OVERALL SEASONAL ENERGY COST ANALYSIS OF SMALLHOLDER PUMPED IRRIGATION SYSTEMS IN THE ARID AND SEMI ARID LANDS OF KENYA

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Abstract

In Kenya, there has been a tremendous increase in the number of smallholder farmers using motorized pumps in their farming operations. The recent increase in uptake of pumps in irrigated agriculture is as a result of need to increase food production to meet the rising demand as well as modernize farming operations and has been met by various challenges. Among the challenges facing adoption of pumps is rising cost of energy particularly fuel used, diminishing energy reserves as well as lack of technical knowledge in selection, design and operation of these pumps. The result has been significant rise in cost of crop production in pumped irrigated agriculture. Combined with other factors such as market competition for agricultural produce and low market prices, the operation costs of smallholder pumped irrigated agriculture has as a result tremendously increased. The aim of this study was therefore to investigate the uptake rate as well as the cost of production due to pumps use in smallholder agriculture. This study was hence carried out in Kakuzi and Yatta divisions both located in the Arid and Semi Arid Lands and 80 smallholder farmers growing various horticultural crops such as French beans (*Phaseolus vulgaris* L), Tomatoes *(Lycopersicon esculentum L)* and Water melons *(citrullus lanatus)* were considered. Face to face questionnaire as well as observational study was used to gather information. Detailed analysis of 10 pumps used in 10 sample farms was done to evaluate pumps working efficiency, fuel consumption rate and pumps water discharge under different operating conditions. This analysis helped in computing the overall seasonal energy cost of pumped irrigation. The study found out that despite the increase in cost of production as a result of pumping, farmers still adopted it with 80% of the studied population engaged in it. It emerged that high cost of fuel was the most limiting factor for 65% of the sampled population practicing pumped irrigation. Results indicated a big variation in fuel used to irrigate a unit piece of land from one farm setup to the other. In some farms growing similar crops, mean fuel (petrol) amount used to irrigate 1 hectare of land was in excess of 60L while in others, fuel used was as low as 5L. The overall seasonal energy cost in nearly all the farms investigated was over 50% of the total cost of production. The high value for overall seasonal energy cost could be attributed to several factors such as pump operating efficiency, fuel consumption rate and farm operating conditions (elevation, water conveyance distance and time of irrigation).

Key words: Energy use, pump performance, pumped irrigation, overall seasonal energy, cost (OSEC), Kenya

Introduction

1.1 Trend in Energy Use in Agriculture

Energy has been a key input of agriculture for many decades when subsistence agriculture has been practised. It is an established fact worldwide that agricultural production is positively correlated with energy input (Singh, 1999). Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energy, such as seed, manure and animate energy, as well as commercial energies, directly and indirectly, in the form of diesel or petrol, electricity, fertilizer, plant protection, chemical, irrigation water, machinery etc. Efficient use of these energies helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living (Singh *et al.*, 2002). Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land and a desire for higher standards of living (Kizilaslan, 2009). It is predicted that fossil fuels will be the primary source of energy for the next several decades (Demirbas, 2003, Dincer, 2001).

1.2 Challenges due to Energy Use in Agriculture

Rising energy prices will alter water allocation and distribution. Water extraction and conveyance will become more costly and demand for water pumping will grow as the prices of fuel continue to rise (Schoengold *et al.*, 2008). Past studies done by Amin *et al.,* (2010) showed that almost half of the total cost of production of Soya beans resulted from energy use. Nowadays, agricultural sector for providing more food needed by the population increase like other sectors has depended on energy sources like electricity and fossil fuels (Hatirli *et al.*, 2005).

More intensive energy use has further brought some important human health and environment problems so efficient use of inputs has become important in terms of sustainable agricultural production (Yilmaz *et al.*, 2005). Recently, environmental problems resulting from energy production, conversion and utilization increased public awareness in all sectors of the public, industry and government in both developed and developing countries. Apart from the rise in energy prices in the recent decades (Gay, 1994), improperly designed systems as reported by Smajstrla *et al*., 1993, design based on minimum investment costs without prior thought on operation costs over many years (FAO, 1992) are some of the challenges limiting smallholder pumped irrigation systems. Low irrigation efficiency (Ogombe*,* 2000) and Lack of appropriate skills in irrigation system selection, design and operation (Kay *et al.*, 1992) limit pumped irrigation systems. When water is pumped, every liter of fuel used has a real cost due to energy needed. More/less water pumped results to inefficient irrigation hence rise in operating costs.

1.3 Solutions to these Problems

Efficient use of resources is one of the major assets of eco-efficient and sustainable production in agriculture (De Jonge, 2004). Energy use is one of the key indicators for developing more sustainable agricultural practices (Streimikiene *et al.*, 2007) and efficient use of energy is one of the principal requirements for this sustainable agriculture (Kizilaslan, 2009). It is important, therefore, to analyze cropping systems in energy terms and to evaluate alternative solutions (Sartori *et al.*, 2005). Agriculture, a typically resilient sector, has been hard hit disproportionately by the recent energy price increases due to energy's relatively high share of costs and the inability of the farmers to pass along these costs. Energy use, previously thought of as a fixed cost, is now beginning to be viewed as a controllable cost through demand – side energy efficiency and onsite and renewable energy production. Energy efficiency is the streamlining of energy use and cost while maximizing productivity (Sartori *et al.*, 2005). Energy cost is the cost of providing fuel to the irrigation system. In some cases, it can be the most important of the operating costs, and needs to be considered most carefully at the design stage (FAO, 1992).

