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On-farm smallholder irrigation performance in Ethiopia: From water use efficiency to equity and sustainability

On-farm smallholder irrigation performance in Ethiopia: From water use efficiency to equity and sustainability

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Acronyms

CPWF	Challenge Program on Water and Food
CWP	Crop water productivity
EIA	Ethiopian Investment Agency
ET	Evapotranspiration
FGD	Focus group discussion
GVP	Gross value of production
IFWP	Irrigation financial water productivity of major crops
IWMI	International Water Management Institute
IWPP	Irrigation water physical productivity
LP	Land productivity
PFP	Partial factor productivity
RIS	Relative irrigation supply
SSA	Sub-Saharan Africa
WP	Water productivity
WPet	Water productivity based on evapotranspiration
WPf	Water productivity based on field supply

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Abstract

The performance of smallholder irrigation schemes are challenged by several factors: among which water insecurity and low land and water productivity are the main ones. This paper evaluates the on-farm management of nine smallholder irrigation schemes from four regional states in Ethiopia. The schemes are diverse in several aspects and we clustered them into three typologies: Modern, semi-modern and traditional. Indicators such as land productivity (LP), crop water productivity (CWP) were used in evaluating performances. Data input to the target indicators was collected through household survey, field observation, measurements (canal water flow monitoring), literature review and focus group discussion (FGD). The result illustrates apparent variability of LP among schemes; scheme typology and reaches. The lowest value of LP was estimated for the traditional schemes and inter-scheme variation was also notable. For example for onion, the value for LP ranged between 7.13 and 14.55 tonnes/ha. For tomato the range was even wider: 0.9–10.29 tonnes/ha. Meki scheme showed the highest land productivity for onion and tomato with the magnitude of 14.55 and 10.29 tonnes/ha respectively. For irrigated cereals (maize and wheat) LP values showed a similar trend as for vegetables. For example the LP value for maize range between 0.65 and 3.92 tonnes/ha and for wheat the range was narrower (0.6 and 1.56 tonnes/ha). Generally these values are less than the values reported as sub-Saharan Africa (SSA) regional average suggesting the need to address yield limiting factors in smallholder schemes in Ethiopia. Water productivity by water supplied at field levels (WPf) for cereals was generally on the lower side; it is somewhat on the higher side for vegetables compared to observations from SSA. Schemes and reaches with higher land productivity do not necessarily shows higher WPf. Modern schemes and head irrigators have usually higher land productivity but low water productivity. The opposite holds true for the traditional irrigation and tail irrigators. The traditional schemes and tail irrigator normally suffer from water shortage and most often practicing forced deficit irrigation and also select crops with low water requirement. Hence they save water while trying to minimize impact on the yield through crop selection. Implicitly future direction of improving smallholder irrigation need to acknowledge this reality and put efforts to save water on head irrigators and increase land productivity under traditional and tail irrigators and promote sustainability and equitable share of water in smallholder irrigation. Probably alternatives such as valuation of water and a consumption-based water charge need to be taken into account in efforts to discourage over irrigation and enhance equitable water management by smallholders. It is also important to note that smallholder water management decisions are complex and so are the values for their performance indicators. Therefore, any development efforts dealing with smallholder irrigation need to disentangle and understand this diversity and ensure interventions are context specific.

Key words: Productivity, land, water, irrigation, typology, water scarcity, Ethiopia.

1. Introduction

Land and water are the two important but scarce resources for agricultural development and globally these resources are shrinking (CPWF 2007). Schultz et al. (2005) suggested that the largest proportion of the required increase in agricultural production would have to be realized from already cultivated lands through intensification (e.g. through irrigation). CPWF (2007) suggested that while it is possible, with good management, to treat the symptoms of water scarcity, it is also possible, with bad management, to create water problems in areas of abundance. As such, enhancing productivity of irrigated lands remains one of the key approaches to meet ever increasing demands for food and fibre. In contrast to the popular perception, closing the yield gap is not only about increased infrastructure to enhance water abstraction and delivery. There is ample evidence suggesting the need to integrate practices of soil nutrient replenishment and high yielding varieties into optimum water allocation and change in cropping pattern (Drechsel et al. 2015).

In this context, on-farm water management targeted at narrowing-down yield gaps refers to practices that involve optimum and timely water application and those enhancing plant water uptake (Rockström and Barron 2007). Although households on schemes might have many things in common (e.g. governance), decisions made at farm household levels are divergent and could be the potential sources of information to enhance productive uses of water (Lempériere et al. 2014). Farm households make decisions regarding the selection of crops, and the allocation of labour, inputs and capital with due considerations to the constraints they face and the opportunities they want to use. But also the decision is influenced by many exogenous factors. For example in many large scale communal irrigation schemes serving smallholders, there are possibilities that government policy and market circumstances influence the crop choice of farmers (Yami 2013).

Smallholder irrigation schemes in Ethiopia are generally characterized by poor on-farm water management practices and hence poor performances (Derib et al. 2011; Van Halsema et al. 2011; Eguavoen et al. 2012). The poor on-farm water management emanates from both excesses and insufficient allocation of resources that enables optimum and timely water supply and also plant water uptake. Putting it differently, inappropriate irrigation scheduling, non-uniform on-farm water distribution, wrong duration of irrigation, etc. are some of the factors contributing to poor on-farm water management. Farmers' lack sound knowledge on on-farm water management, particularly on how much to irrigate and when to irrigate (as they tend to over-irrigate as long as water is available) results in water shortages and conflicts in other parts of the schemes. This also means on-farm water management places direct costs on scheme level performance.

Irrigation enables the abstraction of more nutrients from the soil. This needs to be replenished to maintain soil fertility and sustain productivity. Numerous scholars argue that poor soil nutrient replenishment is one of the chief causes of yield gaps [nutrient limited yield gaps (Erkossa et al. 2011; Alemu et al. 2010)]. Contrastingly emerging evidence also suggests that many intensively managed smallholder irrigation schemes in Ethiopia are over applying fertilizer. Implicitly smallholder irrigation systems are trapped in a manifold situation (both for water and nutrient). Smallholder irrigation schemes are acquired, used and managed in various ways (Derib et al. 2011; Awulachew et al. 2005; Eguavoen et al. 2012). Production systems, land and water rights, as well as their accompanying social dynamics, are not homogeneous and subtly influence on-farm management and performance. This calls for better understanding of these between and within diversity through empirical evaluation of indicators (Van Halsema et al. 2011). In the present study, we focus on land and water productivity and their concurrence across reaches and schemes, and the implications for equity and sustainability.

2. Materials and methods

2.1. Location and farm characterization

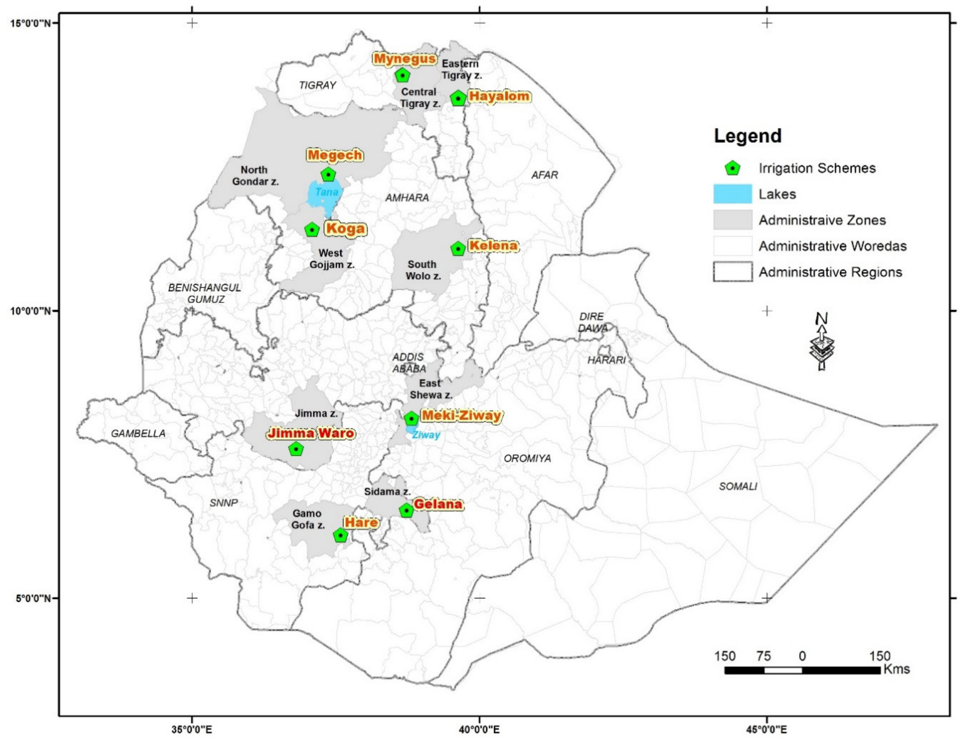
The present study is based on nine irrigation schemes located across four regional states of Ethiopia (Figure 1). The study sample schemes were selected using criteria such as representativeness for different scales (large, medium and small) and managed by smallholders; crop types, agro ecology (e.g. altitude range 1500–2725 masl). Salient features of the schemes related to on-farm management are summarized in Table 1. All study schemes are located within a range of 2–30 km from main roads and have diverse soil texture. Clay to clay loam and sand and loamy are major texture of the soils. Onion (*Allium cepa L.*) tomato (*Solanum lycopersicum*) cabbage (*Brassica oleracea*) and pepper (*Capsicum annuum*) are major high value vegetable crops grown in all the schemes. Staple cereal crops, such as maize (*Zea mays*) and wheat (*Triticum aestivum*), are also cultivated in most of the study schemes. Perennial crops are not common with the exception of Gelana and Hare schemes where coffee (*Coffea arabica*), ensete (Ensete *venticosum*) and banana (Musa species), respectively, are commonly grown. Meki scheme has the largest mean land holding size followed by Koga. The lowest land holding sizes were recorded for May Nigus and Gelana (Table 1). The common field water application technique is furrow, but from field observation it was apparent that the skill of farmers in deciding the length and depth of furrow is different. In some cases furrow irrigation was recently introduced (e.g. Gelana); therefore farmers lack experience, while in other schemes the practice is well developed (e.g. Meki scheme).

