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Optimizing Irrigation Water and Nutrient Management Strategies for Maize Production through a Participatory Approach on the Selected Irrigation Schemes of Eastern Amhara, Ethiopia

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***Abstract*—In the semi-arid regions of Eastern Amhara, inadequate and unevenly distributed rainfall negatively affects rainfed agriculture, particularly maize production. To address this, a pre-scale-up study was conducted to evaluate improved irrigation technologies using the Farmer Research Extension Group (FREG) approach. Two irrigation practices traditional and improved were compared at Golina1 and Sedeni sites. The improved practice included the use of the Melkassa-6Q maize variety, row planting (75 cm × 30 cm), furrow irrigation (with specific dimensions and gradient), a seed rate of 25 kg ha^{-1}, and recommended fertilizers (200 kg ha^{-1} Urea and 50 kg ha^{-1} NPS). In contrast, the traditional practice involved local varieties, broadcast sowing (40 kg ha^{-1}), traditional flooding at 12-day intervals, and lower fertilizer rates (50 kg ha^{-1} Urea and NPS). The improved practice significantly outperformed the traditional method, achieving higher green cob yields (38,125 ha^{-1} at Golina1 and 34,330 ha^{-1} at Sedeni), better water productivity (17 and 16 cobs m^{-3}), and greater net benefits (222,575 ETB ha^{-1} and 174,487 ETB ha^{-1}, respectively). This represented yield increases of 29.9% and 30.2%, and net benefit improvements of 79.63% and 86.84% over traditional practices. Additionally, improved irrigation reduced seasonal water demand by 72.4 mm and 131.6 mm, indicating substantial water savings.Overall, the study demonstrated that improved irrigation and agronomic practices significantly enhance maize yield, water use efficiency, and profitability, and were positively received by participating farmers.**

***Keywords*—FREG, scale up, Small-scale irrigation, technologies**

I. INTRODUCTION

In semi-arid and arid regions, maize plays a vital role in farming systems, being widely cultivated for grain, green cob, and forage. Farmers grow under both irrigation and rainfed conditions, making it a key crop for food and feed security in areas facing water scarcity [1, 2]. In Eastern Amhara, climate change has become a serious humanitarian concern, affecting the daily lives of communities. With rising temperatures, unpredictable rainfall, and frequent droughts, smallholder farmers who rely on rainfed agriculture are facing growing uncertainty [3, 4]. In the Sedeni and Golina 1 areas rain-fed agriculture has frequently suffered by drought shocks leading to food insecurity due to uneven distribution and shortage of rainfall. Building resilience through smarter farming practices, improved irrigation, and sustainable land use can help communities better cope with the challenges and work toward a more secure and stable future. Irrigation has the main strategies to alleviate income and food shortages and enhance the sustainability of livelihoods [5] stated that global agricultural production is heavily sustained by irrigation to feed an ever-growing human population. However, the irrigation practices are often surprisingly localized. In study areas, the flooding irrigation method is widely adopted posing soil salinization and waterlogging. Efficient use of irrigation water in combination with improved crop variety, soil water management technologies, efficient fertilizer application, and integrated disease and pest control are vital for income generation and increase resilience to climate change. Therefore, furrow irrigation is the principal means of applying irrigation water for crop production. Therefore, the pre-scale-up aimed to promote improved irrigation technologies to increase grain yield, water use efficiency, and net benefit of maize.

II. METHODS AND APPROACH

A. Description Of The Study Area

The study was conducted at Sedeni and Golina1 small-scale irrigation schemes which are located in Habru and Raya Kobo district respectively, North Wollo zone Amhara region during 2022 irrigation season. The irrigation schemes were found at about 55 and 50 km from the South-east and North-east of Woldia for Sedeni and Golina1 respectively. Geographically the Golina1 is found between 39.32^{o} longitude and 12.04^{o} latitude whreas, the Sedeni irrigation scheme is located 39° 43' 0" longitude and 11° 34' 0" latitude (Figure.1). Both sites have the same agro-ecological nature and classified as dry sub-humid Kola [6]. The average annual rainfall of the schemes have within the range 644.08 to 668 mm and the mean minimum and maximum temperature are 8.49 to 9.3 °C and 35.7 to 36.58 °C respectively. The rainfall is attributed by an erratic nature with uneven distribution in time and space.

