC fields. The seedlings were transplanted between 15th of January and 3rd of February 2016 depending on farmers' preparedness. During the nursery stage the cabbage seedlings received 100 and 104 mm in nursery 1 and 2, respectively. Given the delay in the drip installation and the operation of the tractor mounted pump a third nursery was prepared on 21st of November 2015 and cabbage was transplanted on 13th to 15th of February 2016 to 11 farmers (3 MP with drip and 8 control) and on 10th of March 2016 to the remaining 3 drip farmers in Upper Gana. The delays for the MP with drip farmers in Upper Gana occurred due to challenges with the tractor mounted pump and the repair of the trailer for water delivery. The cabbage seedlings in third nursery received 89 mm up to 13th of February and 37 mm till 8th of March 2016. All other crops were directly seeded. Farmers who cultivated more than one crop in 2016 planted carrot and fodder around the same time as the cabbage was transplanted.

Monitoring irrigation and agronomic performance

Soil sampling and nutrient analysis

Soil samples were taken in Upper Gana[6] as part of the Innovation Laboratory for Small Scale irrigation project (ILSSI, USAID-FtF funded) by students from Arba Minch University (Table 5). Disturbed soil samples were taken from the top soil (0-20 cm) in 16 farmer fields and one in FTC. Samples were analysed on texture, bulk density total nitrogen (TN), organic matter (OM), potassium (K) and electrical conductivity (EC) using standard laboratory analysis at Arba Minch University. Potassium was analysed using an ammonium acetate extraction, total nitrogen using Kjeldahl method and organic matter using a back titration with 0.1M ferrous ammonium sulfate.

[6] In the first year samples were taken in Jawe but due to delays in laboratory analysis and inappropriate storage samples were discarded.

Table 5: Overview of the number of soil samples taken for each of the technology treatment.

Technology	Control	FTC	RW	Solar	Tractor mounted pump with drip
Number of samples	2	1	9	3	2

Using the textural, organic matter and EC results the field capacity (FC) and permanent wilting point (PWP) was estimated using the SPAW software following the Saxton method[7] (Keith *et al.*, 2006).

Soils ranged from sandy loam to clay loam-loam (Table 7). The estimated field capacity and wilting point followed the variability in organic matter and textural differences between the fields. Field capacity (FC) ranged between 23 and 36 % whereas permanent wilting point (PWP) ranged between 11 and 23 %. Assuming a root depth of 100 cm for oats, 60 cm for carrot and cabbage (Allen *et al.*, 1998) the estimated average total available water in the respective root zone is on average 87 ± 11 mm for vegetables and 145 ± 18 mm for oats. Using the depletion factor according to FAO 56 (Allen *et al.*, 1998) the readily available water or maximum allowable deficit would be 39 ± 5 mm for cabbage, 31 ± 4 mm for carrot and 80 ± 10 mm for oats. Results show that there is some variation on readily available water for the various crops among the farmers which will contribute to the difference in irrigation requirement.

Table 6: Overview of soil physico-chemical properties in Upper Gana (number of observations = 17).

	Min.	Max.	Mean ± SD[1]	CV (%)[1]
Bulk density (%)	0.99	1.83	1.3 ± 0.2	18
Field capacity (%)	22.5	36.3	32.3 ± 3.9	12
Permanent wilting point (%)	10.8	22.9	17.9 ± 3.2	18
Texture – Sand (%)	18.0	60.0	37.9 ± 9.5	25
Silt (%)	22.0	54.0	36.1 ± 7.7	21
Clay (%)	14.0	36.0	26.0 ± 6.1	23
Electrical conductivity (dS m^{-1})	0.04	0.59	0.19 ± 0.15	79
Organic Matter (%)	3.1	5.6	4.3 ± 0.8	19
Total Nitrogen (%)	0.12	0.36	0.22 ± 0.07	31
K (cmol kg^{-1})	0.31	1.22	0.63 ± 0.27	42

[1] SD = standard deviation; CV = coefficient of variation

[7] SPAW stands for Soil-Plant-Air-Water Field & Pond hydrology Software version 6.02.75, © USDA Agricultural research service in cooperation with the Department of Biological Systems Engineering Washington State University which is freely available at: https://hrsl.ba.ars.usda.gov/SPAW/SPAWDownload.html

Salinity levels found in Upper Gana are below the salt tolerance levels of cabbage (i.e. 1.2 dS m^{-1}) and carrot (i.e. 1.0 dS m^{-1}) (Tanji and Kielen, 2002). Coefficient of variation are found moderate aside from the electrical conductivity (EC). Although the measured electrical conductivity levels are below the threshold levels for cabbage and carrot there was a high variability found among the various samples. The variation might be inherent linked to the inherent soil fertility differences and/or soil management given that the majority of the irrigation fields are found surrounding the homestead and receive higher organic inputs. Given that no water samples were taken the linkage of soil – EC values to the quality of irrigation and household irrigation history could not be verified.

A further insight into the soil properties per technology group does indicate some variability within and among the water lifting groups for electrical conductivity, organic matter, field capacity, wilting point (Table 7).

Table 7: Mean and standard deviation for the soil physico-chemical properties per technology group in Upper Gana.

Technology[1]	Control	FTC	RW	Solar	Tractor mounted pump with drip
Number of observations	2	1	9	3	2
Bulk density (%)	1.1 ± 0.1	1.28	1.3 ± 0.3	1.3 ± 0.1	1.1 ± 0.2
Field capacity (%)	33.8 ± 1.4	35.9	30.8 ± 4.8	33.7 ± 2.3	33.15 ± 1.6
Permanent wilting point (%)	18.2 ± 2.7	22.9	17.3 ± 3.7	18.1 ± 1.2	17.5 ± 3.2
Texture – Sand (%)	34.0 ± 0	38	41.6 ± 10.3	31.3 ± 12.2	35.0 ± 1.4
Silt (%)	40.0 ± 5.7	26	33.0 ± 5.1	43.3 ± 11.0	40.5 ± 7.8
Clay (%)	26.0 ± 5.7	36	25.4 ± 7.0	25.3 ± 3.1	24.5 ± 6.4
Electrical conductivity (mS cm^{-1})	0.16 ± 0.11	0.13	0.11 ± 0.07	0.34 ± 0.13	0.43 ± 0.22
Organic Matter (%)	5.0 ± 0.4	3.6	3.8 ± 0.53	5.2 ± 0.69	5.0 ± 0.14
Total Nitrogen (%)	0.22 ± 0.01	0.21	0.18 ±0.04	0.33 ± 0.05	0.24 ± 0.02
K (cmol kg^{-1})	0.71 ± 0.4	0.70	0.48 ± 0.13	0.87 ± 0.26	1.04 ± 0.26

[1] Control= farmers who have no water lifting technology and fetch water from their own shallow well, have a pond or fetch water from a river; FTC = research plot at farmer training center; RW = rope and washer; Tractor mounted pump with drip = the combination of tractor mounted pump and service provision of irrigation water for drip

Given the limited number of observations for the control and the MP with drip group no statistical tests could be performed to verify whether significant differences between the group occur as differences between the group might influence the analysis on irrigation amount (i.e. due to FC and PWP differences) and eventual yield (i.e. due differences in water holding capacity and soil fertility).

Discharge calibration and irrigation quantification

Discharge calibrations were conducted for solar pump, rope & washer pump, the tractor motorized pump and the emitter discharge of drip kits. Discharge calibration for rope & washer, solar and tractor mounted pumps were estimated by recording the time to fill a bucket with known volume. For rope & washer and solar bucket volumes ranged between 15 and 30 L whereas for the tractor mounted pump a container of 500 L was used. The discharge was calculated as the ratio of bucket/container volume to the total time taken to fill the bucket. For the drip[8] emitter discharge calibration, three cups with known volume were used installed under emitters at 0, 5 and 10 m along the drip lines.

Figure 5: Discharge calibration rope & washer (left) and solar pump (right) (photo credit: Desalegn Tegegne).

The irrigation volume was noted during each event by counting the number of buckets applied for the rope and washer farmers and control farmers, monitoring the duration of time and the known discharge for the solar pumps and counting the drip tanks for the drip farmers.

Monitoring of agronomic performance

The length of the various crop stages for fodder, cabbage and carrot were monitored as to calculate the total amount of water applied per stage. Fresh yields were measured at harvest and sub-samples to determine the moisture and total nitrogen content were analysed at ILRI- Addis Ababa facilities. Afterwards dry matter yield was calculated.

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[8] More information on the drip installation and functioning of the service providers can be found in the service provision report from the International Water Management Institute.

Labour and profit

Farmers were asked to record the time spend on all irrigation and agronomic activities throughout the year. Additional, recordings on seed cost, fertilizer and pesticides were captured to estimate the total cost of production and assess potential differences in profitability using less labour intensive irrigation technologies.

Data analysis

Data on irrigation and agronomic performance were analysed on normality. Differences between treatments were assessed using the Proc MIXED procedure in SAS University Edition (Using the virtual Machine Platform: VMWare Workstation 12). The crop, site and technology were taken as fixed effects while farmers within one group were treated as repetition to assess the impact of the water lifting technologies. Gender, effective rainfall and well depth was added as random effects but was not found to significantly improve the models. For the assessment of WFD on irrigation, yield and irrigation water productivity the crop, technology (i.e. rope and washer or tap water for the FTC- research plot) and water management were taken as fixed factors. Differences between groups were analysed using the least square means comparison (LS-means function in SAS). Homogenous of variance and normality of the residuals were checked for each model run. In case of non-normality data were log-transformed prior to the analysis.

The profit of production was estimated for both carrot and cabbage using data on labour, which included all agronomic activities (fertilizer application, weeding, pesticide application, ploughing, irrigating, harvesting etc.), input costs (fertilizer, pesticides) and operation & maintenance of the technology. Labour was converted using a daily wage of 2.73 USD/day[9]. The production value was estimated using the measured yield and the market price for the vegetables and subtracting it with production costs.

[9] The daily wage is 60 birr with a conversion of 1 USD=22 birr.

Results and discussion

Evaluation of water lifting and application technologies

Discharges estimated from the various water lifting technologies

During the irrigation season the discharge to extract water using one of the water lifting devices was calibrated (Table 8).

Table 8: Overview of the discharge ($l\ min^{-1}$) found for rope and washer (rope and washer), solar pump and tractor mounted pump

Technology[1]	RW	Solar pump	Tractor mounted pump – Jawe	Tractor mounted pump– Upper Gana
N	15	27	18	18
Min ($l\ min^{-1}$)	6.7	11.3	125	125
Max ($l\ min^{-1}$)	20.0	22.5	250	167
Mean ± SD[2] ($l\ min^{-1}$)	14.0 ± 6.0[a]	15.1 ± 2.4[a]	188 ± 48[b]	150 ± 21[b]
CV (%)	42	16	26	14

[1] RW = rope and washer; Tractor mounted pump with drip = the combination of tractor mounted pump and service provision of irrigation water for drip. The calibration data for rope and washer are for Jawe only.
[2] Different superscript within the row points towards significant difference in discharge at a p-level= 0.05.

No differences were found between the rope and washer and the solar pump ($p>0.05$). Furthermore, the few data points for solar pump did not show a significant correlation with the hourly radiation observed by the CIAT weather stations on site. Most likely a finer resolution of solar radiation data is needed to establish a relationship between discharge, solar radiation and water levels in shallow wells. On the other hand the discharge by the tractor mounted pump is around a factor 10 larger than the manual rope and washer and the solar pump. The tractor mounted pump filled the 500 L water tanks in 2 to 4 minutes depending on the head between the water source (i.e. river) and the tank.

