Improved irrigation technologies for efficient and sustainable agricultural water management in rural Mali: Results Based on the Sustainable Intensification Assessment Framework

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The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-in-development projects supported by the United States Agency for International Development (USAID) as part of the U.S. Government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING is creating opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment.

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Introduction

Irrigation in rural Mali is mostly done from the end of the rainy season to the end of the dry season (between March to May). Irrigation fields are prepared in September and October when water is abundant in the subsurface. Rural farmers are characterized as smallholder farmers with low income and low agricultural productivity due to rainfall variability and depleted soil nutrients. These farmers usually plant vegetable gardens in the dry season to supplement the main cereal crops (maize and sorghum). Vegetable gardens allow these farmers to diversify the food consumed within their households and fight against malnutrition in children and women. Traditional irrigation is mainly practiced using shallow wells, but is restricted by water availability. Recently, rural farmers have started organizing themselves into groups to build solar water pumps for agricultural production and other domestic uses. Some of these farmer groups have been supported by different development projects being implemented within these communities with a focus on promoting solar water irrigation pumps. Africa RISING (AR) has been implementing its research activities in some of these villages, however, within most AR intervention villages the farmers had more hand pumps than solar pumps. The few available solar powered pumps in these villages were primarily constructed for domestic use. This report provides the outcomes of a survey to assess the usage of solar irrigation pumps within the AR intervention villages. Data analysis was conducted using SPSS 20 and RStudio.

Descriptive statistics of the respondents' profile

Table 1 presents the demographic characteristics of the respondents using solar powered irrigation pumps within the Africa RISING intervention villages. The average household size is 27, and age of respondents ranged between 20 to 70 years, with a mean value of 46 years. Farmers are active in rainfed agriculture until a certain age (around 50 to 60 years). Some farmers are actively engaged in vegetable production using irrigation until the age of 70. In the rural areas, old aged farmers that are still involved in agricultural production mainly use irrigation systems for crop production. Female farmers, supported by their children, mainly use irrigation system at homestead for dry season vegetable production.

The average number of years for solar powered irrigations pumps in the studied area was 4.55, with an average yearly farm area coverage by each farmer is 0.15 ha. Before the introduction of solar powered irrigation pumps, farmers were using traditional irrigation systems for over 9 years.

Survey results highlighted that female farmers are better users (64%) of irrigation systems. (Annex I). The respondents were grouped in three categories as *head*, *spouse* and *member of the household*. Spouse represented 54% of the respondents while household member was 30%, and head of the households represent 16% (Annex I).

Table 1: Statistical description of respondents

Parameter	N	Mean with SD	Min	Max
Age (year)	112	46 ±9.82	20	70
Household size	112	27.89 ± 22.18	03	130
Use of solar powered irrigation pump (year)	112	4.55±2.99	02	12
Farm size under irrigation (ha)	112	0.15± 0.10	0.01	0.25
Experience in agriculture production (year)	112	27.91± 10.73	06	60
Experience in use of irrigation (year)	112	8.71± 5.83	03	30
Yearly income from primary activities (agriculture) in FCFA	78	185,269.23±181031.2	40,000	750,000
Yearly income from secondary activities (non-agriculture) in FCFA	71	90,781.69 ±81453.0	20,000	300,000

N: number of respondents

Education

Despite the presence of many primary schools within the rural area, few people are able to progress up to university. Forty six percent of respondents (46%) did not receive any type of education. The alphabetization system is a local language learning technique accounting for 37% of the education system in the studied area. This was followed by 14 % receiving primary education and 4 % receiving secondary education. The highest level of the education system is the secondary level. Improved irrigation systems require formal training or education, but with more than 80% of respondents being illiterate, it may be difficult for the rural communities to properly use solar powered irrigation systems in the dry seasons.

Sustainable Intensification Assessment Framework (SIAF)

This report presents information regarding solar powered irrigation system as compared to the traditional irrigation system using the SIAF. A minimum of two indicators from each of the five sustainable intensification domains (productivity, environmental, economic, social and human well-being) were considered.