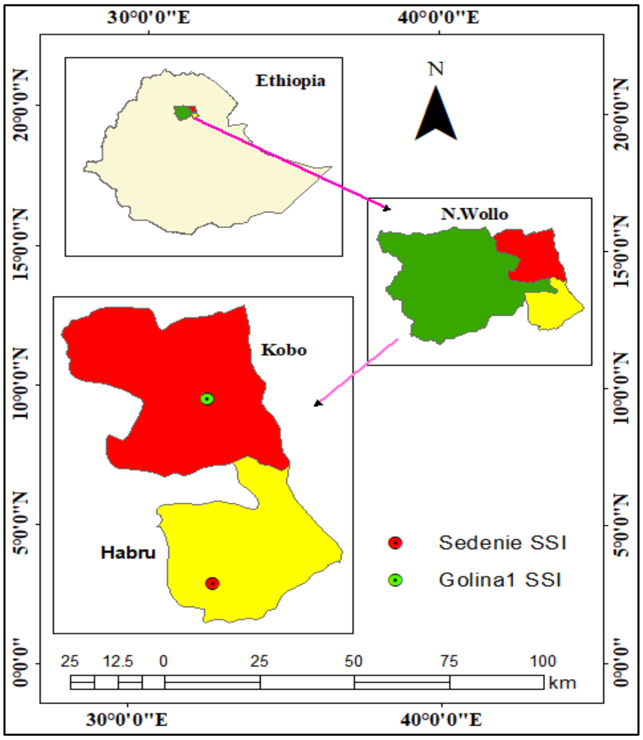

Fig. 1. Study area map

B. Study Approach

From each scheme, one Farmer Research Extension Group (FREGs) with 21 (20 male and 1 female household heads) and 35 (25 male and 5 female household heads) members were formed for Sedeni and Golina1 schemes respectively. Totally in the two irrigation schemes, practical training was given for agricultural experts (8), extension agents (5), and FREG membere with their wives (25 male and 10 female). The contents of the training was focus on irrigation water management (when and how much to irrigate), furrow construction, agronomic practices (row planting, fertilizer rate and application, seed rate), and disease and pest management. Then maize was preferred by many farmers based on economic, social, environmental and national policy priorities. Sirinka Agricultural Research Center (SARC) was handle the overall activitiy incolaboration with International Crop Research Institute for Semi Arid Tropics (ICRISAT). The partiner organizations participated in the promotion activity include as Dessie Seed Quality Control and Assurance Agency, Agricultural experts, and farmers. The improved seed (Melkassa 6Q) was supplied by SARC in collaboration with ICRISAT. Therefore, 175 kg maize seed was provided for 14 FREG members (7 farmers from each scheme) with 25 kg ha-1 rate to cover 5 ha and 2 ha of Golina1 and Sedeni irrigation schemes repectively.

C. Irrigation And Agronomic Practices

In the improved practice, the fertilizer application rate was 200 kg ha^{-1} Urea and 50 kg ha-1 NPS supplied by the district office of agriculture. The spacing between rows and plants was 0.75 m and 0.3 cm respectively. The furrow length (10 m), furrow height (0.15 m), furrow gradient (0.2%), and furrow width (0.25 m) was applied. Depending on the CROPWAT model version 8.0 result, the net irrigation depths in Sedeni irrigation scheme were 11.2 mm, 28.4 mm, 36.6 mm, and 24.7 mm for initial, development, mid, and late stages respectively. In the Golina1 these respective net irrigation depths were 12.4 mm, 30.6 mm, 37.8 mm, and 27.4 mm. The irrigation interval for the two sites were 10 days. The farmers practice inclue: a local variety, flood irrigation with 12 days interval, broadcast sowing (40 kg ha^{-1}), inadequate fertilizer rate and management (50 kg ha^{-1} urea an NPS each).