Irrigation water applied per event

The supplementary irrigation applied per event for the various crops is low (Table 9). Especially vegetables receive around 3 to 5 mm per event which is roughly 1 to 1.5 times the daily potential evapotranspiration rate. The amount of water applied per irrigation event by the farmer in FTC did differ significantly from those applied by the control and technology groups in Jawe and Upper Gana (Table 9). While the FTC made use of tap water, the other technologies used either surface water from rivers and ponds (e.g. control and tractor mounted pump) or groundwater from shallow wells (e.g. rope and washer, solar pump and control) (Table 9). The difference of the various technologies, with the exception of drip, could be related to differences in water availability, in the case of the shallow wells, or related to water allocation preferences and labour involved in water lifting (rope and washer) or fetching (control farmers). The water application for drip was defined by the tank volume and the emitter rate which constantly supplied 4.0 mm to the fields. The water application for solar was not higher compared to the rope and washer which might indicate that either labour involved in irrigating with a hose or solar radiation was restricting longer application periods and hence larger volumes. Given that there is no power storage the discharge is directly influenced by the prevailing solar radiation at that given time, hence if discharges are low during low solar radiation periods, labour constraints might influence the amount of time a farmer spent irrigating.

The sampling size included too few female irrigators to assess whether gender had a significant influence in the amount of water applied for each of the technologies (13 female irrigators from which 9 had a rope and washer and 4were control farmers). Within both the rope and washer and control group no significant difference was found between male and female irrigators in amount of water applied for fodder, cabbage or carrot. Furthermore the well depth that ranged between 5 to 10 m did not have a significant effect on the total amount of water applied for any of the 3 crops.

Table 9: The number of observations (N), average (Mean), standard deviation (SD) and coefficient of variation (CV) for the irrigation amount (mm) applied per event for the various technologies and irrigated crops across both sites Jawe and Upper Gana.

				Irrigation water applied per event (mm)					
Crop[1]	Year	Growth period		Control SW & GW[4]	FTC DW[4]	RW GW[4]	Solar GW[4]	MP & drip[5] SW[4]	*Average[6]*
Oats-vetch SC[2]	2015	56-72	N	-	-	294	-	-	294
			Mean ± SD (mm)	-	-	2.0 ± 0.4	-	-	2.0 ± 0.4[a]
			CV (%)	-	-	*21*	-	-	*21*
Cabbage[3]	2016	86-149	N	132	61	142	69	98	502
			Mean ± SD (mm)	3.6 ± 0.8[a]	8.5 ± 1.3[b]	3.9 ± 0.7[a]	4.0 ± 0.9[a]	4.0 ± 0.0[a]	4.4 ± 1.7[b]
			CV (%)	*23*	*18*	*18*	*23*	*0*	*4*
Carrot[3]	2016	116-167	N	133	56	158	93	100	546
			Mean ± SD (mm)	3.4 ± 0.8[c]	9.8 ± 1.6[b]	4.1 ± 0.9[a]	3.9 ± 1.1[a]	4.0 ± 0.0[a]	4.5 ± 2.1[b]
			CV (%)	*23*	*16*	*22*	*28*	*0*	*46*
Oats SC[2]	2016	117-121	N	-	55	86	48	-	189
			Mean ± SD (mm)	-	7.0 ± 1.0[b]	7.9 ± 1.7[ab]	8.7 ± 2.8[b]	-	7.9 ± 2.0[c]
			CV (%)	-	*15*	*21*	*32*	-	*26*
Oats MC[2]	2016	144-161	N	-	-	171	48	-	219
			Mean ± SD (mm)	-	-	4.6 ± 0.8[a]	5.5 ± 1.0[b]	-	4.8 ± 0.9[b]
			CV (%)	-	-	*17*	*18*	-	*19*
Oats-vetch SC[2]	2016	117-121	N	-	-	154	48	-	216
			Mean ± SD (mm)	-	-	8.8 ± 1.5[a]	8.7 ± 1.2[a]	-	8.8 ± 1.4[c]
			CV (%)	-	-	*17*	*14*	-	*16*
Oats-vetch MC[2]	2016	158-162	N	-	-	171	48	-	219
			Mean ± SD (mm)	-	-	4.8 ± 0.9[a]	5.4 ± 0.8[a]	-	5.0 ± 0.9[b]
			CV (%)	-	-	*18*	*15*	-	*18*

[1] Differences in superscript within the row indicates significant differences in irrigation applied per event between technologies for the same crop at p=0.05 (this excludes the average column); [2] SC refers to one cut while MC refers to multiple cut (i.e. total of three cuts during the cropping season); [3]Drip kits were delayed which resulted in later transplanting dates for carrot and cabbage compared to other technologies. Hence, growth period is shorter for drip compared to the other water lifting treatments; [4] SW, GW and DW refers to surface water, groundwater and drinking water (i.e. tap water), respectively; [5] MP = tractor mounted pump; [6] Average and standard deviation of irrigation amount applied for all technologies. Differences in superscript within the column indicates significant differences in irrigation applied per event between the different crops at p=0.05.

Effect of water lifting and application on the irrigation of high value crops

Irrigation during the cropping period

Given the bi-modal rainfall pattern the irrigation was predominantly carried out in January and February. As difference in rainfall, irrigation and potential evapotranspiration were minimal between both villages. Hence, the data from both sites were pulled together to assess the effect of the various technologies on total water received by the various crops (Table 10). The differences in effective rainfall for the various crop were influenced by their growing period and transplanting/sowing date. However, despite the differences in sowing dates for a particular crop, the effective rainfall and potential evapotranspiration did not differ strongly among the water lifting technology groups. Given the relatively small fraction of supplementary irrigation towards the total water received by the crops (i.e. irrigation and effective rainfall), the amount did not differ between the treatment groups despite the differences in cropping length and planting dates. Irrigation only contributed on average to 19% of the total water applied. The amount of water irrigated on average was 45 mm for oats-vetch SC in 2015 to 83 mm for cabbage, 86 mm for carrot, 71 mm for oats MC, 73 mm for oats-vetch MC, 121 mm for oats SC and 124 mm for oats-vetch in 2016 (Figure 6 and Table 10). The big difference between both years for the single cut oats-vetch lies in the substantial longer growing period of the fodder in 2016 (Table 4). Oats-vetch in 2015 was planted late April and harvested fresh after 58 to 72 days of growing period whereas in 2016 the growth period was double ranging between 117 to 131 days. Hence, the amount of water a crop received was relatively the same but the portion of irrigation water and effective rainfall or potential evapotranspiration differed slightly in some particular cases (e.g. FTC).

Differences among the various stages did not result in different total irrigation amounts, applied through the season, using any particular technology with the exception of the FTC trial for cabbage and with a slight lower application for the control group when irrigating carrot (Table 10 and Figure 6).

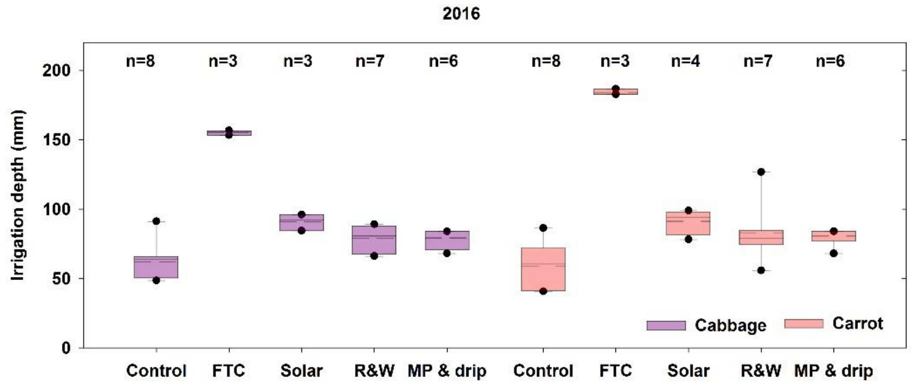
Table 10: Average total irrigation (I, mm), effective rainfall ($R_{eff, mm}$), potential transpiration (PET, mm) and their respective ratios for the various technology groups and crops in 2015 and 2016.

		Growing period	Season	Control[1]	FTC[1]	RW[1]	Solar[1]	MP with drip[1]
Cabbage	I (mm)	120	2	59 ± 17[b]	155 ± 2[a]	79 ± 10 [b]	91 ± 6[b]	79 ± 7[b]
	R_{eff} (mm)		2	427 ± 65[a]	363 ± 0[a]	363 ± 27[a]	368 ± 25[a]	323 ± 36[a]
	I+R_{eff} (mm)		2	486 ± 61[a]	518 ± 2[a]	442 ± 33[a]	459 ± 30[a]	402 ± 36[a]
	PET (mm)		2	433 ± 43[a]	414 ± 0[a]	426 ± 31[a]	426 ± 47[a]	344 ±73[a]
	I/I+R_{eff}		*2*	*0.12*	*0.30*	*0.18*	*0.20*	*0.20*
	I/PET		*2*	*0.14*	*0.37*	*0.19*	*0.21*	*0.24*
	I+R_{eff}/PET		*2*	*1.12*	*1.25*	*1.04*	*1.08*	*1.20*
Carrot	I (mm)	143	2	56 ± 18[c]	184 ± 2[a]	83 ± 21[bc]	91 ± 9[a]	81 ± 6[a]
	R_{eff} (mm)		2	495 ± 57[a]	486 ± 0[ab]	421 ± 34[b]	463 ± 64[b]	437 ± 20[ab]
	I+R_{eff} (mm)		2	551 ± 45[a]	670 ±2[a]	504 ± 42[a]	554 ± 56[a]	518 ± 25[a]
	PET (mm)		2	467 ± 44[a]	460 ±0[a]	470 ± 59[a]	506 ± 17[a]	413 ± 47[a]
	I/I+R_{eff}		*2*	*0.10*	*0.27*	*0.16*	*0.17*	*0.16*
	I/PET		*2*	*0.12*	*0.40*	*0.18*	*0.18*	*0.20*
	I+R_{eff}/PET		*2*	*1.19*	*1.46*	*1.09*	*1.10*	*1.27*
Oats SC	I (mm)	121	2	-	126 ± 2[a]	115 ±19[a]	140 ± 2[a]	-
	R_{eff} (mm)		2	-	395 ± 0[a]	346 ± 6[a]	336 ± 5[a]	-
	I+R_{eff} (mm)		2	-	521± 2[a]	460 ± 23[a]	476 ± 3[a]	-
	PET (mm)		2	-	460 ± 0[a]	421 ± 14[a]	412 ± 12[a]	-
	I/I+R_{eff}		*2*	-	*0.24*	*0.25*	*0.29*	-
	I/PET		*2*	-	*0.27*	*0.27*	*0.34*	-
	I+R_{eff}/PET		*2*	-	*1.13*	*1.10*	*1.16*	-
Oats MC	I (mm)	158	2	-	-	65 ±10[a]	87 ± 10[a]	-
	R_{eff} (mm)		2	-	-	458 ± 29[a]	457 ± 2[a]	-
	I+R_{eff} (mm)		2	-	-	523 ± 34[a]	544± 24[a]	-
	PET (mm)		2	-	-	532 ± 19[a]	525 ± 19[a]	-
	I/I+R_{eff}		*2*	-	-	*0.12*	*0.16*	-

		Growing period	Season	Control[1]	FTC[1]	RW[1]	Solar[1]	MP with drip[1]
	I/PET		*2*	-	-	*0.12*	*0.17*	-
	I+Reff/PET		*2*	-	-	*0.98*	*1.04*	-
Oats-vetch SC	I (mm)	64	1	-	-	45 ± 11	-	-
	Reff (mm)		1	-	-	176 ± 30	-	-
	I+Reff (mm)		1	-	-	220 ± 25	-	-
	PET (mm)		1	-	-	167 ± 27	-	-
	I/I+Reff		*1*	-	-	*0.21*	-	-
	I/PET		*1*	-	-	*0.28*	-	-
	I+Reff/PET		*1*	-	-	*1.33*	-	-
Oats-vetch SC	I (mm)	121	2	-	-	119 ±16[a]	139 ± 8[a]	-
	Reff (mm)		2	-	-	346 ± 6[a]	336 ± 5[a]	-
	I+Reff (mm)		2	-	-	465 ± 19[a]	475 ± 12[a]	-
	PET (mm)		2	-	-	419 ± 17[a]	412 ± 12[a]	-
	I/I+Reff		*2*	-	-	*0.26*	*0.29*	-
	I/PET		*2*	-	-	*0.29*	*0.34*	-
	I+Reff/PET		*2*	-	-	*1.11*	*1.15*	-
Oats-vetch MC	I (mm)	161	2	-	-	68 ± 9[a]	86 ± 4[a]	-
	Reff (mm)		2	-	-	466 ± 18[a]	457 ± 21[a]	-
	I+Reff (mm)		2	-	-	534 ± 23[a]	543 ± 22[a]	-
	PET (mm)		2	-	-	536 ± 18[a]	525 ± 19[a]	-
	I/I+Reff		*2*	-	-	*0.13*	*0.16*	-
	I/PET		*2*	-	-	*0.13*	*0.16*	-
	I+Reff/PET		*2*	-	-	*1.00*	*1.04*	-