Environment domain

Water availability

Communities in rural Mali are faced with limited access to groundwater reserves and this adversely affects their daily activities. The severity of the water access problem varies from one place to the other and within seasons as well. An analysis of farmers' perceptions on water availability revealed that about 39% admitted to always lacking water within the villages surveyed, whereas 61% described periodical water shortages. In general, all respondents noted that there is significant water shortage during the dry season, a situation which influences farmers' decisions about water use priorities.

Residents of the surveyed communities noted that they experienced severe water shortage at least one month every year. The duration and severity of water scarcity depends not only on people's needs but also on the types of water sources available. For example, users of shallow wells observed a longer duration of water scarcity in comparison to those using deep wells. This is because before the end of the dry season, wells dry according to the frequency of use and their depths. Survey results showed that 40% of respondents observed a lack of water for more than four months in the year. Twenty nine percent (29%) of respondents expressed problems with the quality and quantity of water during the three months preceding the start of the rainy season. Durations of water shortage not exceeding one and two months was 18% and 13% respectively.

Water sufficiency was assessed for various activities concerning domestic need, livestock water consumption and irrigation purposes. Water from solar powered irrigation pumps was always available for household consumption (60%), livestock water need (28%) and irrigation (15 %). A small percentage of respondents (8%) highlighted they have never used solar pump for irrigation purposes.

Irrigation water use and quantity applied

The study revealed that onion (49%) and tomato (27%) were the two most widely grown vegetables by farmers during the dry season using irrigation systems. Other vegetables produced by farmers include: Pepper, African Eggplant, Amaranth, Okra, and Lettuce. Water quantity supplied to the irrigated fields per day and irrigation intervals for each vegetable crop is presented in Table 2. Result showed that the quantity of applied water ranged between 50 and 1,200 liters per day. These values are in relation to the field size and water availability. The overall mean of the quantity of applied water was 353 liters with a standard deviation of 245.

In the studied villages, single vegetable growers (monoculture farmers) are very few. Among the vegetables grown by farmers, onions were the highest water consumers using up 1,200 liters per day with a mean value of 369 liters per day. Results of water consumption for other crops is presented in Table 2.

Irrigation interval

The interval between watering periods (irrigation interval) depended on the location of water source and the amount of water quantity supplied in the previous period. In general, the irrigation interval varied from 12 to 72 hours with a mean value of 14.41 hours. The soil's ability to store water for all vegetables varied from 1 to 5 days with an average of almost two days. The percentage of irrigated land was estimated, and results revealed that 67% of land under irrigation had sufficient water. The source of water varied from 2 to 94 meters depth with an average of 19 meters.

Table 2: Summary of statistical analysis of water quantity for dry season irrigation

Parameter	N	Mean	SD	Min	Max
Overall Water (liter/day)	83	353.24	244.93	50	1,200
Onion (liter/day)	57	369.82	302.88	80	1,200
Tomato (liter/day)	50	204.2	127.22	80	500
Lettuce (liter/day)	39	217.56	195.19	40	800
Pepper (liter/day)	32	158.91	126.39	40	400
Amaranth (liter/day)	15	118.67	69.06	40	240
African Eggplant (liter/day)	22	233.64	204.14	40	600
Carotte (liter/day)	43	188.84	159.57	40	600
Interval between two watering (hour)	112	14.41	9.30	04	72
Soil dry after Watering (days)	110	02	0.86	01	05
Field with sufficient water (percentage)	112	66.56	29.17	10	100
Water source depth (m)	112	18.91	25.84	02	94

Productivity domain

Production yield and stover

Total production (yield and stover) data of vegetable crops produced using solar irrigation pumps are shown in Table 3. Of the vegetable crops produced, pepper had the least yield recorded with 200 kg/ha. The highest yield recorded was for tomato (25,000 Kg/ha). The mean yield production of Lettuce and Tomato varied from 3,167 to 8,547 Kg/ha respectively. The mean yield in Kg/ha for other crops is as follows: Onion (4,355), Pepper (4,310), African Eggplant (5,774), Amaranth (3,823), and Okra (3,511).

