

# Effects of Smallholders' on-Farm Water Application Methods on Tomato Yields in Baringo County, Kenya

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## Abstract

*Baringo County experiences frequent rainfall failures, resulting in crop failures. This requires requisite on-farm water management. This study examined the effects of various water application methods on tomato, *Solanum lycopersicum*, yields of small-scale farmers in Baringo County. The study employed a descriptive survey design to collect data from target population of 672 households living within 10km of Marigat Town. Gross margins were highest in motor pump, followed by manual pump, gravity, and lastly, in rain fed; suggesting that all forms of irrigation were more profitable than rain fed agriculture in the farming of tomatoes. Semi log functions revealed that lift, gravity, seeds, DAP, CAN, and labour had a significant and positive effects (at  $p < .05$ ) on tomato yields. The results suggested that the best on-farm water application regime was the lift system hence adoption of appropriate irrigation systems by farmers in areas with plentiful supply of water.*

**Keywords:** Tomato, irrigation, rain-fed, yield, Baringo.

## INTRODUCTION

The importance of agriculture to Kenya cannot be gained, as it accounts for 65 per cent of Kenya's total exports and supports, directly or indirectly, the livelihoods of 80% percent of the Kenyan population, which live in rural areas (Government of Kenya [GoK], 2015). Kenya has two agricultural production systems: rain-fed and irrigated agriculture (GoK, 2010). Whereas Kenya's agriculture is mainly rain-fed (only a trivial 1.8% of the country's cropland is under irrigation), only 12% of Kenya's land area, receiving 800 – 2700 mm annual rainfall, is suitable for arable rain-fed farming (FAO, 2009; GoK, 2015). More than 80% of the country's land area is semi-arid and arid (ASAL) with an annual rainfall average of 400 mm and a moisture index of less than 50%, making rain-fed agriculture unsuitable (GoK, 2015).

Tomato is one of the most highly consumed vegetable in Kenya, being grown for fresh market, processing and export. Tomatoes are excellent sources of antioxidants, dietary fibre, minerals, vitamins A and C, and potassium. However, growth of this crop in ASALs, such as Baringo County, is hampered by often unreliable and low precipitation. Water stress is considered one of the most important factor limiting tomato growth and yield (Zilberman *et al.*, 2008).

One strategy to enable growing of tomatoes in the country's marginal and sub-marginal lands is to use irrigation, and thus, weaning the crop from rain-dependency. Studies have shown that irrigation increases yield of most crops by between 100 and 400 per cent and it is expected that, over the next 30 years, 70% of the grain production will be sourced from irrigated land in the world (FAO, 2009). However, although irrigated agriculture offers opportunities for all-year round farming compared with rain-fed agriculture, it also has

several potential drawbacks. Energy is required in the extraction and conveyance of water in irrigation systems compared with rain-fed agriculture, making water in the former system to be more expensive (Zilberman *et al.*, 2008). Secondly, the water used in irrigation may originate from an external source, such as a municipal council, which implies that it has first to be bought before it can be distributed on the farm. Thirdly, irrigation water might be insufficient or simply unavailable, especially, for water deficient countries, such as, Kenya (GoK, 2015). An enduring debate has therefore ensued on whether irrigation should be expanded or whether irrigation water is too expensive and therefore, priority should be given to rain-fed agriculture which could potentially assist more people using the limited resources available (Zilberman *et al.*, 2008).