[1] No water lifting technology (i.e. control), rope and washer (RW), solar and tractor mounted pump (MP) with drip farmers, FTC refers to farmer training center. No statistical assessments were conducted as differences were observed between sites for some of the technologies and crops.

a)



b)

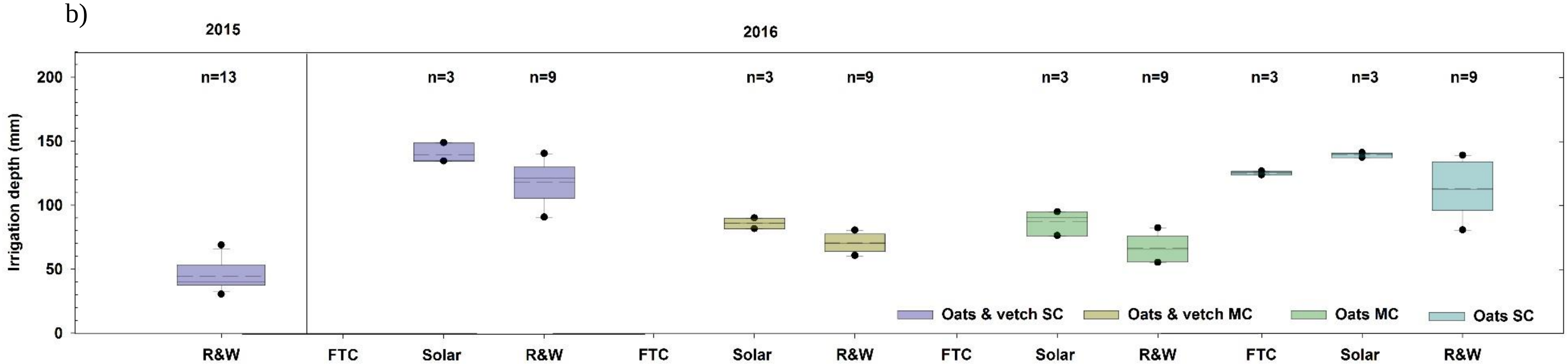


Figure 6: Total supplementary irrigation depth applied to a) cabbage, carrot and b) oats, oats-vetch single and multiple cut using no water lifting technology (i.e. control), rope and washer (RW), solar and tractor mounted pump (MP) with drip farmers. Results from the farmer training center (FTC) is plotted for comparison. Data only include those from the water management treatment representing farmers' practice.

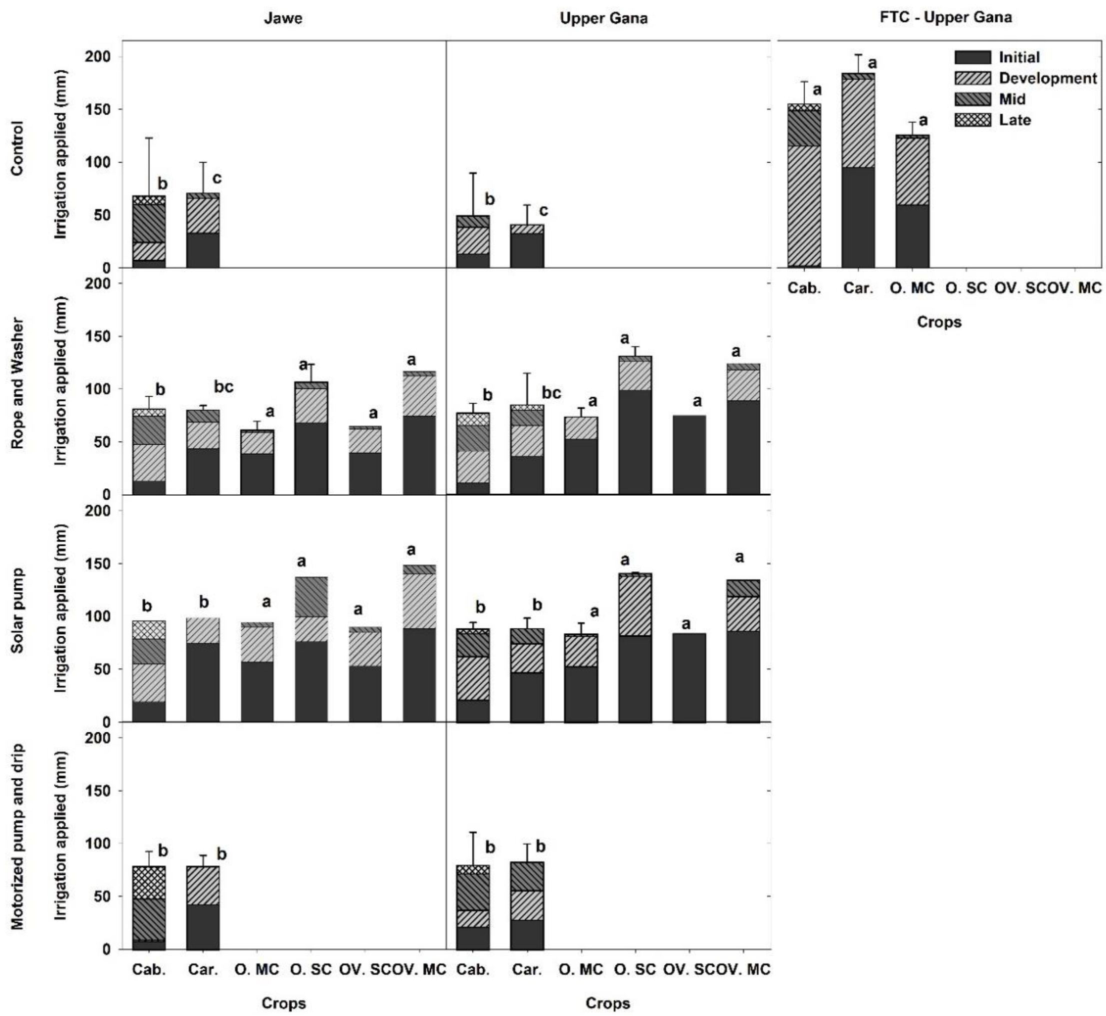


Figure 7: Stacked bar chart showing the amount of irrigation water applied (mm) for each cropping stage (i.e. initial, development, mid and late stage) for control farmers (top left and middle), the farmer training center (FTC, research plot, top right) and farmers using rope and washer, solar and motorized pump (i.e. tractor mounted pump) + drip kits for Jawe (left) and Upper Gana (middle). The error bars show the total standard deviation of the overall irrigation amount based on all the farmers using that technology within that site. There are no error bars for the solar pump in Jawe as this is a single farmer. Letters for the same crop show significant differences between the site and technologies at a p-level = 0.05. The crops are: ccabbage (cab.), carrot (car.), oats multiple cut (O. MC), oats single cut (O. SC.), oats-vetch single cut (OV. SC) and oats-vetch multiple cut (OV. MC.). Data is only shown for 2016.

The amount of water applied to carrot and cabbage by a single farmer in the research – FTC plot was higher than those observed in the rope and washer, solar or drip groups. The irrigation in FTC was conducted using tap water which was not affected by occasional challenges in water availability of shallow groundwater. While there is still labour involved in irrigating fields using tap water there is a potential reduction in labour when it comes to water lifting.

Effect of water lifting technologies on irrigation labour

Similarly to the analysis of irrigation water applied per event, no differences were observed in the amount of water applied throughout the season by male and female irrigators for the control and the rope and washer group. This could indicate that rope and washer did provide similar constraints and opportunities to both irrigator groups with regards to water lifting.

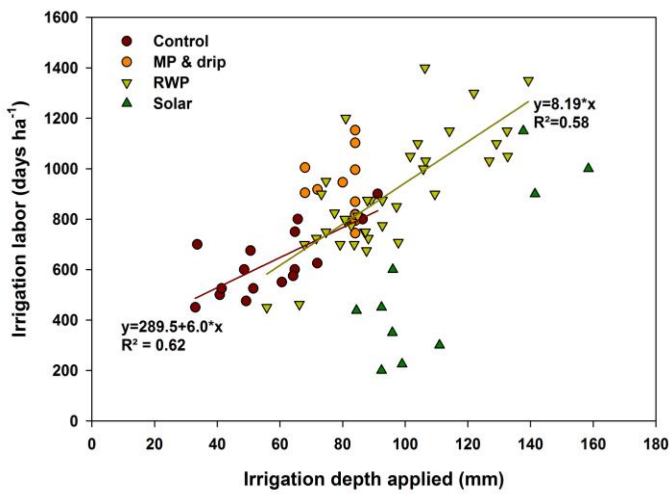


Figure 8: Irrigation depth applied during 2016 and associated number of irrigation labour days to irrigate one hectare.

The total irrigation labour for each of the particular technologies and corresponding application of irrigation water showed that for both the control group and the rope and washer the labour is relatively the same (Figure 8). This would mean that using a rope and washer does not decrease the amount of labour going into irrigation compared to when you have no water lifting technology. Results seem to indicate that, when using a solar pump the labour to apply the same amount of irrigation depth would result in less labour needed. This is mainly linked to the fact that no labour is needed to lift the water, as compared to the rope and washer, and hence only labour is needed to apply the water which is depending on the discharge of the pump and hence solar radiation and well depth. However, the data points available for solar are to limited for regression analysis. It is interesting to observe that the drip kits filled using a tractor mounted pump resulted in equal to slightly higher labour compared to the control and rope and washer when irrigating a particular amount. This is explained by the distance of the household to the water source. The analysis takes into account the labour of lifting, transporting and applying the water. Whereas the labour involved in water application (drip) as well as lifting (tractor mounted pump) is relatively low for irrigation, the labour involved in transporting the water (i.e. distance to the water source) is rather significant in this particular case. This shows that in order for drip kits to reduce labour in irrigation the portion attributed to transporting water needs to be reduced.

Effect of water lifting on yield

Fresh yields obtained for the crops in 2015 and 2016 varied strongly among farmers both within a technology group as well as between technology groups but not between villages for the same crop and technologies (Figure 9). The median yield for oats-vetch production using rope and washers in 2015 was, 58.9 t ha^{-1} fresh or 15.2 t ha^{-1} dry biomass from which 12.1 t ha^{-1} dry matter oats and 3.2 t ha^{-1} dry matter vetch. In 2016 the single oats trial resulted in 27.2 t ha^{-1} (6.0 t ha^{-1} dry matter) in the single cut, the oats-vetch plots in 2016 yielded 28.2 (5.7 t ha^{-1} dry matter) in the single cut. The multiple cut plots were harvested irregularly by farmers and not sufficient data is available. Hence, the multiple cut plots are excluded for further analysis. The dry matter weight of 15.2 t ha^{-1} obtained in 2015, exceed the average expected yield of an oats-vetch mixture. According to ILRI research oats in its pure stand can yield up to 8 ton t ha^{-1} and vetch 3-4 tons t ha^{-1} dry matter in Ethiopia whereas the oats-vetch mixture can yield up to 6-7 t ha^{-1} under optimum condition. However, the normal seedling rate for oats-vetch mixed cropping was increased to 90 kg oats and 30 kg vetch per hectare. While the same seeding rate was taken in 2016, results are lower but comparable to those reported in Bezabih *et al.* (2016).

Median for cabbage fluctuated between technologies ranging from a 34.8 t ha^{-1} fresh yield for the control group to 37.3 t ha^{-1} for the rope and washer group and a high 61.4 t ha^{-1} (4.6 t ha^{-1} dry matter) in the by service provision-drip irrigated plots. The obtained median yield for carrot followed similar trends with the lowest yield observed in the control group 33.1 t ha^{-1} and the highest in the service provision-drip plots (67.4 t ha^{-1} fresh) (Figure 9 and Table 11).