The study also revealed most farmers in the study areas seldom used vegetable stover after harvest. Most respondents had a difficulty in estimating the quantity of stover produced because they didn't know how to. The stover from onion, and amaranth were directly consumed from farm fields at different times and it was not possible to get the estimated data. The average production of stover showed that Okra had 717 Kg/ha followed by tomato with 519 Kg/ha, while Pepper, and African Eggplant had the lowest stover yields with 517 and 491 Kg/ha respectively.

Table 3: Yield and stover production by different vegetables produced using solar powered irrigation pump

Production in kg/ha	N	Min	Max	Mean	SD	SE	CV
Onion	51	800	12,500	4,355.39	3,726.54	521.82	85.56
Tomato	49	800	25,000	8,547.16	7,503.55	1,071.94	87.79
Lettuce	23	600	10,000	3,166.65	2,959.53	617.1	93.46
Pepper	41	200	13,333	4,310.27	4,135.44	645.85	95.94
Amaranth	13	600	10,000	3,823.08	3,704.12	1,027.34	96.89
African Eggplant	39	800	17,500	5,774.05	5,340.34	855.14	92.49
Okra	19	389	10,000	3,510.68	2,707.07	621.04	77.11
Tomato Stover	51	53	1,600	519.06	390.6	54.69	75.25
Pepper Stover	25	80	1,333	517.04	421.68	84.34	81.56
African eggplant Stover	31	60	1,600	491.42	426.68	76.63	86.83
Okra Stover	17	200	1,600	717.06	365.44	88.63	50.96

The stover yield from vegetables are used for different purposes such as animals feed, composting and fuel wood. Survey results revealed that 39% of respondents used the stover to feed animals, 34% left the stover in the field to improve soil nutrients (manure), the remaining 27% use the stover as source of energy for cooking.

Frequency of cultivation

Irrigation of vegetables with solar powered irrigation pump is conducted at the end of the rainy season. Sixty nine percent (69%) of respondents conduct one time irrigation in the dry season, and 24% responded that they conduct two-time irrigation in the year (rainy and dry season). The supplementary irrigation during the rainy season is mostly for Okra and Pepper. Despite the shortage of water in the dry season, 7% of farmers practice irrigation two times.

Economic domain

Investment in irrigation system

Table 4 shows investment made in solar powered irrigation system by survey respondents. Investment in irrigable water sources was mostly done by projects and unlike solar pumps, most farmers directly make the initial investments for shallow wells. Results showed that the cost of constructing water sources varied from 25,000 to 500,000 FCFA with mean of 156,204 FCFA.
In the rural areas, land that is demarcated for agricultural use is almost never sold. However, it can be borrowed or rented. In this condition it was difficult to estimate the cost of land, but some farmers who visited the cities estimated their land value. The average price for their land is 176,818 FCFA, while it varied from 20,000 to 400,000 FCFA. Rural farmers are willing to work together than hire extra labor. The mean cost allocated to labor work per season was estimated to be 3,293 FCFA. The cost allocated to labor work was for constructing shallow wells and mostly the gardening activities. Only 26 % of respondent hired labor, mainly for construction of the shallow wells and gardening.

The number of persons working in irrigated fields varied from 1 to 20 with a mean of 4 persons. The time spent in the irrigation field depended much on water availability. It varied from 1 to 9 hours with a mean of 4 hours. The minimum number of working days per week was four with a mean of 6 days. Labor salary per day depend to the location and the work type, the price varied from 500 to 2500 FCFA.

Table 4: Capital input in the solar irrigation system (all in FCFA)

Parameters	N	Min	Max	Mean	Stdev	CV
Cost of constructing water source (shallow aquifer)	112	25,000	500,000	156,204	141,180.8	507.97
Land cost in a season (per hectare)	112	20,000	400,000	176,818	119,734.6	199.7
Labor cost	112	500	10,000	3,293	2,786.34	84.61
Number of people working in the irrigated field	105	1	20	3.86	4.06	105.3
Time spent in the field (hrs)	112	1	9	4.21	2.02	47.82
Number of days of work per week	112	4	7	6.68	0.82	12.26
Salary labor	29	500	2,500	1,337.82	428.61	32.04

Farm size

Despite the smaller land size under irrigation (an average of 0.15 hectare), there were many vegetables cultivated. The results in Table 5 shows onion occupied largest area with a mean value of 38% followed by tomato (29%). Amaranth and lettuce occupied smallest areas with 13% and 15% respectively.