Nowadays, under the context of climate change and the ascending trend of the energy price, it is necessary to develop methodologies, tools, and actions that try to optimize the use of energy resources for environmental and economic benefits. Although irrigation does not require as much energy as the industry or urban activities, energy costs are one of the main inputs for irrigators. In addition, irrigation is one of the sectors of agriculture, which is increasing its energy consumption as a consequence of the modernization of irrigation water-distribution systems (Abadia *et al*., 2008). Several works have been published on the performance analysis of irrigation systems that present methodologies, models, and study cases that help to improve the water and energy efficiency of irrigation systems (Khadra *et al.,* 2006; Lamaddalena *et al.,* 2007a, b; Calejo *et al.,* 2008; Abadia *et al*., 2008).

1.4 Energy Use in the Kenyan Context

In the Kenyan context, modern irrigation development has been on the increase, particularly the smallholder irrigated agriculture. The tremendous increase in the area under irrigation in the period 1985-2005 as shown in Table 1 could be attributed to the attention given to this sector by the government and the donors (Mbatia, 2006).

Category	**Developed (Ha)**		
	1985	**1998**	**2005**
Smallholder public Schemes	17,500	34,650	47,000
National Schemes	11,500	12,000	16,000
Private Irrigation	23,000	40,000	42,800
Total	**52,000**	**87,350**	**105,800**

Source: Mbatia, 2006

Current estimates indicate that Kenya has a potential for irrigation of 540 000 ha (Republic of Kenya, 2003). About 106 600 ha have been put under irrigation, comprising 20% of the potentially irrigable area. Large commercial farms cultivate 40.5% of irrigated land; government-managed schemes cover 15.1%, while smallholder individual and group schemes take up 44.4% of irrigated land (Republic of Kenya, 2006). Recent studies in the arid and semi arid areas of Kenya indicated a tremendous increase in pumped irrigated agriculture (Kang'au *et al.,* 2011) hence an increase in energy use.

The objectives of this study was hence to evaluate the uptake rate of pumped irrigated smallholder agriculture as well as study the energy costs as a result of fuel use and other pump operating conditions.

Materials and Method

The research was carried out in in Kithimani sub location of Yatta division and Mitubiri location of Kakuzi division as shown in figure 1. Kakuzi division is approximately 5 km and 52 km from Thika and Nairobi town respectively while Yatta division is 45 km and 81 km from Thika town and Nairobi town respectively. Kakuzi and Yatta division are on the north east and eastern direction from Nairobi town respectively. The agricultural activities in the study areas were studied into detail as well as the socio-economic activities of the residents. Detailed analysis of pumping system was done.

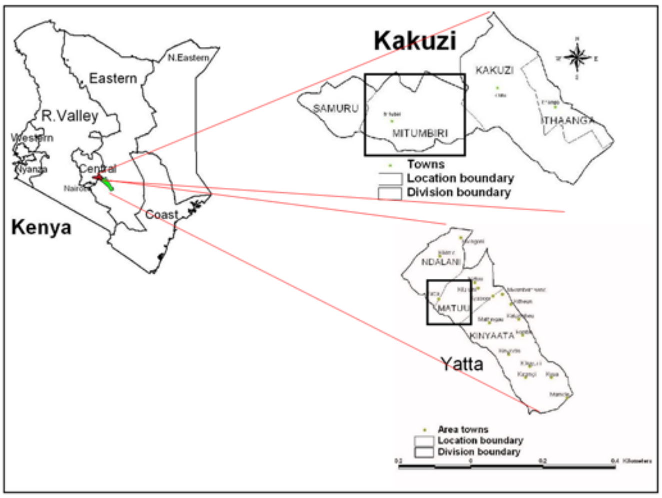

Figure 1: Location maps of Kakuzi and Yatta division with area towns and location boundaries

The population density of Yatta division ranges from 152 Persons/km^2 (Frederick *et al*., 2000) while that of Kakuzi division is approximately 71,622 persons and covers an area of about 481.2 Km^2 hence the population density is approximately 149 persons/Km^2 (Robinson *et al*., 2005).

The available water sources in Yatta division are the Yatta furrow with its intake in Thika River at Mavoloni area. Yatta furrow plays a significant role in water supply to the residents of this area who practice both subsistence and horticultural farming for both local and export market. Its envisaged coverage was 60 kilometers but it covers an area of approximately 40 kilometers from the intake point due to water losses and misuse. The available water sources in Kakuzi division ranges from rivers, streams, springs and shallow wells. River Thika and Kabuku are the main water sources for the division since they are permanent while river Samuru is seasonal and highly polluted. Other springs such as Kasioni spring in Ithanga location is widely used by the residents.

