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Full Length Research Paper

Economic optimal allocation of irrigation water in Egypt

Dawoud, Seham D. Z.

Department of Agricultural Economics, Faculty of Agriculture, Damietta University, Egypt.

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The water scarcity problem is globally getting worse especially in the light of increase in water demand among its competing uses. Thus, it is an important to optimize the water allocation to crops. In this paper, a linear programming model has been formulated to ensure the efficient allocation of scarce water resources among the competing crops. This model was constrained by land, water, labour, production costs, and organization constraints, determining the optimal plan for two possible future scenarios. The mathematical analysis was based on statistical data for the years (2009-2011) from the official statistical institutions in Egypt. The results of the two scenarios are as follows: Under the maximization of the net return per unit of land, there is an increase in total net returns by 3.56% more than the actual net returns. The optimized cropping pattern has been coupled with about 3.24% water saving and about 3.13% reduction in production costs compared to actual cropping pattern. However, under the minimization of irrigation water requirements, the total net returns decreased by 10.20% indicating losses below the actual situation. It has resulted in about 11.05% water saving and 11.24% reduction in the costs of production compared to the existing situation. These results can be used as a reference for indicative cropping pattern and irrigation water management in Egypt.

Key words: Linear programming, efficient water allocation, optimal cropping pattern, water management.

INTRODUCTION

Water is one of the most important natural resources for the world's economic development. In many areas around the world, conflicts have risen due to increase in water demand among its competing uses (World Bank, 2002; Young, 2005). Particularly, agriculture is becoming the sector to which policy makers are pointing out as the core of the water problem (Koundouri et al., 2006). This is clearly the case in Egypt, where water resources are limited to the *Nile* water. It is the major source of fresh water, supplying 96% of renewable fresh water resources. Egypt relies on the availability of its annual share of *Nile* water, which is stored in Lake Nasser. This is approximately 55.5 billion cubic meters annually following agreement between Egypt and Sudan in 1959. Water demand is increasing as a result of the rapid population growth, agricultural expansion, as well as industrial development, and higher standards of living. This increase in demand for the limited water resources puts pressure on the decision-makers to formulate policies to improve the allocation of the scarce water resources. Because agriculture is the major water consumer in Egypt, it will be important to ensure efficient allocation of irrigation water resources.

Linear Programming LP is a widely used mathematical modelling technique to determine the optimum allocation of scarce resources among competing demands. Some

E-mail: sdawoud@du.edu.eg

examples are presented. Kheper and Chaturvedi (1982) applied a linear programming model to make decisions about options of groundwater management in conjunction with optimal cropping pattern and production functions of water. Panda et al. (1983) applied linear programming models for conjunctive use of surface and groundwater to canal command area of Punjab by adopting an optimal cropping. Further, to resolve the complex problem of irrigation management within a large heterogeneous basin, Paudyal and Gupta (1990) applied a multilevel optimization technique. They determined the optimal cropping patterns in various sub-areas of the basin, the optimal design capacities of irrigation facilities, including surface and groundwater resources, and the optimal allocation policies of water for conjunctive use. Mainuddin et al. (1997) used an LP model to determine the cropping pattern to ensure optimal use of available land and water resources in a groundwater irrigation project.

Various reports (Amir and Fisher, 1999; Al-Weshah, 2000; Salman et al., 2001; Singh et al. 2001; Samei Tabieh, 2007) address optimal cropping pattern and optimal allocation of water by using LP model. They observe considerable improvement in the economic return as well as in the utilization of land and water resources by adopting an optimal cropping pattern. Abdelaziz et al (2010) obtained the optimal cropping pattern in North Darfur state, Sudan using the Linear Programming (LP) technique. The optimal plan was different from the farmers' plan. The LP model resulted in a profitable objective function while the farmers' plan gained a loss. Igwe et al. (2011), argue that linear programming technique is relevant in optimization of resource allocation and achieving efficiency in production planning particularly in achieving increased agricultural productivity. They applied LP technique to determine the optimum enterprise combination. The actual land use and the optimum plan were tabled. The results from optimum plans were more superior.

The objective of this paper was to develop a LP model based on an economic efficiency criterion for determining optimal water allocation and crop combination. Specifically, there are three aims for this paper as follows: First, understanding the actual patterns of water allocation and crop production in Egypt. Second, examining the economic analysis of water use in crop production. Third, developing an optimization model to ensure the efficient allocation of water resources among the competing crops. This is to serve as a tool for policy makers of indicative planning in irrigation management in Egypt.

METHODOLOGY AND DATA

Model specification

Linear Programming (LP) is a mathematical technique well suited for such a study because of the following reasons: Many activities and constraints can be considered at the same time, secondary explicit and efficient optimum seeking procedure is provided, results from changing variables can easily be calculated once formulated (Hazell and Norton, 1986). Therefore, linear programming is used to make decisions ensuring optimal allocation of water.

The currently most used algorithm in Linear Programming LP software is the Simplex Method which was developed during the Second War in 1974 by a Northern American scientist staff, and has been published afterwards. However, breakthrough in terms of correlated algorithms efficiency only could be observed in the 1980 through developed studies. Nowadays, LP is broadly used around the world and can be applied for different objectives such as maximize net income or minimize costs, losses etc. The General Algebraic Modelling System (GAMS) modelling language is used to calculate the optimal solutions (Brooke et al., 1998). It is preferred for this study because of its flexibility, and it is easy to apply for modellers familiar with such language.

The objectives of the model tries to achieve are related to maximizing the net return and/or minimizing the use of water resources. The mathematical formulation of the applied model includes the following components.

The objective function

The model is to determine the optimum allocation of water resources among competing activities via optimal cropping pattern. It is assumed that the decision maker has perfect knowledge and that there is no risk. The model was applied in two possible future scenarios in accordance with objective function as the following:

Scenario 1: The model employed maximizes net return subject to a set of constraints on cultivated areas, water resources, and other constraints. The optimal number of *Feddans* of each crop depends on the total amount of water and the crop water requirement. The decision makers choose the optimal number of *Feddans* of each crop for which the optimal quantity of water will be applied. The maximization of net return per unit of area is equivalent to the maximization of net return per unit of water. Therefore, the objective function of LP is to maximize the net return per unit of land from all crops. This can be written as:

$$Max\, \pi = \sum_{j=1}^{n} Z_j X_j$$

Scenario 2: LP model is formulated to suggest the optimal cropping pattern for minimizing the amount of irrigation water used. This scenario modeled a situation of water scarcity in time of drought or a reduction in water supply for agricultural expansion of new lands. This model is to inform decision makers about the impact of a reduction in water supply on crop production. In this case, the objective function is to minimize the total amount of water used for irrigation as follows:

$$Min\ \pi = \sum_{j=1}^{n} W_j X_j$$

Where; π is the objective function value; Z_j is the net return per unit of land (*Feddan*), $Z_j = (P_j Y_j - C_j)$; N is the number of crops; P_j is the price of crop j (LE/Ton); Y_j is the yield per area unit (Ton/*Feddan*; C_j is total production costs per area unit (LE/*Feddan*), X_j is cultivated area under crop j (*Feddan*), decision variables (j = 1, 2,…n), and W_j is the amount of water needed for irrigation (m^3/*Feddan*).

The constraints

The previously stated objectives are subjected to sets of constraints that are to be satisfied within the model, which include the following.

Land area constraints

This implies that the sum of areas allocated to crops in a certain season must not exceed or equal the total land area available for that season. The mathematical illustration of the land resource constraints is presented as follows:

$$\sum_{j=1}^{n} \alpha_{s\,j} X_j \le A_s$$

Where, α_{sj} = 1 if crop j is planted in a season s, otherwise α_{sj} = 0, A_S represents the total land areas available in season S of a year for different crops.

The total available cropped areas for the modeling was about 11540 thousand *Feddan*, representing about 90.06% of the total cropped area of the years (2009-2011) in Egypt. It is distributed over the 3 seasons of the year: 6272 thousand *Feddan* for winter season and 4858.63 thousand *Feddan* for summer and 409.56 thousands *Feddan* for *Nili* seasons, representing land restrictions. Due to the limitations of the data on fruits and other field crops that occupied an area of less than 1000 *Feddans*, they are excluded from this study.

Water constraints

The availability of water for irrigation from the *Nile* water source is limited. Since the amount of water available and water requirement of the crops are different in any month of the year, it is essential for water constraint to be monthly considered. So allocation of water must not exceed the available water in a month. Assuming that there is no recharge of *Nile* water during irrigation season, water constraints can be written as follows:

$$\sum_{j=1}^{n} W_{mj} X_j \le W_m$$

Where W_{mj} represents a matrix of the water requirement in month m for crop j (m^3/*Feddan*).

W_m is a vector of the total irrigation water availability in month m. The total annual volume of water for the modeling amounted to about 36.7 billion m^3 accounting for 90% of the total irrigation water used at the field level as average of the years (2009-2011). It was distributed over the 12 months, representing monthly water restrictions, after excluding the quantity of water resources available for crops that are not included in the models.

Labor constraints

Labor demand per month for all crops should not exceed the total number of labor days available in that particular month; these constraints can be written as follows:

$$\sum_{j=1}^{n} L_{jm} X_j \le L_m$$

Where L_{jm} represents a matrix of the labor requirement for crop j (man- day/*Feddan*) in month m. L_m is a vector of the total current number of labor days in month m.

The total annual number of labor days for the modeling amounted to about 790 million days. It was distributed over the 12 months, representing monthly Labor constraints.

Production cost constraints

The value of production cost for all crops should not exceed the total cost of production for the actual cropping pattern; this constraint can be represented for each input as follows:

$$\sum_{j=1}^{n} I_j X_j \le \sum I$$

Where I_j is input-output coefficient that states the production cost to produce one *Feddan* of crop j, I represents the value of inputs quantities used in actual cropping pattern.

Organisation constraints

Management considerations restrict minimum and maximum value for areas under crops to ensure the supply of the minimum quantities of food commodities and avoid deficiencies and marketing problems. The lower limitations on corresponding acreage were based upon the minimum levels of historical cultivation over the five years (2007-2011) for each crop. On the other hand, to prevent one high value crop from dominating the maximum benefits maximum areas should be considered for each crop. These constraints can be expressed mathematically:

$$LC_j \le X_j \le UC_j$$

Where X_j is the area under j crop (*Feddan*), LC_j is the minimum area of crop j, UC_j is the maximum area of crop during the years (2007-2011).

Non- negativity constraints

$$X_j \ge 0$$

The constraint states that the algorithm must not allocate negative amounts of land use in order to optimize the objective function.

Data sources

This study is mainly based on published and unpublished statistical data from the Ministry of Agriculture and Land Reclamation (MALR, 2009, 2010 and 2011), the Ministry of Water Resources and

Irrigation (MWRI), and the Central Agency for Public Mobilization and Statistics (CAPMAS), Egypt. The technical coefficients that quantify resource requirements are determined as a weighted average for real values of the most recently available three years (2009-2011). Moreover, individual crops are subject to organization constraints, which are the upper and lower limitations.

RESULTS AND DISCUSION

Egypt's water resources and demand

The main source of fresh water for Egypt is *Nile* River. Egypt relies on the availability of its annual share of *Nile* water that is stored in Lake Nasser. That is approximately 55.5 billion cubic meters annually by agreement between Egypt and Sudan in 1959.

The 1959 Agreement was based on the average flow of the *Nile* during the period 1900-1959, which was 84 billion m^3/year at Aswan. Average annual evaporation and other losses from the High Dam Lake were estimated to be 10 billion m^3/year, leaving a net usable annual flow of 74 billion m^3/year. It was agreed that 18.5 billion m^3/year is allocated to Sudan and 55.5 billion m^3/year to Egypt (International Water Law, Documents, http://www.internationalwaterlaw.org/documents/africa.html#*Nile*).

The groundwater aquifer underlying the agricultural lands of the *Nile* Valley and the Delta is entirely recharged and is dependent on deep percolation of irrigation water and seepage for the irrigation system. It cannot, therefore, be considered as an independent resource. And it cannot be added to the country water resources but rather be considered as a reservoir in the *Nile* River system. The total groundwater abstraction was estimated about 5.9 billion m^3/year as average of the period of 2009-2011. For the re-use of agricultural drainage water, the permitted total amount of the recycled water in the *Nile* Delta is about 7.5 billion m^3/year as average of the period of 2009-2011 (CAPMAS, 2009, 2010 and 2011). Sanitary drainage water is used in agriculture and tree planting after treating it to meet the specifications. Some amount of the treated water was about 1.3 billion m^3/year used in irrigation in specific locations outside the greater Cairo regions. Rainfall on the Mediterranean coastal strip decreases from 200 mm/year at Alexandria to 75 mm/year at Port Said. It also decreases inland to about 25 mm/year near Cairo. The average total amount of rainfall is about 1.30 billion m^3/year. This amount cannot be considered a reliable source of water due to a high spatial and temporal variability.

