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Soil and Irrigation Water Management: Farmer's Practice, Insight, and Major Constraints in Upper Blue Nile Basin, Ethiopia

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Abstract: This study assessed farmers' soil and irrigation water management practices, perceptions, and major constraints at Koga, a large-scale irrigation scheme in Ethiopia. Key informant interviews, structured and semi-structured questionnaires, focus group discussions, and field visits were used for data collection. Soil samples were collected for the assessment of soil properties and a comparison with the respondents' perception of soil-related constraints. A total of 385 respondents were involved in the questionnaire. All of the respondents had a good perception of soil acidity and its management strategies. Respondents' perception was in line with the mean soil pH, soil texture, infiltration rate, exchangeable acidity, and soil organic carbon obtained from lab analysis and field tests. Soil acidity, unwise use of water, water scarcity, and lack of market linkages hampered the performance of the Koga irrigation scheme. Yet, respondents had a low awareness of irrigation water management. Farmers never used irrigation scheduling, but apply the same amount of water regardless of the crop type. As a result, low yield and water use efficiency were reported. To reduce soil acidity, an adequate lime supply for farmers with hands-on training on how to apply it would be desirable. Farmers should be aware of how to design effective irrigation scheduling and adopt water-saving management strategies.

Keywords: crop yield; water scarcity; soil acidity; water use efficiency; upper Blue Nile basin

1. Introduction

Irrigated agriculture withdraws more water compared to other sectors [1]. The demand and competition for water are growing because of the growing global population [2]. Irrigated agriculture might provide approximately 55% of the world's food supply by 2050 [3]. Yet, the expansion of irrigation would need 40% more extractions of water for this sector alone, which will affect aquatic systems. However, in Sub-Saharan Africa (SSA), there is very little irrigation expansion [4], and the development of irrigation seems realistic [5]. Increasing the irrigated area in SSA would raise irrigation's impact on access to food from merely 5% today to an optimistic 11% in 2050 [3].

As of 2050, global food production needs a 70% increase [6]. This increases the demand to harvest sufficient food for future generations with limited available water for agriculture. Applying suitable and water-saving irrigation strategies are required to realize the rising food demand with the available water [7]. In developing countries, irrigated agricultural productivity has been constrained by socio-economic and institutional factors including insufficient access to credit and lack of access to inputs [7]. Also, lack of access to improved technologies, the absence of irrigation infrastructures, inadequate water supply, and improper water management decrease the success of irrigation performance [8].

Land degradation including soil salinity, soil acidity, and low nutrient content [9] along with bad climate conditions affect crop production through crop failure and facilitating pests/weeds or diseases [7]. The absence of leveled irrigable land restricts the expansion of irrigation areas. Lack of transport infrastructures [9] and limited market-linkages also hamper the development of irrigation schemes [10]. Securing irrigation water and constructing roads could simplify irrigation works and mobility that could improve sustainable productivity [11].

Most of the time, farmers over-irrigate, which unnecessarily increases the cost of production and may leach nutrients out of the root-zone [12]. Yet, occasionally, farmers under-irrigate resulting in reduced productivity because of water shortage during critical stages of plant life [13]. Increasing irrigation efficiency by applying improved water management strategies could be the prime objective for sustainable irrigated agriculture [12]. This could be achieved by improving farmer's knowledge, particularly on how, how much and when to irrigate [8]. This could reduce labor and fuel costs, improve the quality of the products, and foster equitable water distribution within the irrigation schemes [14].

Different small, medium and large-scale irrigation schemes are being practiced in various parts of Ethiopia, yet productivity is low [15]. For irrigation to become effective and sustainable, its development needs to solve the major constraints [16]. To date, there is no information about farmer's soil and irrigation water management strategies, their awareness and major constraints in Ethiopia, particularly where large-scale irrigation schemes are found. Koga is among the currently functioning large-scale irrigation schemes (>7000 ha) in the country, but with performance being constrained by many problems [17], was selected as a study object. It is representative of other large-scale irrigation schemes in the country. This study targets to (i) evaluate farmers' soil and irrigation water management strategies; (ii) assess the major constraint's related to soil and irrigation water management and agricultural productivity; and (iii) explore farmer's perception about soil and irrigation water management practices, agricultural productivity, and water use efficiency.

2. Materials and Methods

2.1. Description of the Study Site

Koga irrigation scheme (KIS) is located south of Lake Tana, in the Upper Blue Nile Basin at 12°20′–12°31′ N and 37°02′–37°08′ E (Figure 1). The dam has a volume of 83 million cubic meters. KIS is one of the latest large-scale irrigation schemes for farmers which, through its 1750 ha reservoir, provides irrigation to nearly 5828 ha from a planned total of 7004 ha in the dry season, and about 10,356 beneficiaries [18]. The reservoir feeds twelve irrigation blocks (Figure 1c) and eleven-night storage reservoirs. Each block has a secondary lined canal with a total length of 42 km. Water user associations are established at the quaternary canal outlets within all irrigation blocks to improve water allocation at the quaternary canals. The mean electrical conductivity (ECe) of the irrigation water was 0.91 dS/m. In terms of water availability to crops, using water of this quality will not impose any restriction on use according to the FAO guidelines for water quality in irrigation [19].

The climate data was collected from the National Meteorological Service Agency (NMSA, 2019), Addis Ababa. The rainfall distribution is characterized by a unimodal pattern. The rain typically starts in May and increases gently in frequency to reach the highest values in July or August (Figure 2).

