

# 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 an increase in the number of smallholder farmers using motorized pumps in their irrigation activities. Increased fuel costs have led to significant rise in cost of crop production in irrigated agriculture. Combined with other factors such as demand and supply, market price variation, the operation costs have hence gone up. The aim of this study was therefore to investigate the uptake rate of smallholder pumped irrigated agriculture as well as evaluate cost of production as a result of fuel use. The study was carried out in Arid and Semi Arid areas and data was collected from 80 smallholder farmers through face to face questionnaire and observational study. 10 pumps used in 10 different sample farms were considered in analysis. 80% of the studied population used motorized pumps indicating a high uptake rate. 65% of the sample population cited that high cost of fuel was the most limiting factor in smallholder irrigated agriculture. There was high variation in amount of fuel used to irrigate 1 hectare of land in the studied farms. In nearly all the farms investigated, over 50% of the total cost of production resulted from fuel used to run the pumps.

**Keywords** — Energy use, Pump performance, Pumped irrigation, overall seasonal energy cost, Kenya.

## 1.0 Introduction

In Kenya, 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 is shown in Table 1 and could be attributed to the attention given to this sector by the government and the donors (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). Smallholder irrigated agriculture produces the bulk of local horticultural produce consumed in Kenya, as well as some export crops, and a substantial amount of dairy products. In the medium and high rainfall areas, supplementary irrigation based on surface flows has been instrumental in increasing productivity of high-value crops (Herdijk *et al.*, 1990; Mati, 2002).

In Kenya, only 2% of the area is equipped with irrigation infrastructures as compared to the 20% of the potential irrigable land, (Republic of Kenya, 2006). The role irrigation can play in agricultural development, by increasing yield, crop quality, development of semi-arid areas and water saving has long been recognized. This is especially so in the development of rural areas in a semi-arid country such as Kenya. Besides, Kenya has a significant export oriented horticulture industry where crop quality is essential. The need for irrigation technologies in agricultural production is hence apparent (Kulecho and Weatherhead, 2006).

High uptake of pumped irrigated agriculture in Kenya has been noted in the recent past with most farmers opting to increase food production through irrigation. This is particularly being practiced where rainfall is unreliable (Kang'au *et al.*, 2011). The high uptake of water pumping for irrigation hence calls for energy use to operate the pumps and as a result lead to increased cost of pumping. To ensure increased food production, the agricultural sector is now depending heavily on energy sources such as electricity and fossil fuels (Hatirli *et al.*, 2005). 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, 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). The need for increased food production, limited supply of arable land and a desire for higher standards of living have resulted to increased use of energy in agriculture (Kizilaslan, 2009).

However, more intensive energy use has 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. It is predicted that fossil fuels will be the primary source of energy for the next decades (Demirbas, 2003; Dincer, 2001). 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 principle requirements of sustainable agricultural practices (Kizilaslan, 2009).

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.

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).

It is due to the above findings that a study was commenced to study the energy uses for smallholder pumped irrigated agriculture and its related cost implications.

## *1.1 Study area*

### **1.1.1 Location of the study area**

Two study areas with most smallholder farmers practising pumped irrigated agriculture were chosen. These are Kakuzi and Yatta divisions. Kakuzi division is located in Thika district of central province while Yatta division is located in Yatta district of Eastern province. Kakuzi division lies between longitudes of 36° 40'W, 37° 21'E and latitudes - 1°20' N,-1°15'S while Yatta division lies between longitudes of - 0.8°W,-1.27°E and latitudes of 36.66°N, 37.10°S. 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. Figure 1 shows the location of the study area.

### **1.1.2 Population density**

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

### **1.1.3 Water sources**

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 farming as well as 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.

#### **1.1.4 Climatic conditions**

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 17-24<sup>0</sup>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<sup>0</sup>C to 30<sup>0</sup>C but reduce to between 18<sup>0</sup>C and 20<sup>0</sup>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).

#### **1.1.5 Agricultural activities**

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.

### **2.0 Materials and Method**

The research was carried out in two study sites i.e. Kithimani sub location of Yatta division and Mitubiri location of Kakuzi division. 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.