From the above, the actual water resources currently available for use in Egypt are 55.50 billion m^3/year and 1.3 billion m^3/year effective rainfall on the northern strip of the Delta, while water demands for different sectors are about 76 billion m^3, comprising of agriculture, industrial and municipal demand of 61.63, 1.33, and 10.43 billion m^3, respectively (CAPMAS, 2009, 2010 and 2011). The gap between the water supply and water needs is overcome by recycling.

Irrigation water requirements for actual cropping pattern

Allocation patterns of irrigation water use

Table 1 shows the irrigation water use for major crops in the current cropping pattern according to the season of cultivation at the field. The total water needs of summer crops was the highest, followed by winter crops and *Nili* crops, representing 62.59, 34.62 and 2.80% of the total irrigation demand, respectively, as shown in Figure 1; Winter Crops: Total area under winter crops was about 6.271 million *Feddan*. The corresponding water use reached about 13596 million m^3. Wheat and perennial clover are determined to be the most water consuming crops in winter season, as the irrigation requirements for these crops reached about 5377 and 4619 million m^3, respectively, representing 14.57 and 12.52% of the total irrigation requirements at the field level, respectively. Summer Crops: The area under summer crops amounted to 5.178 million *Feddan* and its annual water use reached about 21004 million m^3. Rice, maize, sugarcane, cotton, and sorghum are found to be the most water consuming crops in the summer season. The irrigation requirements for these crops amounted to 8879, 5363, 3065, 1154 and 1097 million m^3, respectively, representing about 24.06, 14.53, 8.31%, 3.13 and 2.97% of the total irrigation requirements, respectively. *Nili* Crops: Area under *Nili* crops was about 0.409 million *Feddan*. Maize is the most water consuming crop in the *Nili* season, consuming 748 million m^3. This represented about 2.03% of the total irrigation requirements.

Crop water requirements

Crop water requirements used in the study were directly taken from Government figures available and published by the Central Agency for Public Mobilization and Statistics (CAPMAS). The data on irrigation requirement are available as annual figures, and it is assumed that these annual requirements can be allocated over the months of plant growth-cycle. For modelling purposes, the computations of monthly irrigation water requirements were carried out by multiplying the theoretical monthly percentage crop consumptive water use by annual irrigation requirement. The theoretical consumptive water use is compiled by Water Management Research Institute (WMRI) in Egypt. Figures 2 and 3 show monthly water requirements of major winter and summer crops in Egypt, respectively.

Table 2 indicates that the average water consumption per irrigated *Feddan.* Perennial clover is considered the most water consuming crops in winter season, as the

Table 1. Actual cropping pattern and its water use for modelling in Egypt (2009- 2011).

Crop	Cropping area		Water used at field	
	Area (000 *Feddan**)	%	Quantity (MCM**)	%
Wheat	3055.15	25.76	5377.06	14.57
Barley	229.02	1.93	346.51	0.94
Broad bean	214.46	1.81	282.66	0.77
Fenugreek	10.36	0.09	12.75	0.03
Lentil	2.22	0.02	4.74	0.01
Lupine	3.40	0.03	5.16	0.01
Chickpeas	8.14	0.07	11.42	0.03
One-cut clover	354.88	2.99	391.79	1.06
Perennial clover	1583.61	13.35	4619.38	12.52
Flax	13.61	0.11	17.60	0.05
Onion	122.10	1.03	232.97	0.63
Sugar beet	302.65	2.55	667.04	71.81
Garlic	22.86	0.19	74.12	0.20
Winter tomatoes	229.18	1.93	481.05	1.30
Winter squash	29.05	0.24	60.97	0.17
Winter cabbage	36.31	0.31	76.22	0.21
Winter green peas	54.99	0.46	115.43	0.31
Total winter crops	**6271.98**	**52.88**	**12776.87**	**34.61**
Cotton	322.09	2.72	1154.00	3.13
Summer rice	1410.77	11.89	8879.41	24.06
Summer maize	1687.24	14.23	5363.73	14.53
Summer yellow maize	262.34	2.21	841.84	2.28
Summer Sorghum	341.91	2.88	1097.19	2.97
Soybean	24.65	0.21	78.19	0.21
Sesame	84.34	0.71	237.24	0.64
Peanut	152.33	1.28	631.08	1.71
Sunflower	31.38	0.26	78.45	0.21
Summer potatoes	125.54	1.06	388.05	1.05
Summer tomatoes	272.45	2.30	842.15	2.28
Summer squash	47.47	0.40	146.74	0.40
Summer eggplant	55.11	0.46	170.33	0.46
Summer cucumber	41.00	0.35	126.74	0.34
Sugar cane	320.21	2.70	3065.37	8.31
Total summer crops	**5178.83**	**43.67**	**23100.51**	**62.59**
Nili maize	287.99	2.43	748.49	2.03
Nili potatoes	52.13	0.44	121.67	0.33
Nili tomatoes	60.59	0.51	141.41	0.38
Nili cabbage	8.85	0.07	20.67	0.06
Total *Nili* crops	**409.56**	**3.45**	**1032.24**	**2.80**
Total crops	**11860.38**	**100.00**	**36.909.62**	**100.00**

Source: Data calculated from CAPMAS, irrigation and water resources bulletin, different issues. *Area in thousand *feddan*, **MCM, million cubic meters.

irrigation requirements for this crop was about 2917 m^3. Sugar cane and rice had the highest water consumption per *Feddan* in summer season. Their water requirements amounted to about 9573 and 6294 m^3, respectively.

Economic analysis of water use in crop production

Table 2 reports the profitability to scarce factors land in LE/*Feddan* and water in LE/1000 m^3, in which net return

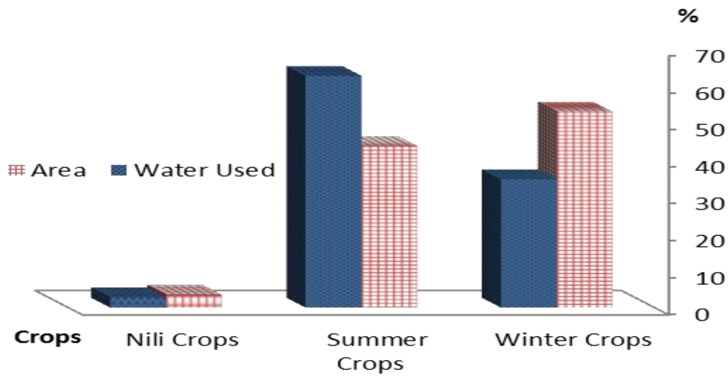

Figure 1. Actual cropping pattern and its water in Egypt (2009-2011).

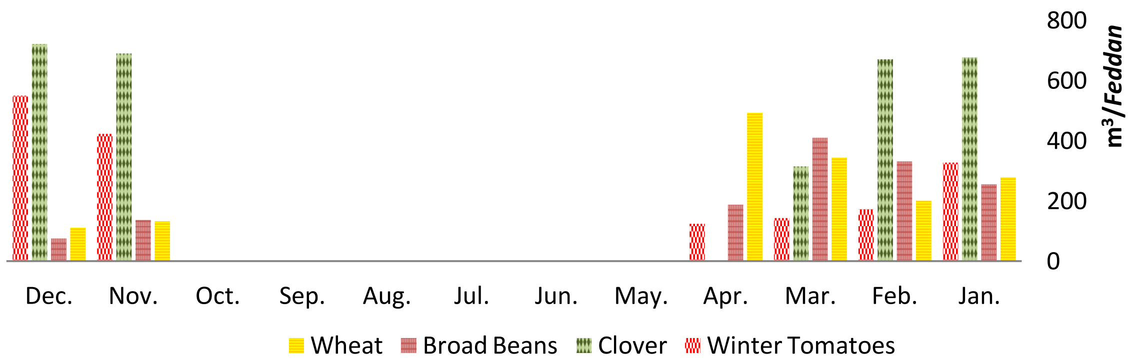

Figure 2. Monthly water requirements of major winter crops in Egypt.

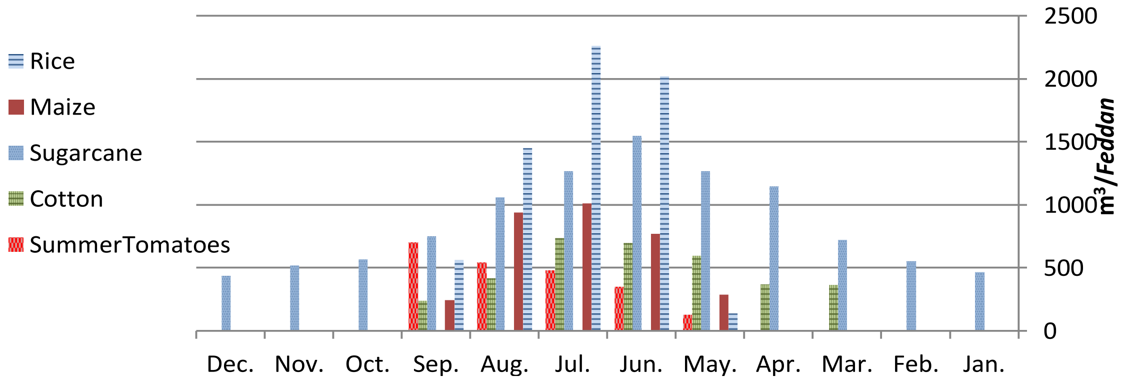

Figure 3. Monthly water requirements of major summer crops in Egypt

per unit of land and water are calculated based on the farm prices. The most profitable crops in winter season were winter tomatoes, garlic, onion, and perennial clover with net return of 9316, 11919, 6520, and 6191 LE/*Feddan*, respectively. For the summer crops: Summer tomatoes were also the most profitable, with net return of 9600 LE/*Feddan*. Summer potatoes cane was among the next most profitable crops, with net return of 6212 LE/*Feddan*. The net returns were 4522, 2716 and 1975 LE/*Feddan* for peanut, rice and cotton, respectively.

For net return per unit of water, it is observed that the most profitable crops in winter season were winter tomatoes and garlic with net return per unit of water of 4438 LE/1000 m^3 and 3675 LE/1000 m^3, respectively. For the summer crops: tomatoes and potatoes were also the most profitable, with net return of 3106 and 2010 LE/1000 m^3, respectively.

Virtual water represents the amount of water needed to raise a certain quantity of food (Allan, 1999). The "virtual water" concept can contribute to a change in water

Table 2. Average net return by unit of land and water for the most important crops in Egypt (2009- 2011).

Crops	Yield (Ton/*Feddan*)	Net return (LE*/*Feddan*)	Water requirement (M^3/*Feddan*)	Net return per unit of water (LE/1000M^3)	Virtual water (M^3/Ton)
Wheat	2.7	3109	1760	1766	651.85
Broad bean	1.4	2040	1318	1548	941.43
One-cut clover	12.8	2912	1104	2638	86.25
Perennial clover	29.4	6191	2917	2122	99.22
Sugar beet	20.5	3286	2204	1491	107.51
Onion	13.8	6520	1908	3417	1060.00
Garlic	9.7	11919	3243	3675	334.33
Winter tomatoes	19.4	9316	2099	4438	108.20
Cotton	1.0	1975	2985	662	2985.00
Summer rice	4.1	2716	6294	432	1535.12
Summer maize	3.3	1931	3179	607	963.33
Summer sorghum	2.3	1419	3209	442	1395.22
Soybean	1.4	1014	3172	320	2265.71
Sesame	0.5	1670	2813	594	5626.00
Peanut	1.3	4522	4143	1091	3186.92
Summer potatoes	12.0	6212	3091	2010	257.58
Summer tomatoes	16.3	9600	3091	3106	189.63
Nili maize	2.8	1489	2599	573	928.21
Nili potatoes	9.7	1789	2334	766	240.62
Nili tomatoes	16.9	1058	2334	453	138.11
Sugar cane	49.8	5748	9573	600	192.23

Source: Calculated from MALR and CAPMAS. *LE Egyptian Pound.

The basic linear programming model solutions

The LP model is used to determine the optimal allocation and crop pattern of the different crops. In order to calibrate the model, the actual cropping plan for the reference average of years (2009-2011) is compared with the results generated by the models. Table 3 compares the optimal values of the net return, land, water and crop areas in the two scenarios vs. the actual cropping pattern in 2011.