Table 5: Percentage of land allocated to production for different vegetables

Parameters (%)	N	Min	Max	Mean	Median	Stdev	CV
Onion	89	10	100	37.93	35	20.18	53.2
Tomato	88	2	100	28.69	30	17.39	60.59
Lettuce	42	3	40	14.6	10	8.55	58.61
Pepper	53	5	60	20.04	15	13.88	69.26
Amaranth	28	2	30	12.75	10	6.32	49.54
African eggplant	67	2	75	24.37	20	14.74	60.49
Okra	25	3	60	15.84	10	13.33	84.12

Percentage of production consumed and sold

The percentage of consumed and sold vegetables produced under irrigation are shown in Table 6. Results revealed that more than 50% of most vegetables produced were for sale. While Pepper, African Eggplant, Tomato and Okra are for sale most of the times, the production of Lettuce was for household consumption with 59% rate of consumption, followed by Onion (53%), and Amaranth (51%).

Table 6: Percentage of vegetable production for sale and household consumption.

Vegetables	N	Min	Max	Mean	Median	Stdev	SE	CV
Sold								
Onion	87	0	98	46.63	50	26	2.79	55.75
Tomato	89	0	100	57.4	60	22.99	2.44	40.05
Lettuce	37	0	90	41.05	50	28.27	4.65	68.86
Pepper	54	0	100	68.7	80	25.7	3.5	37.41
Amaranth	24	03	99	49.21	50	31	6.33	62.99
African eggplant	65	02	100	58.72	60	20.68	2.57	35.22
Okra	24	0	90	50.75	50	26.64	5.44	52.49
Consumed								
Onion	87	02	100	53.37	50	26	2.79	48.72
Tomato	89	0	100	42.6	40	22.99	2.44	53.97
Lettuce	37	10	100	58.95	50	28.27	4.65	47.96
Pepper	54	0	100	31.3	20	25.7	3.5	82.13
Amaranth	24	01	97	50.79	50	31	6.33	61.02
African eggplant	65	0	98	41.28	40	20.68	2.57	50.11
Okra	25	10	100	49.25	50	27.98	5.6	54.57

Income from vegetable production

Income from the sale of vegetable production is shown in Table 7. The results indicated that farmers can get up to 40,265 FCFA per season from selling pepper followed by Onion with 36,457 FCFA. The low-income vegetables were amaranth and lettuce with 6,000 FCFA and 13,919 FCFA respectively. Most of the times amaranth, lettuce and African eggplant are cultivated for household consumption. These vegetables will be available for sale when the production is higher than household need. Producers could gain up to 5 million FCFA from the irrigation in one season.

Table 7: Income from each vegetable growth per season in francs CFA

Vegetables	N	Min	Max	Mean	Median	Stdev	CV
Onion	47	10000	150000	36457.45	25000	31899.78	87.5
Tomato	49	7500	100000	32510.2	18000	31904.23	98.14
Lettuce	31	1500	50000	13919.35	7500	14662.93	105.34
Pepper	34	7000	150000	40264.71	25000	42740.63	106.15
Amaranth	20	1000	20000	6000	5000	5170.77	86.18
African eggplant	40	6000	90000	21612.5	15000	21164.34	97.93
Okra	17	1500	75000	19647.06	15000	18723.12	95.3

Contribution of income

Inspite of farmers' dependence on rainfed agriculture for their livelihoods, they practice irrigation as secondary activity in the dry season to increase household income. Figure 1 illustrated the contribution of solar pumped irrigation system into household agricultural income. Results revealed that solar pumped irrigation contributed more than 40 % of the income for 31% of the respondents. This shows the importance of solar irrigation system in the agricultural development of the area. In 18% of respondent incomes, solar irrigation contributed up to 30%. Additionally, 14 and 15% of respondents indicated that solar irrigation system increased their income by twenty (20%) and ten (10%) percent respectively. For 21% of respondents' agricultural income was increased by five percent.