#### *2.1 Collection of technical and socio-economic data*

Transect walks in the two study sites identified the agricultural activities of the farming community, the irrigation methods used as well as the socio-economic status of the people. Questionnaires were used to gather socio-economic data in the study areas. The questionnaire detailed the socio-economic status of the people, crops irrigated by the farming community, technical information such as irrigation methods used (water abstraction technologies, conveyance and application methods), irrigation equipments used i.e. pumps, pipes, hosepipes and other fittings. Selection of these irrigation equipments was also gathered through the questionnaire. The costs incurred during irrigation of horticultural crops were also identified through the questionnaire. The knowledge gap in selection, design and running of the irrigation systems was also identified. A total of 80 farmers were interviewed, 50 in Kakuzi and 30 in Yatta division.

#### *2.2 Detailed study*

Detailed study of the pumping units used in the study area was done. The make and model of 10 pumps was highlighted and detailed evaluation of their efficiency and fuel use during pumping was done. Overall seasonal energy cost was computed.

### 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 and 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.

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

where

$N_s$  – 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, 2007). 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.

### 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 by connecting a transparent measuring Pitot tube gauge with calibrations on the sides 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.

### 2.2.3 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).

The cost of fuel was determined from the local market dealers at the time of project implementation.

$$OSEC(Ksh) = OSED(Kwh) * F_u C(L/Kwh) * CF(Ksh) \dots\dots\dots 2.2$$

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.

OSD was computed from equation 22.3

where

Q – Volume of water pumped (m<sup>3</sup>)

H – Total dynamic head (m)

PPE – Pumping plant efficiency (computed from equation 2.3).

$$PPE (\%) = FE * PUE * TE * PE * 100 \dots\dots\dots 2.3$$

where

FE – Fuel efficiency

PUE– Pump unit efficiency

TE – Transmission efficiency

PE – Pump efficiency.

The values for fuel efficiency varies from 90 -100% hence an average value of 95 % was used while the power unit efficiency for petrol pumps is 10% and for diesel engines it is 15-35 %, (FAO,1992). Therefore an average value of 25% was used for the diesel pumps.

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 i.e. French beans, Watermelons and Tomatoes were put into consideration during computation of overall seasonal energy cost (OSEC). The questionnaire administered aided in collection of appropriate data used to evaluate the gross margin analysis leading to evaluation of total cost of production. This 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 and for the 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).

## 3.0 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 2. The two study locations i.e. Mitubiri location and Kithimani sub location are in Thika and Yatta districts respectively. From table 2, 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. The crops commonly irrigated in the two study areas are shown in Table 3.

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 is exported while Tomatoes is 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 methods of irrigation in the study area are shown in figure 2. From the findings, it was found out that very few farmers used modern irrigation technologies in the study area. This would be due to lack of advice on appropriate technologies available or financial limitations to obtain modern equipments for irrigation.

From the findings, it was concluded that there was low adoption of modern irrigation technologies by farmers. Few farmers used sprinkler irrigation in their farms while majority continued to rely on furrow irrigation method which apparently has 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 4). A large percentage of the sampled farmers pumped water using small motorized pumps and conveyed it through pipes and then applied it directly in the furrows. The result shows that simple irrigation setups were being used by the farmers which they could probably understand and afford.

### *3.2 Knowledge gaps in selection, design and operation of irrigation equipments*

Figure 3 shows different sources of information on where to purchase the irrigation equipments for the smallholder farmers in the study areas. 60% of the farmers get information on where to purchase the irrigation equipments from other farmers who have experience in using them.

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 were further cited by Kay *et al.*, (1992) and 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 5. 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 L/min to 1100L/min. The pumps had varied inlet and outlet diameters ranging from 1.5 inches to 3 inches respectively. All the pumps had varied fuel consumption rate.

The field measured pumps operating efficiencies are shown in figure 4. All the 10 pumps had different optimal operating efficiency.

### **3.3.2 Fuel use efficiency**

The running speed of the pump was found to have a big influence on fuel use. Figures 5 and 6 shows the fuel use versus running speed of 10 pumps considered.

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  $R^2$  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 results 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 7 shows the mean fuel used in litres per hectare for the 10 farms assessed using different pumps with different fuel consumption rates while Table 6 classifies the fuel use range for the different farm setups.

The 10 farm set ups showed wide variation in the amount of fuel used per irrigation for 1 hectare of land. Only one farm irrigation setup used less than 5 litres per hectare during irrigation while 3 setups used between 10 to 20 litres and a further 3 setups used greater than 60 litres per hectare during irrigation. This shows a wide variation in fuel use 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 perception on the amount of water to apply and 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 8 shows the cost incurred in irrigating the

### **3.3.4 Evaluation of overall seasonal energy cost (OSEC)**

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 7 as well as the ratio of OSEC to TCP.