Kenya practices three major modes of irrigation: large-scale irrigation schemes, smallholder irrigation and agro-industrial irrigation (Miruri *et al.*, 2011). The former involves mammoth schemes, constructed, operated and maintained by the government in which smallholder farmers play a minor role in management and are tied to the government for inputs and marketing of crops. Smallholder irrigation are usually run by individuals or by small groups, which exploit water in streams or small rivers to irrigate small lands to produce crops for domestic consumption or local market. On the other hand, private corporations, such as flower farms, usually run agro-industrial irrigation that produce high-value crops for export (Miruri & Wanjohi, 2017). Most large-scale irrigation schemes divert water from rivers and supply to crops, mostly through surface furrows. Agro-industrial irrigation usually rely on pump- based technologies in combination with drip and sprinkler irrigation. Smallholder irrigation farmers have been found to be more versatile, using simple buckets, motorized pumps, manually operated treadle pumps, low head drip irrigation and sprinklers, to deliver water to their crops (GoK, 2015; Miruri & Wanjohi, 2017; Valipour, 2015; Malano & Burton, 2011). Gravity (surface or flood) irrigation systems deliver water to the farm by force of gravity. The system is the oldest and most prevalent, largely because of its low energy requirement compared to alternatives. However, it is considered as wasteful and inefficient, may cause waterlogging, deep drainage, and salinization (Owen, 2018; O'Mahony *et al.*, 2016). Researchers, for instance, Dittoh *et al.* (2013), Namara *et al.* (2011) have argued that small-scale private pump irrigation could act as promising investment alternatives to the large-scale formalised irrigation schemes. The pumps could use human energy (manual) or petroleum/electricity (motor) pumps to convey water to the farm. The use of pumps provide farmers with the highest level of water control, irrigating at the time of their choosing all year round, provided there is a permanent water source. Rainfed farmers have the lowest control, being at the mercy of the weather whereas the level of water control by gravity flow irrigators may be moderate and low (Owusu, 2016; Valipour, 2015).

Baringo County, a partially ASAL located in the Rift Valley Region of Kenya, practices all the major forms of on-farm water application methods: rain-fed, gravity, manual and motor pump (lift) systems. The county hosts the Perkerra Irrigation Scheme, set up in 1954, with a maximum cultivable area of 810 ha. The Perkerra River was dammed creating a reservoir that provides a gravity furrow irrigation system to farmers contracted by the National Irrigation Board (Keitany *et al.*, 2016; GOK, 2015). In highland areas within the county that receive adequate rainfall, a combination of both rain fed and irrigation agriculture is observed, with farmers growing some crops using rain fall and others using irrigation. On the other hand, lift (manual and motor pumps) irrigation agriculture is more dispersed in the county, clustered along and around water sources which may have been developed with support from either the government or NGOs (GoK, 2015). In the county, rain-fed system is used to grow perennial crops such as mangoes and bananas and early maturing annuals, for

instance, maize, sorghum, millet and beans. On the other hand, irrigation is used to grow maize and high-value horticultural crops such as tomatoes, onions, various vegetables and fruits (Miruri & Wanjohi, 2017; Karina & Mwaniki, 2011).

Studies suggest that different on-farm water management regimens such as the practice of rain-fed agriculture, gravity flow irrigation or the use of small pump irrigation could have differential effects on crop yields (Karina & Mwaniki, 2011; Origa, 2011). In addition to water, tomato yields depend on the quantity and quality of other inputs, such as land, water, labour, fertilizers, chemicals, and seeds utilized (Nimoh *et al.*, 2012; Gani and Omonona, 2009). A paucity of studies in Kenya have analysed the effects of on-farm water management methods together with other inputs (land, labour, fertilizers, chemicals and seeds) on the yield of tomato under natural settings (Miruri & Wanjohi, 2017; Origa, 2011; Karina & Mwaniki, 2011). The objectives of this study were: (1) To describe the on-farm water application methods used by tomato farmers in Baringo County and (2) To estimate the effects of the on-farm water application methods employed by farmers in Baringo County on tomato yields.

## **MATERIALS AND METHODS**

The study was conducted in Baringo County, located approximately 100km north of Nakuru Town, in the Rift Valley Region of Kenya. The study area lies between Latitudes 00 degrees 13" South and 1 degree 40" north and Longitudes 35 degrees 36" and 36" degrees 30" east. Baringo County is arid and semi-arid, receiving low to average annual rainfall, ranging from 600mm in lowlands to 1500mm in the highlands. About 46.3% of the land in the county cannot support meaningful crop production as it is too steep or consists of very dry plains. The study sampled farmers living around Marigat Town, where irrigation is intensively practiced.