Scenario 1: Maximizing the net return

The outputs of maximization model are shown in terms of percentage change of actual values. In winter season, the area under wheat declined by approximately 8.43% below its actual cropped area. Similarly, area under one-cut clover and broad bean decreased by 12.68 and 11.20%, respectively. However, there was an increase in area under perennial clover by about 15.20% above the current area. Area under sugar beet and winter tomatoes would increase by 27.45 and 15.70% above its actual area because of their high profitability. In summer season, area under rice and summer maize decreased by 12.57 and 7.0%, respectively, below existing area, while summer potatoes and tomatoes would increase by 6.70 and 4.63%, respectively. *Nili* potatoes and *Nili* maize crops could decline, while *Nili* tomatoes and *Nili* cabbage crops would increase in the optimal plan. Because of its high profitability, sugar cane recorded an increase in the optimal solution at 4.60%.

The results showed the great potential to generate a net return equivalent to about 3.56% more than the actual total net returns. The optimized cropping pattern in Egypt has been coupled with about 3.24% saving in the water use and about 3.13% reduction in the production cost compared to the existing plan.

Scenario 2: Minimizing the amount of irrigation water used

The objective function of this scenario is to minimize the amount of irrigation water used taking into consideration the same specified constraints. This model is useful in informing water policy makers about the impact of water cuts on the crop production in old lands. The results show that the cropping pattern changes in favour of less water demanding crops. Also, cultivated winter and summer areas would decline by 10.42 and 12.05% below the basic level, respectively. This means that the fallowed lands appeared due to water becoming scarcer. Consequently, cropped area under most of the crops

Table 3. Comparison of cropping pattern under optimal plans with actual plan.

Indicators	Actual plan	Optimal plans	
		Δ_1 %	Δ_2 %
Total Net Return (M.LE)*	42963.11	3.56	-10.20
Resources Utilization:			
Total Water Used (M.CM)	36909.62	-3.24	-11.05
Winter Land Used (000*Feddan*)	6271.98	0.00	10.42
Summer Land Used (000 *Feddan*)	5178.83	0.00	12.05
Nili Land Used (000 *Feddan*)	409.56	0.00	14.37
Production Costs (M.LE)	39391.33	-3.13	-11.24
Crop Area (1000 Feddan)			
Wheat	3055.15	-8.43	-11.12
Barley	229.00	-20.50	-20.50
Broad Bean	214.33	-11.20	-11.20
Fenugreek	10.35	-23.40	-23.40
Lentil	2.12	-34.30	-34.30
Lupine	3.40	-8.94	-8.94
Chickpeas	8.14	-22.20	-22.20
One-cut Clover	354.88	-12.68	-12.68
Perennial Clover	1583.61	15.20	-4.10
Flax	13.61	-41.60	-41.60
Onion	122.10	9.80	-46.37
Sugar Beet	302.65	27.45	-44.71
Garlic	22.86	22.90	-25.57
Winter Tomatoes	229.18	15.70	-12.61
Winter Squash	29.05	3.75	-30.21
Winter Cabbage	36.31	4.20	-25.28
Winter Green Peas	54.99	9.20	-5.61
Cotton	322.09	43.62	-11.69
Summer Rice	1410.77	-12.57	-20.50
Summer Maize	1687.24	-7.00	-7.00
Summer yellow Maize	262.34	-46.00	-46.00
Summer Sorghum	341.91	-3.80	-3.80
Soybean	24.65	-30.80	-30.80
Sesame	84.34	-21.30	-21.30
Peanut	152.33	4.35	-13.29
Sunflower	31.38	-38.70	-38.70
Summer Potatoes	125.54	6.70	-37.02
Summer Tomatoes	272.45	4.63	-20.92
Summer Squash	47.47	-8.16	-8.16
Summer Eggplant	55.11	-3.54	-3.54
Summer Cucumber	41.00	-4.96	-4.96
Nili Maize	278.99	-0.38	-15.60
Nili Potatoes	52.13	-5.66	-5.66
Nili Tomatoes	60.59	21.60	-12.57
Nili Cabbage	8.86	15.80	-10.02
Sugar Cane	320.21	4.60	-1.10

Source: Mathematical programming models results based on CAPMAS, MWRI (NWRC) and MALR Data. MLE Million Egyptian Pound.

decreased. Area under wheat would decline by 11.12% below the current area allocated to wheat in winter season. Area under one-cut clover and perennial clover decreased by 12.68 and 4.10%, respectively. There was a decrease in area under sugar beet by about 44.71% below the actual area. Despite the high profitability of winter tomatoes, its area declined by 12.61% below the basic level due to its high water requirement. Area under cotton recorded also a decrease in the optimal solution at 11.69%. Similarly, in the summer season, area under rice and summer maize would decrease by 20.50 and 7.00% below the actual cropped areas, respectively. This may be attributed to more water consumption for these crops in relation to their net returns. Area under summer potatoes and tomatoes would decrease by 37.02 and 20.92% below the actual area, due to their high water requirements compared to other field crops. Area under Nili maize, Nili potatoes, and Nili tomatoes crops would decrease in by 15.60, 5.66 and 12.57%, respectively.

The results show that the total net returns decreased by 10.20% below the actual total net returns. The optimized cropping pattern in Egypt has been coupled with about 11.05% saving in the water use and about 11.24% reduction in the production cost use compared to the existing plan.

Conclusion

Regarding to the results of above analysis, the following conclusions can be summarized:

1. The model for maximizing net return produced an optimal allocation of water and cropping pattern that gives higher net return compared to the existing plan,
2. Land resource under maximization of net return, had an optimal use, where it is fully used,
3. There is a need for the governmental co-ordination in crop production ensuring the supply of food commodities and avoiding marketing problems.
4. Minimizing of irrigation water requirements is generally difficult. The policy had negative impacts on farm income, the irrigated area decreased and fallow lands appeared.

RECOMMENDATIONS

Several recommendations, based on the results can be made for the future water policies as follows:

1. In order to improve water allocation, farmers should be advised to follow the indicative optimal cropping pattern, which maximizes the net income return.
2. Cultivation of sugarcane in Egypt should be reduced based on minimum requirement of raw material for sugar processing plants.
3. Cultivation of rice should be restricted.
4. The Government of Egypt should encourage utilization of new irrigation technologies.
5. The applied model can be used to provide useful information to decision makers about likely optimal allocation policies for irrigation.

Conflict of Interest

The authors have not declared any conflict of interest.

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Prioritization and cost and returns analyses of selected non-timber forest products in Yobe State, Nigeria

Tee N. Terver[1]*, Orsar J. Tyonzughul[2] and Bugh J. Aondoaseer[3]

[1]Department of Social and Environmental Forestry, University of Agriculture Makurdi, P. M. B. 2373, Makurdi, Benue State, Nigeria.
[2]Department of Wildlife and Range Management, Federal University of Agriculture Makurdi, P. M. B. 2373 Makurdi, Benue State, Nigeria.
[3]Department of Forestry Technology,Yobe State College of Agriculture, Gujba, Nigeria.

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This article describes cost and returns analysis of first five preferred Sahel savanna non-timber forest products (NTFPs) in Yobe State, Nigeria. The results demonstrate that households in Yobe State could realize NGN2,898.48 and NGN142,615.49 from the NTFPs as the least and maximum gross margins (household incomes) respectively. Gross margin ratio of households across all the study sites ranged from 0.925 to 0.980, and that from individual study sites 0.903 to 1.000 respectively. Thus, trade in these NTFPs was profitable to stimulate their domestication.

Key words: Cost and returns analysis, gross margin, gross margin ratio, non-timber forest products, sahel savanna.

INTRODUCTION

Non-timber forest products (NTFPs) are the wide range of species; both flora and fauna that are produced by forests and woodlands, and which are available to humans for use other than commercial timber (Cavendish, 2001; Sunderland et al., 2003; Jimoh, 2006). Dohrenbusch (2006) defined NTFPs as 'all products derived from biological resources found on forest land but not including timber, fuelwood or medicinal plants harvested as whole plants'. Ecosystem services such as water purification and prevention of soil erosion are all considered as NTFPs (Jimoh, 2006); and are among the very vital human livelihood opportunities.

The foregoing definitions indicate that NTFPs do not have a clear-cut definition. For example, the definition by Dohrenbusch (2006) excludes fuel-wood and a whole harvested medicinal plant from the list of NTFPs. Fuel-wood is however a NTFP since it is not used for timber. But it is not a non-wood forest product because it contains lignin. The authors therefore suggest that in defining NTFPs, all forest products like fuel-wood, which contain lignin (wood) and are not used as timber could be classified as woody NTFPs, while those without lignin, like mushroom, could be classified as non-wood forest products (NWFPs). This means NTFPs in general may include the numerous forest extracts such as bark, roots, tubers, leaves, fruits, flowers, seeds, resins, honey as

*Corresponding author. E-mail: drteenobert@gmail.com

well as medicinal plants, oils and mushroom. They may also include fuel-wood, edible seeds/fruits and vegetables, edible oils, spices, fodder, rattan, bamboo, cork, ornamental plants, chemical components, edible animal products, and terrestrial animals. Furthermore, fish, aquatic invertebrates, insects and insects' products, and wildlife products may all be listed among NTFPs.

Based on estimates from the European Tropical Forest Research Network, up to 2000 non-timber forest products can be listed today and many more are being discovered (Gopalakrishnan et al., 2005). In this study, NTFPs are forest tree components like flowers, fruits, leaves, roots, bark, and stems of the Sahel savanna tree species in Yobe State, Nigeria. The cost and returns analysis was limited to only the edible components of these NTFPs with market benefits.

Earlier research findings have shown that NTFPs contribute substantially to the livelihood of the rural poor in the developing economies (Chandrasekharan, 1992; FAO, 2002; Jumbe et al., 2007; Kafeero et al., 2011; Mwema et al., 2012). These contributions are numerous among which include food supply, medicine/health services, income and job opportunities to the members of the rural and urban households. The NTFPs provide essential dietary supplements, especially during lean agricultural production periods and times of emergency (Shackleton and Shackleton, 2004; Belcher et al., 2005; Mwema et al., 2012). They also provide food for man, livestock and wildlife; and trade in them provide alternative sources of cash incomes to man (Shackleton and Shackleton, 2003, 2006; Stark et al., 2006). Thus, they are very useful instruments to tackling poverty and food security challenges of the rural economies of developing countries (Taylor et al., 1996; Popoola and Galaudu, 2000; Anamayi et al., 2005; Tella et al., 2008; Tee et al., 2009). In Nigeria, the inhabitants within the guinea and Sahel savannas of Nigeria also rely appreciably on these NTFPs for income, sustenance, health, and general wellbeing (NEST, 1991; Tella et al., 2008; Tee et al., 2009).

Although they are socio-economically very important to the rural economies, there is paucity of empirical documentations on these benefits, and so, NTFPs are undervalued during national accounting (Popoola and Oluwalana, 2001; Jimoh, 2006; Amusa et al., 2012). Consequently, the sector often receives very meager budgetary allocations from government. Mithofer (2005), however, asserts that economic and financial analyses of natural resources (NTFPs inclusive) are vital empirical evidences that enhance choice among competing investment and development opportunities. They are the fundamental management tools to evaluate, select, and monitor investment opportunities towards maximizing utility and minimizing costs (Queensland Government, 2000; Elevitch and Wilkinson, 2000; Mechler, 2005; Chilvers and Smith, 2009; Cubbage et al., 2012).

Paucity of information on economic potentials of Sahel savanna NTFPs in Nigeria, and particularly in Yobe State (Tee et al., 2009) has therefore negatively influenced its effective planning, policy decisions as well as sustainable management and utilization. This study is therefore very important since it provide additional empirical data and economic evidence to enhances the proper placement of the forestry sector during national development planning.

Another concept of importance employed in this study is prioritization. It is the ranking or ordering of things by their importance or urgency. Prioritization as applied in this study will enhance the validity and workability of information the study produces. The concept is very significant to economists in decision making and choice among the limited available resources that are often open to so many alternative uses. The concept facilitates the choice of opportunities to follow, problems to resolve as well as causes to address and solutions to implement. In fact, it is one of the best approaches in making objective decisions (Gosenheimer et al., 2012).