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.

#### **4.0 Conclusion And Recommendation**

Energy uses during pumping 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 results from energy uses during water pumping. Several factors that led to high energy uses were 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 irrigation methods and high cost of fuel also aggravates the situation. Energy use efficiency can be improved 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 energy use efficiency. 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 and reduced fuel consumption needs not be over emphasized.

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#### **References**

- Abadia, R., Rocamora, C., Ruiz, A., and Puerto, H. (2008), *Energy efficiency in irrigation distribution networks I: theory*. Biosyst Eng **101**:21–27.
- Calejo M. J., Lamaddalena, N., Teixeira, J., L., and Pereira, L., S. (2008), *Performance analysis of pressurized irrigation systems operating on demand using flow-driven simulation modeling*, J Agric Water Management **95**:154–162.
- Davis, and Shirtliff. (2001), *Product manual, Technical reference* Nairobi.
- Demirbas, A. (2003), ‘Energy and environmental issues relating to greenhouse gas emissions in Turkey’, *Energy Conversion and Management journal*, **44**: pp.203-213.
- De Jonge, A., M. (2004), ‘Eco-efficiency improvement of a crop protection product: the perspective of the crop protection industry’. *Crop protect*, **23**(12): pp.1177-1186.
- Dincer, I. (2001), ‘Environmental issues: I-energy utilization’, *Energy utilization, Energy source*, **23**: pp. 69-81.
- Food and Agriculture Organisation, FAO, (1992), Small-scale pumped irrigation: energy and cost. *FAO manual* prepared by Kay M and Hatcho., N., Rome.

Frederick, M., K., Lutta, M., and Samuel, M., W. (2000), *Market survey report on market opportunities for fruits and vegetables processing in ukambani, eastern Kenya*.

Gay, B. (1994), *Irrigation Privée et Petites Motopompes au Burkina Faso et au Niger*. Paris:Groupe de Recherches et d'Echanges Techniques.

Hatirli, S., A., B., Ozkan, U., and Fert, C. (2005), 'An econometric analysis of energy input-output in Turkish agriculture', *Renewable and sustainable Energy Reviews*, **9**, pp. 608-623

Hayrettin, K., Filiz, E., B., and Ali, O., D. (2008), 'Performance assessment for irrigation water management: A case study in the Karacabey irrigation scheme in Turkey', *African Journal of Agricultural Research*, [e-journal] **4** (2), pp. 124-132, [Accessed February 2009] Available online at <http://www.academicjournals.org/AJAR>.

Herdijk, A., Diemer, G., Kimani, J., Mukolwe, M., and Thairu, M. (1990), *Evaluation of Small-Scale Irrigation Development Projects: Smallholder Irrigation: A Large Challenge*. Ministry of Agriculture, Irrigation and Drainage Branch: Nairobi, Kenya; Ministry of Development Cooperation: Netherlands.

Igor, K., M., Joseph, C., Paul, and Charles, H. (2007), *The pump handbook*, McGraw-Hill. 4ed.

Kang'au, S., N., Home., P., and Gathenya, M., (2011), Evaluation of the Performance of Smallholder Pumped Irrigation Systems, in Arid and Semi-arid Areas of Kenya. Agricultural Engineering International: *CIGR Journal*, Vol.13, No. **4**, 2011. Manuscript No. 1665.

Kay, M., & Hatcho, N., (1992), *Small scale pumped irrigation*, Food and Agricultural Organization of United Nations, Rome.

Kizilaslan, H. (2009), 'Input –output energy analysis of cherries production in Tokat Province of Turkey'. *Journal of Applied Energy*, **86**: pp.1354 – 1358.

Khadra, R., Lamaddalena, N. (2006), A simulation model to generate the demand hydrograph in large scale irrigation systems, *Biosyst Eng J* **93** (3):335–346

Kulecho, I., K., and Weatherhead, K. (2006), *Issues of irrigation of horticultural crops by smallholder farmers in Kenya*, Springer Science Business Media B.V. 2006. Irrigation Drainage System.