This study employed a descriptive survey design, which enabled it to obtain requisite information from a large segment of small-scale maize farmers over a short period. The target population was 672 tomato farmers living within 10 km of Marigat Town and practicing various on-farm water application methods of irrigation and rain-fed farming. The specific villages used were Kimalel, Koriema Perkerra and Marigat trading centre. This study collected data from 180 farmers, according to the formula and correction for sampling from small population outlined in Noordzij *et al.* (2010). Stratified random sampling was used to select the 180 respondents. To ensure a proportionate representation of all the farming systems in the study, the sample contributed by each farming system was weighted according to farming systems' target population. A sampling frame of all the accessible farmers in the three study villages was obtained from County Agricultural Officer's office and used to select farmers for the study using simple random sampling, which was accomplished with the help of a table of random numbers.

Field study was conducted between the months of May and June of 2017. Data was collected using structured questionnaires, administered by the researcher and three trained enumerators. Validity and reliability of the questionnaire were tested during piloting, which involved the administration of the research instrument to 20 farmers purposively selected from the neighbouring Keiyo Marakwet County. Content validity of the instrument was determined by checking the responses of the subjects against the research objectives. Reliability was tested by computing Cronbach Alpha values, with items having values equal to or above 0.7 considered reliable. Where the value was less than 0.7, the items were

revised. Descriptive statistics, for instance, frequencies and means were used to describe, summarize, and organize the data. Household characteristics among farmers using gravity, lift and rain-fed systems were compared using chi-square ( $\chi^2$ ) cross tabulations (for discontinuous variables) or Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) test (for continuous variables).

The effects of three on-farm water application methods, lift, gravity, and rain fed systems, on tomato yield (together with other inputs of labour, chemicals, fertilizer and seeds) were analysed by a general production function implicitly of the form represented in Equation (1)

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, \epsilon) \dots\dots\dots(1)$$

Where;

- Y = Production in crates of tomatoes
- X<sub>1</sub> = Dummy variable for Lift
- X<sub>2</sub> = Dummy variable for Gravity
- X<sub>3</sub> = Seeds (kg)
- X<sub>4</sub> = DAP (kg)
- X<sub>5</sub> = CAN (kg)
- X<sub>6</sub> = Chemicals (g)
- X<sub>7</sub> = Labour input (Man days)
- $\epsilon$  = error term, whose variance is normally and randomly distributed

The lift system consists of farmers using manual and motor pumps combined together, as in (Owusu, 2016; Dittoh *et al.*, 2013). Since yield per acre of land was computed and used in the production function, land was not included in equation (1) since it was a constant. As water application methods comprised of a few groups, the data was nominal and hence, dummy variables were used to represent them (Gorgess & Naby, 2012; Giles, 2011; Debertin, 2012). Rain fed agriculture was the reference category and hence was absent in Equation (1).

Data were fitted to three different functional forms, linear, semi – log and double log functions using ordinary least square techniques (OLS) as in Nimoh *et al.* (2012), Gani & Omonona (2009) and Ike & Ugwumba (2011). The equation with the best fit was chosen as the lead equation. The three functional forms were implicitly represented by Equations 2 (Linear), 3 (Semi – log) and 4 (Double – log).

$$Y = \alpha + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + \epsilon \dots\dots\dots(2)$$

Where,

$\alpha$  = constant or intercept

b<sub>1</sub> ... b<sub>7</sub> = Coefficients for the inputs

Y,  $\epsilon$ , X<sub>1</sub> ... X<sub>7</sub> are as defined in equation 1 above

$$\text{Natural log (ln) } Y = \alpha + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + \epsilon \dots\dots\dots(3)$$

Where, variables are as defined in equation 2 above.

$$\ln Y = \ln \alpha + b_1 \ln X_1 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 \ln X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + \epsilon \dots\dots\dots(4)$$

Where, variables are as defined in equation 2 above.