Rainfall patterns in parts of Eastern province exhibits distinct bimodal distribution. The first rains fall between mid-March and end of May and are locally known as the long rains (LR). The second rains, the short rains (SR), are received between mid October and end of December. Average seasonal rainfall is between 250-400 mm. Inter-seasonal rainfall variation is large with a coefficient of variation ranging between 45-58 per cent. Temperature ranges between 17^{o}C and 24^{0}C. Evapo-transpiration rates are high and exceed the amount of rainfall most of the year except the month of November (Fredrick *et al*., 2000). Kakuzi division rainfall distribution is bimodal with high peaks from March to May (long rains), and October to December (short rains). Annual rainfall varies from about 800 mm at an altitude of about 1525m above sea level (ASL). The temperatures are high at the lower altitudes ranging from 25°C to 30°C but reduce to between 18°C and 20°C towards the higher altitudes of 3500m ASL. Mean annual evaporation which is 1485mm and 1625mm in Kakuzi and Yatta division respectively exceeds the rainfall (MOALD, 1998). Irrigated agriculture dominates the two areas due to unreliability of the rainfall. Few farmers practice subsistence agriculture during the short rain period and later on switch to irrigation. Only those farmers near the water sources benefit greatly as they practice supplemental irrigation to their crops. Pump fed agriculture is widely practiced by the residents in the two study areas.

2.1 Collection of Technical and Socio-Economic Data

Transect walks in 80 farms in two study sites helped gather all the socio-economic as well as the technical data. This data was obtained through observational study and focused discussions with the farming communities. Questionnaires were used to gather socio-economic data of the farming community (agricultural information including crops grown, water sources, soil types) as well as technical data such as irrigation methods used (water abstraction, conveyance and application technologies) and irrigation equipments used such as pumps, pipes, hosepipes and other fittings. Methods used in selecting these irrigation equipments was also gathered through the questionnaire. The questionnaire also gathered information on the costs incurred during irrigation of horticultural crops as well as the knowledge gap in selection, design and running of the irrigation systems. A total of 80 farmers were interviewed, 50 in Kakuzi and 30 in Yatta Division.

2.2 Detailed Study

To evaluate the overall seasonal energy cost, detailed study of the pumping units used in the study area was done. A total of 10 pumps of different make and model as highlighted in Table 2 were used in the study. OSEC was computed through evaluation of different parameters such as pump operating efficiency, fuel consumption rate of the pump, water discharged and total dynamic head, pump parameters such as fuel efficiency, pump unit efficiency and transmission efficiency.

Farm Setup	Pump model	Pump make	Horse power	Suction diameter (mm)	Discharge diameter (mm)	Maximum suction head (m)	Total Head (m)	Optimal Speed (RPM)
F1	BX30	Honda	5.5	75	75	8.0	28	3600
F2	No data	Mitsubishi	5.5	75	75	8.0		4000
F4	DP3C-4	ETQ178F	6.6	75	75	14.5	25	3600
F3	PTG205	Robin	5.5	63	63	8.0	32	3600
F5	PTG205	Robin	5.5	63	63	8.0	32	3600
F9	No data	Koshin	4.0	50	50	6.0		3600
F8	No data	Koshin	4.0	50	50	6.0		3600
F7	SCR-80HX	Honda	5.5	75	75	8.0	32	3600
F10	No data	Koshin	4.0	50	50	7.0		3600
F6	SCR-80HX	Honda	5.5	75	75	8.0	32	3600

2.2.1 Pump Working Efficiency

Pump efficiencies were calculated based on method described by (Kang'au et al., 2011) by first evaluating the pump specific speed from equation 2.1. The pump speed was measured using a hand held tachometer at different levels of acceleration while the discharge at specific head were measured using a bucket and a quickset level respectively. The data was obtained over the irrigation period of different crops and mean values calculated.

$$N_s\ (_{USgpm,\ ft}) = 0.861N\left[\frac{Q^{0.5}}{H^{0.75}}\right] \quad \text{……………………………………………………………………….2.1}$$

where

NS – Pump specific speed (RPM)

N – Pump speed (RPM)

Q- Discharge (L/min)

H – Total dynamic head (m)

The operating efficiency of the pump as a function of specific speed was then read off from the nomograph (Igor et al, 2007) shown in figure 2. This procedure was carried out for 10 different pumps used in 10 sample farms during irrigation. Tests were carried out every time irrigation was carried out for a two crop growing season.