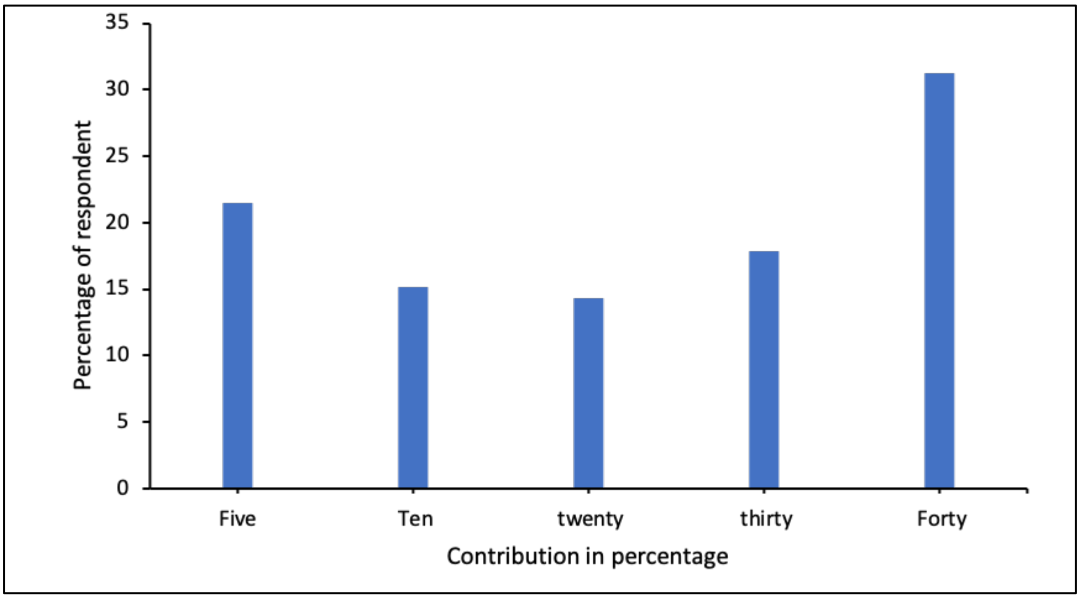

Figure 1: Contribution of solar irrigation into agricultural income.

Human domain

Purpose of vegetable production

Analyzed survey results indicated that 60% of respondents produce vegetables for household consumption, while the rest did so for other reasons including for sale. Most farmers' household income and nutrition diversity were therefore improved thanks to the use of solar irrigation systems. Meanwhile, there were challenges for non-vegetable producers to get nutritious foods because 69% estimated the unavailability of infrastructure for vegetable production. With regards to skills to use solar pumped irrigation system 54% of the respondents noted that they lacked of basic skills for maintenance work in case the pumps break down.

Percentage of vegetable consumption

Table 8 highlighted the distribution in percentage of the quantity of vegetables consumed by members of the household. Household members were categorized into six groups: adult female and adult male, youth female and youth male, children female and children male. The average percentage of vegetables consumed by a household member showed that adult females had high consumption rate with 22% of total production. In addition, youth female consumed 18% of the production while adult male, youth male, children female and male consumed 17%, 16%, 14% and 13% of the vegetables produced respectively.

Table 8 shows vegetable stover consumption by animals and the resulted weight gain. Number of animals able to feed vegetable stover varied from 1 to 20 with a mean of 4 animals, therefore the total weight gain varied from 02 kg to 50 kg with mean of 11.64 kg.

Table 8: Solar irrigation production consumption

Parameters	N	Min	Max	Mean	Median	Var	Stdev	CV
Animals	92	1	20	4.24	14.16	3.76	0.39	88.77
Time	92	0.5	6	1.62	1.1	1.05	0.11	64.79
Animal weight (Kg)	70	2	50	11.64	126.2	11.23	1.34	96.49
Adult male	112	5	50	17.25	46.37	6.81	0.64	39.48
Adult female	112	10	40	22.19	42.68	6.53	0.62	29.44
Youth female	112	0	55	18.21	36.36	6.03	0.57	33.12
Youth male	112	0	30	15.56	22.64	4.76	0.45	30.58
Male children	112	0	25	12.61	30.22	5.5	0.52	43.61
Female children	112	0	35	14.19	40.06	6.33	0.6	44.61

Social domain

Controlling production and benefits

Irrigation is a secondary activity in the rural areas, therefore, whoever conducts the activity has full control on the benefits. In majority of the cases (more than 65%), vegetables produced using irrigation were controlled by the producer. The head of the household is the second person to control the production from solar irrigation. The decision taken on vegetable production using solar irrigation was made by the producer for more than 56% for all vegetables except for tomato which is 50%. The second most important decision maker was head of the household.