Farmers in Upper Gana and Jawe produced equally well for any of a given technology and hence both sites were combined for further analysis. The variation observed within each technology group was highest for rope and washer for carrots, cabbage and oats-vetch in 2015. The variation for the control and solar group was additionally remarkably high for carrot whilst for cabbage only the control group had a considerable variability aside from the rope and washer groups (Figure 9). Variation in yield across the various sites, within and between technology groups (Table 11) could be influenced by potential differences in soil fertility, crop and overall agronomic management. Due to a lack of sufficient soil data the random effect of soil fertility variation on yield could not be assessed.

The results from FTC were relatively inconsistent with low yield for cabbage but reasonably high yields for carrot compared to the other farmer plots. Farmers using a solar pump obtained higher yields when growing cabbage but performed equally with the other (non)technology groups when growing carrot. Using a manual water lifting device (RW) did not result in higher yields compared to the control group for any of both vegetables. The lack of better performance when using a rope and washer or solar pump compared to the control group could be related to water shortages experienced at the onset of the irrigation season (i.e. after transplanting). Water shortages were present in Jawe and Upper Gana for some of the rope and washer and solar farmers in January and February. Given the low rainfall received in 2015 farmers experienced water availability challenges in the beginning of 2016. Both technologies rely on shallow groundwater whereas the drip was filled using surface water from the river through a tractor mounted pump. Equally, the majority of control farmers extract water from the river in Jawe and in some cases in Upper Gana. The seven farmers using rope and washers who experienced water shortage in their wells sought other alternatives (e.g. surface water from streams) during the cropping season. The amount of water supplied by alternative sources ranged between 13% to 38% of the total supplementary irrigation amounts applied throughout the season. Removing the farmers experiencing water stress during the beginning of 2016 did not change the overall conclusions regarding the effect of water lifting technologies on yield. However, it did reduced variability and increased the average yield for cabbage and carrot in the rope and washer group in Jawe.

For the rope and washer as well as the control group no difference between male and female irrigators were found for cabbage and carrot. In this particular case study it seems that female and male irrigators produce similar quantities of the product. However, as mentioned earlier the number of observations was limited. Furthermore, frequently different household members contribute to irrigation. Especially in female headed households when male household members (son, brother etc.) are present they participate in irrigation. Hence, it is challenging to evaluate whether the observed irrigation quantities and corresponding yields in this case are true representations of female and male irrigators.

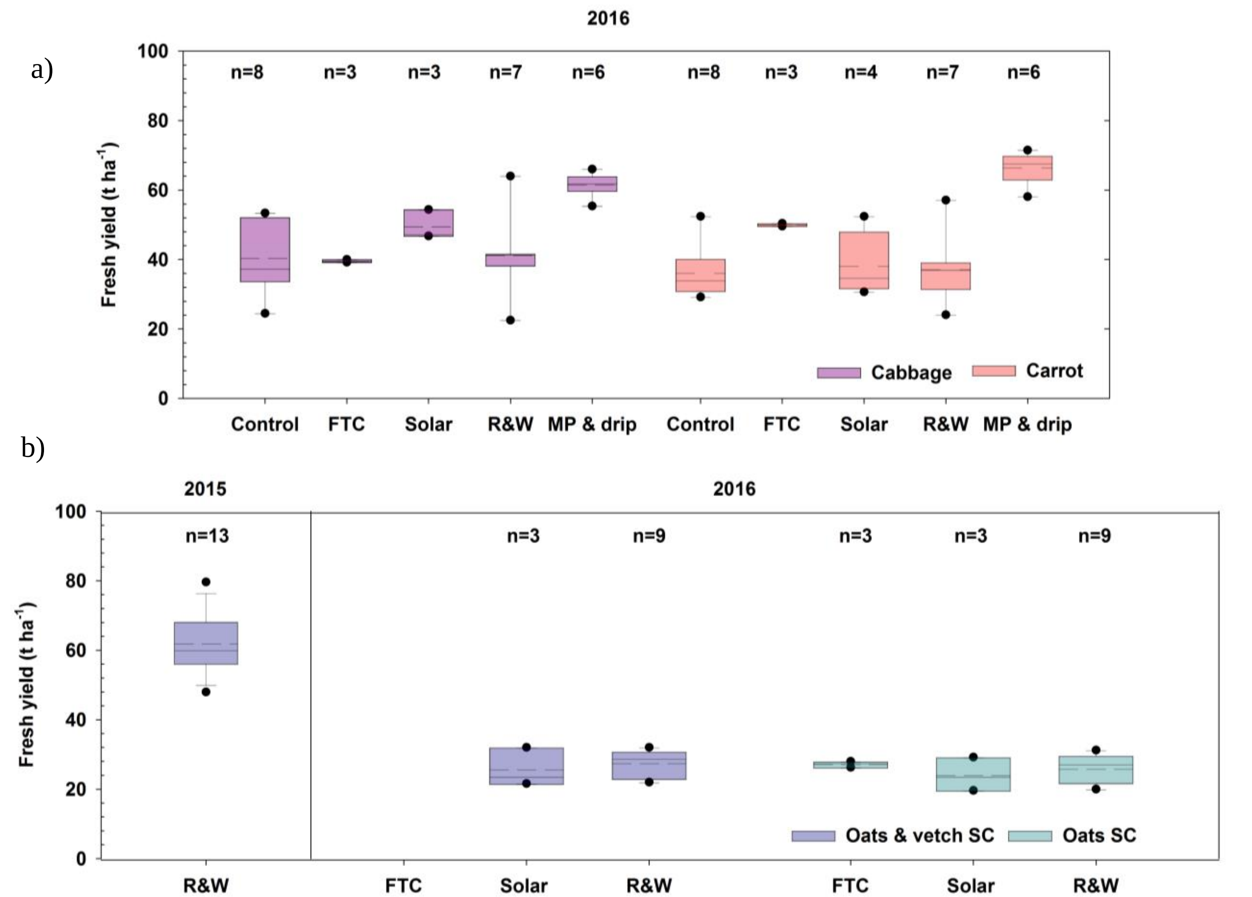


Figure 9: Fresh yield obtained (t ha^{-1}) for a) cabbage, carrot and b) oats, oats-vetch single cut using no water lifting technology (i.e. control), rope and washer (RW), solar and tractor mounted pump (MP) with drip farmers. Results from the farmer training center (FTC) is plotted for comparison. Data only include those from the water management treatment representing farmers' practice.

Table 11: Average and standard deviation of the fresh yield obtained (t ha^{-1}) for the various water lifting treatments (i.e. by control (i.e. no water lifting technology), rope and washer (RW), solar and tractor mounted pump (MP) with drip farmers as well as the research plot at the farmer training center (FTC). Data only include the water management treatment representing farmers' practice.

Crop[1]	Year	Growth period		Fresh yield (t ha^{-1}) Control	FTC	RW	Solar	MP & drip[5]	*Average[6]*
				SW & GW[4]	DW[4]	GW[4]	GW[4]	SW[4]	
Oats-vetch SC[2]	2015	56-72	N	-	-	13	-	-	13
			Mean ± SD (mm)	-	-	61.9 ± 8.7	-	-	61.9 ± 8.7[a]
			CV (%)	-	-	*14*	-	-	*14*
Cabbage[3]	2016	86-149	N	8	3	7	3	6	27
			Mean ± SD (mm)	40.0 ± 10.1[c]	39.5 ± 0.4[c]	41.2 ± 12.1[bc]	49.5 ± 4.3[b]	61.6 ± 5.7[a]	46.2 ± 12.0[a]
			CV (%)	*26*	*1*	*28*	*7*	*6*	*26*
Carrot[3]	2016	116-167	N	8	7	7	4	6	28
			Mean ± SD (mm)	36.1 ± 7.6[c]	50.0 ± 0.4[b]	37.2 ± 10.1[c]	38.1 ± 1.8[c]	66.4 ± 4.5[a]	44.6 ± 14.3[a]
			CV (%)	*21*	*1*	*27*	*25*	*7*	*32*
Oats SC[2]	2016	117-121	N	-	9	9	3	-	15
			Mean ± SD (mm)	-	27.3 ± 0.9[a]	25.9 ± 4.1[a]	24.1 ± 4.8[a]	-	25.8 ± 3.8[b]
			CV (%)	-	*3*	*16*	*20*	-	*15*
Oats-vetch SC[2]	2016	117-121	N	-	-	9	3	-	12
			Mean ± SD (mm)	-	-	27.6 ± 3.9[a]	25.7 ± 5.5[a]	-	27.1 ± 4.2[b]
			CV (%)	-	-	*14*	*21*	-	*15*

[1] Differences in superscript within the row indicates significant differences in irrigation applied per event between technologies for the same crop at p=0.05 (this excludes the average column); [2] SC refers to one cut while MC refers to multiple cut (i.e. total of three cuts during the cropping season); [3]Drip kits were delayed which resulted in later transplanting dates for carrot and cabbage compared to other technologies. Hence, growth period is shorter for drip compared to the other water lifting treatments; [4] SW, GW and DW refers to surface water, groundwater and drinking water (i.e. tap water), respectively; [5] MP = tractor mounted pump; [6] Average and standard deviation of irrigation amount applied for all technologies. Differences in superscript within the column indicates significant differences in irrigation applied per event between the different crops at p=0.05.

Effect of water lifting on water productivity

A high variability of irrigation water applied and dry matter yield was obtained for all technologies and both for vegetables and fodder (Figure 10) which resulted in a large variability of water productivity. Despite the irrigation depth applied to fodder being double that of vegetables the dry matter yield of oats and oats-vetch light within a similar range as those obtained for carrot and cabbage (Figure 10).

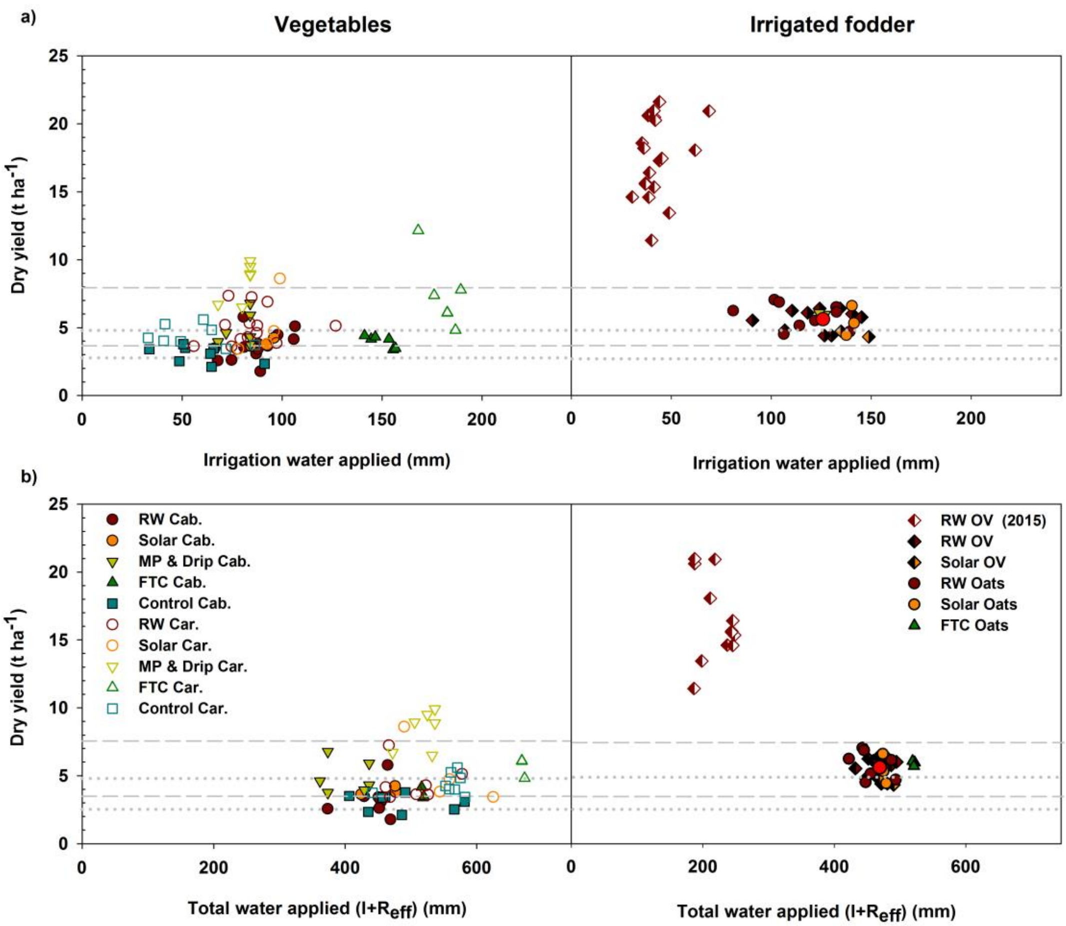


Figure 10: Scatter plot of dry matter yield (t ha^{-1}) vs. irrigation (mm) (a) or total amount of water (irrigation and effective rainfall, mm) applied (b) throughout the season; Cab. refers to cabbage and Car. to carrot. For fodder all data are from 2016 except the RW OV (2015) (red lined half open diamond). For the fodder: Oats refers to oats, OV to oats-vetch, data only refer to single cut. Technologies: RW = rope and washer, MP with drip = tractor mounted pump with drip and FTC = farmer training center. The dotted lines show one standard deviation of the mean representing the upper and lower limit for cabbage while the dashed lines shows the upper and lower limit for carrot in both the vegetable and the fodder graphs. The red dot represents the average dry matter of 5.6 t ha^{-1} based on Bezabih *et al.* (2016) plotted against the average irrigation.