Table 1: On-farm management features of the study irrigation schemes

Features	Tigray		Amhara		Oromia		SNNPR	
	The study irrigation schemes							
	Wukro	May Nigus	Koga	Megech	Meki	Waro	Hare weir/ Diversion[1]	Gelana
Distance from main road (km)	30	5	3	20	3	10	3	10
Method of water abstraction	Diversion weir	Embankment dam	Embankment dam	Diesel pumps	Diesel pumps	Temporary diversion	Diversion weir/ temporary diversion	Diversion weir
Water conveyance	Canals	Canals	Canals	Canals	Pipes/ canals	Canals	Canals	Canals
Dominant soil texture	CL/SCL	C/CL	SIC	C	SL/SCL	L	SICL	C/CL
Major crops	Onion, tomato, maize	Onion, maize, cabbage	Wheat, potato, onion	Onion, garlic, tomato	Onion, tomato	Potato, onion, tomato	Banana, maize, onion, tomato	Coffee, maize, ensete, tomato
Average land holding, (ha)	0.6	0.3	1.2	0.8	2.0	1.0	1.1	0.3
Water application methods	Furrow	Furrow	Furrow	Baisn	Furrow	Furrow	Flood	Flood/furrow
Average land holding, (ha) Water application methods	0.6 Furrow	Onion, maize, cabbage 0.3 Furrow	1.2 Furrow	0.8 Baisn	2.0 Furrow	Potato, onion, tomato 1.0 Furrow	1.1 Flood	Coffee, maize, ensete, tomato 0.3 Flood/furrow

CL stands for clay loam; SCL for sandy clay loam; C for clay; SIC for silty clay; SL for sandy loam; SCL for sandy clay loam; L for loamy; SICL for silty clay loam.

Figure 1: Location map of the irrigation schemes studied.



1. Hare weir and diversion have the same source of water (Hare river); however their headworks are different. Hare weir have a permanent diversion weir, while Hare diversion have a temporary diversion structure; hence the two were considered as separate schemes.

2.2. Data identification and acquisition methods

Selection of performance indicators

The number of indictors are developed to assess on farm performance of irrigation (e.g. Molden et al. 1990). The indicators to evaluate on farm performance of irrigated agricultural systems are hence related to yields, economic value of agricultural produce, water consumed per unit of produce, yield per unit of water used, etc. However, indicators of on-farm performance are not necessarily results of the quality of water management, but are also affected by other elements of the production process (Bos 1997). The following performance indicators were selected from literature to answer the questions related to the on-farm management (Bos 1997; Dejen et al. 2012; Van Halsema et al. 2011; Malano and Burton 2001).

Land productivity for major crops (land productivity) (tonnes/ha): The yield of major irrigated crops per unit area of land is an important indicator of on-farm management (Bos 1997). Estimating yields is often a difficult exercise during a diagnosis study even if one wants to know them with, say a 20% margin of error (Lempériere et al. 2014). However, there is no better way than collecting the information from the farmers as direct measurement on many schemes has implication for cost. So, for this study, yields were estimated from data of the household survey, and values on productivity were validated with similar studies across regions. Irrigation land productivity indicator can be represented by equation 1 below, where by LP stands for land productivity, Y is yield of the major crop in kg and A is the area under major crop in hectare (ha).

$$LP=(Y\ (kg))/(A\ (ha)) \qquad (Eq1)$$

Gross value of production (GVP, USD/ha): This is the total annual value of agricultural production received by farmers per unit area of irrigated land (Malano and Burton 2001). The value of agricultural production received by farmers is at the local markets. Here this was determined based on the household survey data and the computation of the GVP can be represented by Eq 2 below: where GVA is gross value of production in USD, and A is area irrigated in ha.

$$GVP=(GVA\ (USD))/(A\ (ha)) \qquad (Eq2)$$

Irrigation water physical productivity (IWPP, kg/m^3): Enhancing water productivity is a major concern both globally and locally (Haileslassie et al. 2009). Water productivity is particularly important in areas of water scarcity. Excess water supply and wastage are the main causes of low agricultural water productivity. Low water productivity may also result under water shortage conditions if the stress is to the extent to significantly affect yields. For the study schemes, water shortage in some parts and over-supply in others are major observations. It is important to understand the position of different schemes and reaches within schemes, their level of productivity, and benchmark of those performing well (Malano et al. 2004). IWPP can be represented by equation 3 below where IWPP stands for irrigation water physical productivity; Yj stands for yield of crop j and IWJ stands for irrigation water supply to crop j for the given area. Alternatively water lost as evapotranspiration (ET) can be also used to estimate water productivity (eq 4) where WPet stands for water productivity for evapotraspired water, ETj stands for evapotraspired water for crop j

$$IWPP=(Yj\ (kg))/(IWj(m^3)) \qquad (Eq3)$$

$$WPet=(Yj\ (kg))/(ETj(m^3)) \qquad (Eq4)$$

Irrigation financial water productivity of major crops (IFWP-USD/m^3): A recently emerging concept is the economic water productivity of irrigation schemes. This approach is more relevant in areas where the major purpose of irrigation is more cash income and food security than food self-sufficiency. This is also more relevant in irrigation schemes under multiple cropping systems. It helps to aggregate values of production of different crops and compare different schemes under different cropping system by converting to similar unit. IFWP can be represented by equation 5 below, where IFWP is as defined above, Vj stands for value of crop j and IWJ stands for irrigation water supply to crop j. Irrigation water supply to each of the individual crops was estimated based on consultation with sampled farmers on their irrigation schedules for each crop. The farmers tell the interval of irrigation, duration of application and area under each crop. However, they cannot reasonably tell the rate of application [(Q, (Eq6)].

$IFWP=\sum_{1}^{n}(Vj\ (\ USD))/(IWj\ (m^3))$ (Eq5)

Sampling, irrigation strata and data acquisition

Following identification of indicators, a household survey tool, checklists for transect walk and discussion with key informants were developed. The questionnaire covered the size of land holding, major crops, input types and quantities, productivity, irrigation frequencies and length of growing period and farm characteristics. This was also suggested by Van Halsema et al. (2011) for evaluation of on-farm management. Smallholder farmer-managed irrigation schemes are heterogeneous and thus there are arguments that analysis would give better insights if a scheme is disaggregated into reaches; head, mid and tail (Şener et al. 2007). In this study we used this approach to stratify each of the study schemes as head, mid and tail irrigators based on their physical location within the schemes. Approximate boundaries were drawn between these clusters and about 10 plots were randomly selected for each reach (total 30 plots per scheme). The households who own each of the targeted plots were considered as sample for the household interview. The questionnaire was then administered during January–February 2015 targeting 2014 production season.

In addition to the household survey, FGD was used to gain in-depth information on specific topics from farmers and extension workers. Groups consisting of 5–10 farmers were considered for the FGD. Bio-physical data related to the on-farm management, on-site determination of soil textures, landholding sizes of sampled farmers, irrigation supply at the farm inlets, and on-farm water distribution uniformity, were also recorded in transect walk. To estimate the sample plot areas GPS was used, and taping was made around the farm plots. For the water supply and on-farm water distribution, we collected data on water flow at the inlet of the plots. Float method was used for discharge at the inlets of the plots. Data on depth and width of the canal for a known canal length was measured repeatedly and then Eq 6 was used to calculate the discharge. The total volumes of water applied to the plots were determined by equation 7.