In forest management and utilization, the public most often have diverse opinions and perspectives on how and why forests should, or should not, be managed and utilized (Meldrum et al., 2013). Through prioritization such diverse opinions and perspectives would be harmonized to produce more widely acceptable and universal decisions. Approaches to prioritization usually expose people's value judgment of the existing alternatives and in the process ease-up choice and decision making. Popoola and Galaudu (2000), for instance, applied prioritization approach to identify and select indigenous spices for inclusion into agroforestry systems and practices in the semi-arid zone of Nigeria. Criteria for prioritization of the spices were acceptability, range of products and services, income level from them, interaction with other crops, and farmers' willingness to plant them. The final spices selected for improvement and introduction into the agroforestry practices in the area was therefore a product of local peoples' participation.

Background to the study

A number of researchers have studied NTFPs in Nigeria (Popoola and Oluwalana, 2001; Jimoh, 2006; Tella et al., 2008; Tee et al., 2009; Babalola, 2011). However, these studies have focused mostly the general livelihoods and socio-economic benefits with very little analysis on cash income to households. Nevertheless, studies on the values of NTFPs are critical to empowering and informing stakeholders; regulators, policy makers and development agencies for useful, equitable and sustainable interventions (Ingram and Bongers, 2009).

In addition, paucity of information exist on economic analyses of NTFPs in Nigeria, but the Sahel savanna

Table 1. Sampling Frame and procedure.

Senatorial zones in Yobe State	Number of LGAs in a senatorial zone	30% of the LGAs selected in a zone	30% of the Council wards selected per LGA	Villages purposively selected per council ward (2 per council ward)	Households randomly selected per council ward (5 households per ward)	Survey respondents (2 per household)
Zone A	7	2	6	12	60	120
Zone B	4	1	3	6	30	60
Zone C	6	2	6	12	60	120
Total	17	5	15	30	150	300

species are worst hit than those of the guinea savanna and rainforest ecosystems. Aside, Nwema et al. (2012) noted that the recurrent crop failures and livestock losses to drought in the arid regions make the integration of NTFPs in their farming systems imperative. Usually, NTFPs with proven economic potentials for livelihood sustainability elicits farmers' wider acceptability for inclusion in their farming systems (Tee and Amonum, 2008; Ingram and Bongers, 2009; Cubbage et al., 2012). This study will provide information to assist the selection and inclusion of the Sahel savanna NTFPs in domestication programmes of the region to complement the naturally occurring wild NTFPs (UNDP, 2003; World Bank 2004; Kalinganire, 2008). Also, economic studies to generating quantitative and incisive information on NTFPs for effective policies to boost their availability, accessibility, and sustainability, are imperative. This study will therefore prioritize NTFPs in Yobe State and further evaluate their economic potentials to households in the study area.

METHODOLOGY

Description of the study area

Yobe State is located in the Northeastern geopolitical zone of Nigeria between latitudes 10º and 14º North and longitude 11º 30´ to 14°45´East. The climate of the area shows a dry season stretching from October to June and the rainy season between July and September. The mean annual rainfall is; 275 mm, and mean annual temperature varies between 35 and 40ºC (YOSADP, 1992). The major vegetation type is the Sahel savannah. It consists of open thorny savannah with short trees and grasses. The trees are about 5 to 10 m high. The State comprises seventeen (17) Local Government Areas (LGAs) namely: Bade, Busari, Damaturu, Fika, Fune, Geidam, Gujba, Gulani, Jakusko, Karasuwa, Machina, Nangere, Nguru, Potiskum, Tarmuwa, Yunusari and Yusufari. The human population of both male and female in Yobe State is 2,532,395 (NPC, 2006). The major ethnic groups include the Kanuri, Hausa, Fulani, Kerekere and Nufundi, who are predominantly farmers. They also depend on forest products and hunting for their livelihoods.

Population and sampling of observational units

The study population comprises the male and female household members in Yobe State involved with NTFPs as producers, traders or consumers. A multistage random sampling technique, using 30% sampling intensity, was applied in determining sample size and also selecting observational units.

The State was stratified into three Senatorial Zones; A, B and C with the Local Government Areas (LGAs) distributed as seven, four and six respectively for Zones A, B and C. Thus, applying a 30% sampling intensity (SI), five LGAs out of 17 were selected for the study; two LGAs in Zone A, one in Zone B, and two in Zone C. These LGAs comprises 10 council wards each. Thus from every of the 10 council wards in each of the five LGAs selected, three council wards each were sampled using 30% SI. In the end 15 council wards were selected for the study. From these 15 council wards, two villages each were selected for the study based on the prevalence of NTFPs. In the end 30 villages were covered and five households each were sampled at regular intervals from these villages to elicit data. Thus, 150 households were sampled and administered with the copies of the questionnaire; two respondents (one male and one female) each per household to elicit data. A total of 300 respondents were therefore sampled at the end of the process to elicit data. The sampling frame is as shown in Table 1.

Data collection

Data were collected in a survey administered as part of a broader study on the proximate and economic analysis of selected Sahel savanna NTFPs in Yobe State, Nigeria (Bugh, 2014). A reconnaissance survey was carried out between July and August, 2011 to ascertain the reliability of the study area, identify the study sites and contact persons. A list of the most commonly available NTFPs in Yobe State was also produced during the reconnaissance survey. This list was incorporated into the primary data collection instrument; the semi-structured questionnaire, which was validated through a pre-test and editing by social scientists and foresters at seminars and private consultations. This procedure eliminated ambiguities and also made the questionnaire more simple and relevant for the kind of data this study required. Personal observations and focus group discussions were also adopted to ensure good data collection. Three hundred copies of the validated questionnaire were then administered on 300 respondents in the study area; 120, 60 and 120 respectively in zones A, B and C. However, 279 copies out of the 300 copies of the administered questionnaire were valid while twenty one were not valid due to communication problems some field assistants encountered. Thus the twenty one copies of the questionnaire did not provide the desired information, and were therefore not utilized during analysis. Markets were also visited weekly to establish the prices of the selected NTFPs per unit of measurement. These were then aggregated to determine mean market price. All measurements were standardized in kilograms. Respondents were asked to score the identified species of NTFPs based on their preferences using a scale of 0 to 5, with score '5' as the most preferred. This was to obtain data for the prioritization of NTFPs in Yobe State.

Questionnaire administration was completed in 8 weeks, and only 93%, that is, 279 of 300 individuals contacted completed the questionnaire without problems. The remaining 7% (that is, 21) survey respondents truncated the completion of the questionnaire as they could not provide adequate information on their incomes and quantities of products they marketed. The truncated questionnaire copies were not analyzed.

Data analyses

Prioritization of NTFPs in Yobe State

The prioritization of the NTFPs identified during data collection was carried out by ranking. Respondents' opinion poll for ranking the NTFPs was elicited using a five point scale corresponding with the five top priority NTFPs species to be selected for cost and returns analysis. Each respondent was then asked to select and rank five top priority NTFPs species out of the 16 identified in Yobe State. The first preferred species were to score five, while the fifth and less preferred species scored one. The rating was based on respondents' perceived level of importance of each of the NTFPs for income, food, and health needs. The first most preferred NTFP species were scored 5 points, and the fifth most preferred species 1 point. All NTFPs had equal opportunities of being selected by every respondent among the top five priority species. Thus, any species that was not rated among the first five NTFPs species by a particular respondent was scored zero (0). Since 279 respondents participated in this rating exercise, any NTFP that was rated first (5 points) by every respondent could score 1395 points; that is, 100% of the respondents. The mean preference values were then computed using these scores and respondents' frequencies.

Cost and returns of NTFPs using gross margin analysis

Respondents were requested to indicate the plant species they produced, edible products of the species sold, and the monthly quantities produced and sold with the unit prices and expenses incurred. The prevailing market prices were also obtained through personal observations and market surveys to authenticate the information respondents provided. All quantity measurements were standardized in kilograms. Prices and costs were also determined using such standards. Budgetary tool; gross margin was then applied to estimate costs and returns of the Sahel savanna NTFPs. The gross margin analysis, following Cubbage et al. (2012), is specified as follows:

$$GM = GI - TVC$$

Where; GM = Gross Margin; GI = Gross Income (Quantity of NTFPs sold per month × prevailing market price); TVC = Total Variable Cost (Cost incurred in the use of variable inputs, that is, transportation and taxes paid per unit quantity sold); Profitability was estimated using Gross Margin Ratio (GMR) specified as:

$$GMR = (GI - TVC)/GI$$

The higher the ratio, the more profitable is the returns from the products. The mean results of the G.M of the selected Sahel savanna NTFPs were then estimated. Significant differences in mean GMRs were tested using a two-way Analysis of variance (ANOVA) at 5% level of significance to measure the effect of locations and the different species.

RESULTS AND DISCUSSION

Prioritization of NTFPs in Yobe State, Nigeria

Table 2 presents the summary of NTFPs prioritization in Yobe State, and this shows that 16 species of NTFPs trees identified can produce products of economic, health and nutritional value to the people in the area. Based on respondents perceived preferences, the first five priority species in the study area were: *Phoenix dactylifera* (3.043±0.118), *Moringa oleifera* (2.455±0.119), *Adansonia digitata* (2.373±0.107), *Tamarindus indica* (1.219±0.091) and *Diospyros mespiliformis* (1.186±0.113) respectively. The corresponding percentages acceptability were 60.9, 49.1, 47.5, 24.4 and 23.7% respectively. *Haematostaphis barteri* with mean score of 0.122±0.034 and percentage acceptability of 2.4% was the least preferred species in the study area. The scores by the other species were as shown in Table 2.

The prioritization of these NTFPs species was based on respondents' perceived level of the combined importance of each of these NTFPs species for income, food, and health needs. This means *P. dactylifera*, *M. oleifera*, *A. digitata*, *T. indica* and *D. mespiliformis* respectively were the first five most preferred species to the people in terms of usefulness. However, current exploitation pressure on the preferred species in the study area is threatening their sustainability, and there are no established plantations of these species to support their natural populations.

NTFPs exploitation without concomitant regeneration efforts may lead to scarcity and even extinction (Kalinganire et al., 2008; Tee et al., 2008). Policy interventions are therefore necessary to ensure that forest resources exploitation and regeneration operate concomitantly to maintain their numbers in the wild. Since prioritization processes harmonize varying opinions and perspective in management decisions (Gosenheimer et al., 2012), the promotion of the first five preferred NTFPs species (particularly *P. dactylifera* and *M. oleifera* with higher prioritization values) reported in this study for domestication and commercialization would attract wide acceptability.

Cost and returns of the NTFPs studied in Yobe State

Table 3 presents cost and returns analysis of the first five preferred NTFPs in Yobe State. All the variables in the table are ranked based on GMR values in column 8. These GMR values were significantly different ($P<0.05$) with *P. dactylefera* fruits producing the highest GM of

Table 2. Prioritization of NTFPs in Yobe State.

Scientific name	Common Name	Hausa name	Total score	Score as % of 1395*	Mean Score±SE
Phoenix dactylifera	Dates tree	Dabino	849	60.9	3.043±0.118
Moringa oleifera	Horse radish tree	Zogale	685	49.1	2.455±0.119
Adansonia digitata	Boabab tree	Kuka	662	47.5	2.373±0.107
Tamarindus indica	Tamarind	Tsamiya	340	24.4	1.219±0.091
Diospyros mespiliformis	African Ebony	Kanya	331	23.7	1.186±0.113
Balanites aegyptiaca	Soapberry tree	Aduwa	309	22.2	1.108±0.092
Ziziphus mauritiana	Jujube tree	Magarya	230	16.5	0.824±0.079
Parkia biglobosa	Locust bean tree	Dprawa	207	14.8	0.742±0.083
Hyphaena thebaica	Dum palm**	Goruba	118	8.5	0.423±0.067
Vitex doniana	Black pluru	Dinya	99	7.1	0.355±0.058
Vitellaria paradoxa	Shea butter tree	Kadanya	61	4.4	0.219±0.049
Borassus aethiopum	African fan tree	Giginya	58	4.2	0.208±0.045
Ziziphus spinachristi	Christs thorn	Kurna	56	4.0	0.201±0.044
Detarium micropum	Tallow tree	Taura	54	3.9	0.194±0.043
Ximenia Americana	Wild olive	Tsada	40	2.9	0.143±0.036
Haematostaphis barteri	Blood plum	Danya	34	2.4	0.122±0.034

1395* is the Maximum score any NTFP species can score. N = 279. Dum palm** is also known as Ginger bread palm, and Egyptian doum palm.

Table 3. Cost and returns analyses of the first five prioritized NTFPs studied in Yobe State.