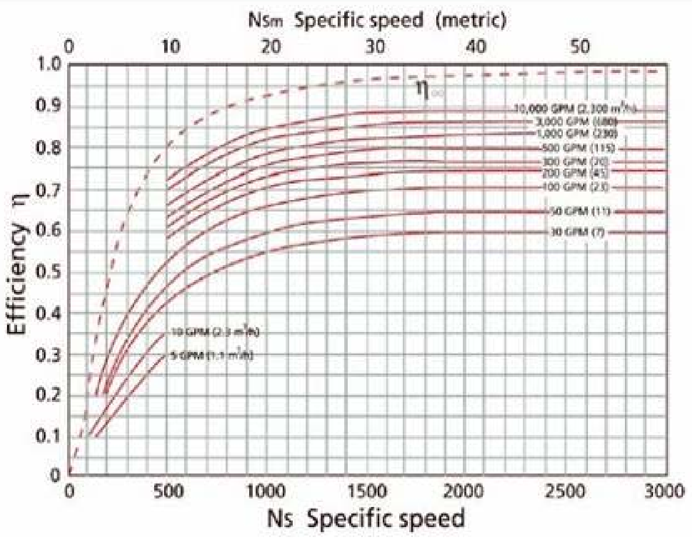

Figure 2: Efficiency values for pumps with different specific speeds

Source (Kang'au et al., 2011)

2.2.2 Fuel Use Efficiency

Fuel consumption rate for each of the 10 pumps used during irrigation was measured at different pump running speeds measured using a hand held tachometer at different levels of acceleration while a transparent measuring Pitot tube gauge with calibrations on the sides was connected to the pump carburetor where the fuel decrease as the pump was being run was read off. This was repeated for several times during pump operation and at different pump running speeds and mean values thereafter computed. This is shown in photo 1.

Photo 1: Measurement of fuel consumption rate of the pump

2.2.3 Overall Seasonal Energy Cost Analysis of Pumped Irrigation Systems

2.2.3.1 Fuel Use and Cost

Mean pump fuel use during irrigation was evaluated for the 10 different pumps used in different irrigation periods. This was further converted to the costs incurred during irrigation. The cost of fuel was obtained from the fuel dealers in the nearest towns where most farmers purchase it.

2.2.3.2 Overall Seasonal Energy Costs

The overall seasonal energy cost was calculated from the overall seasonal energy demand, the fuel consumption of the pump, and the cost of fuel using equation 2.2 (FAO, 1992).

$$OSEC(Ksh) = OSED(Kwh) * F_U C(L/Kwh) * CF(Ksh) \qquad \text{..................................2.2}$$

where

OSEC (Ksh) – Overall seasonal energy cost in Kenya shillings
OSED (Kwh) – Overall seasonal energy demand in kilowatt hour
$F_U C$ (L/Kwh) – Fuel consumption in Litres per kilowatt hour
CF (Ksh) – Cost of fuel in Kenya shillings.

OSED was computed from equation 2.3

$$OSED(Kwh) = \frac{Q * H}{367 * PPE} \qquad \text{..................................2.3}$$

where

Q - Volume of water pumped (m^3)
H – Total dynamic head (m)
PPE – Pumping plant efficiency (computed from equation 2.4).

$$PPE(\%) = FE * PUE * TE * PE * 100 \qquad \text{..................................2.4}$$

where

FE – Fuel efficiency
PUE–Pump unit efficiency
TE- Transmission efficiency
PE – Pump efficiency.

The fuel efficiency value used was 95% while the power unit efficiency for petrol pumps which is 10% and that of diesel engines which varies from15-35 % hence an average value of 25% was used in computations, (FAO,1992). Evaluation of fuel consumption was based on 0.09L = 1 Kwh for diesel and 0.11 L = 1 Kwh for petrol (FAO, 1992). Since the pumps considered were driven through direct coupling to the engine, the transmission efficiency was hence 100%. The pump efficiency was directly determined in the field as described in equation 2.1.

Three different crops grown such as French beans, Watermelons and Tomatoes were put into consideration during computation of OSEC. Evaluation of the gross margin analysis was done from data obtained through administration of the questionnaire. The difference of total sales and all the variable costs involved in crop production aided in computing the revenue generated from the farming operations. This analysis aided in computation of the total cost of production. The evaluation was done for a two crop growing season.

2.3 Data Management and Statistical Analysis

Each measured parameter was carried out in triplicate and repeated over the entire cropping season with two seasons considered and were reported as average values (mean ± standard deviation). Data obtained from the questionnaire were analyzed using SPSS pc + (SPSS Inc., 1993).

Results and Discussion

3.1 Technical and Socio-Economic Results

3.1.1 Agricultural Activities in the Study Area

From the preliminary survey done in the two study areas, smallholder farming dominated the agricultural sector with majority of the farmers practicing irrigated horticultural farming. Most of the horticultural crops are grown for both local and export market. The basic information of the agricultural practices from the two districts as obtained from the two representative locations is presented in Table 3. The two study locations i.e. Mitubiri location and Kithimani sub location are in Thika and Yatta districts respectively. From table 3, horticultural crops dominated the two study sites owing to the favorable climatic conditions, rich water bodies close to irrigated lands and soil types. Subsistence farming is also carried out in the two areas particularly during the rain periods. Mitubiri location is served by a network of rivers used by farmers to irrigate their horticultural crops while the Yatta furrow with its main intake from River Thika is the main source of water for farmers in Mitubiri sub location.