Fig. 2. Performance of improved maize (Melkassa-6Q)

Yield and yield related data (straw yield, grain yield, etc.), amount of water consumed throughout the growth stage, input and labor costs were collected. The cost-benefit analysis and the marginal rate of return was done following [7], guideline. The water productivity was computed as [8]:

$$WP = \frac{\text{Grain yield (kg)}}{\text{Total amount of water supplied m}^3} \text{..............................(1)}$$

$$\text{MRR} = \frac{\Delta\,\text{Gross return}}{\Delta\,\text{Total variable cost}} \text{...(2)}$$

The field-day was conducted at the crop mid season stage and all the FREG memebers were attend. Hence, the perception data were collected from 21 FREG members for Sedeni and Golina 1 each through semi-structured questionnaire. During the field-day, the dicion makers, agricultural experts were participated. The farmers' perception was analyzed by descriptive statistics (SPSS version 26.0) and drown using a five-point Likert scale.

III. Result And Discussion

The application of improved seed with improved irrigation management (IP) gave 38,125 and 34,330 marketable cobs ha−1 for Golina1 and Sedeni irrigation schemes respectively. While, in these respective irrigation schemes the local seed with farmers' parctices (FP) gave lower marketable number of cobs as 29,351 ha−1 and 26,368 ha−1 (Figure.1). This indicates that, most cobs produced from the local seed with local management practices (FP) found under the marketable size. In Golina1 and Sedeni irrigation schemes, the improved seed with improved management practices had 29.9% and 30.2% marketable cob advantages over the farmers practices respectively. The study concieded with many authors reported that the higher maize yield was on furrow irrigation than the flooding irrigation practices [9, 10].

The result showed that the higher fresh stalk yield (14,600 kg ha-1 and 13,700 kg ha-1) was recorded from improved seed with improved management whereas, the farmers practice gave much lower stalk yield (11,800 kg ha-1 and 10,700 kg ha-1) for Golina1 and Sedeni respectively (Figure.1). The higher stalk yield advantage (28.0% and 23.7%) were achieved by the use of improved seed with improved irrigation practices for Golin1 and Sedeni irrigation schemes respectively. The lower stalk yield in farmer practices mainly associated with the limited genetic potential of the local variety and maximum seed rate posing stunted growth and thin physiological stand.