Selected NTFPs	MMQS (kg)/Resp. (a)	MPMP (NGN)/Kg (b)	MVC (₦)/ month/Kg (c)	GI (NGN)/month (a)×(b) = d	TVC (NGN)/month (a)×(c) = e	GM (NGN)/month d-e = f	*GMR Mean ± SE f ÷ d= g
P. dactylifera (fruits)	621.31	234.17	4.63	145,492.16	2,876.67	142,615.49	0.980±0.00[a]
D. mespiliformis (fruits)	79.65	38.06	1.67	3,031.48	133.02	2,898.48	0.956±0.003[b]
A. digitata (leaf powder)	448.11	29.06	1.48	13,022.08	663.20	12,358.88	0.949±0.006[c]
*M. oleifera (*leaves)	141.61	90.00	6.21	12,744.90	879.40	11,865.50	0.931±0.006[bc]
T. indica (fruits*)*	103.08	47.94	3.61	4,941.66	372.12	4,569.54	0.925±0.023[abc]

MMQS = Mean monthly quantity sold, MPMP = Mean prevailing market price, MVC = Mean variable cost, GI = Gross Income, TVC = Total variable cost. GM = Gross margin, GMR= Gross margin ratio. One US$ is equivalent to NGN156. *Value in the same column followed by different superscripts differ significantly (P<0.05).

NGN142,615.49, followed by the GM values of *A. digitata* leaf powder (NGN12,358.88), *M. oleifera* leaves (NGN11,865.50), and *T. indica* fruits (NGN4,569.54) respectively. *D. mespiliformis* fruits generated the least GM of NGN2,898.48. The differences in the mean GM values were explained by mean monthly quantities sold (MMQS), mean prevailing market price (MPMP), and the mean variable cost (MVC) of the NTFPs (Table 3).

Respondents' relative MMQS of NTFPs included: *D. mespiliformis* fruits; 79.65 kg, *T. indica* fruits; 103.08 kg, *M. oleifera* leaves; 141.61 kg, *A. digitata* leaf powder; 448.11 kg, and *P. dactylifera* fruits; 621.31 kg (Table 3). The relative GM of the NTFPs per month also followed a similar order above. Thus, MMQS of NTFPs and their GMs are connected; the higher the MMQS of NTFPs, the greater the GM realized, *ceteris paribus*. The MMQS of NTFPs may also indirectly signify the levels of availability, preferences, and demand for the NTFPs. These factors may also influence GM to be realized.

Although the MPMP did not follow the same ranking, it influenced the GM values realized from the NTFPs. According to Armstrong and Kotler (2000), if other things are equal, the higher prices of commodities will generate greater income or GM from NTFPs sales and vice versa. The price of NTFPs in the study area ranged from NGN29.06/kg of *A. digitata* leaf powder to NGN234.17/kg of *P. dactylifera* fruits. Thus, *P. dactylefera* fruits attracted the highest market price among the NTFPs in this study.

Table 4. Mean Gross Margin ratios of the first five priority NTFPS in Yobe State.

LGA's	*P. dactylifera*	*M. oleifera*	*A. digitata*	*T. indica*	*D. mespiliformis*
Potiskum	0.986±0.008[a]	0.962±0.003[a]	0.960±0.005[a]	0.944±0.011[a]	1.000±0.00[a]
Gujba	0.969±0.006[a]	0.903±0.017[c]	0.955±0.005[a]	0.954±0.013[a]	0.922±0.004[b]
Damaturu	0.977±0.006[a]	0.926±0.037[bc]	0.943±0.008[ab]	0.960±0.009[a]	0.944±0.016[b]
Bursari	0.977±0.007[a]	0.915±0.009[bc]	0.956±0.009[a]	0.934±0.017[a]	0.989±0.007[a]
Bade	0.993±0.000[a]	0.946±0.011[b]	0.925±0.013[b]	0.828±0.119[a]	0.924±0.025[b]

Values in the same column followed by different superscripts differ significantly (P<0.05).

A. digitata leaf powder attracted the least market price. According to Arnold and Dewees (1999), high market values of NTFPs stimulate their selection for domestication programs. Furthermore, Adeyoju (1993) asserts that prices are signals to both producers and consumers in their production and consumption decisions. Price is also a strong indicator of value and success in business, level of income generation and distribution (Armstrong and Kotler, 2000). The high income benefits of the NTFPs reported in this study would build farmers' confidence and desire in these plants for domestication.

The mean variable cost of NTFPs in the study area ranged from NGN1.67 to NGN6.21 per kilogram per month. These were from *D. mespiliformis* fruits and *M. oleifera* leaves respectively. It is worthy to note that in production theory, increase in production cost will result to a decline in the level of benefits. Thus, the disparity in the mean variable costs of NTFPs studied also influenced their GM values differently. Respondents attributed this to the differences in the monthly quantities sold of the NTFPs, their nature (leafy or fruity), and seasonality. Increasing mean variable cost will produce decreasing GMs.

Generally, the differences in the nature of NTFPs, level of demand, location, and availability could explain variations in MMQS, MPMP, and MVC or Marginal costs of the NTFPs studied. Besides, some NTFPs are seasonal through the year (Mithofer and Waibel, 2008). These factors could jointly influence the GM from NTFPs in the area.

The highest GMR of 0.980 was obtained from *P. dactylefera* fruits (Table 3). This was followed by 0.956, 0.949, and 0.931 from *D. mespiliformis* fruits, *A. digitata* leaf powder, and *M. oleifera* leaves respectively. The least GMR of 0.925 was obtained from *T. indica* fruits. Although *P. dactylefera* fruits have the second highest MVC, its relatively higher MMQS explains why its GMR is higher than all the other NTFPs. *D. mespiliformis* fruits have the second highest GMR probably because of the relatively very low and least MVC (NGN1.67) than the other NTFPs studied. *M.oleifera* leaves have the highest MVC and a corresponding third least MMQS of it than the other NTFPs studied. These in part explain why its GMR ranked the fourth out of the five NTFPs studied albeit it's high MPMP second only to *P. dactylefera* fruits. *T. indica* fruits have the least GMR perhaps for the combined high MVC and low MMQS of it. GMR is an approximate estimate of profitability (Cubbage et al., 2012). Thus, the highest and least profit from NTFPs in Yobe state was from *P. dactylefera* fruits, and *T. indica* fruits respectively.

Gross margin ratio (GMR); an approximate estimate of NTFPs profitability in Yobe State

Gross margin ratio (GMR) was utilized to estimate and compare profit margins of the preferred NTFPs across the study sites in Yobe State. Table 4 presents the mean GMRs of the five Sahel savanna NTFPs studied. There was significant different (P<0.05) in the mean GMRs of *M. oleifera* leaves, *A. digitata* leaf powder, and *D. mespiliformis* fruits among the five LGAs, while no significant difference (P>0.05) was observed in the mean GMRs of *P. dactylefera* fruits and *T. indica* fruits. This implies that the NTFPs with significant difference in the mean GMR similarly differ significantly in their profit margins across the LGAs, while those with no significant differences generated very close profit margins. Thus, for *M. oleifera* leaves, the GMR of 0.962±0.003 at Potiskum LGA was significantly higher (P<0.05) than its GMRs in the other four LGAs. However, its GMRs in Bade (0.946±0.011), Damaturu (0.926±0.037) and Busari (0.915±0.009) were similar, while that of Gujba (0.903±0.017) was less than Bade. This means that *M. oleifera* leaves were significantly more profitable at Potiskum than the other four LGAs.

In the case of *A. digitata* leaf powder, the GMRs of 0.960±0.005, 0.956±0.009 and 0.955±0.005 at Potiskum, Busari and Gujba LGAs, respectively, were similar (P>0.05), but significantly higher (P<0.05) than the GMR of 0.925±0.013 at Bade LGA. The GMR of 0.943±0.008 realized from *A. digitata* leaf powder, at Damaturu LGA, was similar (P>0.05) to all the other four LGAs. This means, of all the five LGAs studied, profit margin from *A. digitata* leaf powder was least at Bade LGA; except Damaturu. The GMRs of 1.000±0.00 and 0.989±0.007 realized from *D. mespiliformis* fruits at Potiskum and

Table 5. Supply dynamics of the first five prioritized NTFPs in Yobe State.

Prioritized NTFPs	Jan	Feb	Mar	Apr.	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
P. dactylifera (fruits)	NAA	NAA	*	*	*	NAA	NAA	NAA	NAA	NAA	NAA	NAA
D. mespiliformis (fruits)	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	*	*
A. digitata (leaf powder)	*	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	*	*	*
*M. oleifera (*leaves)	NAA	NAA	NAA	NAA	NAA	NAA	*	*	*	*	*	NAA
T. indica (fruits*)*	*	*	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	NAA	⟷

'NAA' means 'Not Adequately Available'. *The times products from species are mostly available.

Busari LGAs, were similar (P>0.05), but significantly higher (P<0.05) than the GMRs of 0.944±0.016, 0.924±0.025 and 0.922±0.004, respectively, at Damaturu, Bade and Gujba LGAs. Thus, the highest profit margins, realized from *D. mespiliformis* fruits, at Potiskum and Busari LGAs were more than those from Damaturu, Bade and Gujba LGAs.

The GMRs realized from *P. dactylefera* fruits, and *T. indica* fruits, were respectively not different (P>0.05) among the LGAs studied. The GMRs of these two NTFPs- *P. dactylefera* fruits and *T. indica* fruits respectively, ranged from 0.969±0.006 to 0.993±0.000 and 0.828±0.119 to 0.960±0.009. The variation in the level of profit generated from these NTFPs among the LGAs studied could be explained, among others, by the differing volumes of sales, prevailing market prices, level of demand, and trading costs, respectively. The generally high GMRs of the NTFPs studied in Yobe State showed that investment in these commodities with higher GMRs is more profitable than the NTFPs with lower GMRs. However, the GMR of *D. mespiliformis* fruits at Potiskum LGA (1.000 ± 0.00) looks spurious. This could be explained on account of the low and negligible MMQS of *D. mespiliformis* fruits at Potiskum LGA that attracted very negligible transportation cost and tax after sales. Since the two factors were the only items of variable cost estimated in this study, the MVC was negligible and hence its effect on GMR was also negligible.

Since profitability is often the overriding objective of businessmen and women, survey respondents may likely prefer investing in the NTFPs with higher profits (Mithofer and Waibel, 2008). In this study, all the NTFPs yielded high GMRs and thus, are all profitable. Traders will only have to study the spatiotemporal variations in the level of profit realized from these NTFPs to determine when and where to sell their products. However, emphasis should be on spatiotemporal variations in *M. oleifera* leaves, *A. digitata* leaves, and *D. mespiliformis* fruits, whose mean GMRs were significantly different (P<0.05) across the LGAs studied. The result presented in Table 5 shows the months of the year that the first five preferred NTFPs species were mostly available in Yobe State. *M. oleifera* was reported to be mostly available from July to November (5 months period). *A. digitata* was reported to be mostly available for four months (October to January). Both *P. dactylifera* and *T. indica* were mostly available over three month periods (March to May and December to February) respectively. The least distributed species was *D. mespiliformis,* which was reported to be mostly available for only two months (November-December). The result therefore shows that none of the species was available all-year-round; however, there were overlaps and successions (Table 5) in their availability and distribution throughout the year. Due to variations in the maturity period of species, most of the species were noted to be more abundant during their harvest seasons and very scarce and even absent off harvest seasons.

Other reasons for the relatively more abundant supply of the species during the harvesting seasons than the non-harvesting seasons were:

1. Fear of wastages due to the perishable nature of some of the species, example Moringa leaves.
2. Immediate desire for income to address household economic and financial challenges like paying school fees and hospital bills.
3. Poor storage and processing culture amongst the households in the area.
4. Inadequate processing and storage facilities as well as poor knowledge the need to process and store products for future use.
5. Drought, poor rainfall and other weather challenges also influenced their availability.

For products like *P. dactylefera* fruits and *A. digitata* powdered leaf which could be sundried and stored for some time, their supply were relatively stable. Moringa leafs were also more stable because it was possible to sun-dry and store them for some months. The all-year-round supply of any of these species would only be ensured through processing, storage and other sustainable management approaches (Kalinganire et al., 2008). Adequate planning and policy interventions to improve processing, storage and domestication of the species would enhance the availability, distribution and utilization of these NTFPs.

Conclusion

The selected Sahel savanna non-timber forest products

(NTFPs) studied provided alternative income sources to the rural households at Yobe State. The monthly gross margins realized by the households at Yobe from these NTFPs were NGN142,615.49, NGN12,358.88, NGN11,865.50, NGN4,569.54 and NGN2,898.48 from *P. dactylifera* fruits, *A. digitata* powdered leaf, *M. oleifera* leaves, *T. indica* fruits and *D. mespiliformis* fruits respectively. Thus the highest gross margin of NGN142,615.49 was realized from *P. dactylifera* fruits, and the lowest monthly gross margin of NGN2,898.48 from *D. mespiliformis* fruits. By virtue of the gross margin ratios, all the selected NTFPs studied in Yobe state, are profitable; however, *P. dactylifera* fruits are the most profitable with a gross margin ratio of 0.980 (Table 3), followed by *D. mespiliformis* fruits with gross margin ratio of 0.956. The variable cost components of the NTFPs were not fully estimated, particularly that the family labor cost was not imputed. This may have inflated the GI, GM, and GMR values observed in this study.