Lamaddalena, N., and Pereira, L., S. (2007), Assessing the impact of flow regulators with a pressure-driven performance analysis model. *Journal Agric Water Management* **90**:27–35

Mati, B., M. (2002), *Use of geographic information systems for planning and management of small-holder irrigation and drainage*. In *The Changing Face of Irrigation in Kenya: Opportunities for Anticipating Change in Eastern and Southern Africa*, Blank HG, Mutero C M, Murray-Rust H (eds) International Water Management Institute (IWMI): Nairobi; 75–91.

Mbatia, E., D. (2006), *Irrigation sector in Kenya- status and challenges*, Nairobi, Kenya

Ministry of Agriculture and Livestock Development, (MOALD), (1998), Annual Report for Agricultural activities, Thika and Machakos District, Kenya

Ogombe, I., J., O. (2000), *Potential and actual irrigated agriculture in Kenya: Implication for investment strategy*. Paper presented during panel discussions on investment opportunities and challenges in irrigated agriculture for National and household food security, 17 July, 2000 at Grand Regency Hotel, Nairobi.

Republic of Kenya (2003), *Irrigation and Drainage Department, Ministry of Water Resources Management and Development*, Nairobi, Kenya

Republic of Kenya (2006), *Strategy for revitalizing agriculture 2004–2014 Ministry of Agriculture and Ministry of Livestock and Fisheries Development*, Nairobi, Kenya. [http://www.iwmi.cgiar.org/Publications/Working\\_Papers/working/WOR102.pdf](http://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR102.pdf)

Robinson, K., Thomas, M., and Catherine, N. (2005), *Implementation of the national population policy for sustainable development*, published by National Coordination Agency for Population and Development

Singh, G. (1999), Relationship between mechanization and productivity in various parts of India. In: India, *XXXIV Annual Convention, Indian society of Agricultural Engineers, CCSHAU, Hisar*, pp: 16-18.

Singh, H., D., Mishra, D., Nahar, N., M. (2002), ‘Energy use pattern in production agriculture of typical village in arid zone, India –part’ *Energy Convers Manage*, 43(22) pp. 75-86.

Smajstrla, A., G., F., S., Zazueta., F., S., D., Z., and Haman, D., Z. (1993), *Potential impacts of improper irrigation system design. Florida Cooperative Extension Service*, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL. Fact Sheet AE-73.

SPSS Inc. (1993), *Handbooks SPSS for Windows*, Release 6.0. Advanced Statistics, 578 pp., Professional Statistics, 385 pp

Streimikiene, D., Klevas, V., and Bubeliene, J. (2007), ‘Use of EU structural funds for sustainable energy development in new EU member states’, *Renew Sustain Energy Rev.*, 116 (11) pp.67-87.

Yilmaz, I., H. Akcaoz, B., and Ozkan. (2005), ‘An analysis of energy use and input costs for cotton production in Turkey’, *Journal of Renewable energy*, 30: pp.145-155.

#### List of tables

**Table 1: Irrigation development in Kenya (1985 – 2005)**

| Category            | Developed (ha) |        |        |
|---------------------|----------------|--------|--------|
|                     | 1985           | 1998   | 2005   |
| Smallholder Schemes | 17,500         | 34,650 | 47,000 |

|                    |               |               |                |
|--------------------|---------------|---------------|----------------|
| National Schemes   | 11,500        | 12,000        | 16,000         |
| Private Irrigation | 23,000        | 40,000        | 42,800         |
| <b>Total</b>       | <b>52,000</b> | <b>87,350</b> | <b>105,800</b> |

Source: Mbatia, 2006.

**Table 2: Agricultural related site specific findings in the two study areas**

|                     | 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.                                      |

**Table 3: Percentage of smallholder farmers irrigating different crops in Mitubiri and Kithimani areas**

| 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     |

**Table 4: On farm irrigation setups used by smallholder farmers**

| 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         |
| <b>Total</b>                       | <b>80</b>          | <b>100%</b> |