$Qi=((D(m)*W(m)*L(m))/(T\ (s)\ ))*0.8$ (Eq6)

Where D is the depth of water in the canals, W is the width of the canals, L is the length of the canal reach considered to be advanced by the float, T is the time needed by the float to advance the distance L, m is metres and s is seconds.

The above equation will provide only a single event value of discharge. Discharges were monitored twice a day to capture fluctuations. Therefore to estimate the total volume of water used for irrigation (TIW) we multiplied the average discharge (Qa) with total number of irrigation events (nr) per season and duration of irrigation event (du) as illustrated in Eq 7 below.

$TIW=Qa*nr*du$ (Eq7)

2.3. Irrigation typology building and data analysis

Smallholder irrigation schemes in Ethiopia are customarily classified into traditional and modern schemes based on the types of water source or the physical infrastructure for water acquisition, conveyance and distribution or both. (Yami 2013; Dejen et al. 2012). For typology building, a comprehensive and inclusive approach—whereby seven criteria were considered—was followed. Water source, water abstraction method, conveyance, distribution, flow control, on-farm application and institutions were the criteria considered for clustering the schemes as traditional, semi-modern and modern. Several methods of assigning weights for the criteria are proposed. In this study, participatory approach whereby experts involved in data collection process were consulted to assign weight to each indicator on consensus basis was followed. The final results on the rank are presented as mean of all grades on the criteria. While a scheme is classified as modern based on water abstraction structures, it might fail to meet the expectation due to poor water distribution, inequity and low productivity. On the other hand, there are cases where traditional schemes performed better than those classified as modern on mere consideration of headwork. Seven major criteria were identified to determine the typology of schemes. For each of these criteria, a weightage is assigned (out of 10) based on its relative importance. Then the condition of each scheme was evaluated against these criteria and graded on a scale ranging from 0 to 10 by a group of experts (data collectors and other experts) from IWMI. Accordingly irrigation systems of this study are categorized into three namely: modern systems, semi-modern systems and traditional systems. We fixed the weighted grade scales of the schemes and the schemes were classified based on the fixed grades (Table 2). As indicated in Table 2, one scheme came up to be modern, five schemes to be semi-modern and three schemes to be traditional.

Table 2: Typologies of schemes as classified by multi-criteria analysis

Scheme	Grade	Typology	Criteria for classification
Koga	92.5	Modern	If grade > 80%
May Nigus	62.25		
Meki	59.0		
Wukro	58.5	Semi-modern	If 50% < Grade < 80%
Hare Weir	58.0		
Gelana	50.25		
Waro	42.5		
Megech	42.25	Traditional	If Grade < 50%
Hare diversion	36.5		

3. Results and discussion

3.1. Land productivity of major irrigated vegetables and cereals

Figures 2–5 present land productivity of common crops by schemes and by typology. We focused on two clusters of major crops grown in the study schemes: Vegetables (onion and tomato) and cereals (maize and wheat) and also presented the overall land productivity for different crops in terms of their financial value. These crops are not all grown at a specific irrigation scheme, there are some crops commonly grown at one scheme, but not at another. Variation in land productivity for observed crops was apparent. Land productivity for onion ranged between 7.13–14.55 tonnes/ha^{-1}, while for tomato the range was wider (0.9–10.29 tonnes/ha^{-1}). Meki scheme showed the highest land productivity for onion and tomato with the magnitude of 14.55 and 10.29 tonnes/ha^{-1} respectively (Figure 2 and 3). Both values were very close (onion 13.9 and tomato 11.2 tonnes/ha^{-1}) to observations by Van Halsema et al. (2011). Although this value for onion at Meki was on higher side when compared to the national average indicated by Ethiopian Investment Agency (EIA) which is 10.2 tonnes/ha^{-1} in 2012, and also by Abdissa et al. 10.5 tonnes/ha in 2011.This was lower than SSA and global average. Yields of onion at Megech, May Nigus and Wukro are much lower. The yield of tomato at Meki scheme is 10.29 tonnes/ha^{-1}, which is higher than the national average for tomato (7.83 tonnes/ha^{-1}). However, the yields at May Nigus, Wukro, Waro and Gelana are much lower than the national average. The question is also to understand whether these yields are water, fertilizer or variety limited.

As Meki irrigation scheme is located closer to the major market, Addis Ababa, 135 km away, farmers practice intensive irrigation and thus a combination of better agronomic practices, better access to inputs and markets, and climatic factors might explain the reason for higher productivities of Meki scheme. In view of the prevailing over-irrigation and unbalanced nutrient application, it is obvious that the irrigation schemes are performing much lower than the regional and global average. The study showed that the very low yield, particularly at Wukro scheme (e.g for tomato), is primarily due to water stresses. There is an intense competition for water at the Wukro scheme between the head and tail users, particularly throughout low river flows. During field visits, it was confirmed that the serious level water stresses had caused significant loss of yields. Study by Getnet et al. (2015 in press) on profit and financial risk in the smallholder irrigated agriculture of Ethiopia complement the findings of the current work.

Figure 2: Land productivity for onion across schemes (tonnes/ha).

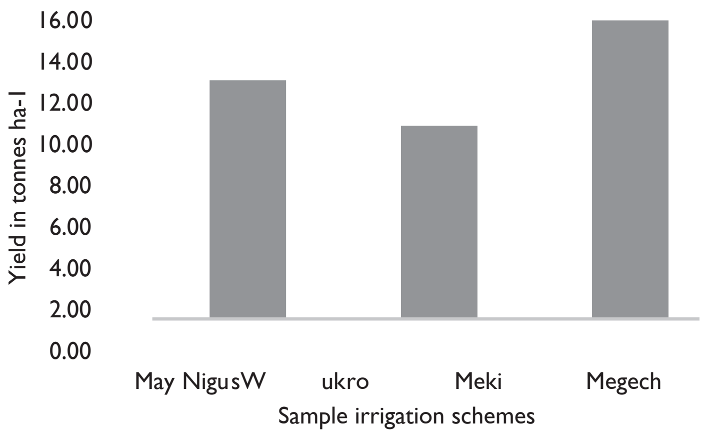


Figure 3: Land productivity for tomato across sample study schemes (tonnes/ha).

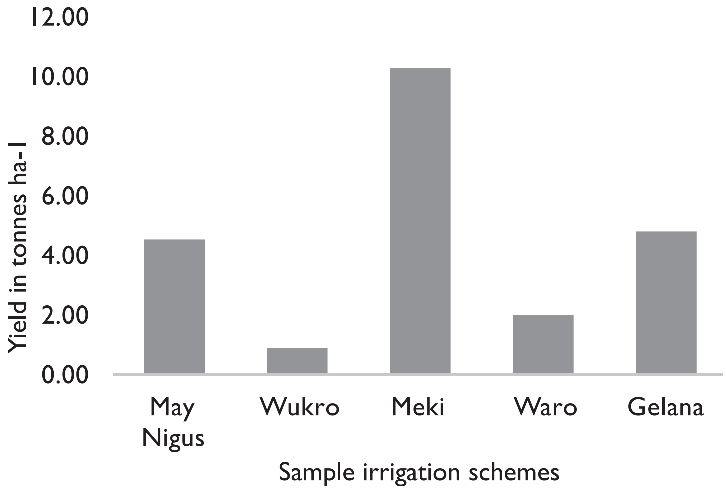


Figure 4 and 5 depict land productivity for maize and wheat respectively. Similar to variability in productivity of vegetables, variations is also observed across schemes for cereals. The recorded values of productivity range between 0.65 and 3.92 tonnes/ha^{-1} for maize and 0.6 and 1.56 tonnes/ha^{-1} for wheat. The highest value was recorded at Meki for maize and Koga for wheat. Average maize yield in SSA is about 2 tonnes/ha^{-1}, and the national average of Ethiopia is also 2 tonnes/ha^{-1}. Maize productivity at Meki and Megech are almost about twice of the national average. Hence land productivity at Meki scheme is adequately high for most of the crops with the exception of wheat compared to the other schemes as well as the national average yields of these crops.