Land ownership and source of water for irrigation

In rural Mali cultivated farmland belongs to the head of the family, however areas which have never been cultivated belong to the chief of the village. Results indicating ownership of irrigation land highlighted that 43% of the land belonged to the head of the household, and 33% was for the village chief (Figure 2). Most of the times project-initiated irrigation systems are constructed on the property land of the village whose decision make is the village chief. Nearly 6.25 % of the farmers borrow land for vegetable production.

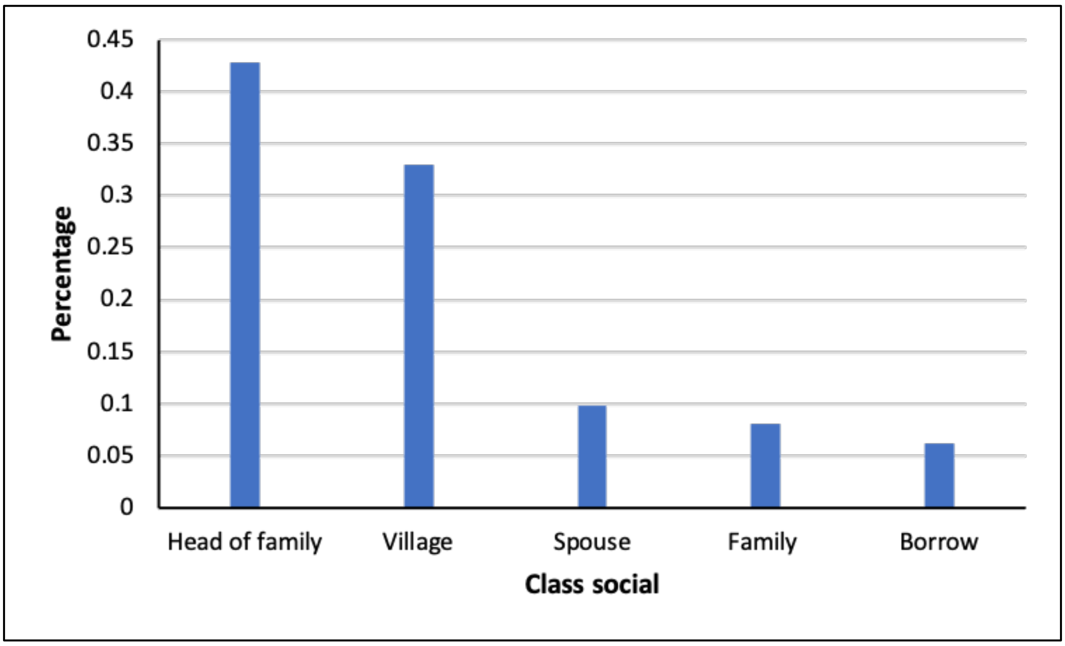

Figure 2: Land ownership for solar irrigation system

Construction of solar irrigation pumps

Constructing a solar irrigation pump in the rural area is very expensive for ordinary farmers, thus they need support from projects or collective investment through farmers groups within the village. Few government workers in the city can also construct solar irrigation pumps in their village for different purposes. Seventy seven percent (77%) of the respondents noted that NGO funded projects constructed solar pump irrigation systems in their villages, while 21% responded that they contributed to the construction.

Awareness about using solar pump irrigation systems

The survey results indicated that 63% of respondents get information about solar pump irrigation systems from innovation platforms. Communities receive information through farmer group interactions and farmer to farmer exchange learning and this accounts to 60%. Nearly 29% of respondents highlighted that they never received information. With regards to conflict management, 86% noted that there were conflicts arising from the proper use of the solar pump irrigation systems.