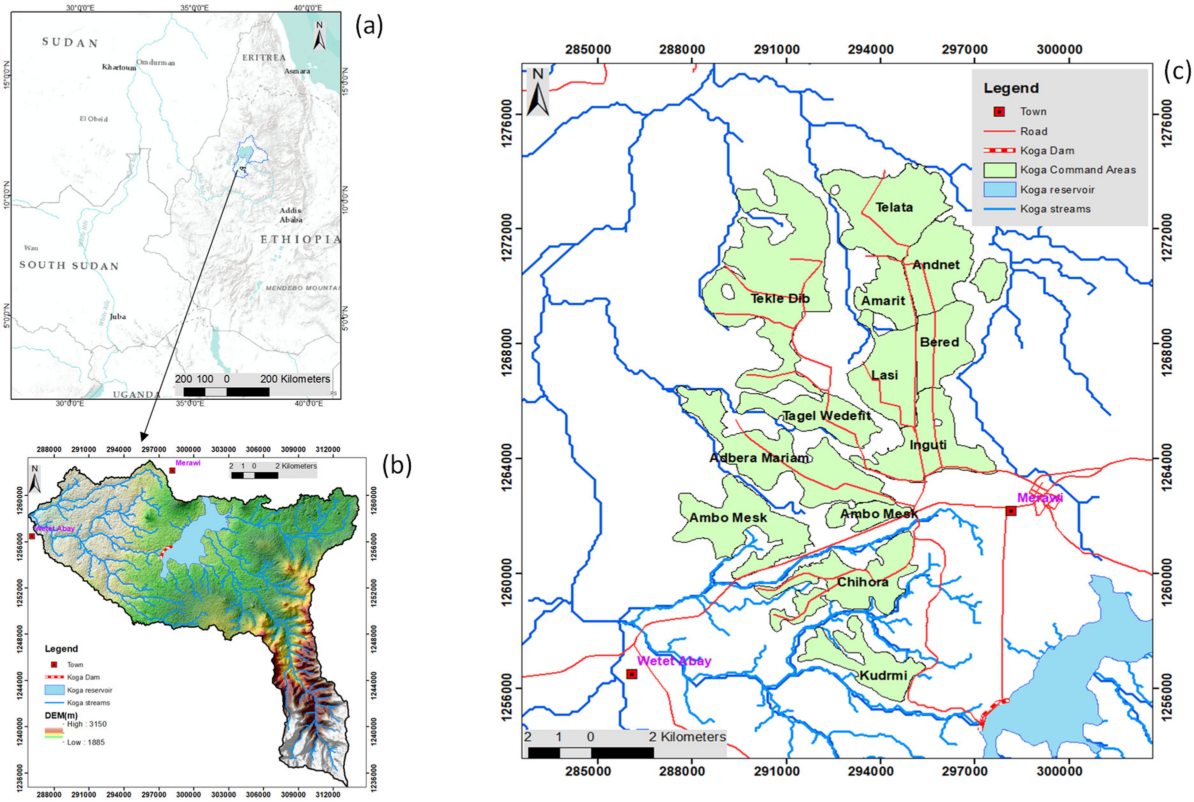

Figure 1. Location of Lake Tana in Ethiopia (**a**), Map of Koga watershed (**b**), and Map of Koga irrigation scheme (**c**).

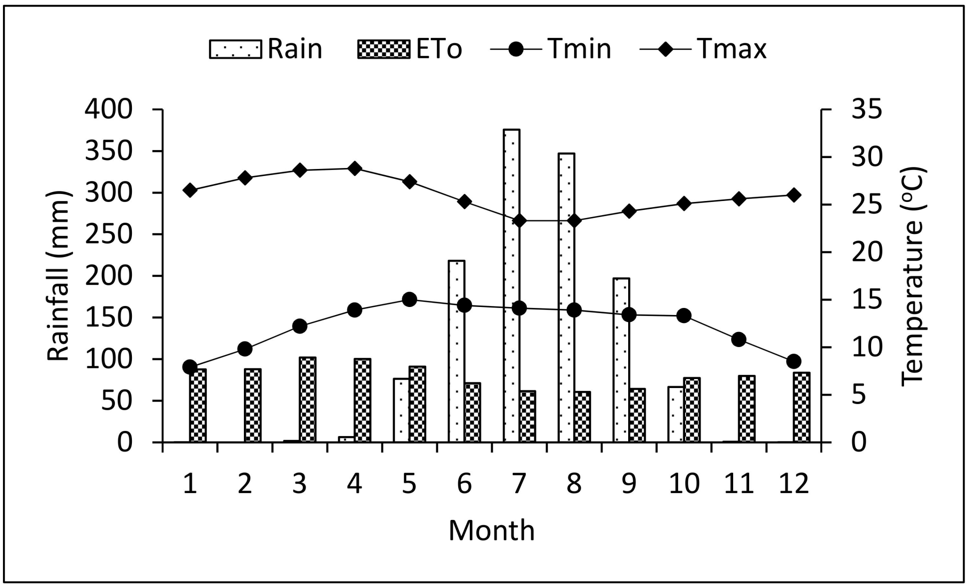

Figure 2. Mean monthly rainfall (RF, mm), reference evapotranspiration (ETo, mm) and temperature (°C) (NMSA, 1987–2019).

In Koga, the farming system is a mixed crop-livestock system, where livestock provides the draught power needed for the farming operation [18]. Maize, finger millet, and teff are mainly planted during the main rainy season, while wheat, maize, and vegetables are grown under irrigated conditions. The average landholding size is 1.2 ha. The land use system in KIS is mainly cultivated except for very few home gardens and eucalyptus woodlots found around roadsides. Furrow irrigation is a common practice in Koga [17].

2.2. *Methodology*

2.2.1. Sampling Procedure and Sample Size Determination

In this study, the respondents were the irrigation beneficiary household heads in Koga (hereafter referred to as HHs) living in 12 irrigation blocks. The record of total HHs was collected from the Koga irrigation development office. The total sample size was determined using Taro [20] Equation (1):

$$n = \frac{N}{1 + N\ (e)2} \tag{1}$$

and the required sample HHs from each block (n_i) was calculated as:

$$n_1 = \frac{N_{1(n)}}{N} \tag{2}$$

where N is the number of the required samples from the scheme (total sample size); N is the total number of HHs of the whole irrigation scheme; e is the confidence level (95%); n_1 is the number of the required sample from each irrigation block (Table 1), and N_1 is the total HHs of each block.

Table 1. The distribution of sample HHs in the irrigation blocks.

Irrigation Block	Number	Percent
Bered	21	5.45
Tagel	50	12.98
Andinet	17	4.41
Amarit	13	3.37
Ambomesk	72	18.70
Teleta	41	10.65
Kudmi	27	7.01
Chihona	29	7.53
Adibera	22	5.71
Tekledib	47	12.20
Inguti	31	8.05
Lasi	15	3.89
Total	385	100

2.2.2. Methods of Data Collection

Household Heads Questionnaire

Open and close-ended questions were prepared and pre-tested to 21 randomly selected HHs. Based on the feedbacks collected from the pre-test, some modifications were done to the questionnaire. It was translated from English to Amharic, the HH's language. The questionnaire covered a wide range of information, including irrigation water management practices, HHs perception about soil and irrigation management, crop yield, soil management strategies, marketing, access to inputs, soil texture, soil fertility status, irrigation water use efficiency, water shortage, and others. In total, 385 HHs were finally interviewed.