The selected Sahel savanna NTFPs studied are profitable, and highly valued by the households in Yobe state. They can therefore be developed and promoted for domestication. Improved marketing strategies and processing of the products from these species for value adding will make significant improvement in the economic life of households at Yobe state.

Conflict of Interest

The authors have not declared any conflict of interest.

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Economic analysis of factors influencing adoption of motor pumps in Ethiopia

Gebrehaweria Gebregziabher[1]*, Meredith A. Giordano[2], Simon Langan J.[1] and Regassa E. Namara[3]

[1]International Water Management Institute, East Africa Office, Addis Ababa, Ethiopia.
[2]International Water Management Institute, Colombo, Sri Lanka
[3]International Water Management Institute, West Africa Office, Accra, Ghana

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The Ethiopian economy depends heavily on smallholder agriculture, and this sector directly affects the country's economic development, food security and poverty alleviation efforts. The adoption of smallholder irrigation technologies as a means to tackle these challenges has become an important policy issue in the development agenda of the country. The lack of access to low-cost irrigation technologies is, however, one of the major bottlenecks to increase smallholder irrigation. This paper examines the factors influencing farmers' decisions to adopt low-cost small motor pumps. The analysis is based on a survey of 800 farm households in four regions of Ethiopia. We use a combination of econometric techniques to find comparable households among adopter and non-adopter sample households. First, we employ a multivariate probit model to check whether a correlation exists between motor pumps and other water lifting technologies (that is, bucket, treadle and electric pumps). A non-parametric matching method is used to identify a counterfactual (control group) among the non-adopter sample households. Finally, a probit model is adopted to model the determinants of farmers' motor pump adoption decisions. Our analysis reveals that gender; age; ownership of oxen; access to extension; access to surface and shallow ground water; social capital and regional differences captured by a regional dummy, all influence farmers' decision of motor pump adoption.

Key words: Smallholder, irrigation technology, propensity score matching, probit.

INTRODUCTION

Investment in irrigation, particularly in small-scale and household level irrigation, has been identified as a core strategy in Ethiopia to reduce the strength of the link between agricultural production from rainfall and climate risk to improve crop production (Hagos et al., 2009). Irrigation also requires the use of modern inputs (such as, fertilizers and improved seeds), which further enhance agricultural productivity (World Bank, 2006; MoFED, 2006; Diao et al., 2010; Gebregziabher and Holden, 2011). To alleviate poverty, the financial gains from

*Corresponding author. E-mail: G.gebregziabher@cgiar.org. Tel: +251 921753737 / +251 11 617 2251(Ext. 2251). Fax: +251 11 617 2001.

irrigation need to be geographically scaled out to widen the access and participation of many poor farmers. Small-scale private irrigation using small pumps has a greater chance to reach and involve many smallholders than command and scheme level irrigation approaches (Rydzewski, 1990; Fan and Hazell, 2001; Shitundu and Luvanga, 1998). Experience from Sub-Saharan Africa shows that investments in scheme level irrigation in the 1970s and 1980s did not meet targets for food production because economic problems, such as high capital investment and management costs, impeded the performance of large scale irrigation (Adams, 1991). Similarly, Lam (1996) shows that in Asia, small-scale schemes perform better than large-scale systems partly due to constraints by government bureaucracy on the latter and has promoted a shift to small-scale irrigation. Furthermore, D'Souza and Ikerd (1996) argued that from a sustainability perspective, small-scale farms are more effective and competitive compared with large-scale farms. Likewise, Ofosu et al. (2010) documented that in the Volta basin, irrigation technologies are frequently better managed by farmers and consequently result in higher productivity and good profit margins. Ofosu et al. (2010) also suggest that as compared to scheme level irrigation, small-scale irrigation technologies are more profitable and financially sustainable than large-scale irrigation, because they provide income opportunities to the wider society in terms of employment and participation of women. Moreover, experience from India suggests that given the right conditions, the use of small pumps and other micro-irrigation technologies commonly used in water scarce areas is an efficient use of irrigation water that can improve the productivity of water; generate income and financial benefits; and enhance food security of farm households (IWMI, 2006).

Likewise, D'Souza and Ikerd (1996) and Lam (1996) argue that smallholder and household level irrigation technology is more likely to bring higher returns per hectare than large-scale irrigation schemes. However, FAO (2005) has documented that only 13% of the irrigation potential of Sub-Saharan Africa is currently developed, largely due to past experience in irrigation development in the region emphasizing large-scale irrigation, which in most cases is constrained by high cost and management complexity. In the 1980s and 1990s, emphasis began to shift to smallholder irrigation using simple technologies, such as small and inexpensive pumps (Abric et al., 2011; Kay, 2001). For example Perry (1997) recommended low-cost manual and/or mechanized irrigation technologies as promising interventions in Sub-Saharan Africa while de Lange (1997) concluded that small-scale irrigation developed from farmers' initiative in Sub-Saharan Africa is more successful than government initiated large-scale irrigation.

Ethiopia has substantial surface and groundwater potential (Makombe et al., 2007; Awulachew, 2010; Awulachew et al., 2006; Cherre, 2006), although to date, farmers have not accessed this at a large enough scale to produce enough food to remove issues of regional poverty and food insecurity. Whilst irrigation has the potential to increase cereal yields by up to 40% (Diao et al., 2010), agricultural producers in Ethiopia have used only about 5 to 6% of the country's irrigation potential (Awulachew et al., 2007), mainly through large- and small-scale community irrigation schemes.

For the purpose of this paper, 'small' motor pumps are between 1 to 10 horsepower and costs between US$200 to US$1,000. Smallholder farmers usually use their own financing mechanisms to purchase these pumps to irrigate less than 5 ha of land to produce cash crops. The pumps are owned and managed individually or by small informal groups of farmers to pump water from rivers, lakes, reservoirs and shallow aquifer.

Data on private smallholder irrigation and the use of small pumps are not readily available and national estimates vary considerably. For example, Kay (2001) report that Ethiopia's potential irrigated area is approximately 670,000 ha, of which in 1992 about 82,000 ha and 5,000 ha were irrigated using large-scale and small-scale irrigation, respectively. More recently, Awulachew et al., (2005) report that the aggregated maximum irrigation potential in Ethiopia (including small, medium and large-scale) is about 3.7 million ha, of which only about 197,000 ha, or 5.3%, is irrigated. Furthermore, Santini et al. (2011) suggest that the potential for small private motor pump irrigation in Ethiopia is between 1.4 and 2.8 million ha, from which about 9 to 18 million people could benefit. However, except for some indicative government statistics, information on the current status of motor pump adoption in Ethiopia is largely unavailable.

The premise of this paper is that smallholder farmers can play a significant role in Ethiopia's irrigation development provided they have access to appropriate low-cost water lifting technologies. Ofosu et al. (2010) defined irrigation technology as "a method and techniques for diverting and/or pumping, storing, transporting and distributing ground, surface and rainwater to agricultural crops", and Perry (1997) has characterized motor pumps as "low-cost irrigation technologies". Based on unpublished reports in the regional bureaus of water resources, motorized small pumps are among the emerging private irrigation technologies in rural Ethiopia. The spread of small pumps occurs through the regional bureaus of water resources mainly distributed on credit and through direct purchase with farmers' own resources. According to Ethiopian government statistics (Ethiopian Revenue and Customs Authority), about 800,000 motor pumps have been imported between August 2004 and December 2010, while unpublished reports from the regions show that at the end of 2009, the regional bureaus of water resources have distributed 19,338 pumps in Oromia, 20,916 in

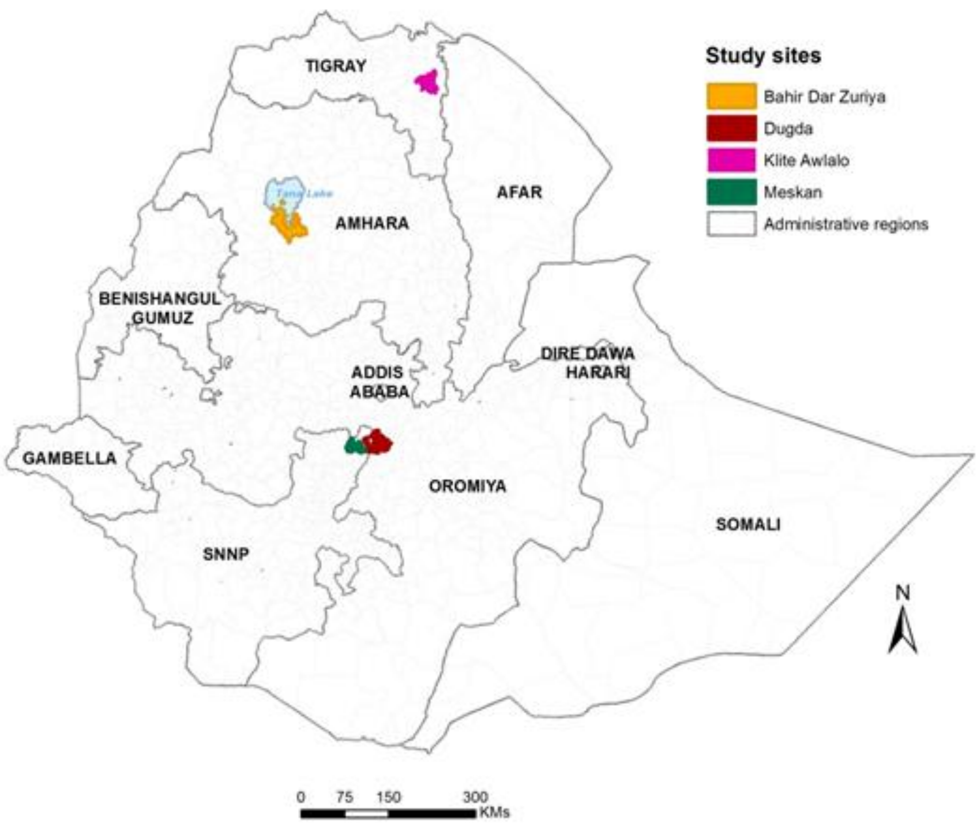

Figure 1. Study areas of Region and Districts

Amhara, and 18,348 in Tigray. Given that only 5 to 6% of Ethiopia's irrigation potential is being used, it is likely that private small-scale irrigation using pumps would benefit smallholder farmers. However, information on factors that influence the adoption of smallholder water lifting irrigation technologies is scant. The main objective of this paper is, therefore, to study the factors that affect smallholder farmers' adoption of small motor pumps in rural Ethiopia. The paper aims to contribute to the growing literature on adoption of smallholder irrigation and informing policy making in a country that has put irrigation at the heart of its agricultural development strategy.

METHODOLOGY

Data collection

In this study, we utilise data from a household survey collected during January-April, 2010 from four districts of the four main regions (Amhara, Oromia, SNNP and Tigray) of Ethiopia (Figure 1). Primary data were collected from 800 randomly selected farm households, using a multi-stage stratified random sampling method. In the first stage, we used information from the regional bureaus of agriculture to identify *wereda* (Districts) with a high concentration of smallholder irrigation technologies, such as buckets, treadle pumps, motorized pumps, and electric pumps. In the second stage, information from agricultural offices of the selected *weredas* was used to select *Kebeles* (communities) that have high adoption rates of these technologies. In the third stage, a list of farm households in the selected communities was used to disaggregate them into adopter and non-adopter households. Finally, we used a proportional random sampling technique to select our sample households. Of the total sample households, 266 were classified as adopters of motor pumps (Table 1).

Empirical analysis

This paper uses both descriptive and econometric analysis techniques. We assume that the production system represents a multi-crop agricultural production unit where land holding is fixed, but the allocation of land into crop type and irrigation is possibly endogenous. The adoption decision of irrigation technology is a discrete outcome where the farmer faces a dichotomous decision to adopt or not to adopt a motor pump. In our context, motor pump adopters are those farmers who were using motor pumps (petrol or diesel, rented or purchased) during the data collection to irrigate all or part of their land, while the rest are non-adopters.