On the other hand, wheat crop productivity is highest at Koga scheme followed by May Nigus. Wheat is the major irrigated crop at Koga due to favourable climate condition and suitable soils. The irrigation schemes cropping pattern is also influenced by the government food self-sufficiency policy during the project design period. The average wheat yield in Ethiopia from 2004 to 2011 was 1.68 tonnes/ha^{-1}, which significantly lags behind other major producers in Africa such as Kenya and South Africa (FAO 2013). While the yield at Koga is nearly similar to the national average, the yields at the other schemes stand very low (Figure 5). According to CAB (2009), the SSA average land productivity for wheat is also nearly 2 tonnes/ha^{-1}. The land productivity for wheat at schemes Wukro, Meki and Waro (Figure 5) remained below 1 tonne/ha^{-1} (less than 50% of the SSA average. The largest productivity obtained in this study at Koga (1.56 tonnes/ha^{-1}) is also less than the average for SSA.

Generally a number of biophysical and socioeconomic factors exert constraints on crop yields, resulting in yield gaps that can be tackled with adequate agricultural input and water management. In view of a prevailing yield gaps, particularly for vegetables, the result here suggests the potential that irrigated crop can contribute to food and nutritional security in Ethiopia. In addition to the differences in yield gaps between the two clusters of major irrigated crops, farmers' choice to grow cereals or vegetable has implication on land productivity and water productivity.

Figure 4: Land productivity for maize across sample irrigation schemes.

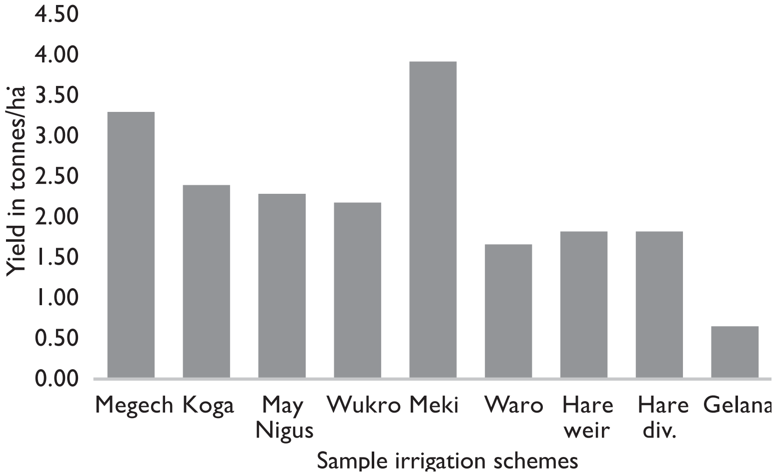
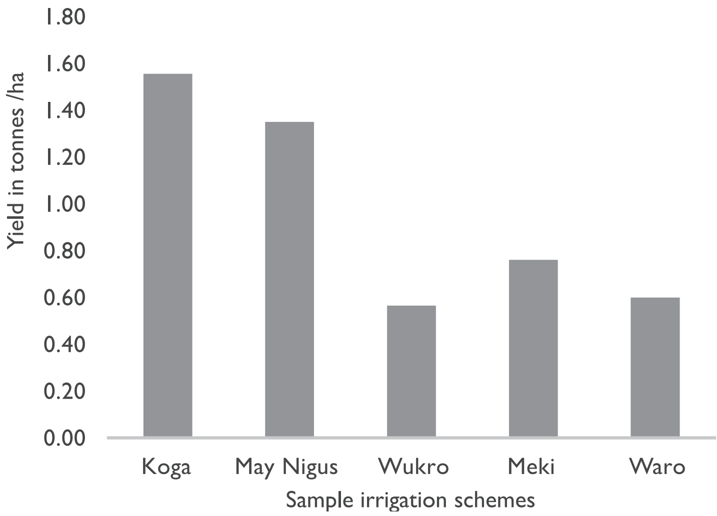


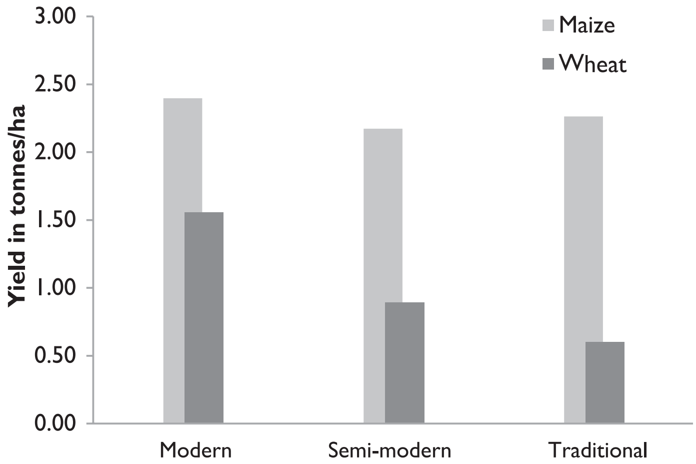
Figure 5: Land productivity for wheat across sample irrigation schemes.



Cereals (maize and wheat) are more common crops across all schemes. However, except at Koga and to some extent at May Nigus and Wukro schemes, these two crops are mainly grown during the rainy season, and hence little irrigation is used to supplement rainfall. Particularly at Koga scheme wheat is the major irrigated crop during the dry season covering over 80% of the irrigated area. This means the point of land productivity between cereals and vegetables when viewed from water, fertilizer input perspectives has contrasting implication and thus, to be conclusive, further analysis in terms of value added and water productivity is needed.

To closely examine variation in land productivity among irrigation typologies land productivity was aggregated by irrigation typology for the two major crops: maize and wheat (Figure 6). Accordingly, the productivity of maize does not show significant variation among typologies unlike for wheat (Figure 6). Productivity is highest for the modern scheme (Koga) followed by semi-modern and traditional typologies. The question is also why the difference for maize productivity among scheme typology is not strong and why it does for wheat? Discussion with experts in the field suggests that this could be also partly due to attention paid by different national and international research institutes.

Figure 6: Land productivity by typology for two crops.



The above observation of land productivity differences across schemes and typologies is just an aggregation to some extent. To see variability within schemes Table 3 shows the average land productivity for different reaches. From Table 3, it can be noted that the yield generally decreases from the head to tail reaches for many of the schemes. Some exceptions also exist where yields in the middle reach are higher than those at the head. These are observed for instance at May Nigus (for onion) and at Gelana (for tomato). These are actually not related to water supplies, but could be accounted for to soil variability. Particularly at Gelana scheme, the head reach is so hilly (>15% slope) and the water quickly runs down the furrows and field channels resulting in serious soil erosion. For many of the study, irrigation schemes trends in yield variations across the reaches as schemes are strongly related to head-middle-tail competitions for water and inequity levels. For instance, assessment of the water delivery system indicated that the competitions for access to water and inequity levels are high at Meki, Wukro and Megech schemes. In each of these schemes, tail users are the most disadvantaged ones in terms of water delivery. It can be noted that at each of these schemes, yields of crops declined from head to tail (Table 3). On the other hand, at Koga and Waro schemes, the water delivery is reasonably equitable across reaches. As such, differences in yield were not remarkable across reaches. Hence, the conclusion is while other factors could contribute to yield differences across reaches, what is observed here is mainly correlated to magnitude of variations in access to water over reaches. This means also addressing yield gap is not only about dealing with inputs as discussed above. Adjusting social components such as equity through proper organizational arrangement is important to consider.

Table 3: Yield of crops by reaches for different schemes in tonnes/ha

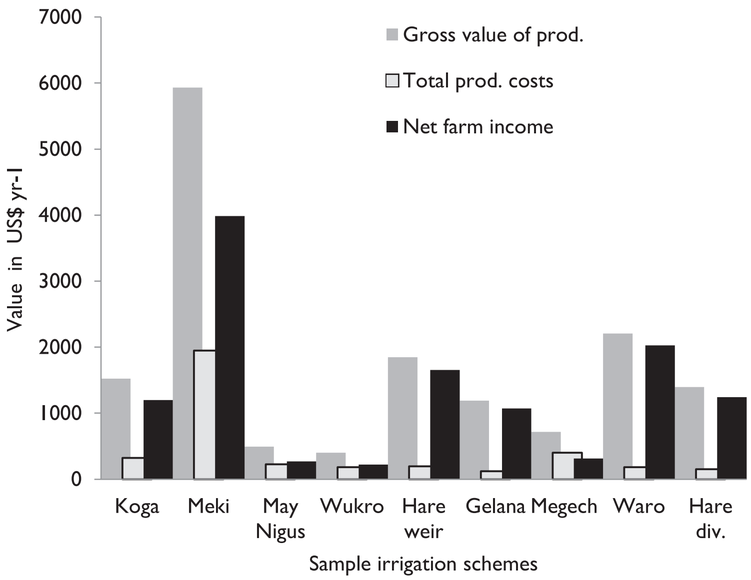
Onion															
Scheme		Meki			May Nigus			Wukro			Megech			-	
Reach	Head	Middle	Tail	Head	Middle	Tail	Head	Middle	Tail	Head	Middle	Tail	Head	Middle	Tail
Yield, tonnes/ha	17.0	15.5	12	7.4	9.7	6.2	10.0	7.0	5.5	11.5	8.0	4.0	-	-	-
Tomato															
Scheme	Meki			May Nigus			Wukro			Waro			Gelana		
Yield, tonnes/ha	12.2	12.2	8.3	4.8	4.8	3.6	1.2	1	0.9	2	2	2	3	5.5	2.8
Maize															
Scheme	Megech			Koga			May Nigus			Wukro			Meki		
Yield, tonnes/ha	4.2	3.6	2.0	2.4	2.4	2.4	2.3	2.1	2	4	3.2	2.1	4.2	4	3.2
Scheme	Waro			Hare weir			Hare diversion			Gelana					
Yield, tonnes/ha	1.67	1.67	1.67	2.0	1.8	1.6	2.0	1.8	1.6	0.7	1.6	0.6			
Wheat															
Scheme	Koga			Meki			May Nigus			Wukro			Waro		
Yield, tonnes/ha	1.56	1.56	1.56	1.1	1.0	0.76	1.35	1.35	0.7	0.7	0.7	0.5	0.6	0.6	0.6