Hence, similar trends for irrigation water productivity were found as those observed during the yield analysis (see section above) where a difference was found between the crops but the effect of water lifting technology on water productivity was less pronounced (Figure 11). The variability of irrigation water, total water, economic dry matter irrigation water and economic dry matter water productivity between the technology groups as well as within the group is very high as various factors (i.e. crop management, time of irrigation application, rainfall variability, fertilizer application method, inherent soil fertility) influence the overall productivity.

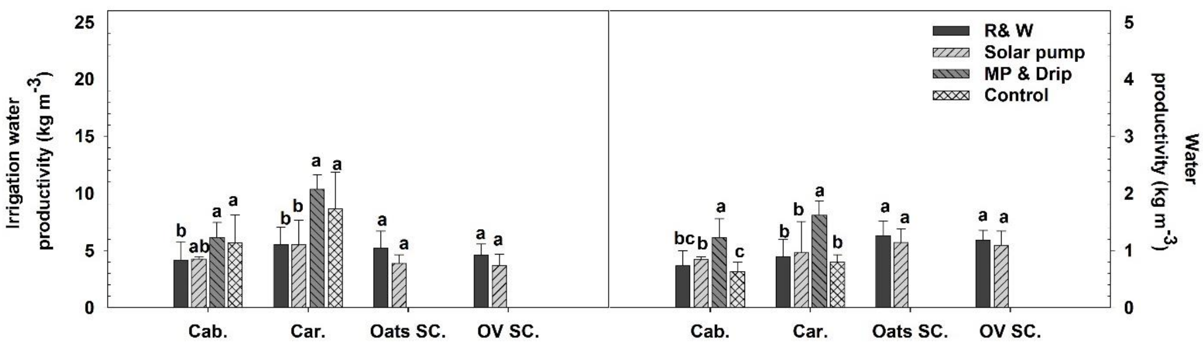


Figure 11: Bar chart showing the supplementary irrigation water productivity (kg m^{-3}) (left) and total water productivity (including effective rainfall) (kg m^{-3}) (right) in 2016 using dry matter yields with standard deviation for the various technology groups with RW referring to rope and washer pumps and MP to the tractor mounted pump and drip combination for both sites combined. Letters for the same crop show significant differences between the site and technologies at a p-level = 0.05. Cab. refers to cabbage, Car. to carrot. Oats refers to oats, OV to oats-vetch, data only refer to single cut (SC).

For both carrot and cabbage the highest irrigation as well as total water productivity was found for the service provision with drip and the control farmers. Using RW pumps resulted in lower irrigation and total water productivity compared to the service provision with drip. Both the irrigation and water productivity for fodder seemed not to be influenced by whether a farmer irrigates using a solar or a rope and washer pump.

The median irrigation water productivity of cabbage was 4.65 kg m^{-3} while for carrot the median was 7.21 kg m^{-3} when including the effective rainfall the water productivity values dropped to 0.79 kg m^{-3} and 0.89 kg m^{-3} for cabbage and carrot respectively. For fodder the highest median irrigation water productivity was found for oats-vetch single cut in 2015 (39.88 kg m^{-3}) followed by oats single cut (2016) (4.63 kg m^{-3}) and lastly the single cut oats-vetch in 2016 (4.41 kg m^{-3}). The median water productivity including effective rainfall followed were 6.55 kg m^{-3}, 1.19 kg m^{-3}, 1.17 kg m^{-3} for oats-vetch single cut (2015), oats-vetch single cut (2016) and oats single cut, respectively. The dry matter based irrigation and water productivity for the single cut fodder lies within the range of cabbage whilst it is lower compared to carrot.

However, when assuming that all crops would be sold fresh on the market using local (for vegetables) and estimated (for fodder) market prices the differences the economic water productivity between vegetables and fodder becomes apparent (Figure 12).

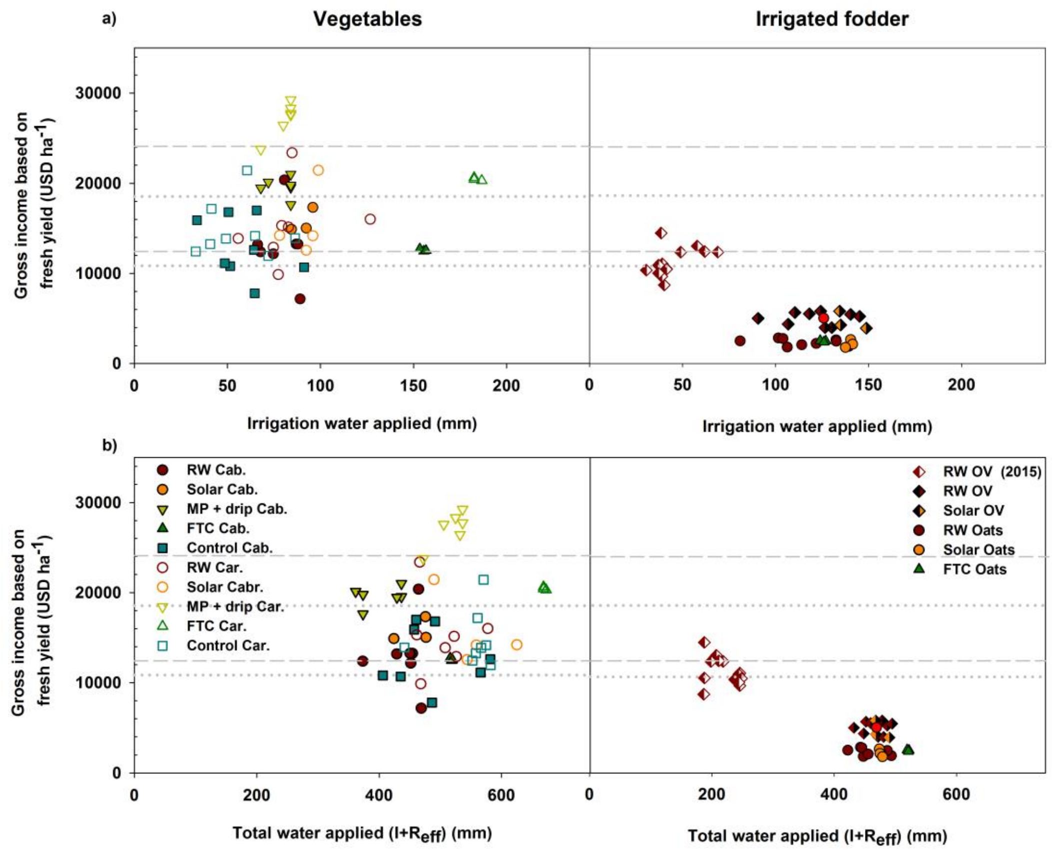


Figure 12: Scatter plot of gross income based on fresh yield (USD ha^{-1}) obtained vs. irrigation (mm) applied (a) or total amount of water (irrigation and effective rainfall, mm) (b) throughout the season. Cab. refers to cabbage and Car. to carrot. For fodder all data are from 2016 except the RW OV (2015) (red lined half open diamond). For the fodder: Oats refers to oats, OV to oats-vetch, data only refer to single cut. Technologies: RW = rope and washer, MP with drip = tractor mounted pump with drip and FTC = farmer training center. The gross income is calculated at a price of 0.09 USD kg^{-1} for Oats, 0.18 USD kg^{-1} for Oats & vetch, 0.32 USD kg^{-1} for cabbage and 0.41 USD kg^{-1} for carrot following the local market price May – June 2016. The dotted lines show one standard deviation of the mean representing the upper and lower limit for cabbage while the dashed lines shows the upper and lower limit for carrot in both the vegetable and the fodder graphs. The red dot represents the average dry matter of 5.6 t ha^{-1} based on Bezabih *et al.* (2016) plotted against the average irrigation depth and total water depth measured in 2016 whilst assuming the same oats-vetch market price of 0.18 USD kg^{-1}.

For cabbage the median economic dry matter irrigation water productivity[10] was similar for the service provision with drip (25 USD m^{-3}) and control (23 USD m^{-3}) group and higher compared to solar (18 USD m^{-3}), the rope and washer group (17 USD m^{-3}) and FTC (8 USD m^{-3}). Similar results were obtained for carrot with service provision with drip (34 USD m^{-3}) and the control having similar results (32 USD m^{-3}) followed by rope and washer (19 USD m^{-3}), solar (18 USD m^{-3}) and FTC (11 USD m^{-3}). In 2015 the oats-vetch had a comparable economic productivity (26 USD m^{-3}) while the 2016 treatments only accounted for productivity values were 2 USD m^{-3} (oats single cut) and 4 USD m^{-3} (oats-vetch single cut). The economic dry matter water productivity including the effective rainfall was low for all technologies and crops and ranged from a low 0.02 USD m^{-3} (oats single cut at FTC) to 0.1 USD m^{-3} (carrot under drip).

Whilst the oats-vetch single cut yield in 2015 could provide a median gross income in the lower range (10,909 USD) of those obtained for vegetables (14,063 USD for cabbage and 15,995 USD for carrot), the production of the single cut forages in 2016 was on the low side (2,473 USD for oats and 5,236 USD for oats-vetch). However, using the oats-vetch production reported by Bezabih et al. (2016) would result in a value of 5,022 USD which is similar to the estimations made for 2016. These results suggest that given the prevailing high market prices for vegetables at the time of harvest compared to the estimated market price of fodder, growing vegetables could be a better option. However, market prices for vegetables is known to be highly volatile. If prices would drop below 0.15 USD kg^{-1} at the time of harvest than similar gross income could be expected from the oats-vetch plots as from the vegetable production. It is known that feeding fodder for fattening or milk production could increase significantly the gross return or irrigating fodder (Bezabih *et al.*, 2016).

[10] The economic irrigation water productivity was calculated as the gross income divided by the irrigation water applied for a particular technology per ha. The economic water productivity was calculated as the gross income divided by the total water received (including effective rainfall).

Effect of water management on irrigation and yield performance

Effect of water management on irrigation applied

This section focusses on assessing whether the access to irrigation scheduling information such as wetting front detectors reduce over-irrigation or improves under-irrigation whilst increasing crop productivity. Both the FTC and rope and washer groups with their different water management treatments where cultivated at the same time.