Focus Group Discussion and Key Informant Interviews

A focus group discussion that included 7–10 participants in a group was carried out in all irrigation blocks. Two focus group discussions (FGD) were held at Ambomesk, Tagel and Tekle Dib irrigation blocks but one FGD was carried out in the other irrigation blocks (Figure 3). The participants were selected based on their experience in irrigation farming, land management, involvement in irrigation water user committees and accepting new agricultural technologies. During the discussion, the key problems were pointed out, and possible irrigation water management strategies were discussed. Semi-structured questionnaires with open-ended checklists were prepared for key informant interviews with irrigation scheme leaders, water user association committees, and model farmers. In total, 65 participants were interviewed in all irrigation blocks.

Figure 3. Photos showing group discussion (**a**–**c**) and interviewing (**d**) in koga irrigation scheme, photos by Desale taken in 2018.

Field Visit

Guided field visits were used to cross-check the data collected using questionnaires, interviews and focus group discussions. Model farmers, development agents, members of water user association committees and experts from the Koga irrigation development office were the main participants. Regular visits at different times in all irrigation blocks, including the main dam, night storage reservoirs, primary, secondary, tertiary, and quaternary canals as well as farmers' irrigation activities were done in 2018/19. During every visit, informal discussions were held with farmers who were working at their farms.

Soil Data Collection

To verify the HHs perception (knowledge) about soil conditions, 80 disturbed and 80 undisturbed soil samples were collected at a soil depth of 0–20 and 20–40 cm from four representative irrigation blocks namely Ambomesk, Kudmi, Andnet and Tekle Dib (Figure 1c). Soil auger and core samples were used to take the samples. Soil samples were taken from a representative of 40 farmers' fields from the selected irrigation blocks. Using a zig-zag pattern, samples were collected at 5 spots in every farmer's field and $\frac{1}{2}$ kg composite samples were taken in each depth and farmers field after well mixed it. The samples were checked with the accompanying information list (including sample number, irrigation blocks, depth, and date of sampling) in the soil preparation room. After air-dried in the soil sample drying room, the samples were ground with a wooden pestle and mortar in the preparation room. Once ground, the soil was screened through a 2-mm sieve. Soil auger and core samples were used to take the samples.

2.2.3. Lab Analysis

Soil pH and EC were determined in 1:2.5 soil-water suspensions using a pH meter and conductivity meter, respectively [21]. The measured EC on 1:2.5 was converted to ECe using an equation as described by Slavich & Petterson [22]. The exchangeable acidity was extracted using the KCl method [23]. The sample was percolated with a not buffered

1 mol (KCl) L^{-1} solution which enables the extraction of exchangeable acidity (H^+ and Al^{3+}). Soil texture was determined using the hydrometer method [24]. Soil organic carbon content was determined by the wet digestion method [25]. Available nitrogen was determined by the Kjeldahl wet digestion and distillation technique [26]. The available phosphorus content was analyzed using the Olsen method [27]. Exchangeable cations (Ca, Mg, K and Na), were extracted using the Mehlich−3 procedure [27]. The contents in the extracts were determined by flame photometry and atomic absorption spectrophotometry [28].

2.2.4. Data Analysis

The data analysis was prepared by descriptive statistical techniques (frequency, mean, percentage, and standard deviation) using a statistical package for social science (SPSS, Version−26, SPSS Inc., New York, NY, USA) software.

3. Results

3.1. Soil Condition

Table 2 shows the basic physical and chemical soil properties of the study site. The soils were very low in sand content (2.6%) and very high in clay content (72%). The clay fractions, on the other hand, constituted the highest amount in both soil layers. The silt content is persistent in both soil depths. A moderately higher bulk density was found in the KIS and it increases with increasing soil depth.

Table 2. Some physical and chemical properties of representative soils. Standard deviations are presented in parenthesis (±).

Soil Depth (cm)	0–20	20–40
Sand (%)	2.6 (1.2)	1.9 (1.1)
Silt (%)	25.3 (14)	25.9 (15)
Clay (%)	72.0 (46)	72.2 (47)
Textural class (USDA)	Clay	Clay
Bulk density (Mg m^{-3})	1.32 (0.24)	1.38 (0.31)
Exch. Al^{3+} (meq/100 g of soil)	0.64 (0.01)	0.96 (0.02)
Exch. H^+ (meq/100 g of soil)	0.32 (0.00)	0.32 (0.00)
Exch. acidity (meq/100 g of soil)	0.96 (0.01)	1.28 (0.22)
pH (H_2O)1:2.5	5.25 (0.51)	5.04 (0.46)
pH (KCl)1:2.5	4.04 (0.42)	4.1 (0.44)
ECe (dS/cm)1:2.5	0.91 (0.00)	0.91 (0.00)
Exch. Na (meq/100 g of soil)	0.3 (0.00)	0.3 (0.00)
Exch. K (meq/100 g of soil)	0.4 (0.00)	0.3 (0.00)
Exch. Ca (meq/100 g of soil)	4.4 (0.21)	4.3 (0.20)
Exch. Mg (meq/100 g of soil)	3.5 (0.18)	3.1 (0.16)
Sum of Cations (meq/100 g of soil)	8.6 (1.22)	8 (1.20)
Sodium adsorption ratio (SAR)	0.15 (0.00)	0.16 (0.00)
Organic carbon (g kg^{-1})	20.3 (3.52)	17.8 (2.43)
Nitrogen (%)	0.23 (0.00)	0.2 (0.00)
Available *P* (mgP_2O_5/kg soil)	55 (4.61)	53 (4.48)
Available K (mgK_2O/kg soil)	192.3 (6.74)	184.1 (6.62)
$CaCO_3$ (g kg^{-1})	Nil	Nil

Based on our soil analysis, the soils in Koga are clayey and classified as Nitisols [29]. The mean soil-pH result indicates the soil is strongly acidic. Also, a considerably great value of exchangeable acidity was found. Exchangeable cations (Ca, Mg, K, and Na) analysis indicates that sodium adsorption ratio, as well as electrical conductivity, were considerably low. The leaching of water-soluble exchangeable cations because of over-irrigation and heavy rainfall could be the possible reason. The organic carbon content is moderately good in the topsoil layer compared with the lower one (20–40 cm). Yet, nitrogen availability is the lowest in both soil layers. The availability of $CaCO_3$ was negligible as the soil is characterized as strongly acidic—see the pH value. The available *P* and K are moderately good in both soil layers.