Coefficients in the linear form are interpreted in straightforward manner, with b representing the change in Y that will occur as X changes one unit (Debertin, 2012). For the double log functional form, b is the elasticity coefficient. However, in the semi log function with discontinuous variables, the proportional effects (p) for the dummy variables are estimated, as in Equation 5 (Gorgess and Naby, 2012; Giles, 2011; Debertin, 2012).

$$P_j = [\exp (C_j) - 1] \dots\dots\dots(5)$$

Where,

$P_j$  = Proportional impact of dummy variable  $j$ ;  $\exp$  = exponent (e); and  $C_j$  = Estimated coefficient of the dummy variable  $j$

The Gross margin analysis was implicitly represented by equation 6

$$M = \sum_{i=1}^n P_{yi} Y_i - \sum_{j=1}^m P_{xj} X_j \dots\dots\dots(6)$$

Where,

GM = Gross margin

$Y_i$  = Gross output (crates)

$P_y$  = Unit price of product  $Y_i$  in Kenya shillings

$X_j$  = Quantity of variable input (where  $j = 1, 2, 3, \dots, n$ )

$P_{xj}$  = Price per unit of variable input in Kenya shillings

$\Sigma$  = Greek Sigma, which means summation

All statistical tests were two-tailed. Significant levels were measured at 95% confidence level with significant differences recorded at  $p < 0.05$ .

## RESULTS

### On-Farm Water Application Methods

Farmers were found to grow tomatoes using two methods for supplying water: naturally by rainfall or artificially through irrigation. Irrigation water was delivered by gravity or the use of lifting devices (mainly manual or motor pumps) (Table 1).

**Table 1: On-farm water application methods used by farmers in Baringo County (180 farmers were sampled)**

| On-farm application method | Percentage |
|----------------------------|------------|
| Gravity                    | 27.2       |
| Manual pumps               | 36.2       |
| Motor pumps                | 13.3       |
| Rain fed                   | 23.3       |
| Total                      | 100.0      |

The study showed that tomatoes in the study area were grown predominantly by lift – irrigation (36% and 13% for manual and motor pump, irrigation, respectively) and to some extent, by gravity farmers (27%) while only a small proportion of farmers grew the crop under the rain fed system (23%). Gravity system was practiced by farmers on National Irrigation Board (NIB) run- Perkerra Irrigation Scheme, and in other schemes such as Kamoskoi, Sandai and Sugutek and in valleys where ground water and run-off could flow to farms. The main water lifting devices were found to be manually operated treadle pumps (popularly, known as ‘Moneymaker’), diesel-operated motorized pumps and buckets. Water for irrigation in both gravity and lift systems was abstracted from rivers/streams, wells, boreholes, and canals and delivered to farms with mainly earthen-lined furrows or flexible pipes.

### Household's Farmer Characteristics

Table 2 presents the data on the relationship between on-farm water application methods employed by farmers in Baringo County and household's farmer characteristics.

**Table 2: Household characteristics of sample farmers in Baringo County grouped by water application methods**

| Characteristics                      | Gravity<br>(n=53)  | Lift<br>(n=65)     | Rain<br>fed<br>(n=62) | Average<br>(n=180) | $\chi^2$ or F-<br>Value |
|--------------------------------------|--------------------|--------------------|-----------------------|--------------------|-------------------------|
| Households headed by a female (%)    | 41.50              | 27.70              | 41.90                 | 36.7               | 0.17                    |
| Mean age of household head (years)   | 39.34 <sup>a</sup> | 37.43 <sup>a</sup> | 49.13 <sup>b</sup>    | 42.02              | 14.55 <sup>***</sup>    |
| Years of formal education            | 10.34 <sup>a</sup> | 10.69 <sup>a</sup> | 8.16 <sup>b</sup>     | 9.72               | 12.92 <sup>***</sup>    |
| Mean household size (persons)        | 4.21 <sup>a</sup>  | 4.58 <sup>a</sup>  | 3.79 <sup>b</sup>     | 4.20               | 2.98 <sup>**</sup>      |
| Mean land size (acres)               | 3.57               | 3.19               | 3.17                  | 3.29               | 0.185                   |
| Households that own bicycle (%)      | 56.6               | 50.8               | 53.2                  | 53.2               | 0.40                    |
| Households that own mobile phone (%) | 83.0               | 87.7               | 82.3                  | 84.4               | 0.66                    |
| Households that own motor cycle (%)  | 9.4                | 3.1                | 8.1                   | 6.7                | 0.33                    |
| Households that own car/tractor (%)  | 11.3               | 3.1                | 9.7                   | 7.8                | 0.20                    |
| Households that own color TV (%)     | 17.0               | 6.2                | 11.3                  | 11.1               | 0.44                    |
| Households that own radio (%)        | 83.0               | 92.3               | 83.9                  | 86.7               | 0.24                    |