The number of irrigation events was only found higher for the oats-vetch rope and washer-WFD farmers compared to the rope and washer group that irrigated based on their own practice in 2015. The amount irrigated per event was in some cases higher or lower in the WFD plots ($p<0.001$) (Figure 13). Overall the use of WFD seemed to influence the amount of water applied during the event and in some occasions (i.e.) decrease the number of irrigation events (Table 12). For cabbage the WFD trials in the FTC received less whereas the cabbage in the rope and washer-WFD plots received more irrigation water per event compared to their control plots. In 2016 the cultivated oats did receive different amounts in the initial and development stage for the rope and washer-WFD compared to farmer practice. However, the total irrigation water applied when farmers had a WFD to guide the scheduling was not higher or lower compared to when farmers had no WFD for any of the crops (Figure 13). Similarly in the FTC plots the lower water applied in the WFD plots did not differ significantly from the plots where now WFD was used to guide irrigation amounts.

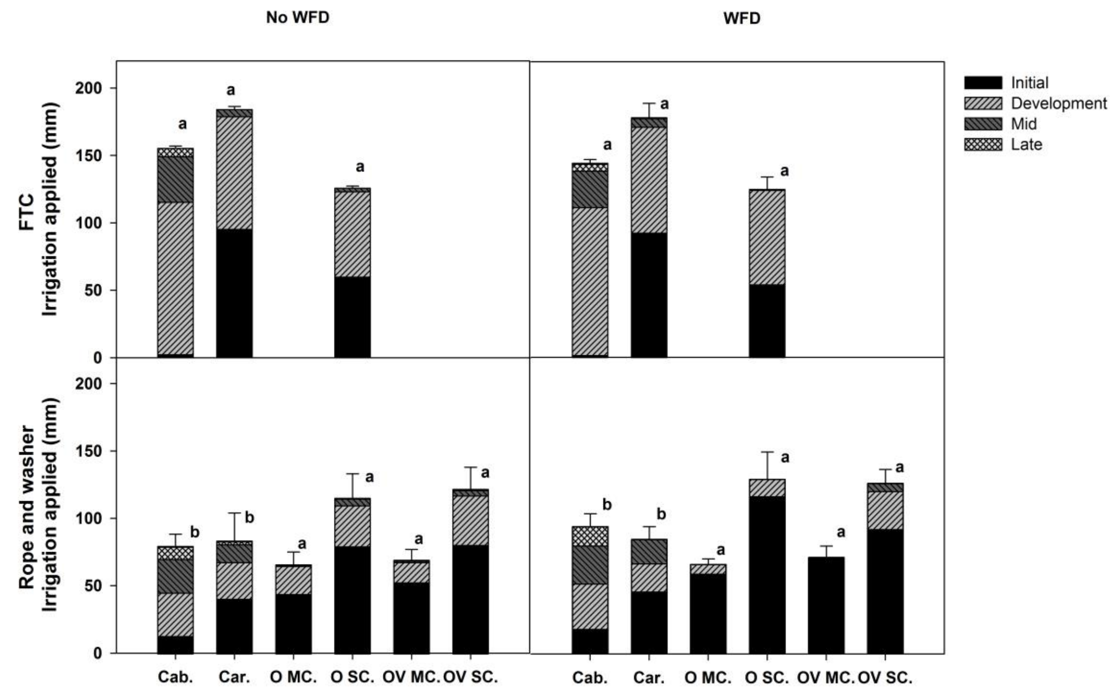


Figure 13: Stacked bar chart showing the amount of irrigation water applied (mm) for each cropping stage (i.e. initial, development, mid and late stage) for the farmer training center (FTC, research plot, top right) and farmers using rope and washer following their own farmers' practice (left) and using the wetting front detector (right). The error bars show the total standard deviation of the overall irrigation amount based on all the farmers using that technology within that site. Letters for the same crop show significant differences between the site and technologies at a p-level = 0.05.

As mentioned above, the rope and washer farmers did experience water scarcity in January and February of 2016. Seven out of eleven farmers using the WFD and two out of seven control farmers experienced water scarcity at the development stage for cabbage and the initial - development stage for carrot. The use of the WFD could have provided guidance for the farmers in applying sufficient water during moments of scarcity. Between 21% and 17% of the water applied for cabbage and carrot respectively originated from surface water during the two months of water scarcity.

Table 12: Average and standard deviation of the irrigation applied per event (mm) and number of irrigation events per season for rope and washer (RW) and at the farmer training center (FTC) following farmers' practice (Cont.) and the wetting front detector (WFD) (Error! Reference source not found.**).**

		Irrigation per event (mm)[1]				Number of events per season[1]			
	Year	FTC- Cont.	FTC-WFD	RW-Cont.	RW-WFD	FTC- Cont.	FTC-WFD	RW-Cont.	RW-WFD
Oats-vetch SC[2]	2015	-	-	2.0 ± 0.4[b]	2.3 ± 0.5[a]	-	-	23 ± 4[a]	18 ±3[b]
Cabbage	2016	8.5 ± 1.3[a]	7.9 ± 1.2[b]	3.9 ± 0.7[c]	4.4 ± 0.7[d]	20 ± 1[a]	20 ± 1[a]	21 ± 2[a]	22 ±1[a]
Carrot	2016	9.9 ± 1.6[a]	9.5 ± 1.6[a]	4.1 ± 0.9[b]	4.2 ± 0.5[b]	18 ± 1[a]	18 ± 1[a]	19 ± 3[a]	21 ± 1[a]
Oats SC[2]	2016	7.0 ± 1.0[c]	7.2 ± 0.8[c]	7.9 ± 1.7[b]	8.8 ± 2.0[a]	18 ±1[a]	17 ± 1[a]	15 ± 2[a]	14 ± 1[a]
Oats MC[2]	2016	-	-	4.6 ± 0.8[a]	4.7 ± 0.7[a]	-	-	15 ± 2[a]	14 ± 1[a]
Oats-vetch SC[2]	2016	-	-	8.7 ± 1.3[a]	9.5 ± 2.0[b]	-	-	15 ± 2[a]	14 ± 1[a]
Oats-vetch MC[2]	2016	-	-	4.8 ± 0.9[a]	5.1 ± 0.8[a]	-	-	15 ± 2[a]	14 ± 1[a]

[1] Differences in superscript within the row indicates significant differences in irrigation applied per event between technologies for the same crop at p=0.05; [2] SC refers to one cut while MC refers to multiple cut (i.e. total of three cuts during the cropping season);

Effect of water management on yield and irrigation water productivity

Even in the rope and washer WFD treatment the variability in vegetable and fodder yield was present, however it was less pronounced than the control plot (Figure 14). Comparing the fresh weight between the two water management treatments does show positive effect of the WFD on the obtained fresh yield ($p<0.001$). The positive effect was pronounced for oats-vetch in 2015, cabbage and carrot ($p<0.05$) but less pronounced for the single cut fodder treatments in 2015 ($p>0.05$) (Table 13). Comparison of the TN content between both water management treatments did not result in a noticeable difference ($p>0.05$).

Table 13: Average and standard deviation of the total yield obtained (t ha^{-1}) for rope and washer (RW) and at the farmer training center (FTC) following farmers' practice (Cont.) and the wetting front detector (WFD) (Error! Reference source not found.**).**

	Year	FTC- Cont.[1]	FTC-WFD[1]	RW-Cont.[1]	RW-WFD[1]
Oats-vetch SC	2015	-	-	61.9 ± 8.7^b	73.7 ± 6.4^a
Cabbage	2016	39.5 ± 0.4^b	46.0 ± 3.0^b	41.1 ± 12.1^b	48.1 ± 5.9^a
Carrot	2016	50.0 ± 0.4^b	65.1 ± 2.4^a	37.2 ± 10.1^b	43.2 ± 7.6^a
Oats SC	2016	27.3 ± 0.9^a	32.4 ± 2.2^a	25.9 ± 4.1^a	29.7 ± 2.1^a
Oats-vetch SC	2016			27.6 ± 3.9^a	29.2 ± 5.9^a

[1] Differences in superscript within the row for the same technology indicates significant differences in yield for the same crop at $p=0.05$.

The results for 2015 show that the combined fresh fodder weight of oats-vetch (excluding weeds) had a higher yield in the RW-WFD plots compared to farmers practice (i.e. 73.7 t ha^{-1} for WFD and 61.9 t ha^{-1} for control plots), the dry matter difference between both irrigation treatments was less pronounced. This is mainly due to the large variability of moisture content among the samples however, this was not related to the water management treatment. Analysis of the dry matter yield for oats showed no difference between the two irrigation treatments in both seasons. On the other hand for vetch, the dry matter yield obtained in the WFD plots was approximately double (6.1 t ha^{-1}) compared to the dry matter vetch obtained from the control plots (3.7 t ha^{-1}) in 2015.

The amount of weeds found in the 2015 season differed fairly between farmers (coefficient of variation = 40.9%) which potentially has influenced the obtained fodder yields, partly masking the effect. In 2016 fodder disaggregated data was not available to support the 2015 effect of water management on vetch production.

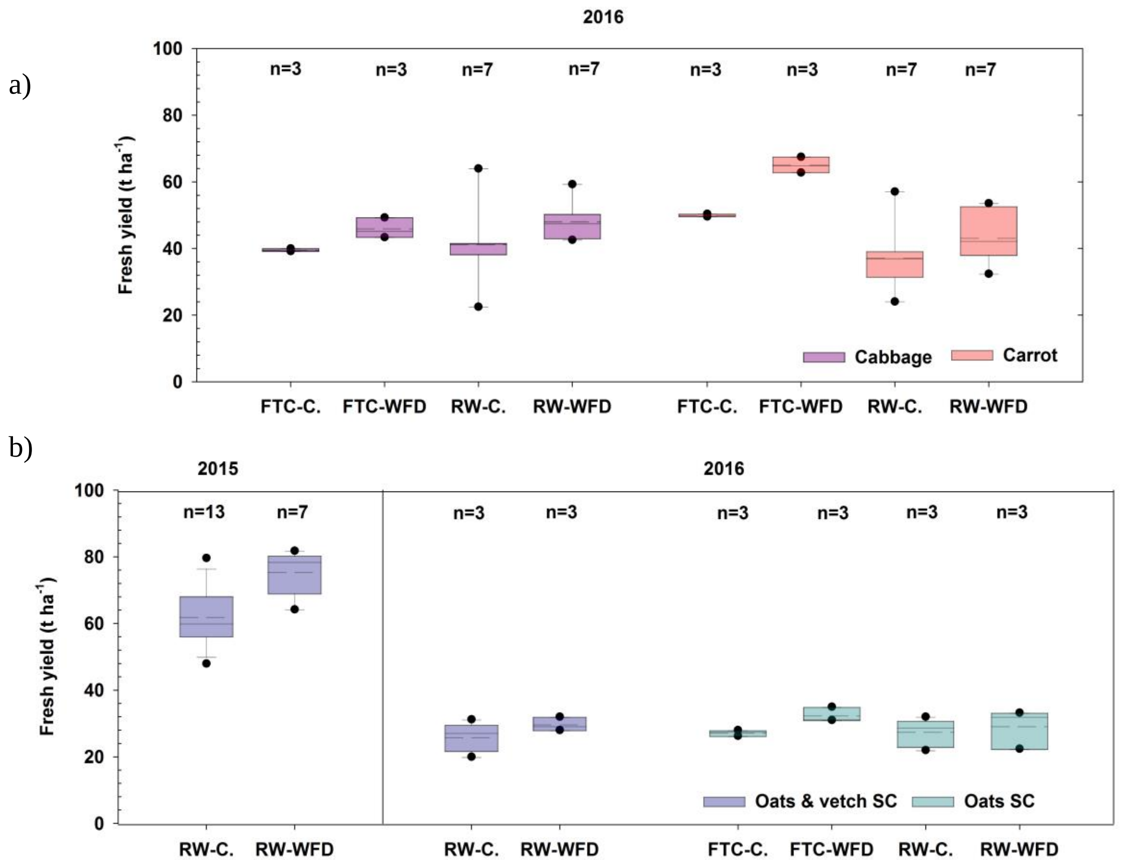


Figure 14: Fresh yield (t ha^{-1}) for a) cabbage, carrot and b) oats, oats-vetch single cut using no water lifting technology (i.e. control), rope and washer (RW), solar and tractor mounted pump (MP) with drip farmers. Results from the farmer training center (FTC) is plotted for comparison.