3.2. Socio-Economic Characteristics

Among the interviewed 385 HHs, 355 of them were male, while the remaining were female (Table 3). The average age of the HHs was 42.8 with a standard deviation of 6.5 years. The mean family size was 7.7, which is comparable to other parts of Ethiopia. Almost all of the HHs (95.1%) were found to be illiterates. According to the district farmer's annual income, most of the HHs (86%) were considered as having a high income (>1875 US$ per annum). Rainfed and irrigated agriculture, selling of eucalyptus wood and animal fattening are the major sources of HHs income. According to the HHs response, irrigation agriculture improved the animal fattening practice/culture in Koga and the income from fattening is increasing year to year. Regarding the farming experience, 69% of the HHs served 20–30 years, whereas the remaining HHs worked 10–20 years.

Table 3. Respondents demographic and socio-economic characteristics.

Variable	Total	
	Number	Percent
Sex		
Male	355	92
Female	30	8
Age category		
30–45	228	59.2
46–60	154	40
>61	3	0.8
Educational level		
Illiterate	366	95.1
Read and write	13	3.4
High schools	6	1.6
Family members		
3 persons	11	2.9
4–5	64	16.6
6–8	274	71.2
9–11	27	7.0
>12	9	2.3
Source of income		
Irrigated and rain-fed agriculture	266	69.1
Selling eucalyptus wood	50	13
Animal fattening	69	17.9
Annual net income in (US$)	385	100
313–625	5	1.3
625–1250	40	10.4
1250–1875	8	2.1
>1875	332	86.2
Farming experience (years)		
10–20	120	31.2
20–30	265	68.8

3.3. Land Management

3.3.1. Perceived Soil Texture and Fertility Status

Results demonstrated that the majority of the HHs (97) know the soil types of their farmland, but few HHs did not distinguish the soil types (Table 4). About 57% of HHs identified soil types because of their long-time farming experience. The remaining HHs understood the soil types via soil response to yield (30%), and experts information (14%), respectively. About 83% of the HHs perceived that the soil texture of Koga is clayey, whereas the remaining HHs believed that it is silt. Our soil lab analysis confirmed that the soil texture of Koga is clay (Table 2).

Table 4. HHs perceived soil type in Koga.

Questions	Response	Number	Percent
Do you own land?	Yes	374	97.14
	No	11	2.86
Do you know the soil types of your land?	Yes	372	96.62
	No	13	3.38
If your response is yes, how do you know it?	Own experience	218	56.63
	Development agents information	52	13.50
	Soil response to yield	115	29.87
Soil texture	Clay	321	83.38
	Silt	58	15.06
	Sand	1	0.26
	Loam	5	1.30

Among the sampled HHs, 78% perceived that the soil fertility of their farmland was decreasing (Figure 4), whereas 12% of HHs believed that soil fertility was increasing. However, the remaining HHs said that there is no soil fertility change. The decline of soil fertility was recognized from persistent yield reduction, as perceived by 58% of HHs. The remaining HHs believed that the decline of soil fertility was due to the incessant increasing fertilizer demand of their farmland. They further argued that crop yield increased when farmers apply an over-dose of urea fertilizer (400 kg ha^{-1}); when 200 kg ha^{-1} fertilizer was used, they noted that yield declined.

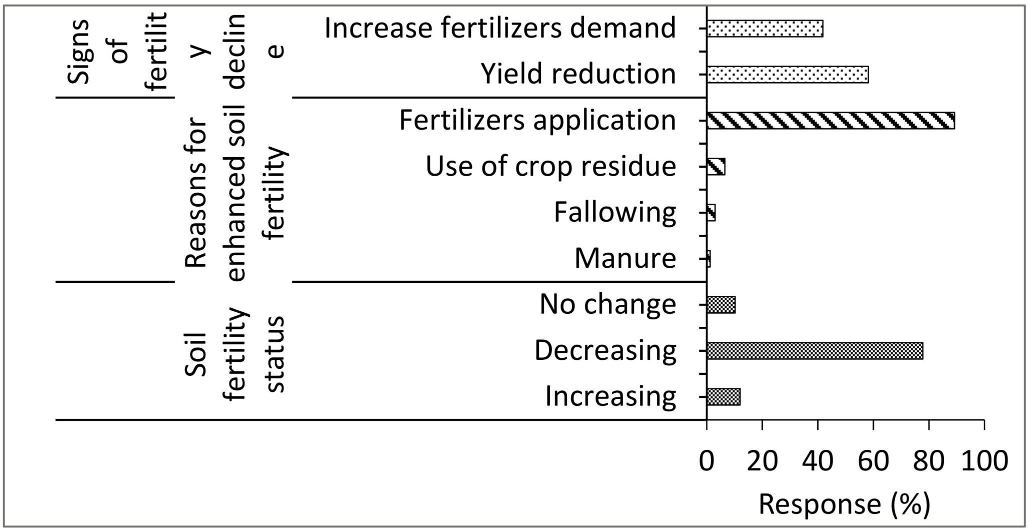

Figure 4. Soil fertility status as perceived by HHs.

3.3.2. Land Management Strategies

As explained earlier, repeated cross-ploughing has been widely used in Koga. Moreover, 80% of the HHs replied that they operated 9 tillage passes per cropping season (Table 5) using cross-ploughing. On average, HHs operated seven tillage passes per cropping season. All of the HHs (100%) responded that farmers do not use the same tillage passes for all crops. The field observations also confirmed that farmers devoted most of their time to prepare a better seedbed for teff, potato, onion, finger millet, and cabbages.

Table 5. HHs perceived soil management practices.

Questions	Response	Number	Percent
Frequency of tillage passes per cropping season	4	3	0.8
	6	45	11.7
	8	28	7.3
	9	309	80.2
Do you apply the same tillage passes for all crops?	Yes	0	0
	No	385	100
Reasons for repeated tillage	To control weed	309	80.3
	To increase fertility	53	13.7
	To prepare better seedbed	23	6.0
Are you applying cross-ploughing?	Yes	385	100
	No	0	0
Reasons for applying cross-ploughing	To disrupt surface crust	85	22
	To control weeds	180	46.8
	To prepare a better seedbed	120	31.2
Water holding capacity enhanced by many tillage passes	Yes	21	5
	No	364	95
Reasons for low water holding capacity	Soil structure degradation	355	92
	Loss of soil OM	30	8
Perceived strategies to improve water holding capacity	Use reduced tillage	272	71
	Apply manure	46	12
	Compost	28	7.3
	Crop rotation	39	10
Perceived status of the infiltration capacity	High	25	6.5
	Moderate	351	91
	Low	9	2.5
Fertilizer used as a soil management strategy	Yes	385	100
	No	0	0
Urea application dose (kg ha^{-1})	200	15	3.9
	250	6	1.6
	300	47	12.2
	400	317	82.3
NPSB application dose (kg ha^{-1})	150	10	2.6
	200	60	15.6
	300	315	81.8
Development agent advises on how to apply fertilizer	Yes	383	99.5
	No	2	0.5

OM = organic matter; NPSB stands for nitrogen, phosphorus, sulfur, and boron.