\*\*\*, \*\* Significant at the one and five percent levels of probability, respectively. Means or percentages with similar letters across a row are not significantly different from each other by Tukey's HSD test or  $\chi^2$  test, respectively

There were no significant differences in the number of households headed by females in the three types of farming systems. The study found that the average age of farmers in the county was 42 years, which suggests that farmers in the county are young. The results also show that farmers who practice rain fed agriculture are likely to be older (mean age, 49.13 years) compared to those who practice gravity (mean age, 39.34 years) or lift (mean age, 37.43 years) agriculture. Farmers who used gravity or lift systems were found to have significantly more years of formal schooling (10.3 and 10.7 years, respectively) compared to those who practiced rain fed agriculture (8.16 years), suggesting that education could be critical in embracing irrigation technology. Mean household sizes were significantly greater among farmers using gravity and lift irrigation systems compared to farmers who engaged in rain fed agriculture. The farmers in the county own relatively small farms, with the average acreage being just 3.3 acres. Ownership of capital goods, for instance, cars/tractors (8%), motorcycles (7%) and color-TV (11%) was low. Cheaper goods, for example, bicycles (53%), radios (87%) and mobile phones (84%) had higher ownership.

### Gross – Margin Analysis

Table 3 presents the average gross margin of tomato production grouped according to four water application methods: gravity, manual pump, motor pump and rain fed.

**Table 3: Average Gross Margin of Tomato production**

|                                          | Gravity                       | <u>Lift System</u>            |                               | Rain fed                      |
|------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
|                                          |                               | Manual pump                   | Motor pump                    |                               |
| Average area (acres) cultivated for crop | 0.62                          | 0.46                          | 0.50                          | 0.64                          |
| Yield per acre (crates)                  | 114.8(24.1)                   | 143.7(11.7)                   | 168.3(12.1)                   | 63.7(20.2)                    |
| Gross tomato income (Kshs) / acre (TI)   | 321,440 <sup>a</sup> (67,727) | 402,220 <sup>b</sup> (32,669) | 471,240 <sup>b</sup> (33,800) | 178,372 <sup>c</sup> (38,918) |
| Capital Operating Inputs (C.O.I)         |                               |                               |                               |                               |
| Land preparation per acre (Kshs)         | 3,000                         | 3,000                         | 3,000                         | 3,000                         |
| Number of seedlings per acre             | 4648.7(950)                   | 4981.3(52.7)                  | 5140.2(63.4)                  | 4610.8(208.5)                 |
| Cost of seedlings per acre (kshs)        | 13,946.1(2,852)               | 14,943(158)                   | 15,420(190)                   | 13,832.5(625)                 |
| Amount of DAP per acre (kg)              | 140.5(11.1)                   | 147.4(8.8)                    | 149(5.6)                      | 107.8(23.9)                   |
| Cost of DAP per acre (Kg)                | 7,023.8(554)                  | 7371.3(440)                   | 7450(279)                     | 5388.6(1197)                  |
| Amount of CAN per acre (Kg)              | 121.1(16.9)                   | 139.6(8.1)                    | 139.5(10.1)                   | 82.4(23.6)                    |
| Cost of CAN per acre (Kshs)              | 4,843.8(675)                  | 5,582(325)                    | 5,580(404)                    | 3296.4(942)                   |
| Chemicals per acre (g)                   | 107.7(20.7)                   | 127.3(13.3)                   | 129.7(11.9)                   | 71.7(17.0)                    |
| Cost of chemicals per acre (Kshs)        | 10,448.3(2,006)               | 12,351.3(1,287)               | 12,583.3(1,154)               | 6,957.5(1,650)                |
| Irrigation cost per acre (Kshs)          | 8,200                         | 13,000                        | 26,000                        | -                             |
| Total COI cost (Kshs)                    | 44,462.0 <sup>a</sup> (2,922) | 56,247.6 <sup>b</sup> (1,870) | 70,033.3 <sup>b</sup> (2,158) | 32,475 <sup>c</sup> (4,402)   |
| <b>Labour Input (LI)</b>                 |                               |                               |                               |                               |
| Labour input (Man days/acre)             | 182.3(19.8)                   | 200.5(4.6)                    | 200.3(5.7)                    | 151.7(25.4)                   |
| Cost of labour input per acre (Kshs)     | 16,410(1,782)                 | 18,047.3(416)                 | 18,030(514)                   | 13,655.5(2,286)               |
| Total variable cost(TVC) = COI+LI        | 60,872 <sup>a</sup>           | 74,294.9 <sup>b</sup>         | 88,063.3 <sup>b</sup>         | 46,130.5 <sup>c</sup>         |
| Gross margin (TI-TVC-FC)                 | 260,568 <sup>a</sup>          | 327,925.1 <sup>b</sup>        | 383,176.7 <sup>b</sup>        | 132,241.5 <sup>d</sup>        |