3.2. Gross and net value of production based on all irrigated crops

While the GVP in USD/ha is more useful as it is related to land which is limiting, total household production in USD can indicate the general economic situation at a scheme. The average gross and net values of household production for each scheme are shown in Figure 7. These are based on incomes from all irrigated crops. It shows that both the gross and net household production values are highest for Meki scheme. Higher values of household production do not necessarily imply higher land productivity of irrigated crops, but could imply larger landholding sizes. Of course the highest values of gross and net household production at Meki scheme are the combined effects of both higher land productivity as was already determined and larger land holding sizes. So this indicator tells the wellbeing (the income) of average households without due consideration of the productivity levels. It is also interesting to note the relative amount of the production costs and the net household incomes. While for all the schemes, the production costs are less than the net incomes, Megech is the exception at which the production costs are higher than the net income. At Megech, farmers use either communal or private diesel engine pumps to pump water from the river. Fuel costs and maintenance costs of pumps, including spare parts, are the major costs of production. This tells that diesel pumping schemes can be justified by growing cash crops, with good market access and adequate technology support services. A recent study by Gebregziabher et al. (2016 in press) suggests that pump based irrigation for below certain irrigable land is not financially remunerative.

However, gross and net values of productions per hectare of land is a more important indicator to assist efforts to maximize benefits per unit of land cultivated in multi-crop situation. Obviously land is a limiting resource and thus a closer observation on the gross and net value of production per unit area gives better insight. Figure 8 shows the average net values of production derived from all irrigated crops/ha of land/year. Crop selection and markets play significant role to affect the value of production/ha.

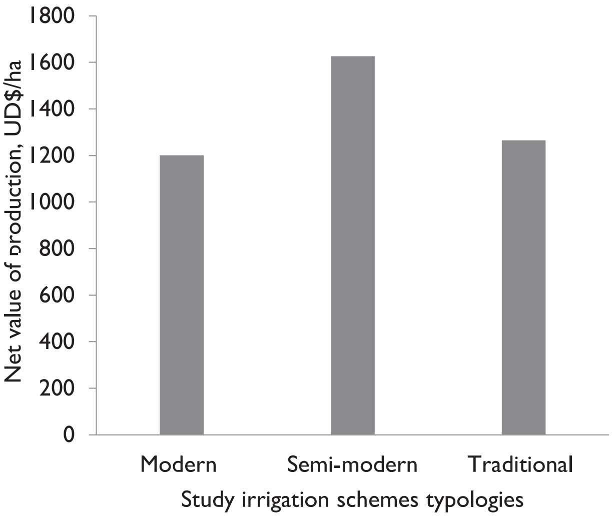
Figure 7: Average gross and net values of total household production for all crops.



The net value of production per hectare is highest for Gelana scheme, probably due to large coffee production in the scheme. Net output per hectare at Meki scheme stands as the second highest. Results indicate that land productivity, values of total household production and net values of production per hectare of land perform adequate and better for Meki scheme, which can be attributed to crop selection, better access to technology and better market access, all of which better financially justify the use of diesel engine pumps. Waro, being a traditional scheme has the third highest net value of production per hectare, better access to water, suitable soils and market access are the factors. The lowest net production values were recorded for Wukro and Megech schemes. For Wukro, the main attributer is water stress and competition for water, while for Megech the main reasons are the operation and maintenance costs of pumps and limited market access.

The net output per hectare of land for all irrigated crops (by values of crops at local price) was also then aggregated by typologies in order to enable better and logical comparison (Figure 9). It was observed that semi-modern irrigation schemes had the best net output values per hectre of irrigated land. The reason for better value of production is not straight forward due to the complex nature of the factors affecting the agricultural production system. But the overall lesson here is that modern irrigation does not necessarily imply higher values of production per unit of land or per family. Several factors other than the water supply system, such as crop selection and agronomic practices, agro-climatic condition, soil type and fertility, access to inputs, condition of irrigation water availability, market chain, etc. affect the value of gross and net productivity per household and per unit of land. Hence performance evaluation of irrigated agriculture, particularly at farm levels, needs to combine water management and other equally important elements in the production process. Crop selection plays a major role for the higher value of production in the semi-modern schemes in this case. Major crops at the semi-modern irrigation schemes are either high value vegetable crops (Meki, May Nigus and Wukro) or annual crops (coffee or fruits) at Gelana and Hare weir. Wheat being the major irrigated cereal crop and specialized at the modern scheme (Koga), the yield and value of production is by far lower. Crop selection in public irrigation schemes are very often affected by government policies and priorities. For example, when the Koga irrigation scheme was initiated in the early eighties, food self-sufficiency was the apriority and the road to the main market centre was not well developed. Thus in the feasibility study of the scheme wheat and maize constituted the major cropping pattern and farmers start producing what they were advised to produce.

Figure 8: Average net values of production per hectre by typology for all irrigated crops.



The question is whether food self-sufficiency or food security focused irrigation is water productive and sustainable. As part of this work, we asked farmers whether they do irrigation for food security or food self-sufficiency or both. The result illustrates that there is little specialization for food self-sufficiency or cash income. The majority of the farms in the study schemes were focusing on both. The major driver for these variations can be associated with access to market and land holding size. For example in Meki irrigation schemes, which is about 100km from the capital and crossed by a highway connecting the capital and Hawasa, a significant proportion of farmers (63%) responded as cash oriented, whilst in south Wollo where land is fragmented and rain fall is less reliable, significant proportion of farmers (50%) responded that the purpose of irrigation is mainly food self-sufficiency. According to a widely accepted definition from the Food and Agriculture Organization, food security is achieved when "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". In contrast, food self-sufficiency is defined as being able to meet consumption needs (particularly for staple food crops) from own production rather than by buying or importing. There is a longstanding debate as to whether food self-sufficiency is a useful strategy to achieve food security. Supporters of this proposition argue that relying on the market to meet food needs is a risky strategy because of volatility in food prices and possible interruption in supplies. The opposing view is that it is costly for a household (or country) to focus on food self-sufficiency rather than producing according to its comparative advantage and purchasing some of its food requirements from the market. From the angle of productive water use recent attention is to high value crops such as vegetables and fruits despite a more water demand. Thus in view of conserving water while achieving food security, it is important that government policy support the transition of smallholder irrigation systems to high value crops.

3.3. Irrigation water productivity for major crops

Irrigation water is generally limited or mismanaged in all irrigation schemes and water scarcities in the whole scheme or part of a scheme are among the major challenges constraining agricultural production. Hence, management of irrigation water should aim at increasing the yield (production/value) per drop of water (Haileslassie et al. 2009). Water productivity can be determined based on water delivery at different locations within the irrigation system. For instance, water productivity determined at the headwork (head of the scheme), at the tertiary canal offtake or at the field levels in canal irrigation systems will be different due to unavoidable conveyance, distribution and on-farm application water losses (Dejen 2014).

Water productivity can also be determined based on water supply or water demand (potential ET). Water productivity based on ET depends basically on climatic factors affecting ET, and it has less significance for water management under water scarcity as it assumes sufficient water supply which is optimum (CPWF 2007). However, water productivity based on water supply can significantly vary from one scheme to another, because it depends on the nature of irrigation water supply, type of water conveyance system, on-farm water management, scheme water use efficiency, etc. Water productivity indicators can give a clue about the entry point for efficient and productive uses of water.