Most of the HHs (95%) perceived that the water holding capacity did not improve due to repeated cross-ploughing. Development agents and the FGD participants explained that the quick drying of the irrigated soil signifies the declining soil water content. They further stated that repeated cross-ploughing provokes soil structure degradation (92%) as it gets more pulverized and loss of organic matter content (8%) via evaporation, respectively. With regard to infiltration capacity, 91% of the interviewed HHs agreed that the infiltration capacity of the soil is moderate.

All of the HHs used fertilizer as a major soil management strategy. However, they applied over-does fertilizers. About 82% of HHs applied 400 kg ha^{-1} urea containing 46% Nitrogen at a rate of 200 kg ha^{-1} between 30 to 40 days after sowing, and 200 kg ha^{-1} during flowering stages. They also applied NPSB (nitrogen, phosphorus, sulfur, and boron) at a rate of 300 kg ha^{-1} containing 18.9% *N*, 37.7% *P*, 6.95% S, and 0.1% B at sowing as perceived by 82% of HHs. The other 16% of the HHs indicated that they applied 200 kg ha^{-1} urea, regardless of the crop types and soil fertility status.

3.3.3. Irrigation Scheduling

The majority of the HHs (96%) never used an irrigation schedule (Table 6). They applied the same amount of water, regardless of the crop types and growth stages. However, because of over-irrigation during the beginning of the irrigation season, farmers have been constrained by water scarcity when crop water needs were critical. Also, 60% of the HHs stated that due to water shortage, they irrigated every three weeks, irrespective of the crop type. About 46% of the HHs applied more water for potatoes, while the remaining HHs irrigated more water for cabbage (22%), onion (22%), and maize (9%) compared to wheat (0.8%). The distributed water for the farmer's field was wastefully used as replied by 99% of the HHs. The field visits also confirmed that the irrigation water was applied without proper furrows. Moreover, 98% of the HHs said that water management was mainly challenged by over-irrigation.

Table 6. HH's perception of irrigation water management strategies.

Variables	Response	Number	Percent
Practiced irrigation schedule	Yes	15	3.9
	No	370	96.1
Days to next irrigation	Every 9 days	11	2.9
	Every 12 days	6	1.6
	Every 21 days	230	59.7
	Every month	138	35.8
Water allocation to crops	Maize	35	9.1
	Potato	176	45.7
	Wheat	3	0.8
	Onion	85	22.1
	Cabbage	86	22.3
Was the allocated water used efficiently?	Yes	2	0.5
	No	383	99.5
Water management related problem	Yes	379	98.4
	No	6	1.6

3.4. Crop Yield

In Koga, HHs primarily cultivated maize, potato, onion, cabbage and tomato under irrigated agriculture (Table 7). Currently, the majority of HHs (72%) irrigated wheat and the remaining HHs planted maize. About 89% of the HHs irrigated wheat because of the current good market demand, while 11% of the HHs irrigated wheat because of its ease for management and grain storage compared to other perishable crops.

Table 7. Perceived irrigated crops and reasons for crop selection in Koga Irrigation Scheme.

Variable	Response	Number	Percent
High economic value crops for irrigation farming	Maize	91	23.64
	Wheat	277	71.95
	Potato	3	0.78
	Onion	8	2.08
	Cabbage	6	1.55
Reasons for crop preference	Market demand	341	88.57
	High yielding	2	0.52
	Households choice	1	0.26
	Easy for store	41	10.65
Strategies to increase yield	Use better water management	332	86.23
	Improve the soil	22	5.71
	Use improved seeds	23	5.97
	Grow high yielding crops	8	2.08

The remaining HHs irrigated wheat because of family choice and its high yields. Few HHs irrigated potato, onion and cabbage because of its perishability, absence of a common storehouse equipped with refrigerators and low market-linkages between producers and buyers. HHs reported relatively lowest yields when growing wheat though they invested more capital (Figure 5). The majority of the HHs (86%) believed that crop yield could be enhanced by applying improved irrigation water management strategies.

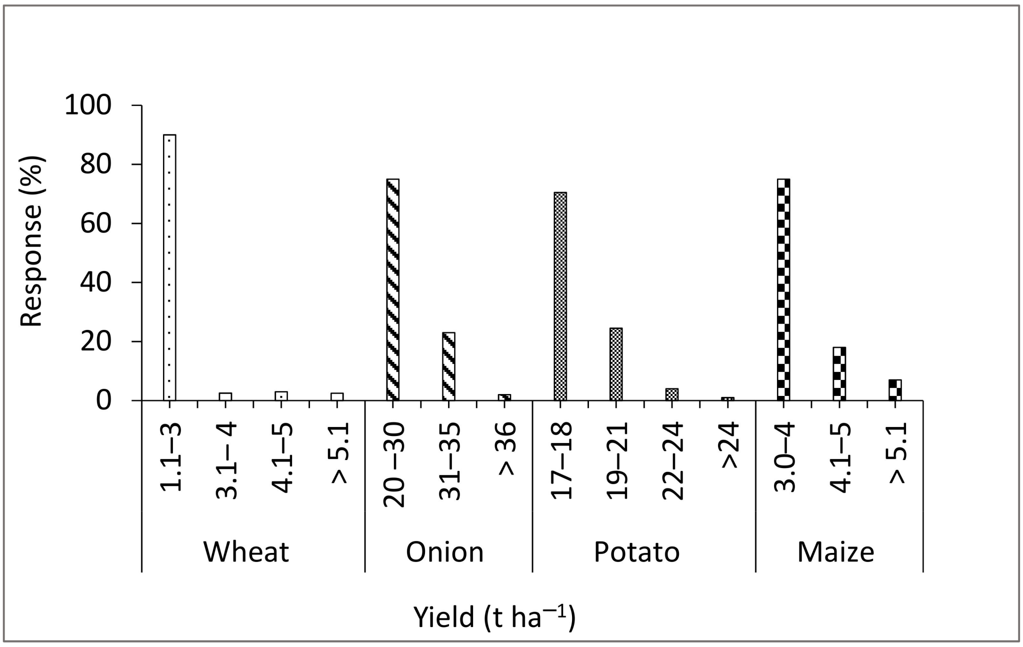

Figure 5. Major irrigated crops in Koga irrigation scheme.