	Mitubiri location	**Kithimani sub location**
Crops grown	Water melons, French beans, Baby corns, Vegetables, Bananas, Tomatoes, Mangoes and Subsistence crops (maize, beans, potatoes).	Water melons, French beans, Baby corns, Vegetables, Bananas, Tomatoes, Mangoes and Subsistence crops (maize, beans, cassava).
Main water sources	River Thika, Kabuku, Samuru, seasonal streams and springs	Yatta furrow and river Thika
Soil types	Sandy clay, Sandy loam, Loam.	Sandy clay, Sandy loam, Loam

Climatic conditions	Arid and semi arid zone with low rainfall, high temperatures and high evaporation rates.	Arid and semi arid zone with low rainfall, high temperatures and high evaporation rates.

The crops commonly irrigated in the two study areas are shown in Table 4.

Area	**French Beans**	**Tomatoes**	**Water melon**	**Baby corns**	**Cabbages**	**Onions**	**Kales**
Mitubiri location	18	10	4	5	6	3	4
Kithimani sub Location	7	7	4	6	3	1	2

French beans were irrigated by majority of smallholder farmers in the two study areas. The second crop in popularity was Tomatoes. Both French beans and Tomatoes played an important economic role in the agricultural sector of the two areas. Over 90% of French beans produced are exported while Tomatoes are sold particularly in the local markets and generally in large town centers. Due to the high demand of these two products, farmers have intensified their production through irrigation.

3.1.2 Irrigation Practices in the Two Study Areas

The percentage of the farmers using different water application methods in the study area are shown in figure 3. From the findings, it was found out that very few farmers were using modern technologies of water application in the study area such as sprinklers and drip irrigation systems. This would be due to lack of advice on appropriate technologies available or financial limitations to obtain modern equipments for irrigation. Lack of technical knowhow could also be another factor leading to lack of use of these technologies.

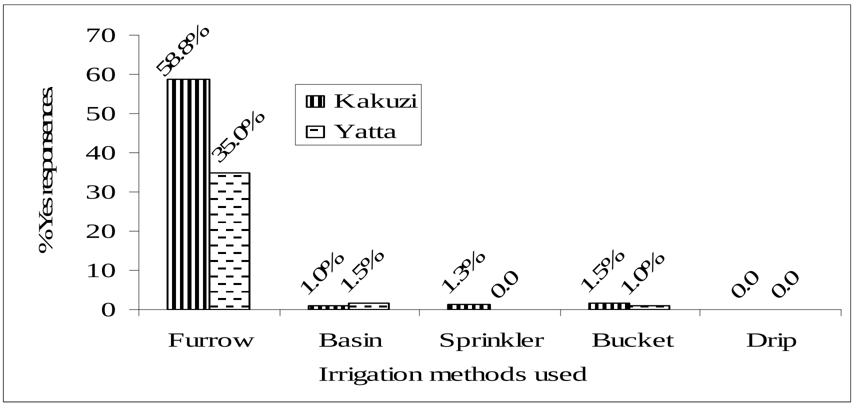

Figure 3: Smallholder irrigation methods used in the study sites

Few farmers used sprinkler irrigation in their farms while majority continued to rely on furrow irrigation methods which apparently have very low water use efficiency (Hayrettin et al., 2008). The result of low water use efficiency for pumped irrigation systems means more pumping time leading to excessive water loss and subsequent fuel use. Applying right amount of water during irrigation leads to less pumping time with reduced fuel use and labour cost. In the study area, different on farm irrigation set ups were being used (Table 5). 78.8% of the sampled farmers used motorized pumps to pump water to their farms and conveyed it through pipes and then applied it directly in the furrows or basins. The result shows that simple irrigation setups were being used by the farmers which they could probably understand and afford.

On farm irrigation set up	No. of respondents	Percentage
A) Pump-pipes-sprinklers	1	1.3
B) Pump-pipes – hosepipe – furrow	52	65
C) Pump – pipe –sub canal - furrow	8	10
D) Pipe- sub canal – furrow	15	18.7
E) Bucket	2	2.5
F) Pump – pipe – hosepipe – basin	2	2.5
Total	**80**	**100%**

3.2 Knowledge Gaps in Selection, Design and Operation of Irrigation Equipments

Figure 4 shows different sources of information on where to purchase the pumping equipments for the smallholder farmers in the study areas. 60% of the farmers get information on where to purchase the pumping equipments from other farmers who have experience in using them.

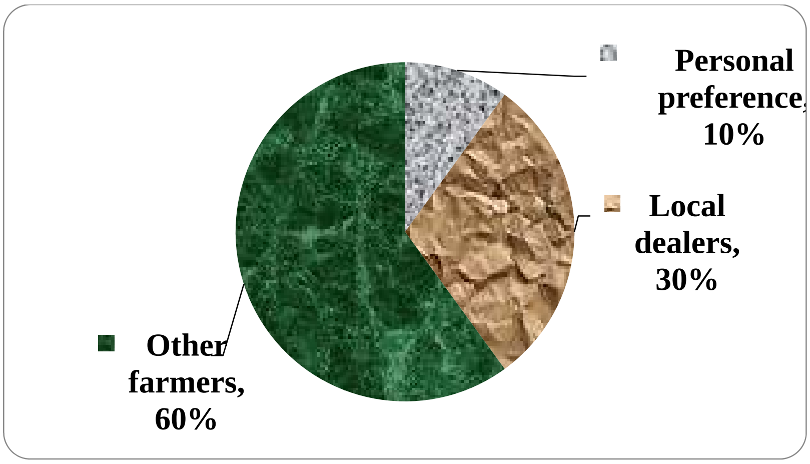

Figure 4: Source of information in purchasing irrigation equipment

A small proportion of the farming community bought irrigation materials of their choice probably with an influence from other external forces or their own tastes and preferences.