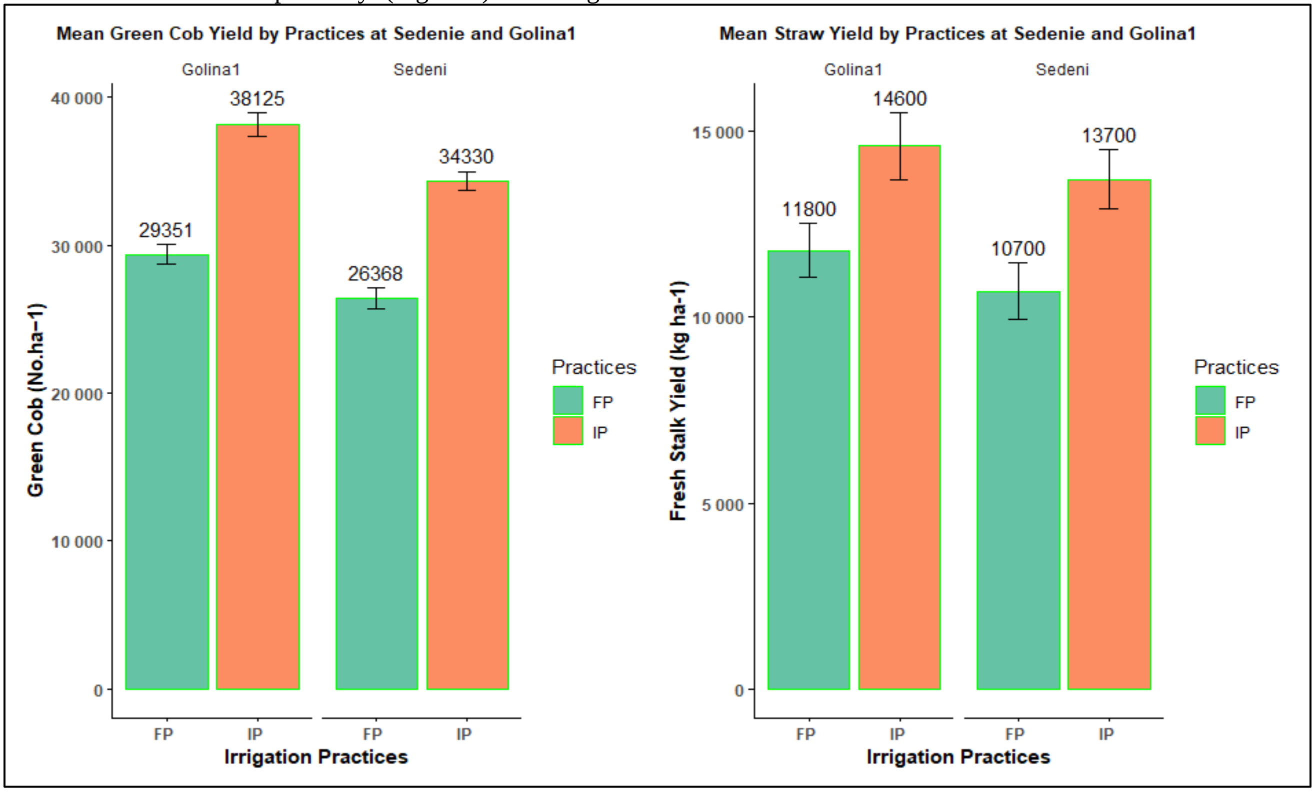

Fig. 3. Mean marketable green cob and stalk yield
Where, IP: Improved practices; FP: Farmers practices

From the result (TABLE I), the higher water productivity (17 cob m-3 and 16 cob m-3) was recorded from the improved seed with improved management (IP) practices while, the local seed with local management gave lower water productivity (10 cob m-3 and 8 cob m-3) for Golina1 and Sedeni irrigation scheme respectively. For those respective schemes, the improved practice had 70% and 100% water productivity advantage over the local practice. This means the improved practice could doubled the water productivity than the farmers practices. Similar studies reported that furrow irrigation practices were significantly increases the water productivity of maize than the flooding irrigation [10, 11].

The result showed that the farmer's practices had higer net seasonal irrigation demand (302.4 mm and 351 mm) whreas, the lower net irrigation depth was recorded from the improved practices (230 mm and 219.4 mm) for Golina1 and Sedeni correspondingly (TABLE I). Therefore, in Golina1 and Sedeni irrigation schemes the improved practices were saved 72.4 mm and 131.6 mm of water respectively over the farmers practices. Based on the field observation and farmer’s feedback, flooding irrigation harms soil health, soil productivity reduction, aggravating of soil salinization and water-logging. Inline with the study as furrow irrigation is the salinity management strategy to ensure the suastainability of irrigation land [12]. The saved water in the Golina1 (23.94%) and Sedeni (37.49%) can irrigate an additional 31.48% and 59.98% of land respectively.