In this study, water productivity (WP) was determined based on both water supplies at field level and ET (demand) in USD/m^{-3} to compare the difference across commodities and schemes (Figures 9 to 10). Comparison of water productivity based on field supply (WPf) with that of water productivity based on evapotranspiration (WPet) provides a useful idea of the on-farm water losses during irrigation of each crop. For instance, for onion (Figure 9), Meki, May Nigus and Megech schemes have WPf values less than WPet values for all crops, showing that the field water application is higher than the ET demands. On the other hand, at Wukro scheme WPf is higher than WPet which indicates field water stress. The same is true for tomato crop at Wukro, Gelena and Waro schemes (Figure 10). For wheat (Figure 11), the WPf is higher than the WPet which indicates field water supply lower than ET demand. Similarly for maize (Figure 12), the WPf is less than WPet at Hare weir, Hare diversion and Gelana schemes. Generally at Wukro and Gelana schemes, and to some extent Waro and Hare (weir and diversion), farmers practice deficit on-farm supply. Particularly Wukro and Gelana schemes have significant head-tail reach water delivery inequity and competition for water, with head users are significantly over-supplied, while tails are generally under-supplied. The irrigation practice at these schemes particularly in the middle and tail reaches is generally deficit irrigation. There is generally large variability in the WP values across schemes.

The WP values reported here are in many case lower than the global values and but there are also cases that complement the findings of the present study (Maurya et al. 2014). While WPf for cereals at the schemes is generally on the lower side, it is somewhat on the higher side for vegetables. For instance, the average WP of tomato is reported to vary between 0.20 and 0.31 USD/m^3 at two irrigation schemes (Tono and Dorongo) in Ghana (Mdemu 2008). WPf for tomato in this study varied between USD 0.23/m^3 and USD 1.12/ m^3.

Figure 9: Irrigation water productivity for onion.

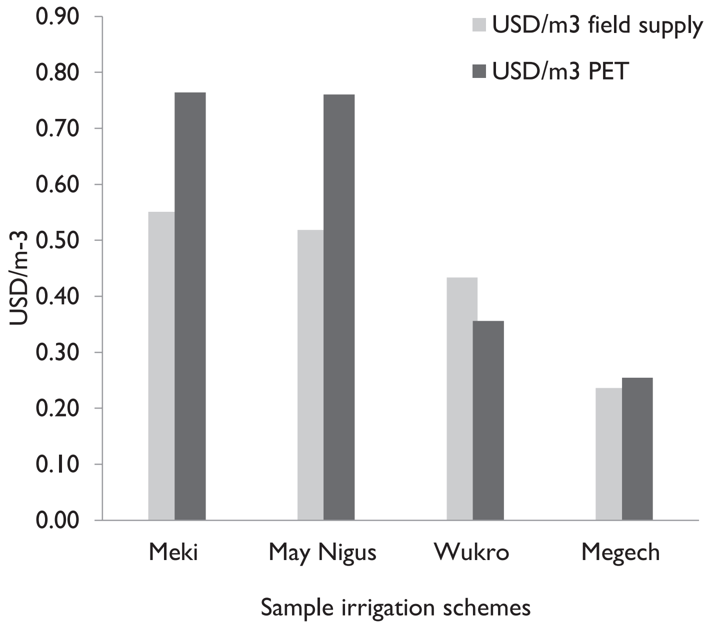


Figure 10: Irrigation water productivity for tomato.

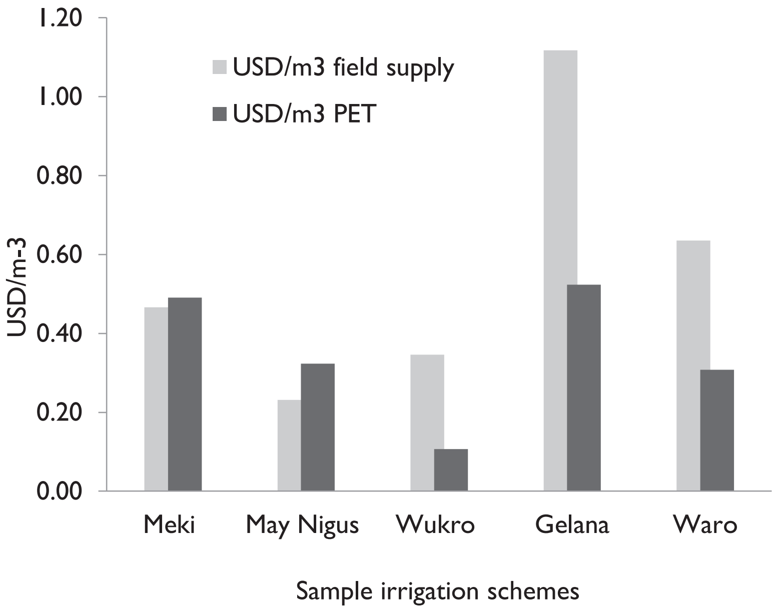


Figure 11: Irrigation water productivity USD/m^{-3} for wheat.

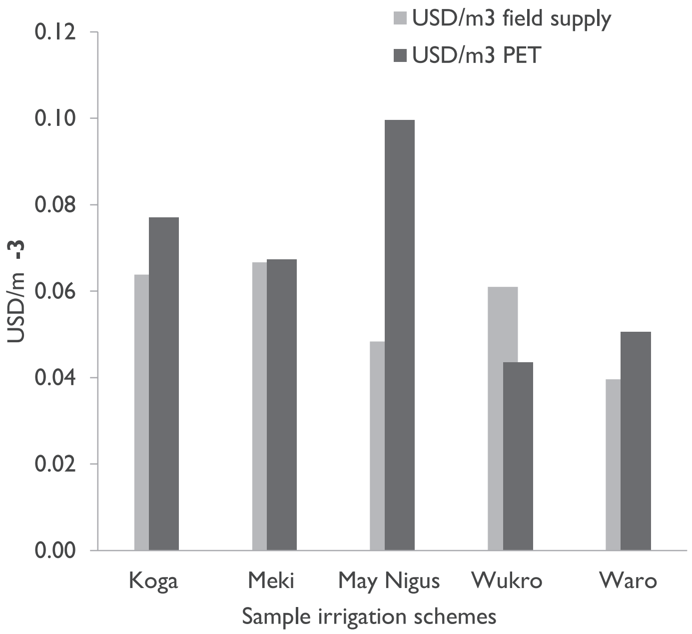
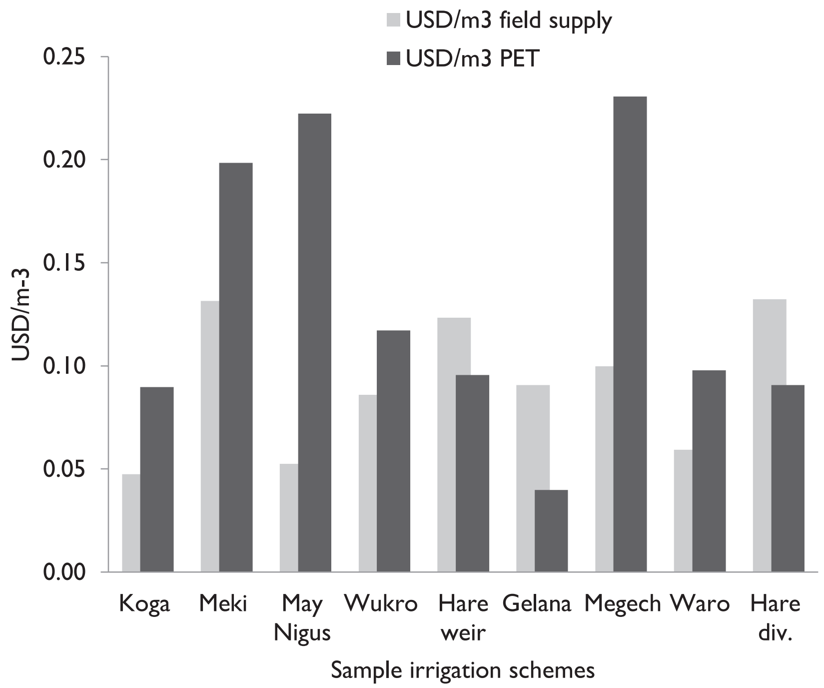


Figure 12: Irrigation water productivity USD/m^{-3} for maize.



For the common cultivated crops across the study schemes (maize and wheat), water productivity (WPf) was aggregated by typology (Figure 13 and 14). Similar to the value added by irrigation, water productivity decreased from modern to traditional typologies for wheat; while it increased from modern to traditional typologies for maize. The WP values for semi-modern and traditional schemes for maize are almost the same and higher than that for modern (Koga). The comparatively low WP for maize at Koga is probably due to excess on-farm water delivery and less specialization of maize at the scheme. The WP values obtained for the two cereals are low even compared to SSA. Molden et al. (2007) state that typical water productivity figures for wheat is 0.5 kg/m^{-3} in low-performing irrigation systems and 0.2 kg/ m^3 in rain-fed SSA. The WPf values obtained in this study for wheat varied from 0.11 to 0.17 kg/m^{-3}, which is by far low. Improving land productivity through intensification of water saving strategies would help to improve water productivity.