**Table 5: Pumps specifications**

| 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 |

*Source (Davis and Shirliff, 2001)*

**Table 6: Quantity of fuel used during irrigation**

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

**Table 7: Comparison of OSEC to TCP in percent**

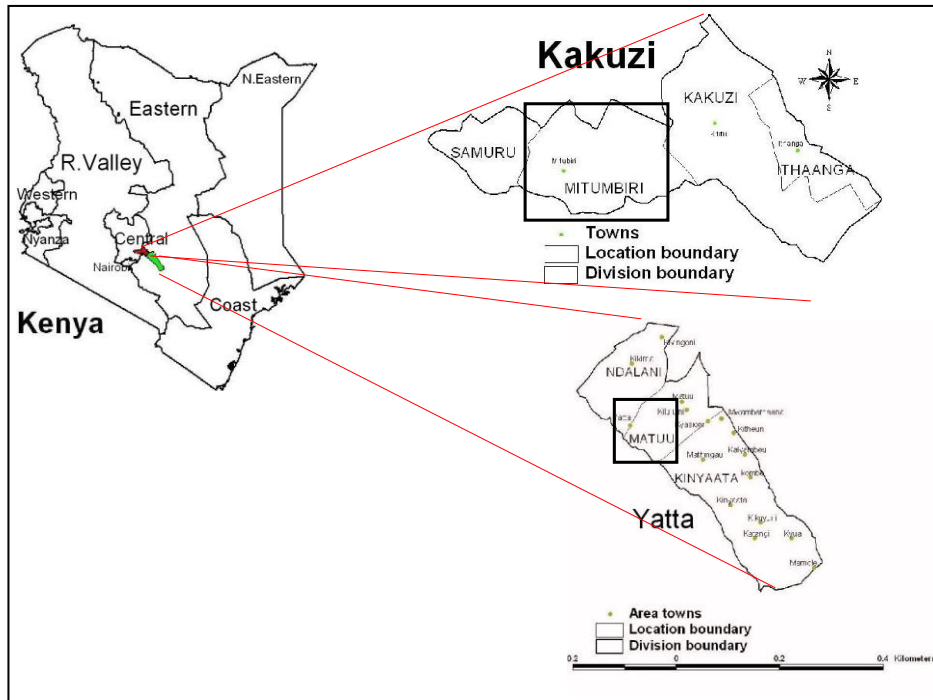
| Crop         | 1 <sup>st</sup> season |              |                 | 2 <sup>nd</sup> season |              |                 |
|--------------|------------------------|--------------|-----------------|------------------------|--------------|-----------------|
|              | OSEC (Ksh/ha)          | 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

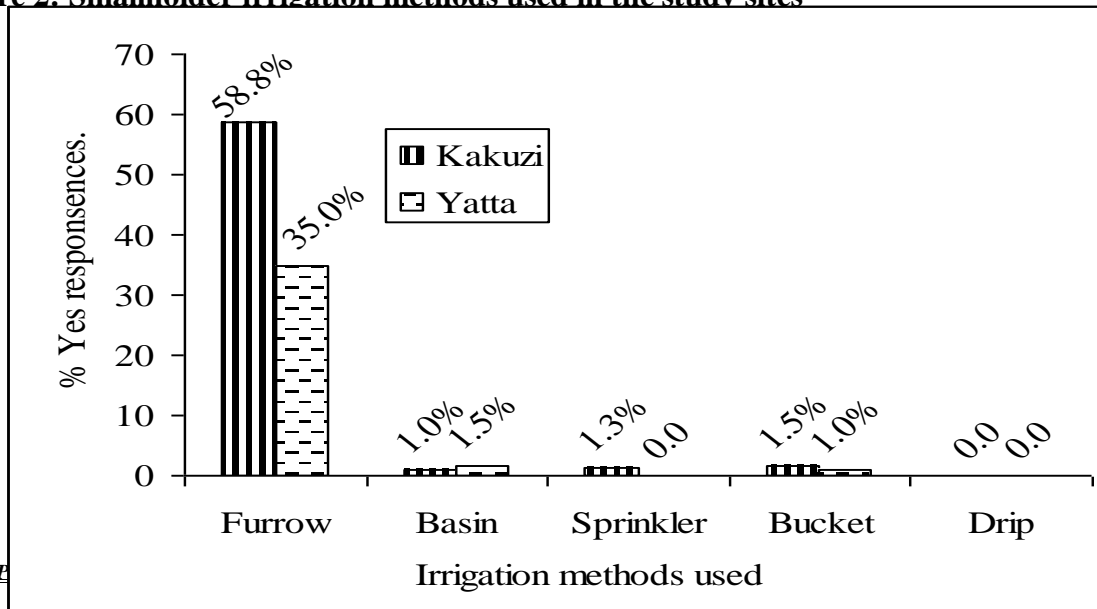
TCP(Ksh/ha) = Total cost of Production in Kenya shillings per hectare