TABLE I. IRRIGATION REGIME AND WATER PRODUCTIVITY FOR MAIZE

Scheme	Practices	Growth Stage	Irrigation Events	Net irrigation (mm)	Seasonal Net irrigation (mm)	Net Seasonal CWR (m^3)	WP (cob/m^3)	Saved water (mm)
Golina1	IP	initial	2 times	12.4	230	2300	17	72.4
		Development	3 times	30.6				
		Mid	3 times	37.8				
		Late	NI	-				
	FP	initial	2 times	21	302.4	3024	10	
		Development	3 times	40.6				
		Mid	3 times	46.2				
		Late	NI	-				
Sedeni	IP	initial	2 times	12.2	219.4	2194	16	131.6
		Development	3 times	28.4				
		Mid	3 times	36.6				
		Late	NI	-				
	FP	initial	2 times	25.5	351	3510	8	
		Development	3 times	47				
		Mid	3 times	53				
		Late	NI	-				

Where, Tr: Treatments; IP: Improved practice; FP: Farmers practice; WP: Water productivity, NI: Not irrigated

A. Farmers Perception And Cost Benefit Analysis

1) Farmers perception

Except the labor cost (disagree), the overall farmers perception about the improved practices was laid under agree and strongly agree category. The mean scores, standard deviations, minimum and maximum observations were calculated for all five point Likert scale items (TABLE II). In general, all the participant farmers have a positive reaction to the technology in terms of easiness of water application and water saving.

TABLE II. FARMER'S PERCEPTION ON GREEN MAIZE TECHNOLOGIES AT SEDENI AND GOLINA1

Variable	5-Point Likert Scores				
	Obs	Mean	Std.Dev.	Min	Max
Easiness of the IP for application	21	1.5	0.74	1	4
IP saves time for watering	21	1.5	0.59	1	3
IP minimize water loss	21	1.64	0.58	1	3
IP increase yield	21	1.73	0.55	1	3
IP minimize environmental impact (salinization, waterlogging…)	21	1.91	0.61	1	3
IP minimize agriculture labor	21	4.18	0.73	2	5
Generally demand of the IP (to apply next time)	21	1.73	0.77	1	4

Where, 1-1.8 = strongly agree; 1.81-2.6 = agree; 2.61-3.4 = Neutral; 3.41-4.2 = disagree; 4.21-5 = strongly disagree.

2) Cost Benefit Analysis

From the result (TABLE III), the comparatively higher net benefit (174,487.00 ETB ha^{-1} and 222,575.00 ETB ha^{-1}) was recorded by the improved seed with improved practices (furrow irrigation and agronomic packages) for Sedeni and Golina1 respectively. It indicates that the improved practice had 81,097.00 ETB ha^{-1} (86.84%) and 98,670.00 ETB ha^{-1} (79.63%) net benefit advantage over the local practice for Sedeni and Golina1 respectively.

TABLE III. FINANCIAL COST-BENEFIT ANALYSIS FOR IRRIGATED GREEN MAIZE (ETB/HA)

Income An Expense	Sedeni		Golina 1	
	IP	FP	IP	FP
Gross benefits	264,810.00	154,140.00	306,875.00	184,055.00
Green cob yield	240,310.00	131,840.00	266,875.00	146,755.00
Fresh Straw yield	24,500.00	22,300.00	40,000.00	37,300.00
Total Variable costs	90,323.00	60,750.00	84,300.00	60,150.00
Fertilizer cost	9,950.00	3,950.00	9,950.00	3,950.00
Seed cost	3,150.00	1,200.00	3,150.00	1,200.00
Labor cost	48,400.00	38,800.00	46,400.00	35,600.00
Agrochemicals	10,800.00	6,600.00	10,800.00	6,600.00
Others (transport, ploughing..)	18,023.00	10,200.00	14,000.00	12,800.00
Net benefit	174,487.00	93,390.00	222,575.00	123,905.00
MC	29,573.00		24,150.00	
MR	81,097.00		98,670.00	
MRR (%)	274.23		408.57	

Where, IP: Improved practice; FP: Farmers practice.

IV. CONCLUSION AND RECOMMENDATION

Based on the study, improved irrigation management including the agronomic practices (furrow irrigation, irrigation schedule, amount, row planting, plant spacing, seed rate, and recommended fertilizer application and improved seed Melkassa- 6Q) were more efficient to achieve high green cob yield, water productivity, water saving, and higher net benefit with higher acceptability by the FREG members. Therefore, the technology should be further scale-up.

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