Means with similar letters across a row are not significantly different from each other by Tukey's HSD test. Numbers in parentheses represent standard deviations.

Source: Field survey, 2017

The gross tomato income was highest in both manual and motor pump systems, followed by gravity system and was lowest in rain fed agriculture,  $F(3, 65) = 65.86$ ,  $p < .001$ ). This was because both manual and motor pump systems had comparatively more inputs (more water, chemicals, labour, and fertilizers) than gravity and rain fed systems. This is reflected in the significantly higher variable costs recorded in the manual and motor systems compared to gravity and rain fed systems. Gross margins were also found to be highest in the manual and motor pump systems compared with the other water application methods. The returns for gravity were lower because although the water was cheap, it could not be applied when required, as farmers could not control its application (irrigation schemes determine when it is applied). Total capital operating inputs were found to be highest in motor pump systems (because of more expenditures on fuel for irrigation), followed by gravity and manual systems, while they were lowest in the rain fed system,  $F(3, 105) = 16.82$ ,  $p < .001$ .

### Effects of Various Inputs on Production of Tomatoes

To estimate the effects of water application methods on the productivity of maize, dummy variables for “Lift” and “Gravity” water application methods were created while the “Rain fed” method was made the reference category. Data were fitted to three different functional forms, linear, semi – log and double log functions and the semi log function gave the best fit (Table 4).

**Table 4: The production function for tomatoes**

|                         | Coefficient±SE | t-value |
|-------------------------|----------------|---------|
| Lift                    | 0.101±.03      | 2.99**  |
| Gravity                 | 0.069±.02      | 2.83**  |
| Seeds                   | 0.00003±.00001 | 2.34*   |
| DAP                     | 0.009±.001     | 7.52**  |
| CAN                     | 0.005±.001     | 3.69**  |
| Labour                  | 0.003±.0009    | 3.21**  |
| Chemicals               | -0.001±.001    | -0.99   |
| Constant                | 2.079±.53      | 21.88** |
| R-squared               | 0.76           |         |
| Adjusted R <sup>2</sup> | 0.75           |         |
| F-statistic             | 643.85         |         |
| Prob.(F-statistic)      | P<0.001        |         |

Prob = probability; SE = standard error; \*\*, \* = t value significant at the one and five percent levels of probability, respectively