Effect of water management on irrigation water productivity

The estimated water productivity for cabbage and carrot between the rope and washer and the FTC were different, potentially due to differences in the applied fertilizer and amount of water irrigated during the growth period. However, within the FTC or the RW group the irrigation water productivity did not differ between the two water management treatments. In the control treatment in FTC resulted in a median irrigation water productivity of 2.46 kg m^{-3} and 3.35 kg m^{-3} while the WFD treatment produced 3 kg of dry matter cabbage and 5.71 kg of dry matter carrot per cubic meter. The irrigation water productivity in the rope and washer group for the control and WFD treatment were 3.83 kg m^{-3} and 4.36 kg m^{-3} for cabbage and 5.21 kg m^{-3} and 6.81 kg m^{-3} for carrot, respectively. On the other hand for the rope and washer there was no difference between the WFD and the control. The two water management treatments in 2016 for oats resulted in similar productivity values of 4.7 kg m^{-3} - 4.9 kg m^{-3} for the control and 5.5 kg m^{-3} - 6.0 kg m^{-3} for the WFD treatment. In 2016, the high biomass produced resulted in significantly higher values (WFD: 49.5 m^{-3} vs. control: 42.1 kg m^{-3}). Water productivity based on the total water received during the period did not show significant differences for any of the crops in any of the technologies.

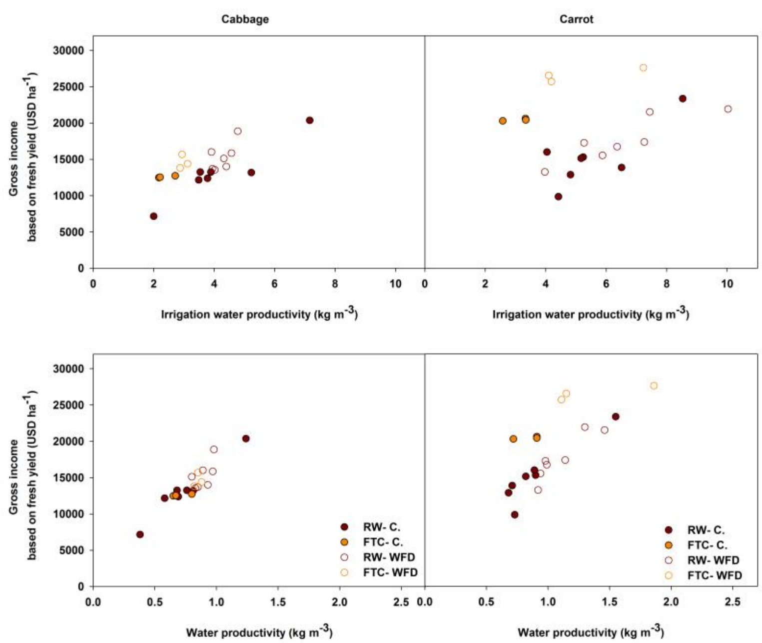


Figure 15: Scatter plot of gross income based on fresh yields (USD ha^{-1}) vs. dry matter based irrigation (top) and total water productivity (bottom) (kg m^{-3}) for cabbage (left) and carrot (right). The gross income is calculated at a price of 0.32 USD kg^{-1} for cabbage and 0.41 USD kg^{-1} for carrot following the local market price May – June 2016.

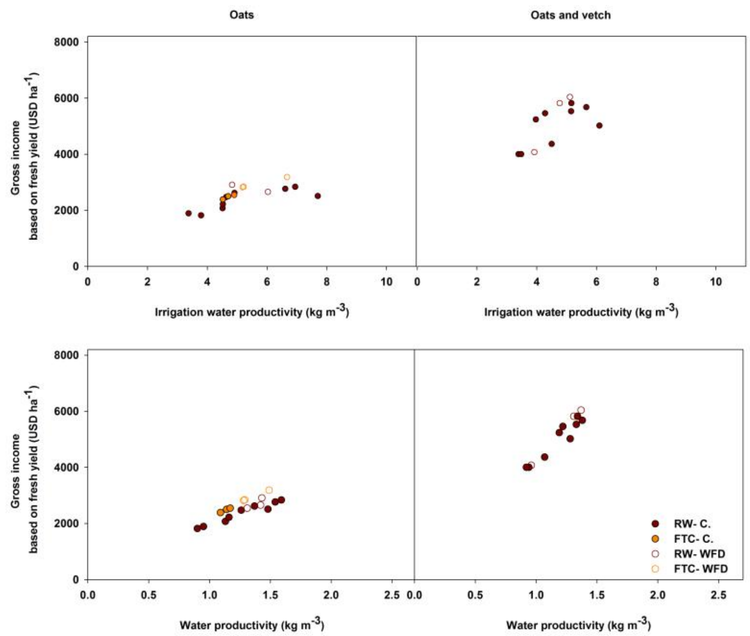


Figure 16: Scatter plot of gross income based on fresh yields (USD ha^{-1}) vs. dry matter based irrigation (top) and total water productivity (bottom) (kg m^{-3}) for oats 2016 (left) and oats-vetch 2015 (right). The gross income is calculated at a price of 0.09 USD kg^{-1} for Oats, 0.18 USD kg^{-1} for oats- vetch, following an estimated market price.

The guidance in water management using the WFD resulted in different irrigation amounts applied in some of the crop stages resulting in higher yields. Despite the lack of differences in water productivity between the two water management treatments the increase of water productivity tend to correspond to higher gross income obtained from the plots. Especially for the vegetables, the plots who were irrigated following the WFD tend to result in slightly higher gross income and water productivity (Figures 15 and 16).

Profitability of the water lifting and management technologies

As the guidance of water management affected the production of vegetables the effect of the water lifting technology on the profitability only included farmers who were irrigating based on their own traditional knowledge (Figure 17). The farmers who had no water lifting device actually obtained a higher (for cabbage) or slightly higher (for carrot) profit compared to those owning a rope and washer. These results suggest that a rope and washer might not necessarily improve profits which is most likely related to the fact that it does not reduces irrigation labour significantly (Figure 8).

Despite the small sample number the results are encouraging for solar. Using solar pumps for irrigation resulted in higher profits for cabbage and similar profits for carrot compared to the control group and the rope and washer group. The significant higher yield the farmers obtained when using drip kits, was not reflected in a higher profit when one included the fuel cost and labour for fetching, transporting water and filling the drip kits. The difference in profit observed between the service provision & drip and the solar pump irrigated plots are a result of the differences in yield (i.e. significantly higher yield for service provision & drip) and irrigation labour (i.e. lower labour for solar pump). Especially households which are further away from the water source will have a higher input cost translating in a lower profit. Excluding the fuel cost showed that if the distance to the water source would be reduced or water lifting devices not using fuel would be used to fill the drip kits, the production would be more profitable for carrot compared to the other technologies and equally profitable to solar for cabbage. Further reducing the labour to fetch water and fill drip kits would potentially increase it further. These results suggest that using solar pumps in combination with drip kits, assuming that the water source is nearby, could be a solution for vegetable production in Lemo.

The profit of growing fodder remained low for both the rope and washer and the solar pump (Figure 17) which is mainly related to the low estimated market prices. If markets would be developed and demand increases irrigated fodder might show potential. Most likely the use of irrigated fodder to produce milk and meat products could be a more viable option than selling fresh fodder.

However, the number of observations are low for any of the technologies and crops tested. Additionally, the small plot measurements most likely overestimate the vegetable yields when converted to one hectare. Hence, the values presented here are just indicative and should not be taken as “true” profit estimates but rather be used to identify trends and differences between technology groups. A second year is currently being finalized for all technologies to support these initial findings.

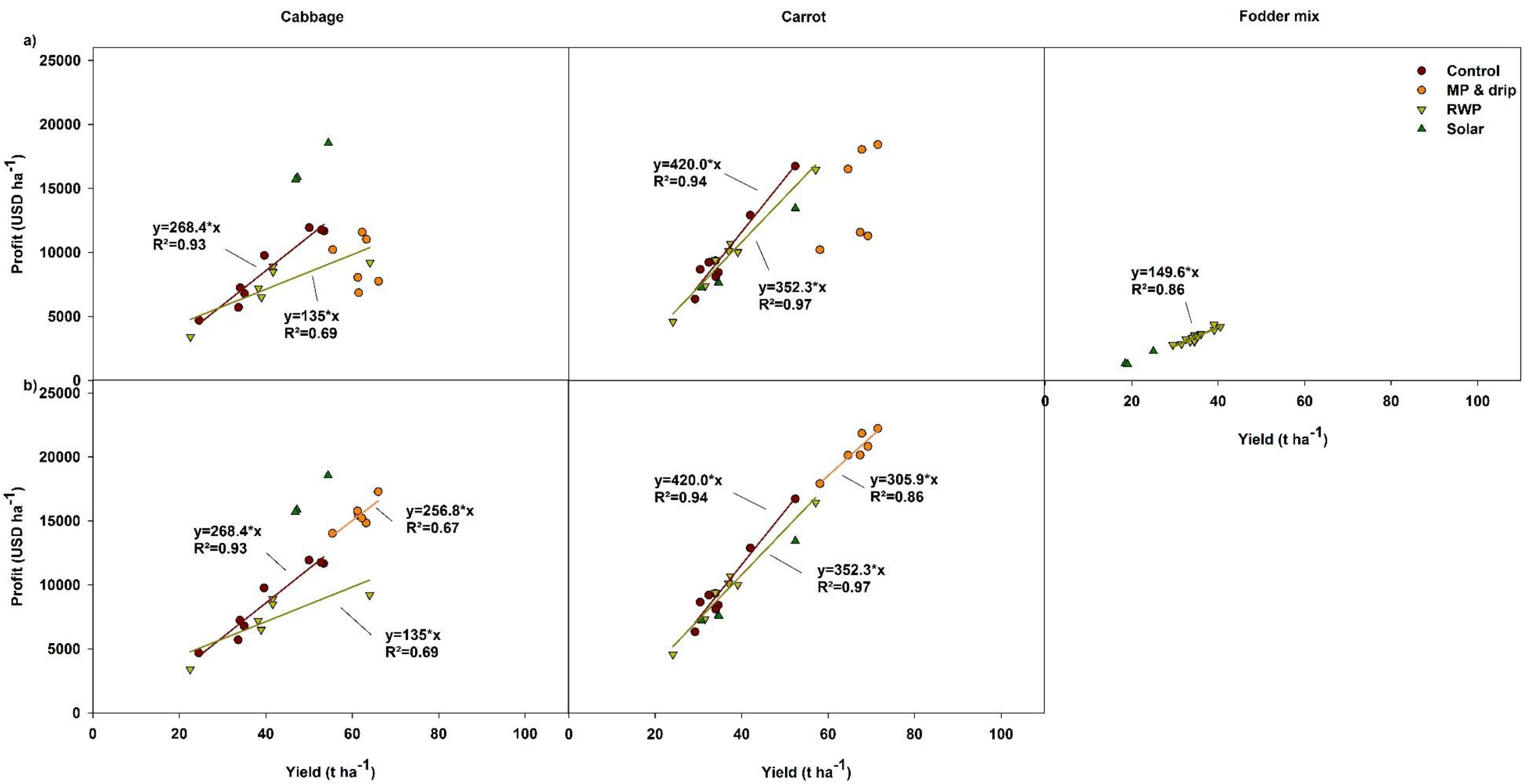


Figure 17: Yield (t ha^{-1}) and corresponding profit converted to USD ha^{-1} for cabbage, carrot and fodder mixed depending on the water lifting and application technology used (i.e. control or no technology, rope and washer (RWP), solar and tractor mounted pump (MP) with drip farmers. For the service provision the analysis included the cost of fuel for the water delivery service as an extra cost (a) and excluded the fuel cost (b). The data on labour, input costs and income were not disaggregated when collected and hence the values represent the total value of a single cut-multi-cut oats and oats-vetch system.