On average, 92% of HHs reported 1.1 to 3 t ha^{-1} of wheat grain yield. Also, 75% of the HHs responded that they obtained an average of 20–30 t ha^{-1} of marketable onion yield. However, few HHs harvested a maximum of 35 t ha^{-1} of marketable onion yield, which implies that their practice is not profitable given the production cost. Seventy percent of HHs replied that they had commonly 17 to 18 t ha^{-1} potato tuber yields. Twenty-five percent of HHs stated that the seasonal potato tuber yield ranged from 19 to 21 t ha^{-1}, although few HHs (5%) confirmed that potato tuber yield even ranged from 22 to 24 t ha^{-1}. About 75% of the HHs reported that on average, they attained 3 to 4 t ha^{-1} maize yield. However, few HHs stated yields greater than 5 t ha^{-1}.

3.5. Water Use Efficiency (WUE)

In the present study, 96% of the HHs perceived that WUE was found to below. The field visits and focus group discussions agreed with HHs perception. From the interviewed HHs, 75% believed that WUE could be increased via improving soil fertility (Figure 6). The remaining HHs said that applying proper irrigation practices, planting high-yielding crops, and high water use efficient crops could increase WUE provided that sufficient fertilizer is applied.

3.6. Soil and Water Management Constraints

Figure 7 displays the major constraints for agricultural productivity and causal relationships in Koga. The main problems are low crop yields and cropping intensity. Water scarcity, soil acidity, limited access to production inputs and poor market-linkage aggravated the occurrence of low farmer's income. The details are described in the following sections.

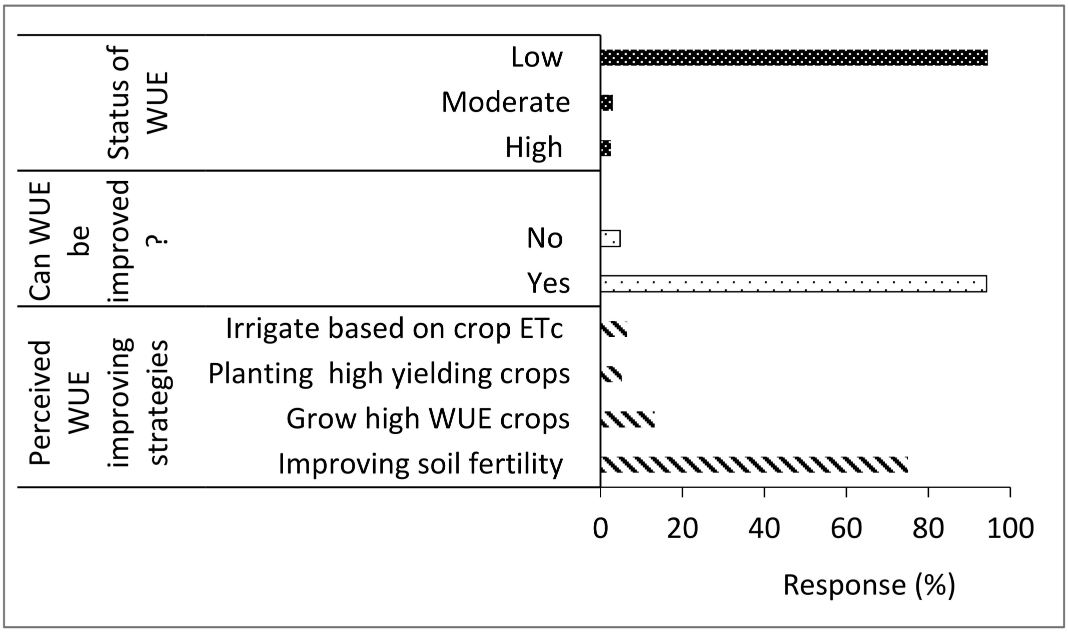

Figure 6. WUE as perceived by respondents (ETc = crop water requirement).

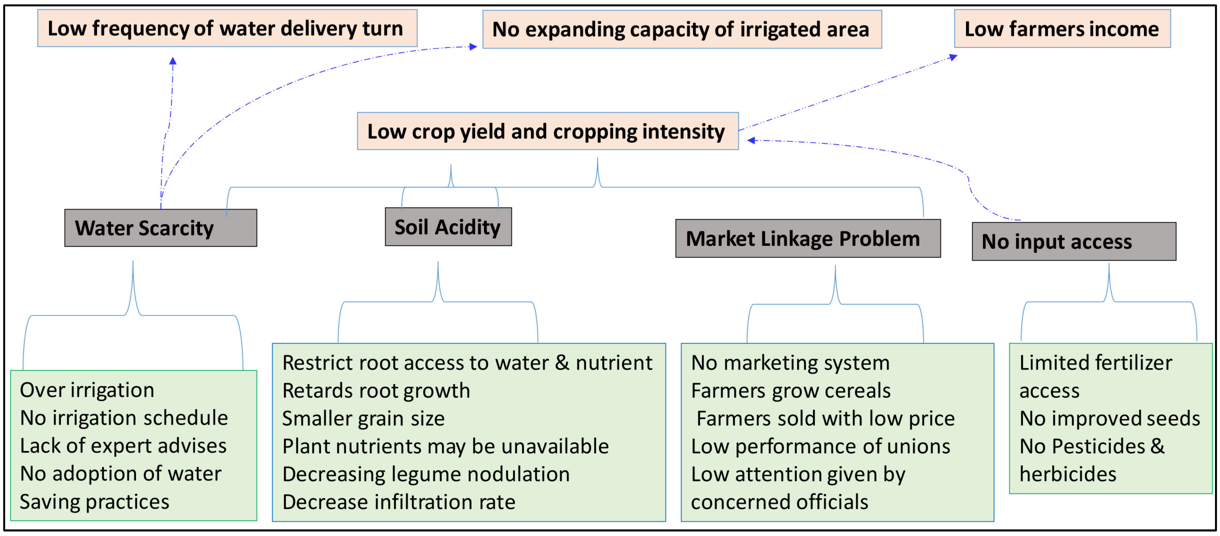

Figure 7. A conceptual framework showing that water shortage affects the frequency of water delivery turn, and the expansion capacity of the irrigated area. The interaction of these constraints affects crop yield and farmer's income. Modified from Ghazouani et al. [30].

3.6.1. Soil Acidity

About 90% of the interviewed HHs perceived that soil acidity was the main soil degradation problem in Koga (Table 8). Soil analysis also confirmed that the soil acidity is strong (Table 2). The exchangeable soil acidity results show that the level of acidity is extremely high which was in line with the HH's perception.