Further information revealed that the farmers depended on past experiences in dealing with irrigation equipments and that no information was provided by irrigation personnel's or engineers in the two areas. This therefore indicates that there was no engineering approach that was adopted in selection, design and operation of the irrigation equipments. It was also found that the local dealers who sell the irrigation equipments provided information on the best equipments they thought were suitable for use. The problem of lack of proper selection of irrigation equipments hence poor design was further cited by FAO (1992). Past studies showed that the results of poor irrigation components selection and lack of engineering approach in design resulted to poor system performance and reduced irrigation lifespan (Gay, 1994). Poorly designed irrigation systems results to inefficient energy use and as a result render the system uneconomical.

3.3 Technical and Economic Evaluation of Smallholder Pumped Irrigation Systems

3.3.1 The Pumps used in the 10 Farms

Different types, makes and models of pumps were found in the two study areas and the 10 pumps that were studied into detail are shown in table 2. All the pumps used in the 10 farms were small motorized centrifugal pumps run by petrol and ranging from 4.0 to 6.6 horsepower. The total head for the different pumps ranged from 25 to 32m while the discharge rate varied from 520 to 1100 L/min. The pumps inlet and outlet diameters ranged from 1.5 to 3 inches for different pumps considered. All the pumps had varied fuel consumption rate.

Table 6 shows the measured as well as calculated values that aided in computation of the pump efficiency values used in computing the OSEC values.

Table 6: Calculated values

Measured Parameter	**Farm**									
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
Total dynamic head (m)	6.3	10.3	6.4	5.2	11.0	24.3	21.9	13.8	9.8	9.4
Polyvinyl chloride (PVC) Pipe size (mm)	37.5	37.5	37.5	75	63	37.5	63	37.5	37.5	50
Pipe flow rate Q, (L/s)	3	5.7	2	5	2.2	2.7	2.7	0.6	1.85	1.80
Pump operating speed (RPM)	2300	2500	2150	2400	2100	2200	2250	2000	2050	2100
Pump efficiency (%)	62	65	57	66	60	56	55	30	50	48

The field data obtained as shown in table 6 and using equation 2.1 aided in computation of pump operating efficiency. The results of pumps operating efficiencies are shown in figure 5. All the 10 pumps had different optimal operating efficiency.

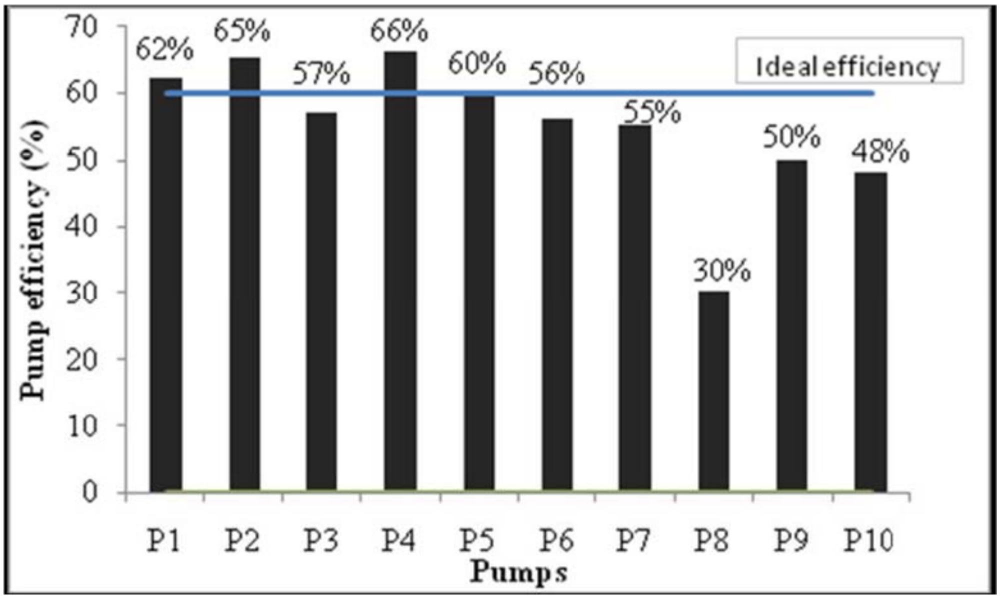

Figure 5: Pump efficiency for 10 pumps used by smallholder farmers

3.3.2 Fuel Use Efficiency

The running speed of the pump was found to have a big influence on fuel use. Figures 6 and 7 shows the fuel use versus running speed of 10 pumps considered.