Figure 13: Physical water productivity in kg m^{-3} field supply by typology.

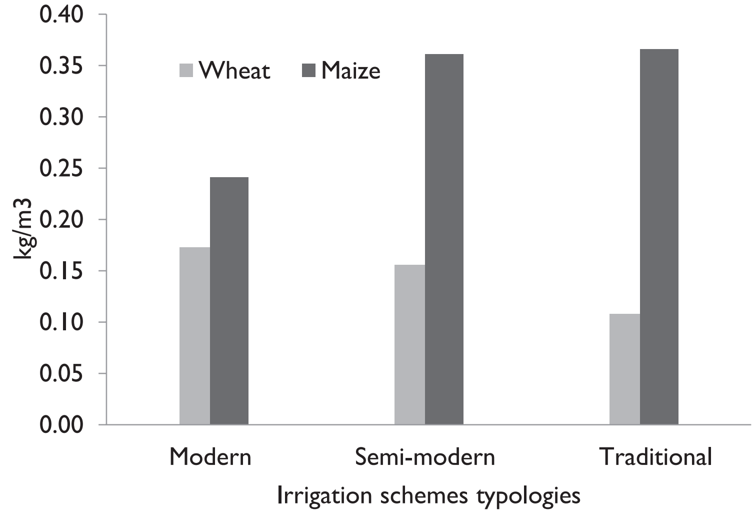
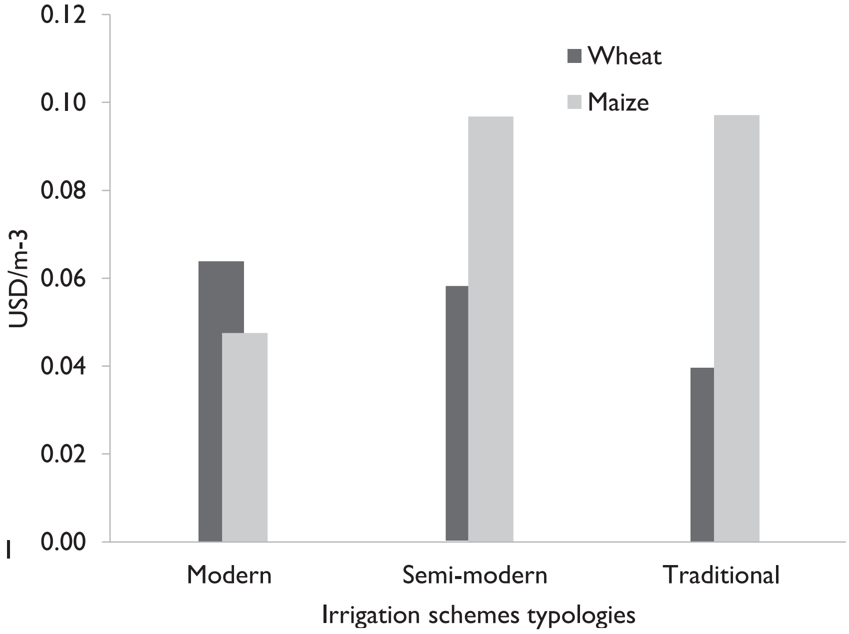
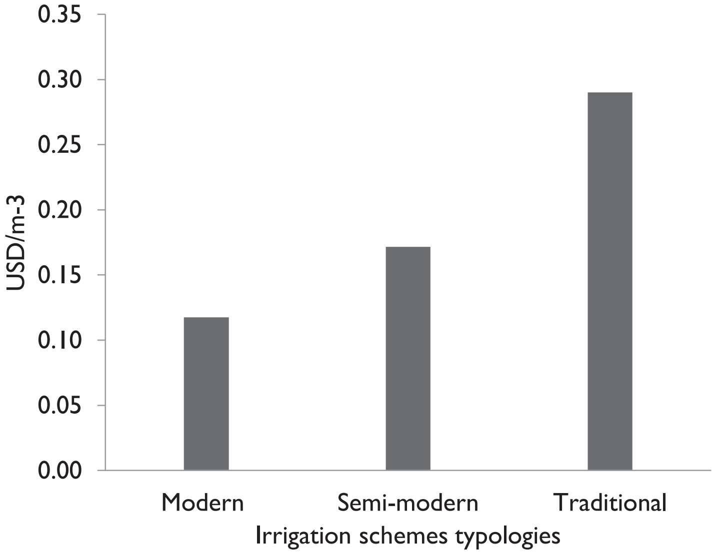


Figure 14: Economic water productivity USD m^{-3} of field supply by typology.



In addition to WP for individual crops, the total WP at headwork was aggregated by typology (Figure 15). The WP is higher for the traditional typology and is lower for the modern typology. These can be mainly attributed to the supply of irrigation water (non-reliability of the water diversion, control and distribution). The temporary structures for water diversion and distribution do not allow adequate and equitable water distribution, which occasionally cause shortages particularly during low flow in the rivers; as such water is generally in deficit at these schemes. Deficit irrigation with acceptable yield reductions in these schemes combined with lower water diversion resulted in higher total water productivity in the traditional typology. Lower water productivity at Koga (modern typology) is mainly due to excess water diversion at the headwork and the main irrigated crop type. The relative irrigation supply (RIS) which is the ratio of diverted to required flow at Koga is 1.9 and 3.4 for seasons I and II respectively, and the type of crop grown (wheat) which has lower value compared to vegetables. Note that land productivity is relatively low for traditional irrigation schemes, while having high total WP. Hence, enhancing land productivity can result in higher WP; however it cannot ensure it due to several other factors.

Figure 15: Total economic irrigation water productivity at intake (diversion) by typology.



One of the factors that can significantly affect the productivity of the field supplied water is the relative location of the fields in the scheme; head, middle, tail (Molden, Gates. (1990). This is due to the fact that the location of the farmers' fields will determine their level of access to water and efficiency of water use and hence agricultural production, particularly in gravity irrigation systems. The water supplied to sample fields in the head, middle and tail reaches of the schemes along with the total values of agricultural productions needs to be determined for this. The total values of production for sample farmers were collected with the household surveys. The water supplied to sample fields in the head, middle and tail reaches were determined by combining household surveys on farmers' irrigation practices and field measurements. The reach water productivity for each scheme is shown in Table 4. There were apparent variations in WP across reaches. Variations in water productivity across reaches does not only relate to the general consensus that tail users are more efficient in their water use. While tail users are more efficient, the reductions in yields due to water shortages play an equal role in WP values. Tail users can be more water productive provided the water stresses are within acceptable limits, and sometimes farmers have smart ways of dealing with water scarcity, for instance through crop selection. Tail farmers at May Nigus scheme, for instance, grow crops that are less water intensive (mainly legumes). These crops can be grown with less volume of water compared to vegetables (onion or tomato); however, their financial outputs are lower. For the individual schemes, reach water productivity (Table 4), tail farmers are generally more water productive (WPf) than head users. The exception being at Megech scheme where head productivity is higher than tail. This is reasonable because in this scheme water is pumped from a river and there are occasions where the river flow cannot reach the tails. In order to create temporary water storages, groups of farmers block the river flow using sand bags and materials like soil and stones there by creating a pool from which they pump. This ultimately causes critical water stresses to the tail users, drying up the river during low flows, and leaving them at a risk of losing their harvest. WP at Wukro is highest for the middle reaches, primarily due to serious water stress in the tail parts when the river flow is totally stopped by head users, which causes series yield losses at the tail.