About 86% of the HHs perceived that the annual increasing yield reduction might be due to the existence of soil acidity. The remaining HHs recognized soil acidity because of the growth of acid-tolerant weeds. Most of the HHs (87%) used inorganic fertilizer as the main soil management practice. However, very few HHs used compost and manure as a soil management strategy. Moreover, 69% of HHs stated that the absence of lime around their vicinity was the main constraint for acidic soil management. The other few HHs pointed out to a lack of knowledge (23%) and insufficient expert advice (8%) as bottlenecks for soil management. In addition, about 81% of the HHs applied crop residue as locally available soil management strategies.

Table 8. Perceived soil management problems and farmers' management practices.

Variables	Response	Number	Percent
Soil degradation problem	Acidity	346	90
	Fertility decline	39	10
	Salinity	0	0
Soil acidity indicators	Yield reduction	330	85.7
	Growing of acid-tolerant weeds	55	14.3
Implemented soil management practices	Fertilizer	334	86.8
	Compost	10	2.6
	Manure	41	10.6
Acid soil management constraints	Absence of lime nearby	266	69.1
	Lack of knowledge	90	23.4
	Absence of expert advice	29	7.5
Locally available soil management strategies	Manure	9	2.3
	Crop residue	311	80.8
	Compost	12	3.1
	Crop rotation	53	13.8

3.6.2. Water Scarcity

All of the interviewed HHs (100%) replied that water shortage has been a serious problem in all of the irrigation blocks. The focus group discussion participants confirmed that because of insufficient water supply, farmers only grow one crop during the dry season (from October to May). Moreover, during our deficit irrigation experiment at Ambomesk, one of the biggest irrigation blocks in Koga during 2018/2020, we had a similar problem. The Abbay Basin Authority office head at the Koga branch advised us against the experiment from February to May, as there is no adequate water supply. However, after he was informed about the objective of the deficit irrigation project, the office provided better support for the project, believing that it will solve the water scarcity problem in Koga.

Over-irrigation during the first irrigation season (October to January) was the main reason for the occurrence of water scarcity in the second irrigation season (February to May) as perceived by 85% of the HHs (Figure 8). The remaining HHs also stated that the use of improper furrows (14%) during the first irrigation season inducing poor water supply were the possible factors for water scarcity occurrence. The field visits also confirmed that over-irrigation was the main reason for the water scarcity.

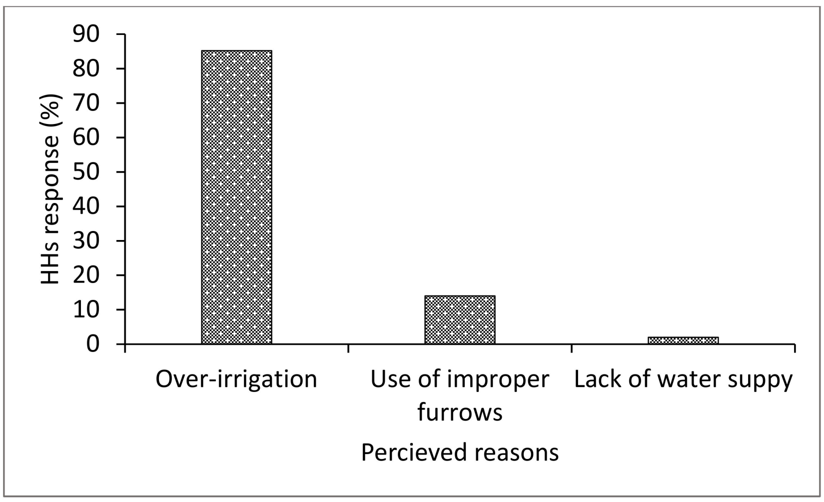

Figure 8. Perceived reasons for water scarcity in the Koga irrigation scheme.

3.6.3. Market-Linkage

All of the HHs (100%) responded that the absence of a better market-linkage between the producers and potential buyers was the major bottleneck for Koga farmers (Table 9). According to the focus group discussion (FGD) and key informant response, during the beginning of the Koga irrigation scheme, all of the HHs planted potato, onion, cabbages and tomato for a few years. However, due to the lack of market access, HHs sold the product at a low price which discouraged them to produce perishable crops again. The FGD participants and field observations proved that during the 2018/19 irrigated cropping season, more than 85% of the irrigation scheme was covered by wheat and maize crops. As a coping strategy, 74% of the HHs indicated that establishing better market-linkage between producers and buyers could be a sustainable solution.

Table 9. The market-linkage problem as perceived by HHs.

Variables	Response	Number	Percent
Is there good market-linkage?	Yes	0	0
	No	385	100
The responsible body for the absence of market-linkage	Koga union	304	79
	Local government	57	14
	Farmer themselves	30	7
Strategies to establish sustainable market-linkage	Establish better market link	283	74
	Growing crops in a cluster	15	4
	Producing quality yield	49	12
	Change the time of cropping	38	10

Planting crops in a cluster (4%), producing a competitive quality product (12%), and changing the time of cropping or delaying or vice versa (10%) from the nearby farmers could reduce the marketing problems, respectively. HHs planted similar crops in all irrigation blocks at the same time, which could be taken as the main reason for the price reduction. For instance, one of the model farmers who were involved in our deficit irrigation and soil management field experiment stated that in 2018/19 the price of a kilogram of wheat at the time of harvest was 0.56 US$ only as all farmers harvested at the same time, while three to four months later the price raised to 0.89 US$.

4. Discussion

In strongly acid soils like in Koga large-scale irrigation scheme, potassium, calcium and magnesium are depleted probably due to leaching. The sodium adsorption ratio was low, which indicates that the salinity level is low and has no impact on crop growth with these ranges [19]. The farmers' perception and soil lab results showed that farmers' local knowledge is vital, and should be valued and combined with scientific findings to have a better soil type and fertility status information. Farmer's described and classified the soils using locally acquired knowledge from generations of experience that fit local conditions [31]. Orimoloye [32] found that farmer's soil fertility ranking was significantly associated with values of organic carbon and available *P* gained from lab analysis. Also, Assefa & Hans-Rudolf [33] reported that farmers have a wealth of experience in recognizing soil fertility decline. Obour et al. [34] agreed on the need for integration to exploit the strengths of local knowledge, improve mutual learning between farmers and soil scientists, build the capacity of farmers, and improve their decision on the soil used for agricultural production. Abera and Belachew [35] also reported that farmers used soil color, texture, water holding capacity, fertilizer requirement (inherent fertility), and workability as criteria to identify different soil types.