Among the sample households, some of them have adopted a combination of technologies, such as motor pumps, bucket, treadle pumps, electric pumps and other water lifting technologies. These households may have adopted these technologies as substitutes or complements as they may have faced interdependent/correlated choices of technologies in their adoption decisions. Moyo and Veeman (2004); Marenya and Barrett (2007); Nhemachena and Hassan (2007); Yu et al. (2008) and Kassie et al. (2009) argue that farmers usually consider a set of possible technologies and try to

Table 1. Sample households and type of technologies by region.

Type of technology	Region				Total
	Amhara	Oromia	SNNPR	Tigray	
Purely rain-fed cultivators (Non-adopters)	115	118	120	146	499
Bucket	0	0	5	0	5
Treadle pump	3	1	5	0	9
Motor (petrol/diesel) pump[a]	66	68	73	59	266
Electric pump	0	21	0	0	21
Other type of technology	21	6	0	0	27
Total number of sample household[b]	200	200	200	200	800

a, Other type of technology includes rope and washer, wind mill, solar pumps, etc; **b,** the sum exceeds the total sample size, because some households have adopted more than one technology

Table 2. Correlation coefficients between irrigation technologies.

Irrigation technology	Motor pump	Bucket	Treadle pump
Bucket	ρ_{21} 0.436***(0.072)		
Treadle pump	ρ_{31} 0.298***(0.092)	ρ_{32} 0.193(0.270)	
Electric pump	ρ_{41} 0.222* (0.119)	ρ_{42} 0.198(0.184)	ρ_{43} -0.024(0.148)

χ^2 (6) = 27.483; probability > χ^2 = 0.000.

Table 3. Sample households that adopt bucket, treadle pump, electric pump and other irrigation technologies by region.

Technology	Region				Total
	Amhara	Oromia	SNNPR	Tigray	
Bucket	7(7)	14(13)	9(3)	2(2)	32(25)
Treadle pump	5(5)	7(4)	9(7)	0	21(16)
Electric pump	1(1)	23(14)	0(0)	0(0)	24(15)
Other	21(2)	7(3)	0(0)	0(0)	28(5)
Total	34(15)	51(34)	19(10)	2(2)	105(61)

1) Figures in parenthesis shows number households who also adopt motor pump; 2) Other types of technology includes rope and washer, wind mill, solar pumps, etc.

adopt a mix of technologies they assume can maximize their expected utility. While the adoption decision is inherently multivariate, recent studies on technology adoption (Tsefay, 2011; Nata and Bheemalingeswara, 2010; Deressa et al., 2009; Amha, 2006) assume a single technology without addressing the correlation and interdependence between the technologies. When a multitude of technology option exists, like in our case, a household may have equal opportunity, given their financing options, to choose from the set of technologies. In this situation farmers may well consider some combination of technologies as complementarity or competing. Hence, failure to capture such correlation/interdependence is likely to mask the reality that decision-makers face in their adoption decision. Consequently the results will be potentially biased and inefficient leading to underestimate or overestimate the influences of various factors in the adoption decisions.

Therefore, to identify the possible correlation that may exist between the irrigation technologies, we adopt and estimate a multivariate probit (MVP) model, which establishes a positive correlation between motor pumps and the other three (bucket, treadle pump and electric pump) irrigation technologies. This implies that a household's decision to adopt one of these technologies is likely to influence motor pump adoption (Table 2). A likelihood ratio test [χ 2 (6) = 27.48 and probability > χ 2 = 0.000] indicates significant joint correlations between the irrigation technologies under discussion implying the error term in the adoption of motor pumps is not independent of the other irrigation technologies. Both the correlation and likelihood ratio test justify that the estimation of the multivariate as opposed to separate univariate model is appropriate.

Given the very small number of bucket, treadle pump and electric pump adopters (Table 3); it may not be possible to generate illustrative regression results in relation to these technologies. Moreover, information on the adoption of bucket, treadle pump and electric pump is missing from the dataset of some study areas. For example, the data that we have from Tigray is only on motor pumps. Although, unless due to problems attributed to data collection, this does not mean bucket and treadle pumps are not used in the region. Furthermore, electric pumps are only an option in Oromia, where there is a large-scale electric pumped scheme at Lake Zeway. In general, due to practical reasons, our dataset on adoption of irrigation technologies is dominated by motor pumps, hence, even though small in number, treating the households that adopt bucket, treadle pump or electric pump as non-adopters in the analysis is likely to result in data contamination and inefficient results. To control for this potential problem, we omitted the 94 sample households who adopted irrigation technologies other than motor pumps. This left a sample of 706 (212 motor pump adopters and 494 are purely non-adopters) households. The reason the number of omitted sample households is less than the total in Table 3 (that is, 105) is because 11 households adopted more than two technologies and were double counted in the summary.

Since the adoption of motor pumps is not random, a selection bias is still a potential problem, as the adoption of motor pumps can be related to a number of factors (such as: unobserved household characteristics; proximity to water source; access to information and others). In addition, the remaining non-adopter sample households may not properly approximate the adopting sample households to serve as a counterfactual (control group). Hence, comparing adopters with the non-adopters without matching may still result in biased and inconsistent results.

In controlling the potential problem of selection bias, a propensity score matching method was used to identify 'real' comparable (counterfactual) sample households (Cobb-Clark and Crossley, 2003; Heckman et al., 1998; Ravallion, 2005). The basic assumption of using propensity score matching is that the matched non-adopter sample households approximate the adopters if they had not adopted. Given the control variables, this implies that the counterfactual outcome for the adopter group is the same as the observed outcomes for the non-adopting group (Heckman et al., 1998). In some cases, however, matching of adopting and non-adopting households based on observable characteristics may not be feasible, especially when the dimension of control variables is large. To overcome this problem, we employ the propensity score, $p(X)$ method that summarizes the multi-dimensional variables (Rosenbaum and Rubin, 1985). Propensity score is a conditional probability that household i has adopted a motor pump given the conditioning variables, written as:

$$p(x) = pr(MP = 1)|x \qquad (1)$$

Where p (the propensity score) represents the probability of motor pump adoption given unobservable household characteristics (x) and $MP(motor\ pump)$ is equal to 1 for adopters and 0 for non-adopters. For the propensity score to be valid, the balancing properties need to be satisfied, implying that households with the same probability of adoption will be placed in the treated (adopter) and untreated (non-adopter) samples in equal proportions. Once the propensity score (pscore) is estimated, the data is split into equally spaced pscore intervals, implying that within each of these intervals, the mean pscore of each conditioning variable is equal for the adopter and non-adopter (control) households, known as the balancing property (Cobb-Clark and Crossley, 2003).

In line with this, the adopter and non-adopter households were matched based on observable characteristics (such as, household head's gender, off-farm participation, family size, access to credit, access to extension service, social capital in the form of household's membership in farmer associations, household's leadership role, farm size and tenure arrangement). Finaly, we found that out of the 494 non-adopter sample households, 420 of them have satisfied the balancing property implying that they can be used as counterfactuals (control group) in the adoption analysis.

Concern about endogeneity is quite high in the adoption decision, because only households with access to water sources might consider adopting motor pumps. In an effort to account for such structural issue, we used WU-Hausman for the endogeneity test and found insignificant *F-test* coefficients [*F (1,669) =2.330 and P=0.128*], implying that the suspected variable (that is, access to water sources) is not endogenous in the adoption equation.

After identifying counterfactuals (control households) in the adoption analysis and validating that the suspected variable is not endogenous, we employed a binary outcome (probit) adoption model to estimate factors that influence households' adoption of motor pumps using the matched sample households. The probit model assumes that while we only observe the values of 0 for non-adopters and 1 for adopters for the outcome variable (Y), there is a latent unobserved, continuous variable that determines the value of (y^*). The probit model is specified as:

$$\begin{aligned} &y^* = \alpha + \Sigma X_i \beta + \varepsilon, \varepsilon \approx N(0,1) \qquad (2)\\ &If\ \ y^* > 0, \quad Y = 1\\ &if\ \ y^* \le 0, \quad Y = 0 \end{aligned}$$

Where y^* is the outcome variable (adoption of motor pump) equal to 1 if household i adopted motor pump and 0 otherwise. X_i is a vector of values for the ith observation, β is a vector of parameters to be estimated and ε_i is the error term.

Explanation of variables and hypotheses

Following the adoption literature (e.g., Kassie et al., 2012; Pender and Gebremedhin, 2007; Marenya and Barrett, 2007; Bandiera and Rasul, 2006; Lee, 2005), the explanatory variables included in our regression analysis and their hypothesized effect on adoption of motor pumps are discussed below.

Human capital

Household characteristics, such as education, age, family size and gender may affect a households' decision to adopt irrigation technologies. Households with more educated members may have greater access to non-farm income and are able to finance the purchase of irrigation technologies. Furthermore, better educated farmers are likely to be more informed about the benefits of modern technologies and may have a greater ability to translate information and analyse the importance of technologies (Pender and Gebremedhin, 2007; Kassie et al., 2011). On the other hand, educated farmers are able to earn higher returns on their labour and capital if they are used in other activities (Pender and Gebremedhin, 2007).

Similarly, age may capture farming experience and exposure to production technologies implying an ability to respond to unforeseen events/shocks. It may also imply that older farmers have a life time accumulation of physical and social capital suggesting greater respect in their community. On the other hand, age can be associated with loss of energy, short-planning horizons and being risk averse. Thus, the impact of age on technology adoption is ambiguous prior to being empirically tested. It has been argued that women have less access to crucial farm resources (land, labour, and cash) and are generally discriminated in terms of access to external inputs and information (De Groote and N'Golo, 1998; Quisumbing et al., 1995). In Sub-Saharan Africa, there are gender specific constraints, such as women's poorer access to education, land and production assets (Ndiritu et al., 2011). It is obvious that these constraints have direct effects on technology adoption including irrigation technologies where women are usually less likely to adopt. In this paper, gender is specified as dummy variable equal to 1 for male and 0 for female.

Access to market

Access to markets can influence farmers' decision making in various ways, such as availability of technology, the use of output and input markets, and access to information and support organizations, for example, credit institutions (Jansen et al., 2006; Wollni et al., 2010; Pender and Gebremedhin, 2007). It can also increase the amount of labour and/or capital intensity by rising output to input price ratios. The hypothesis here is that the further away a village or farming household is from a market, the less likely it is to adopt new technology.

Physical capital

This variable is represented by livestock ownership and farm size as proxies of household wealth. Wealthier households are better able to bear risk associated with the adoption of motor pumps and to finance purchase of motor pumps. Furthermore, as mixed farming (crop-livestock farming) production system is common practice in the Ethiopian context, livestock may serve as source of manure and draft power. In such a situation irrigated crop production may generate fodder for livestock; hence, the linkage between crop and livestock production systems may encourage adoption of irrigation technologies.

Off-farm participation

Economic incentives play an important role in the adoption of technologies, although their effects may be complex and subtle (Lee, 2005). Household access to alternative sources of employment and return from such activities are likely to influence the adoption of motor pumps, but in different directions. For example, households that have alternative sources of income may have greater capacity to pay and adopt the technologies. On the other hand, off-farm activities may divert time and labour from agricultural activities, reducing investments in irrigation technologies and the availability of labour that can be used in irrigation. In this paper, off-farm participation is defined as equal to 1, if the household has participated in off-farm activity and 0 otherwise. The hypothesized effect of off-farm participation on the adoption of irrigation technologies is, therefore, ambiguous.

Land tenure

A number of studies have demonstrated that security of land ownership has a substantial effect on the agricultural performance of farmers (Besley, 1995; Kassie and Holden, 2007; Deininger et al., 2009). In this paper, tenure security is indicated by land tenure (1=owned by the farmer, 0=otherwise) and we assume that households who produce on their own land have better tenure security and are more likely to invest in irrigation technologies.

Social networks

This represents a combination of variables, such as membership in farmer groups or associations and number of traders that a respondent knows as a proxy of market network. Isham (2007) and Bandiera and Rasul (2006) suggest the positive effects of social networks and personal relationships on technology adoption. With scarce or inadequate information and imperfect market, a social network allows and facilitates the exchange of information, enables farmers to access inputs and overcome credit constraints. Social networks also reduce transaction costs and increase farmers' bargaining power, helping farmers to earn higher returns when marketing their products that can also affect technology adoption (Wollni et al., 2010; Lee, 2005). Farmers who do not have contacts with extension agents may still find out about new technologies from their networks, as they share information and learn from each other. Membership in farmers' groups or associations is therefore hypothesized to be positively associated with adoption of motor pumps.