Table 4. Total water productivity of schemes (based on water supplied at the head of the fields) by reach

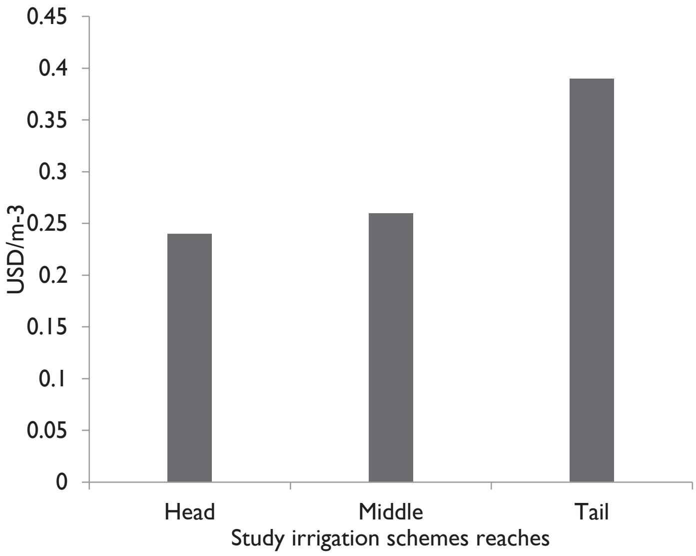
Scheme	Water productivity, USD/m^{-3}		
	Head	Middle	Tail
Koga	0.07	0.10	0.10
Meki	0.12	0.12	0.14
May Nigus	0.09	0.09	0.22
Wukro	0.09	0.31	0.17
Hare weir	0.43	0.30	0.64
Gelana	0.34	0.50	0.86
Megech	0.18	0.17	0.13
Waro	0.10	0.27	0.47
Hare diversion	0.74	0.50	0.82

The average total field water productivity (WPf) (value of irrigation water) of all the schemes were then determined for each reach (Figure 16). The average WPf increased from the head to the tail reaches. This was also observed from the water productivity of individual schemes. Most of the schemes under consideration have significant excess diversions at their headworks and the losses are in the distribution system and mainly in the head and middle reach fields. Although tail reaches have the lowest total value of household production, they produce it with much less water. Regardless of large inequity levels and water stresses at the tail ends, farmers are able to cope by using different approaches of their own, such as crop selection, better on-farm water management, and hence higher water productivity as discussed earlier.

Water productivity in SSA and in some parts of Asia is generally low compared to other regions. Kadigi et al. (2012) state that WP for water consumed in agriculture ranges from USD 0.05 to 0.90/m^{-3}, with the majority of observations in the range of USD 0.10 to 0.20/m^{-3}. Savoskul et al. (2003) found that water productivity calculated on the basis of three major crops (cotton, wheat, rice) in Syr Darya in Central Asia is 0.11 USD/m^{-3}. Average total economic water productivity for SSA ranges between 0.1 and 0.3 USD/m^{-3} (Demeku et al. 2011). The total WP values obtained for the schemes under consideration are comparable. The question then is whether higher WP implies higher farmer benefits, short-term economic progress and equity?

Higher water productivity does not ensure higher economic return for farmers, at least in the short term. This is the case as evidenced by analysis of land and water productivities for traditional schemes and tail irrigators. Higher land productivity does not ensure higher water productivity (modern irrigation) and vice versa (traditional irrigation). Smallholder farmers are more interested in their economic return from their plot of irrigated land, and higher yield per drop of water is not of big interest to them. There is no incentive for fairness for saving irrigation water, and irrigation water prices are not well set or does not exist in many cases. Kumar and van Dam (2010) state that the main considerations involved in analysing WP in the west are in reducing the amount of water required to produce a unit weight of crop, but this is not the concern in many developing economies like in Asia, where land use intensity is already very high in many regions. Higher WP would be more important in the schemes considered in this study if there were appropriate irrigation water pricing in place and water costs were set so as to discourage excess deliveries.

Figure 16: Aggregated water productivity by reaches across all schemes.



4. Synthesis of key challenges and entry points to addresses issues of on farm irrigation performance

In the preceding section empirical values illustrating on farm irrigation performances based on the most commonly used indicators such as land productivity; water productivity and gross value of output across three scale in interactive way were presented. Based on these findings the following sections will summarize key challenges and opportunities to address them.

i. Low land productivity: As observed from empirical evidences presented earlier land productivity of crops is generally low. There is greater variability among schemes and within schemes as displayed by analysis at schemes level and by irrigation reaches. The lowest value of land productivity is estimated for the traditional schemes. Achievable yield reported by the Ethiopian Institute of Agricultural Research (EIAR 2004) for many varieties of maize, for example, is 200% higher than the values recorded here with and among scheme variation. The gaps for vegetables are even greater. This indicates the potential of irrigation commodities to contribute to food and nutritional security if the major yield limiting factors are properly addressed. Major contributors to yield gap, in addition to the over-application of water (in modern and many semi-modern typologies) and under-application (in traditional typologies and tail reaches), involve a lack of adequate knowledge of agricultural extension and limited access to improved seeds (DCG 2009; IFPRI 2010) and the injudicious management of fertilizer.

Suitable methods of irrigation, direction of furrows (irrigation), amount of application, duration of application, irrigation scheduling, uniform on-farm water distribution techniques, etc. are some of the skill gaps identified in discussions with farmers. This is basically what drives over-application of water in many cases and this is accounted for the dominant poor on-farm water management leading to non-uniformity of distribution along farms, water losses and under supplies. Farmers manage their irrigation water by themselves in many cases and they get very limited practical training on on-farm irrigation. So, adequate training on on-farm irrigation water management practices, including crop based duration of irrigation, field application rates, irrigation scheduling, on-farm water application methods, method of on-farm uniform water distribution, etc. are crucial for more efficient and sustainable irrigation management. The next important thing to consider is factors that help to convert the depleted water to beneficial outputs. These involve better quality seed, fertilizer and proper pest and disease control. The seed supply system in Ethiopia is generally not well developed and in some cases it lacks transparency. In almost all studied irrigation schemes, farmers indicated that limited supply of seeds particularly for vegetables is seen as a major concern limiting productivity of farmers. Formal, transparent and well-established seed supply system can significantly improve farmer outputs.

Nutrient depletion is one of the major attributors to low productivity in Ethiopia, and nutrient limited productivity gaps are well established. As such, the fertilizer input rate is a major aspect of on-farm management. Data on the rates of fertilizer use were collected from household surveys and focus group discussions. Average fertilizer inputs at each scheme for different crops was determined. Fertilizer inputs for Meki and May Nigus schemes are significantly higher than at any other scheme for all the major crops and also well above the blanket recommendation rate. A simple partial factor productivity (PFP) and agronomic efficiencies analysis indicate that fertilizer application is in transition for Ethiopian smallholder farmers: i.e. in contrast to widely recognized low fertilizer inputs (Haileslassie et al. 2005; Haileslassie et al. 2006), high rate of application is emerging in intensively managed irrigation systems such as Meki. Drechsel et al. (2015) indicated the typical values of PFP for N is 40–90 and for P is 75–200 for cereals. Lower values suggest less responsive soils or over application of nutrients, while higher values suggest nutrient supply is limiting agricultural productivity. Accordingly, our estimated values of the PFP for maize for both N and P were lower than the typical values for modern and semi-modern typologies, showing over application of fertilizers. However, for the traditional schemes, the PFP values for both N and P are higher and lie within the typical ranges of PFP. This suggests that the yield at the traditional schemes could be limited by nutrient availability. On the other hand, for wheat the PFP for both N and P are lower than the typical ranges of PFP for all the schemes. Hence, either fertilizer is over applied or the soils are less responsive to nutrient supply for wheat. Although these arguments need further analysis, it is important to understand that the trend has both environmental and economic implications if not well addressed and the research system should pursue context-specific water and fertilizer optimization.

ii. **Low physical and financial water productivity**: Improving water productivity of irrigation scheme is one of the Ethiopian government strategic directions in relation to smallholder farmers. In principle, higher water productivity agriculture means higher outputs per unit of water input. As illustrated in this work this does not always hold true. Schemes for higher land productivity does not necessarily shows higher WP. The situation as indicated in this report is contrasting. Modern schemes and head irrigators have usually higher land productivity, but low water productivity. The opposite holds true for the traditional irrigation and tail irrigators. The reason for this is that modern schemes and head irrigators usually over irrigate and thus elevate the denominator of the WP. The traditional schemes and tail irrigator normally suffer from water shortages and most often practicing deficit irrigation and also select crops with low water requirement. Hence they save water while trying to minimize the impact on the yield through crop selection. Partly this could be accounted for by the fact that water is a free commodity and farmers do not consider water as an economic good as they do not pay for it. This also means future direction of improving smallholder irrigation needs to acknowledge this reality and make efforts to save water on head irrigators and increase land productivity under traditional and tail irrigators as the road to sustainability and equitable water allocation.

iii. **Head-tail water access disparity**: Inequity in water distribution across reaches is a serious challenge in almost all the schemes except at Koga (modern typology scheme). In semi-modern and traditional schemes head reaches are generally over supplied, while tails are undersupplied. It is evident that the water productivity in the head reaches is lower in many cases due to excess application. Tail irrigators are observed to have higher water productivity, although their total return is lower as indicated earlier. Water stresses at the tails in the schemes considered are serious, often causing major loss of production. There are often differences in crop selection between the head and tail irrigators. This urges aggressive intervention in the areas of optimum water application; the need to strengthen the governance including irrigation water user association and also support in maintenance of irrigation schemes. A better insight in the water cost and recovery can help with determining charges.

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