Irrigation scheduling allows an improvement in water resources management, which is very important in arid and semiarid areas. In line with this idea, Derib [36] reported that improving the water use efficiency (WUE) of irrigation systems entails designing an efficient irrigation schedule decision support system. Detailed information and knowledge about water availability, soil conditions, crops response to water stress and root depth are required to design effective irrigation scheduling [37]. However, in our study area, the tradition of applying irrigation scheduling was very low, and farmers applied over-irrigation. Improved irrigation scheduling is thus important to use the optimum amount of limited water [38]. In agreement with this finding, previous studies stated that irrigated agriculture has been constrained by unwise use of water due to lack of technical skills [39,40].

In irrigated agriculture, WUE can be taken as a measure of sound and sustainable irrigation water management strategy. In Koga, the WUE of irrigated crops was found to be very low and needs to be improved for sustainable crop production and food supply. This could be achieved through applying integrated soil fertility management combined with deficit irrigation strategies. Under deficit irrigation and integrated soil fertility management field experiment, an enhanced wheat WUE (2.21 and 2.36 kg m^{-3}) was found from lime and manure treated fields compared with only fertilizer treated plots (1.10 and 1.34 kg m^{-3}) with the same amount of irrigation water in 2018 and 2019, respectively [41]. A study conducted to simulate soil fertility effects on WUE in northwest Ethiopia by Erkossa et al. [42] showed increased maize WUE by 48% and 54%, with near-optimal and non-limiting soil fertility conditions. Derib [36] also found that the WUE of wheat varied from 0.2 to 1.63 kg m^{-3}, which revealed that a substantial amount of water was lost due to over-irrigation in the case of low WUE practices. Similarly, comparable findings were reported [43,44]. To improve the WUE of crops, considering soil management parallel to irrigation water management is of paramount importance.

In Koga large-scale irrigation scheme, crop yield was considerably low. The yield reduction in Koga may be attributed to over-irrigation and soil fertility decline. Over-irrigation may adversely affect production through creating poor soil aeration, water-logging associated root diseases and leaching of nutrients from the shallow crop-root zone [12]. From four seasons deficit irrigation and integrated soil fertility field experiment, Asmamaw et al. [41] found 3.2 and 5.4 t ha^{-1} in 2018 and 3.3 and 5.6 t ha^{-1} wheat grain yield in 2019, respectively, under only inorganic fertilizer, and liming and manure treated plots at full irrigation, respectively. The higher yield increment at liming and manuring plots proved that soil fertility decline could be one of the main reasons for low yield. This infers that the existing soil and irrigation water management strategies have to be improved to improve yield. Similarly, many findings revealed that in irrigated agriculture low crop yield reports were documented [18,43,45].

Soil salinization, waterlogging and soil nutrient mining are the most widely observed problems in irrigated agriculture fields [19]. However, in the Koga irrigation scheme, soil acidity has been hindering crop productivity. The soil lab analysis results and household perception showed that the soil is strongly acidic and needs to be addressed through applying integrated soil fertility management practices. A study by Abate et al. [46] found that soil acidity and Al-toxicity problems are mostly found in high rainfall areas of the northwest parts of Ethiopia, where this study was conducted. The use of crop residues for fuel, livestock feed, and building materials also hampered the extensive application of compost and manure for soil management [47]. Similarly, the use of lime is constrained by inaccessibility, high cost related to the bulk volume, and transport [46]. They further explained that soil acidity and mineral toxicities stunted the growth of plants, and thus, resulted in low productivity. Haileslassie et al. [18] reported that nutrients, particularly soluble salts, are depleted due to leaching by over-irrigation and high rainfall, hence soil acidity could develop overtime.

Water scarcity has been hampering the performance of the Koga irrigation scheme and unwise use of irrigation water was mentioned as the main reasons. This implies that improved irrigation water strategies have to be introduced to enhance sustainable productivity. In line with our finding, Yohannes et al. [48] reported that water shortage adversely affects farmers in northern Ethiopia. Similarly, Hagos [13] stated that irrigation water applied by farmers in every irrigation event was higher than the required depth. Also, Lebdi [49] indicated that irrigation expansion and better water management are important to increase production under water scarcity conditions. Under these conditions, designing improved irrigation water management strategies could be essential to address irrigation challenges facing water scarcity in quantity [50,51]. Similarly, adopting deficit irrigation strategies can result in expanding the area under irrigation with 100–137%, 100–300%, 100–233%, and 100–134% more land for maize, wheat, onion, tomato, and teff, respectively, for the same quantity of irrigation water [52]. This implies that the water scarcity problem could be reduced if farmers apply deficit irrigation. Haileslassie et al. [18] also confirmed that the existing irrigation water management has to be improved to increase productivity in Ethiopia.

Market-linkages are very essential to the success of irrigated agriculture [53]. It is not only important to realizing cash crop's income potential, but also critical to ensuring that farmers produce properly for existing demand and invest wisely for future inputs. Many irrigated crops are highly perishable, making speed-to-market especially important to capture their value. Local markets may not be as strong, given crop's high prices, which means strong links to profitable urban markets is essential [40]. Strong market-linkages also encourage irrigators to invest in high-value crops [53]. In line with this study, Mengistie and Kidane [10] reported that market access was the main problem for irrigation development. Even in cases where markets are available, now, if various farmers grow similar crops, markets eventually become saturated. The absorption of produce and market access has been the main constraint for farmers [54]. In an irrigation performance assessment conducted in Ethiopia, Descheemaeker et al. [40] found that limited access to market infrastructure was the most common problem for the strengthening of irrigation schemes.

5. Conclusions

We have investigated farmer's irrigation water and soil management strategies, their perception and major constraints in Koga large-scale irrigation project supported with soil analysis. The study showed that farmers have a good understanding of soil degradation problems with possible management strategies. Based on the soil analyses and the farmer's perception, the soil condition in Koga is strongly acidic. However, farmers had a low understanding of irrigation water management strategies, which was explained by over-irrigation regardless of the crop type.

Unwise use of irrigation water, water scarcity, and lack of market access were recognized as the key constraints. To reduce water scarcity, designing effective irrigation scheduling, which focuses on applying the right amount of water at the right time to meet the crop needs, and reduce non-productive water loss, integrated with the reclamation of the acidic soils using lime and manure are imperative. Considering the limitations of market access, it is critical to create sustainable market-linkages with buyers and build common storehouses equipped with a refrigerator that can serve farmers to store perishable crops.

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