Biophysical characteristics

Agricultural production in Sub-Saharan Africa is characterized by wide variability of agro-ecological and biophysical factors. We asked our respondents whether they have year round access to surface and shallow groundwater. Two dummy variables (access to ground and surface water) are included in the regression. The assumption is that those households have access to surface and/or ground water are more likely but not certain to adopt motor pumps. Moreover, other biophysical (e.g., rainfall, topography, soil type) and socioeconomic characteristics (e.g., population, production risk) may influence the adoption of water lifting technologies. For example, in the Ethiopian highlands, topography follows a gradient from flat lowlands to mountainous area (Pfeifer et al., 2012). The same report indicates that most of the western Ethiopian highlands are dominated by Nitisols that are stable and relatively less prone to erosion, while the eastern part and highland plateau of the Blue Nile Basin are dominated by leptosols and vertisols, respectively. Leptosols are relatively shallow and prone to erosion while vertisols are low drainage heavy clay soils, implying that topographical and soil characteristics may influence the recharge and availability of groundwater, suitability of irrigation technologies. However, due to lack of site specific biophysical and socio-economic data, we use region dummies to capture unobserved site specific biophysical and socioeconomic differences.

RESULTS

Descriptive results

The definition and summary statistics of variables used in the analysis are presented in Table 4. About 34% of the total matched sample households have adopted motor pumps. In many parts of the Sub-Saharan African countries, male farmers dominate the farming system and technology adoption, which our data also show. Male headed households constitute about 92% of the total sample households and about 97 and 89% of the adopter and non-adopter sample households, respectively.

Table 4. Definition of variables and descriptive statistic.

Dependent variable			Mean		SD		
Adoption of Motor pump (1 = yes, 0 = no)			0.335		0.473		T-test/significance of difference
Independent variables	Total sample households		Non-adopters		Adopters		
	Mean	SD	Mean	SD	Mean	SD	
Household head's gender (1 = male, 0 = female)	0.916	0.277	0.890	0.313	0.967	0.179	0.001***
Household head age (years)	44.323	14.024	45.464	14.043	42.061	13.739	0.004***
Ownership of oxen in tropical units (TLU)	1.212	1.116	1.069	1.049	1.495	1.190	0.000***
Ownership of non-oxen livestock in tropical units (TLU)	2.747	3.006	2.451	2.827	3.333	3.261	0.000***
Adult household member (number)	3.036	1.564	2.983	1.453	3.142	1.763	0.230
Educated household member (number)	2.723	2.096	2.590	2.034	2.986	2.195	0.025**
Access to extension (1 = yes, 0 = otherwise)	0.560	0.497	0.524	0.500	0.632	0.483	0.010**
Access to credit (1 = yes, 0 = otherwise)	0.237	0.426	0.224	0.417	0.264	0.442	0.261
Household has market network (1 = yes, 0 = no)	0.071	0.257	0.057	0.232	0.099	0.299	0.053*
Household membership in farmer association (1 = yes, 0 = otherwise)	0.650	0.477	0.626	0.484	0.698	0.460	0.074*
Farm size (ha)	2.323	1.540	2.184	1.397	2.600	1.761	0.001***
Land tenure (1 = owned, 0 = leased in)	0.992	0.089	0.990	0.097	0.995	0.069	0.520
Availability of surface water (1 = yes, 0=otherwise)	0.381	0.486	0.236	0.425	0.670	0.471	0.000***
Availability of ground water (1 = yes, 0=otherwise)	0.166	0.373	0.100	0.300	0.297	0.458	0.000***
Region dummies							
Amhara (1 = yes, 0 = otherwise)	0.245		0.245		0.245		
Oromia (1 = yes, 0 = otherwise)	0.223		0.240		0.189		
SNNPR (1 = yes, 0 = otherwise)	0.264		0.248		0.297		
Tigray (1 = yes, 0 = otherwise)	0.267		0.267		0.269		

The summary statistics also show that younger farmers are more likely to adopt motor pumps as compared to older farmers. This is consistent with Ahmed et al. (2002) that older farmers are risk averse and usually stick to traditional farming systems. Physical assets (proxied by ownership of livestock) are significantly different from those who own more physical assets being in a better position to finance the purchase of new technologies, especially when credit is a constraint. Farm size as a proxy of physical assets is also significantly higher for adopters as compared to non-adopters. Education and access to extension are positively related to adoption. Finally, the summary statistics reveal that those who have a positive perception about the availability of surface and shallow ground water are more likely to adopt motor pumps. One may argue that these households are located in more favorable settings, so that they have better access to a source of irrigation water leading to a high adoption rate. However, the fact that we use matched sample households in the analysis possibly invalidates such an argument.

Assessment of market prices of motor pumps is an integral part of this study. A motor pump of 3.5 HP[*] that can irrigate about 2 ha costs about US$1,087 (equivalent to 12,500 Ethiopian Birr). Data from the revenue and customs authority of Ethiopia also show that the average cost of a motor pump is estimated at US$565 of which government taxes account for about 37% of the costs[†]. Furthermore, since motor pumps do not stand alone, the cost of accessories and other irrigation infrastructure are important in the motor pump adoption process. Information from our survey suggests that the average cost of motor pump accessories, maintenance and construction of wells is in the order of US$165 (Table 5), which makes the investment more expensive.

Results from the regression analysis

Here, we discuss the results obtained from the probit model. Table 6 presents regression results of the adoption (probit) model. The data suggest that household, socioeconomic and biophysical characteristics all affect households' motor pump adoption decisions. For example, male headed households are more likely to adopt motor pumps as compared to female headed households indicating that female headed households are less likely to benefit from motor pump adoption than male headed households.

The negative association between adoption of motor pumps and age imply that older farmers are less likely to adopt as compared to younger farmers. This can be associated with short planning and risk averse behavior

[*] HP represents horsepower.

[†] The Ethiopian Birr was devalued by about 20% in September 2010, significantly increasing the price of imports, including motor pumps, so that the current price of pumps is likely much higher.

Table 5. Average cost and tax rate of imported water pumps.

Cost Component	Average
Average CIF value of water pump (Birr)	4668
Average tax per unit of water pump (Birr)	1832
Average purchase price/water pump (CIF+Tax) (Birr)	6500
Tax rate	36%

Source: Summarized Based on Data from Ethiopian Customs and Revenue Authority

Table 6. Regression results of the adoption (Probit) model.

Variable description	Coefficient	Robust Std. Err.
Household head's gender (1 = male, 0 = female)	0.664***	0.249
Household head age (years)	-0.015**	0.006
Ownership of oxen in tropical units (TLU)	0.145*	0.080
Ownership of non-oxen livestock in tropical units (TLU)	0.008	0.031
Adult household member (number)	0.051	0.057
Educated household member (number)	-0.024	0.043
Access to extension (1 = yes, 0 = otherwise)	0.319**	0.140
Access to credit (1 = yes, 0 = otherwise)	-0.112	0.187
Household has market network (1 = yes, 0 = no)	0.365	0.262
Household membership in farmer association (1 = yes, 0 = otherwise)	0.292*	0.151
Farm size (ha.)	0.067	0.045
Land tenure (1 = owned, 0 = leased in)	*0.614*	*0.484*
Availability of surface water (1 = yes, 0 = otherwise)	*1.767****	*0.169*
Availability of ground water (1 = yes, 0 = otherwise)	0.936***	0.183
Region dummies (control region is Tigray)		
Amhara (1 = yes, 0 = otherwise)	-1.391***	0.278
Oromia (1 = yes, 0 = otherwise)	-0.918***	0.272
SNNPR (1 = yes, 0 = otherwise)	-0.641***	0.240
Constant	-2.103***	0.591
Number of observation	632	
Log pseudo likelihood	-278.493	
Wald χ^2(17)	155.190	
Prob > chi2	0.000	
Pseudo R^2	0.31	

*, **, *** are levels of significance at 10, 5 and 1%, respectively. Figures in parentheses are robust standard errors.

of older farmers and supports the findings of previous research (Kassie et al., 2012; He et al., 2007). In terms of wealth factors, ownership of oxen is positively related to the adoption of motor pumps, suggesting that wealthier farmers are more likely to take risk as compared to poor farmers. This is consistent with the findings of research carried out in Egypt (Mourshed, 1995), which found that risk causes anxiety towards new innovations and unfamiliar techniques can produce uncertain yields. As a result, farmers with limited incomes or assets are reluctant to adopt unproven/unfamiliar technologies.

Access to extension is also positively related with the adoption of motor pumps as farmers' awareness and skills to efficiently use of the technology is expected to increase. For example, Mourshed (1995) documents that Egyptian small desert farmers adopt drip irrigation after witnessing the success of nearby large farmers. This may hint to the importance of strengthening extension service. This can be achieved, for example, by organizing formal and informal experience-sharing tours and farm 'field-days' to learn from nearby better performing model farmers and from that scaling up best practices in technology adoption.

As expected, farmers' perception about the availability of surface and shallow ground water has both a positive and significant effect (both at 1% level of significance) on the probability of motor pump adoption. This suggests that scientific evidence about the potential of ground/surface availability to increase farmers' confidence and willingness to adopt irrigation technologies is an important factor. Furthermore, the adoption of motor pumps varies by region. This variation is most likely due to region specific socio-economic and biophysical characteristics differences, such as rainfall, topography, erosion, and soil and water conservation. The negative coefficients for Amhara, Oromia and SNNPR dummies for adoption of motor pumps suggest a lower probability of adoption of motor pumps in these regions as compared in Tigray. This probably reflects the effect of unobservable spatial differences (such as rainfall, land degradation and land fertility) as well as the difference in soil/water conservation and watershed management activities between the regions. For example, since the 1970s, there have been intensive and relatively successful soil/water conservation and watershed management activities in Tigray (Woldearegay, 2012), which has led to increased infiltration and groundwater recharge and in turn an increased adoption of household level private irrigation technologies. On the other hand, previous research (Pender et al., 2006; Aiayi, 2007; Kassie et al., 2012) stated that several biophysical and socioeconomic factors have been identified as limiting factors for increasing food production for most smallholder farmers in Sub-Saharan Africa. Furthermore, Kassie et al. (2012) argues that such unfavourable biophysical factors are likely to encourage farmers to adopt production enhancing technologies as a coping mechanism.

DISCUSSION AND CONCLUSIONS

In Ethiopia, agriculture is the main sector that substantially influences economic development, food security and poverty alleviation. The sector is dominated by smallholder farmers. However, low and high variability of rainfall combined with low levels of technology adoption characterize the performance of agriculture. As a result, in a country where there is substantial surface and groundwater potential, farmers are unable to access it to produce enough food. Moreover, information on private smallholder irrigation and the use of smallholder irrigation technologies is not readily available and lacks consistency. Recent studies indicate that the potential for small private motor pump irrigation in Ethiopia is in the order of 1.4 up to 2.8 million ha (Santini et al., 2011) and can benefit between 9 to 18 million smallholder farmers.

Regression results show that there is heterogeneity with regard to the factors that influence the adoption of motor pumps. It underscores the importance of gender; age; ownership of oxen; access to extension; social capital in the form of farmers' membership in farmer associations; access to surface and shallow ground water and region specific socio-economic and biophysical differences. There is a need for more research to identify site specific socio-economic and biophysical factors in the adoption and dissemination of smallholder water lifting technologies and then targeting these technologies where they perform well.

Our results also suggests that the probability of motor pump adoption increases with farmers' participation in farmer associations implying local rural institutions can assist farmers in providing information, credit, experience sharing and market outlets. The positive effect of access to extension on motor pump adoption emphasizes the need to improve the extension system. Finally the adoption of motor pumps is influenced by farmers' gender, age and wealth. The policy implication of this result is that targeting women's groups to address their constraints to actively participate in the adoption of irrigation technologies and rural economic activities in general can have a significant impact on the adoption of smallholder water lifting irrigation technologies and improved livelihoods.

Beyond the regression results, our survey data also show that the cost of motor pumps is high and prices continue to increase. Government taxes account for about 37% of the prices. The cost of accessories and irrigation infrastructures are also quite high for resource poor farmers. The supply of agricultural inputs, fuel and maintenance service is a critical problem. The output market is highly fragmented where informal brokers have un-proportional power to set market prices, usually against the interest of farmers. Frequent mechanical breakdowns are widespread due to farmers' lack of skills, while the supply of spare parts and maintenance services are lacking in the rural areas. Knowledge about environmental risk of motor pump use (that is, risk of groundwater depletion) is seldom. Hence, we suggest that further studies need to understand welfare and environmental implication of motor pump adoption and policies to support the dissemination of motor pumps for smallholder irrigation as a poverty reduction strategy.

Conflict of Interest

The authors have not declared any conflict of interest.

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