Annexes

Annex I

Sex of respondents

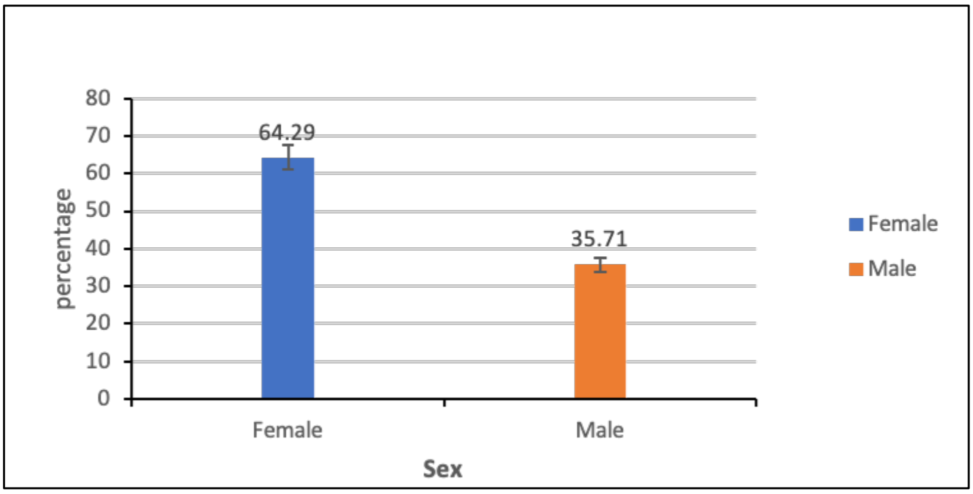

Figure 1: Sex of respondents in the study area

Respondents position within the household

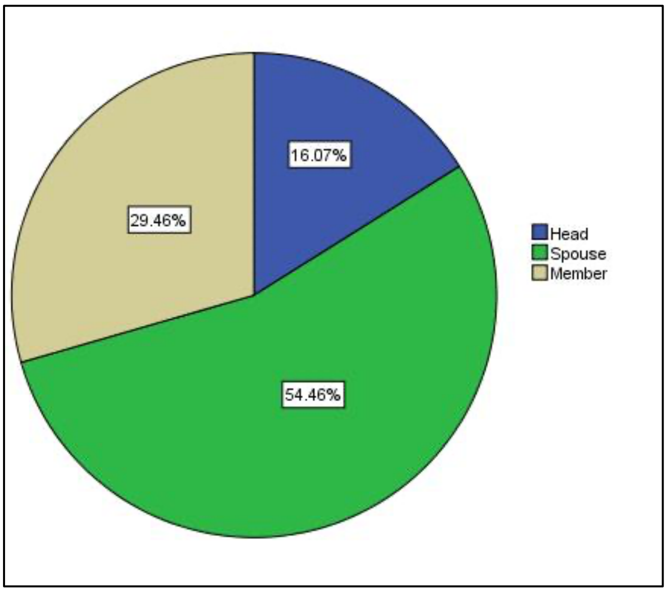

Figure 2: Position of respondents in the family within AR communities.

Paid labor hired within irrigation fields

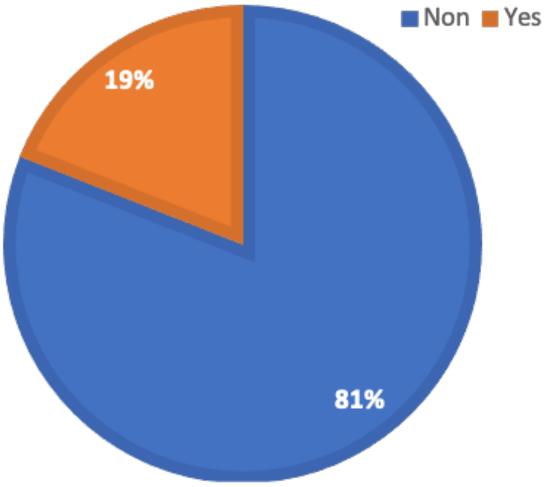

Figure 3: Paid labor hired within irrigation fields