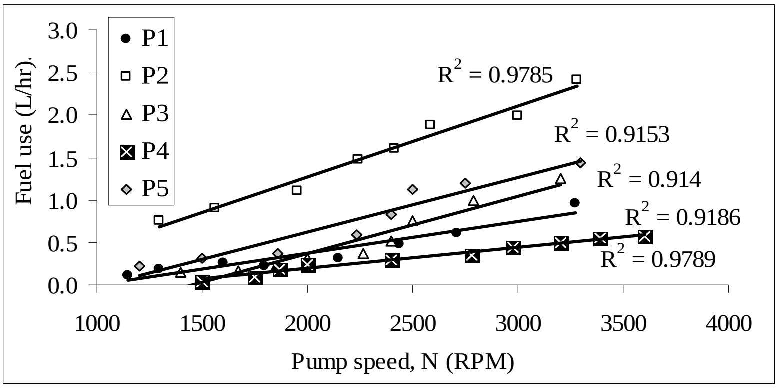

Figure 6: Fuel use versus pump speed for different pumps in Kithimani sub location

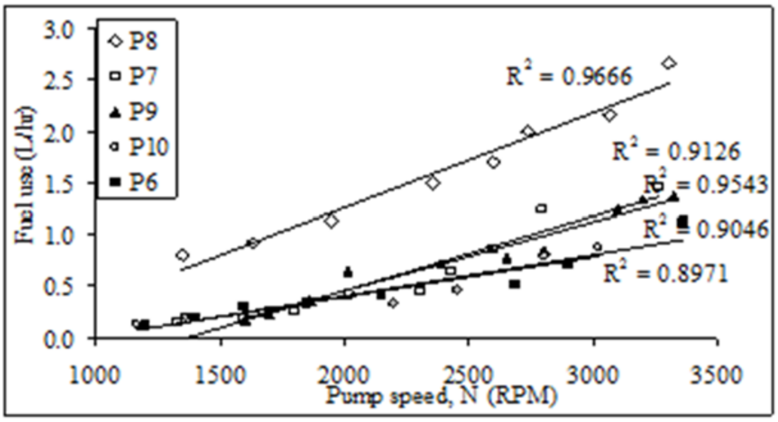

Figure 7: Fuel use versus pump speed for different pumps in Mitubiri location

The 10 different pumps showed different fuel consumption rate that increased with increase in pump speed. A regression analysis indicated that the fuel consumption rate of the pumps depended on the pump running speed. The relation is actually linear with R2 for the pumps lying between 0.89 to 0.98. A slight change in pump running speed greatly results to increased fuel consumption rates of the pumps. Increase in pump speed significantly leads to increase in fuel use while water discharge rate is increased. As a result, by increasing the discharge rate, irrigation time is shortened. Farmers should operate their pumps at a speed that results to considerable fuel use while discharging manageable water.

3.3.3 Fuel Use and Cost

Figure 8 shows the mean fuel used in litres per hectare for the 10 farms assessed using different pumps with different fuel consumption rates while Table 7 classifies the fuel use range for the different farm setups.

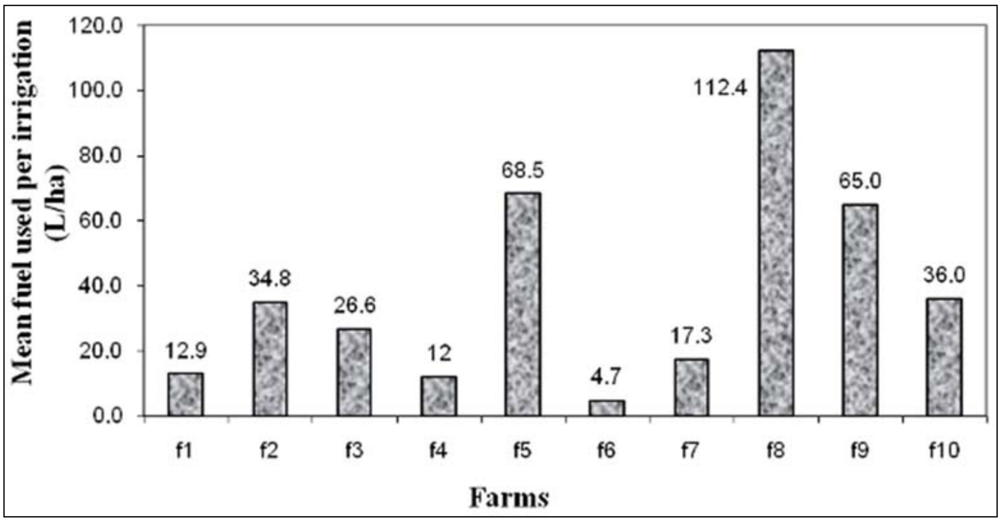

Figure 8: Mean fuel used per irrigation (L/ha) in the 10 farms

Table 7: Quantity of fuel used during irrigation

Mean fuel use Range per irrigation (L/ha)	Farm irrigation setup
<5	F6
10-20	F1,F4,F7
20-40	F2,F3,F10
>60	F5,F8,F9