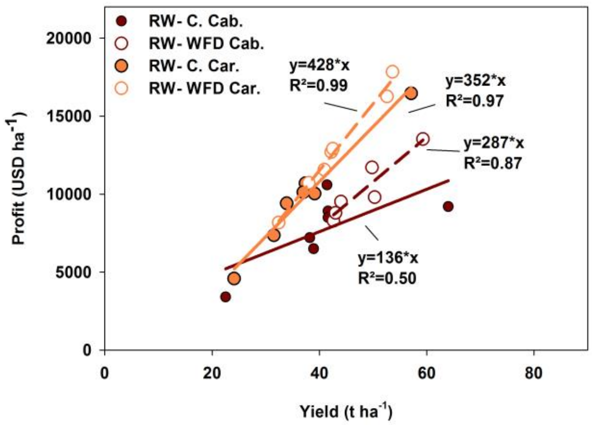


Figure 18: Yield (t ha^{-1}) and corresponding profit converted to USD ha^{-1} for cabbage and carrot for the rope and washer technology (RW) when irrigation was performed without support of a WFD (control, C.) and with a WFD.

The high production variability observed in farmers' fields suggested that there is potential for improved management to further boost production aside from which water lifting technology is used for irrigation. One of the management practices that would positively contribute to higher production and profit is better water management (Figure 18). Despite the lower profit the farmers obtained using a rope and washer compared to the control, better water management could boost production in some cases. Hence, the upscaling of water lifting technologies should be strongly embedded with a best management package with water management as one of the important components.

Multiple use of water lifting technologies supplied

Some households irrigated vegetables, avocado, fodder or a combination thereof. Households were asked to monitor their own water abstraction for domestic, drinking water and livestock in addition to irrigation (Figure 19). Farmers who obtained a solar pump or a rope and washer seemed to extract more water compared to control farmers or farmers depending on service delivery. Only two rope and washer (N=17) and 1 solar (N=4) reported to have grown pepper, tomato or onion aside from the project crops using supplementary irrigation in very small amounts. Farmers who used rope and washer or solar and grew carrot, cabbage and fodder used between 17 m^3 and 20 m^3 irrigating between 140 to 200 m^2. The MP with drip and control group only grew carrot and cabbage or avocado with the MP with drip group using between 6.8 and 8.4 m³ and the control irrigated between 3.3 and 6.5 m³ for 100 m².

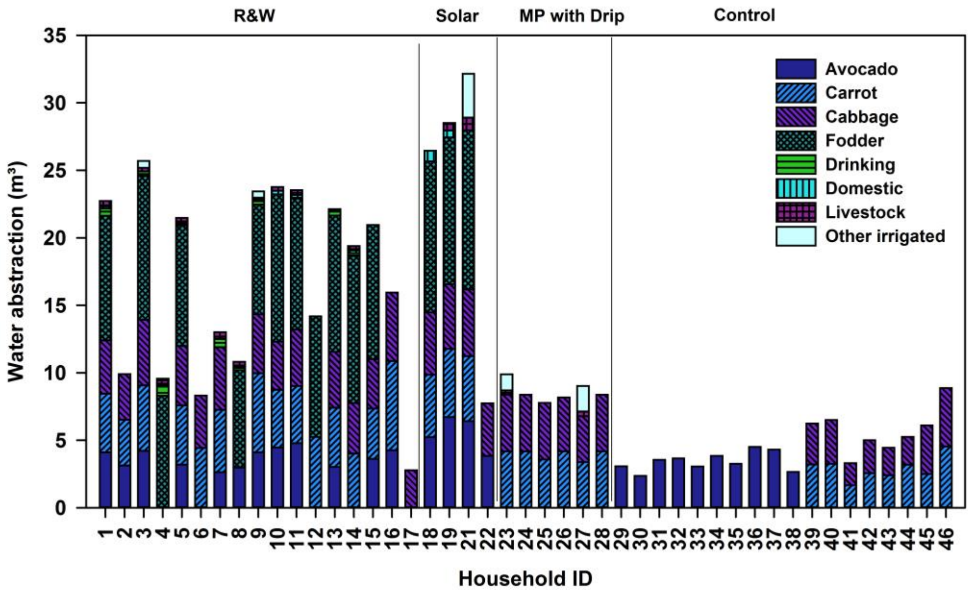


Figure 19: Total water consumption (m³) for each household during December – June 2016.

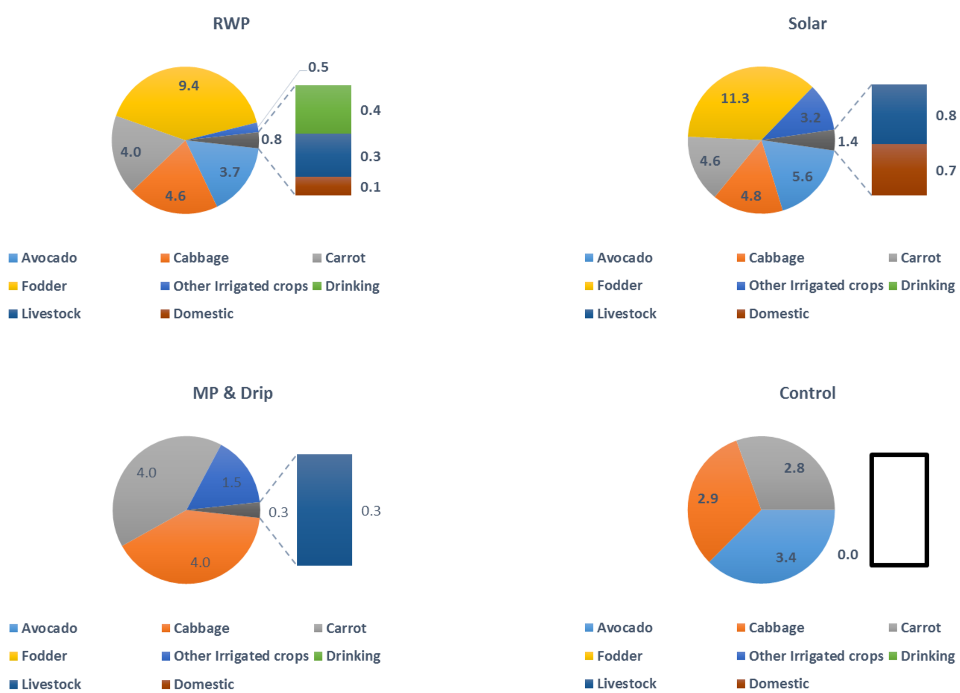


Figure 20: Pie chart showing the proportional abstraction in m³ for multi-purpose use. The portion of water used for livestock, drinking or domestic use is extracted from the pie chart and represented in the stacked bar.

The majority of water extracted went to 100m² of fodder (40-50%), followed by vegetables (14-30%) and avocado (18-30%). Only two rope and washer (N=17) and 1 solar (N=4) reported to have grown pepper, tomato or onion aside from the project crops using supplementary irrigation in very small amounts. More water was used to irrigate other crops when farmers used a solar pump (Figure 20). From the 17 rope and washer households, 10 households noted to have used the technology for livestock -drinking, household drinking and domestic use whereas 3 out of four solar pump have used the technology for fetching drinking water for livestock. For the rope and washer farmers additional water consumption using the water lifting technology reported a usage 2 % to irrigate other crops, 1% for livestock, 1% for domestic use and 2% for drinking water. Solar farmers reported 11% to irrigate other crops, 2% for livestock and 3% for domestic purposes.

Aside from irrigation related to the crops piloted in the Africa RISING project, farmers owning a rope and washer mainly extract additional water for drinking water and domestic use whereas those owning a solar pump used the technology mainly for additional irrigation activities. Overall the additional abstraction for the reported period seems to be small both for livestock, domestic and other irrigation activities. The village has boreholes that are mainly used for drinking and domestic purpose whereas the river is the main source for livestock drinking water. Additional follow up is required to understand whether the low amounts are related to the abundance of the other abstraction points (i.e. boreholes and river) for domestic and livestock use or whether the abstraction is under reported.

Technology challenges

Tractor mounted pump and drip

When the drip technology was tested during the dry season several opportunities and challenges were reported. After some delay in installation the farmers appreciated the water application efficiency and reduction in labour. They noted a uniform application of water compared to the bucket technology. This was confirmed by the technology calibration which indeed showed a relatively uniform application rate along the various drip lines. Farmers also noticed a reduction in weed production. The fact that the water was delivered by the service provider and farmers did not need to go and fetch water leading to less labour, time and different family members participating in the irrigation activities.

However the service provision also did undergo some challenges. Even with considerable training the service providers were not able to operate the tractor as well as its mounted pump. This was particularly the case in one village hence the activity needed to be taken over by the project assistant. Furthermore the connector between the tractor and trailer broke. Farmers were forced to go and fetch water at the river (1 km) using donkeys and other transport mechanisms during that time. There were some challenges with respect to maintenance of both the tractor, its mounted pump and the drip kits despite frequent training by researchers and field assistants. The tractors do consume a lot of fuel per trip.

Rope and washer

Despite the fact that the technology is capable to extract water from a deeper well depth than the solar pump and is used for multi-purpose (domestic, livestock and irrigation), given that the majority of the wells are close to the homestead, there were a number of challenges. The rope and washer needs frequent lubrication of the wheel and changing of ropes. Despite frequent trainings maintenance remains an issue. Furthermore the quality of the rope and washer between both villages was different. In one village frequent breakage occurred of the rope and washer, leading to some farmers giving up on using the technology for irrigation. Other challenges reported was shortage of groundwater in January –February and the high labour intensity of lifting the water from the well with increasing well depth.

Solar pump

Although the solar pump does reduce irrigation labour with and is easy to operate its shallow depth requirement puts a constraint on its suitability in the area where many shallow wells are below 6-7 m. Repair is a bit more complex compared to the rope and washer and farmers reported that fixing the solar panel is difficult with the current setup and to flexible. When the wind blows the solar panel easily moves its position reducing the energy production. Farmers prefer to irrigate early morning and evening to reduce water consumption (as you reduce evapotranspiration). However, given the low sunlight the solar pump has considerably lower discharges compared to mid-day. Given the absence of a battery, the technology had its limitations to accommodate farmer's preference in irrigation times. The non-irrigation related benefit reported by the farmers and neighbours was the opportunity to charge your cell phone (for 2 birr per phone) and in some cases farmers even sold water to neighbours.

Conclusion and recommendation

The study tested several water access technologies for small scale irrigators (e.g. solar pumps, rope and washer pumps, tractor mounted pump with drip) and management options (wetting front detector) for improved precision in crop-water management. Depending on the water source and availability, the technologies led to a multi-crop and multi-use (agriculture, domestic and livestock) system. Aside from irrigation, the abstraction of water for multi-purpose use seem to be important for households and could influence technology selection. While the results show great promise, the sample size remains small and results should be interpreted with care. Plots were relatively small and hence yield conversion to ha are most likely at the higher end of the spectrum. The experiment is currently being repeated to provide a more robust assessment of all technologies involved.

Comparing the various water lifting technologies in terms of irrigation labour, water use and profitability show the high potential of solar pumps in smallholder farmer irrigation (Table 14).

Table 14: Summary of the opportunities and challenges related to each of the water lifting technologies respectively towards the control. ++, + and – represent a high, medium and low effect.

	Labour saving	Yield	Water productivity	Profit	Multi-purpose use
Control	0	0	0	0	0
RW	0	0	0	-/0	+
Solar	++	+	0	++	++
Service provision & drip	+/-	++	++	+/-	-

In cases where households are dependent on communal water sources, service provision of water to drip kits could be a viable alternative. However, profits related to drip, despite the higher crop productivity, are dependent on the distance to the water source as well as the time consumed to fetch water. As such, when the water sources are too far the option might become less or non-profitable. Furthermore, results suggested that using a rope and washer pump results in similar labour requirements and in some cases even lower profits compared to a simple rope and bucket.

Testing a simple water management tool, wetting front detectors (WFD), provided farmers with improved crop yields. The feedback of the WFD in times of water availability challenges in January-February did inform and stimulate farmers to fetch water somewhere else. Guiding farmers in how much to irrigate at specific crop stages did not only increase yield but also positively affected the profit obtained from the plots. Results suggest that providing appropriate water management advice as one of the core components of best management practices need to be combined with the information on appropriate water lifting devices to provide relevant information for farmers' best option and choice whilst ensuring sustainable intensification.

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