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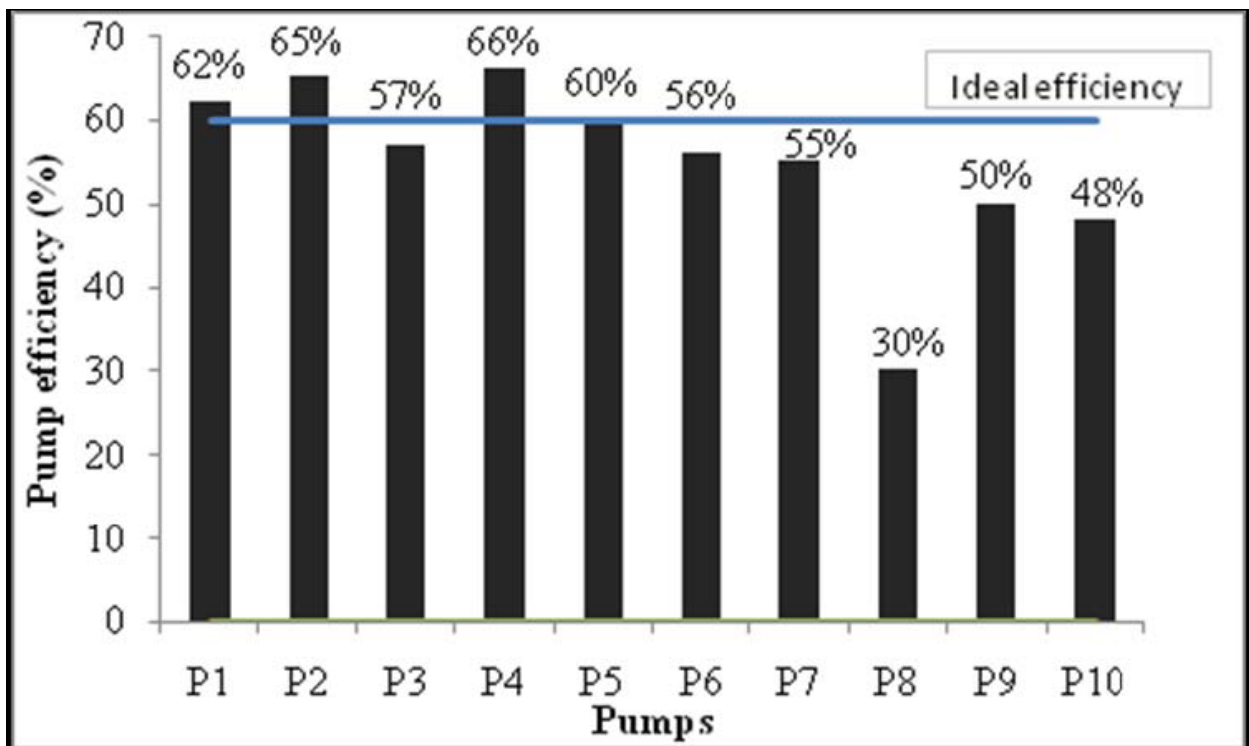
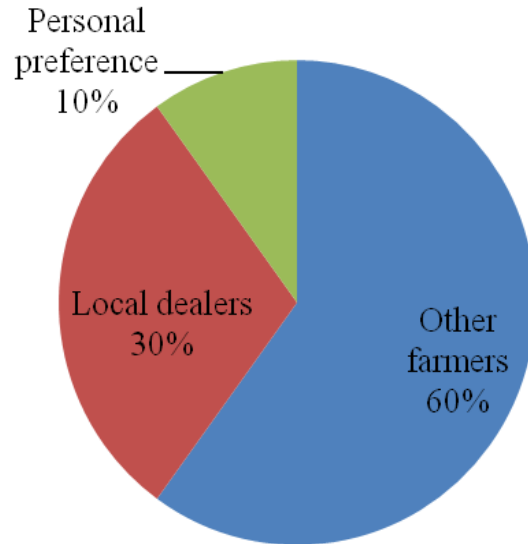
**Figure 1: Location maps of Kakuzi and Yatta division with area towns and location boundaries**