The 10 farm set ups showed wide variation in the amount of fuel used per each irrigation session per hectare of land. It was found that the amount of water applied varied from one application session to the other as well as from one farm to the other. Only one farm irrigation setup used less than 5 litres to irrigate 1 hectare of land while 3 setups used between 10 to 20 litres and a further 3 setups used greater than 60 litres during irrigation. This shows a wide variation in fuel used in irrigating the 10 different farms and the possible causes of this variation could be due to use of different makes and models of the pumps with differences in fuel consumption rates, different sizes of pipes and fittings used, farm orientation (elevation, length) and irrigators knowledge on the amount of water to apply as well as the irrigation time. The differences could result to some farms operating at a loss or on marginal profit while others having more returns on investment. Proper pump selection and matching it to the field condition would be necessary if its performance is to be optimized. Frequent repair and maintenance as well as routine checkups of the pumps devices and irrigation equipments used would ensure reduced operating costs as well as higher returns on investments. Figure 9 shows the cost incurred in irrigating the 10 farm setups as a result of fuel use. The costs of fuel was obtained from the current market prices (year 2009 estimates) where 1 litre of petrol and diesel were sold at 75 Ksh and 69 Ksh respectively.

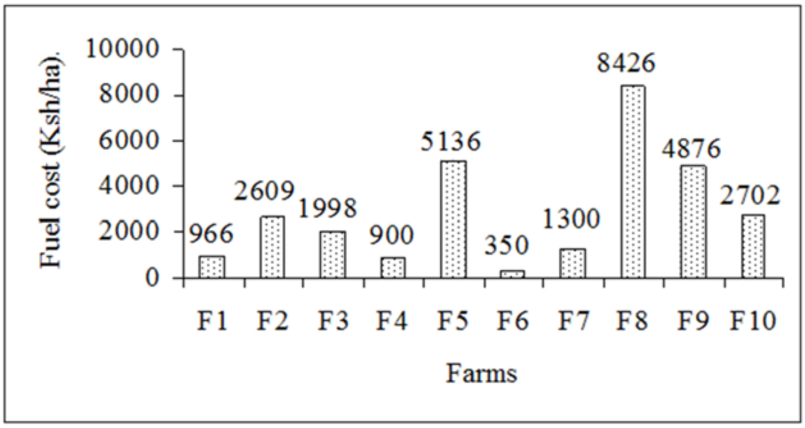

Figure 9: Fuel cost per irrigation (Ksh/ha)

3.3.4 Evaluation of Overall Seasonal Energy Cost

The mean OSEC for the three crops were calculated and the values for the OSEC versus total cost of production (TCP) are shown in Table 8 as well as the ratio of OSEC to TCP.

Table 8: Comparison of OSEC to TCP in percent

	1st season			**2nd season**		
Crop	**OSEC (Ksh/ha)**	**TCP (Ksh/ha)**	**OSEC to TCP (%)**	**OSEC (Ksh/ha)**	**TCP (Ksh/ha)**	**OSEC to TCP (%)**
French beans	175,000	258,820	68	131,336	215,305.20	61
Water melons	94,796.70	166,310	57	89,521.50	172,157	52
Tomatoes	318,881.30	708,625	45	254,004.50	498,048	51

OSEC (Ksh/ha) = Overall Seasonal Energy Cost in Kenya shillings per hectare

TCP (Ksh/ha) = Total cost of Production in Kenya shillings per hectare

From table 7, over half of the total cost of production was found to result from energy used for pumping water during irrigation. OSEC is a function of different factors combined such as pump operating efficiency, fuel consumption rate of the pump, cost of fuel, volume of water pumped during irrigation, total dynamic head, transmission efficiency and power unit efficiency. Other factors such as irrigation timing and right amount of water applied which depends on irrigators knowledge also affects the OSEC. In order to reduce the overall seasonal energy cost for any farming enterprise, all the above factors must be ensured to operate at optimal range. Reduced overall seasonal energy cost would subsequently result to increased net benefit of the farming enterprise.

Conclusion and Recommendation

Overall seasonal energy cost was found to immensely contribute to the total cost of production in smallholder pumped irrigation systems. It was found out that approximately 50% of the total cost of production resulted due to the OSEC as a result of water pumping. Several factors that led to high values of OSECwere highlighted and some of them are lack of technical assistance during selection, design and operation of the irrigation components and improperly matched systems to the farm conditions. Traditional methods of water application and high cost of fuel also aggravates the situation. The values of OSEC can significantly be lowered through a multidisciplinary approach such as proper selection and matching of the pumping equipments to match the field conditions, operating the pumps at recommended efficiency levels, irrigation timing to monitor water use and frequent monitoring and evaluation to check on system performance. Improved modern irrigation methods can also result to lowered OSEC values. Due to the ever increasing cost of fuel, alternative methods of water pumping can be developed that would be appropriate for smallholder pumped irrigation systems. The need to design and develop pumps with low power matching different field conditions and reduced fuel consumption needs not be over emphasized.

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