**Figure 2: Smallholder irrigation methods used in the study sites**



**Figure 3: Source of information in purchasing irrigation equipment**



**Figure 4: Pump efficiency for 10 pumps used by smallholder farmers**

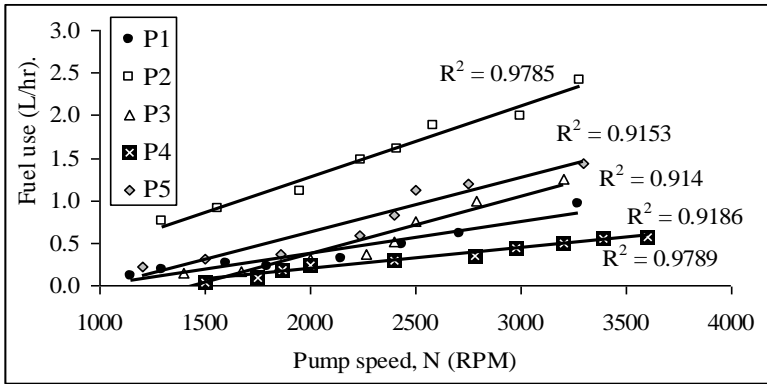


Figure 5: R<sup>2</sup> for Pumps 1-5

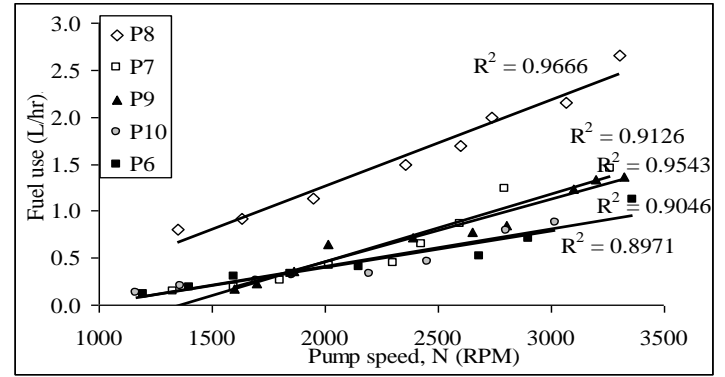
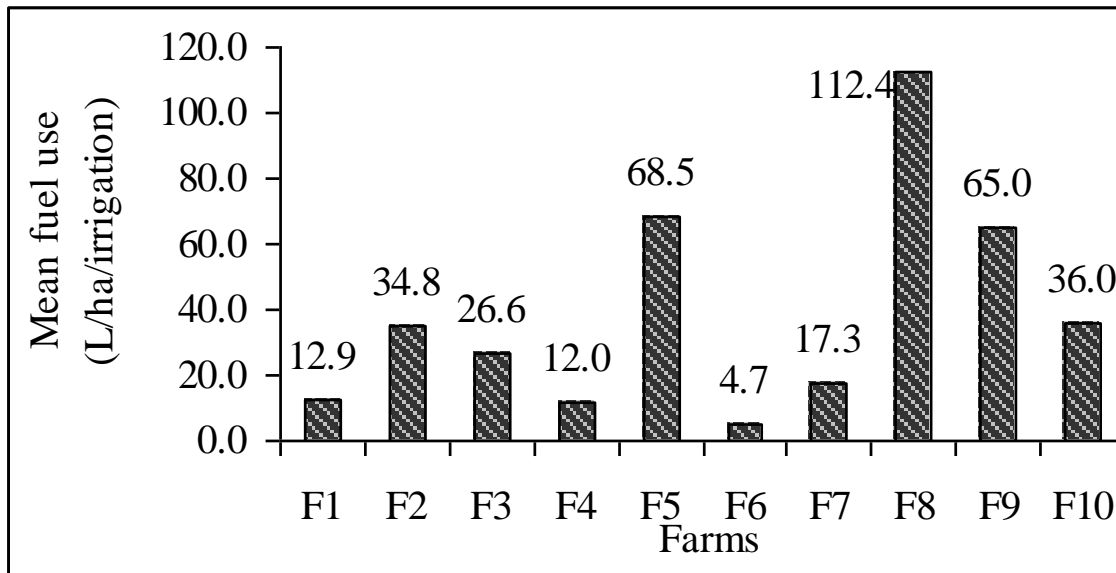


Figure 6: R<sup>2</sup> for Pumps 6-10

Figure 7: Mean fuel used per irrigation (L/ha) in the 10 farms



Based on 1 litre petrol @ Ksh 75 and 1 litre diesel @ Ksh 69 (Year 2009 estimates)

Figure 8: Fuel cost per irrigation (Ksh/ha)