**Source:** Field survey, 2017

The semi log function gave the best fit for tomatoes. The estimated equation in the log linear form for tomato production can thus be written as:

$$\ln \text{ Tomato Yield} = 2.079 + 0.101 \text{ Lift} + 0.069 \text{ Gravity} + 0.00003 \text{ Seeds} + 0.009 \text{ DAP} + 0.005 \text{ CAN} + 0.003 \text{ Labour} - 0.001 \text{ Chemicals} + \varepsilon \dots\dots\dots(7)$$

The  $\beta$  coefficients for lift, gravity, seeds, DAP, CAN, and labour were all significant at  $p < .05$  (Table 4), which indicated that they all influenced tomato yields. The coefficients were all positive, which suggested that when the quantity of any of these factors (seeds, DAP, CAN, or labour) is increased, tomato yields would also increase, when others are held constant. However, the amount of chemicals was not significantly ( $t = -0.99$ ,  $p = .327$ ) related to yield, suggesting that merely increasing gross volume of chemicals might not be helpful.



Lift and Gravity were dummy variables in the regression model presented in Table 4. The proportional effects (p) for lift and gravity systems were:

$$p(\text{Lift}) = (e^{1.01} - 1) \times 100 = 10.6\% \dots\dots\dots (8)$$

$$p(\text{Gravity}) = (e^{0.069} - 1) \times 100 = 7.1\% \dots\dots\dots (9)$$

The results indicated that practicing lift and gravity agriculture increased the total yield of tomatoes by 11% and 7%, respectively, when compared to rain fed system. The  $\beta$  coefficients in Equation 7 all exhibited diminishing returns to scale.

## DISCUSSION

The finding in this study of two main water management systems (rain fed and irrigation) is in line with the observation that Kenya has two agricultural production systems: rain-fed and irrigated agriculture (GoK, 2010; GoK, 2014). The use of lift and gravity systems to grow tomatoes, was in line with the observation made that land mainly under private smallholder irrigation is devoted to production of vegetables and fruits, for example, spinach, kales, brinjals, melons, corgets and chillies, and citrus fruits (Karina & Mwaniki, 2011). This is because these crops can be grown profitably, even on small lands, by using basic irrigation equipments, such as buckets, pumps or gravity flow- based irrigation (Ike & Ugwumba, 2011; Owusu, 2016). Given that these crops fetch relatively good prices in the local and external markets (Karina & Mwaniki, 2011) and that manual and motor pump irrigation give the individual farmer more flexibility in determining water application to crops compared to mammoth government-run irrigation schemes, this might be the best model for carrying out irrigation in the country. This is supported by the fact that the large scale irrigation schemes established by the government in the past, for instance, Mwea, Perkerra, Bura, Hola, Ahero, West Kano and Bunyala, have been beset by management failures, are unable to exploit available land fully and traditionally grow one crop, with little or no rotation (Karina & Mwaniki, 2011). The finding that farmers contracted by the NIB practice gravity irrigation is in line with the fact that damming the Perkerra River created a reservoir that supplies water to farms by gravity through furrows (Keitany *et al.*, 2016; GoK, 2015).

The average age of farmers in the study was 42 years, which suggests that farmers in the county are young. The finding of more youthful farmers in the study county is in contrast with the notion that the average age of a Kenyan farmer is 60 years (Tirop, 2013) and contradicts the finding by Mambala (2007), who found that most farmers in Bunyala Rice Irrigation Scheme were aged over 50 years. The greater prevalence of gravity or lift systems among better-educated farmers, suggested that education could be critical in embracing irrigation technology. Mean household size of four people was found to be lower than the national average of six members in rural households (GOK, 2015). The mean farm size (3.3 acres) was relatively higher than the national average of 1.7 acres (GOK, 2015), could be because the county is arid. The low ownership of capital goods, suggested that poverty could be significant in the county.

The gross tomato income was highest in both motor and manual pump systems, followed by gravity system and was lowest in rain fed agriculture, indicating that overall, irrigation improved the gross production of tomato, and therefore revenue from the crop. The gross margin for irrigation systems obtained by this study (Kshs 260 568, 327 925, and 383 176 for gravity, manual, and motor pump irrigation, respectively) was comparable with tomato income recommended by the Ministry of Agriculture's Extension Department of between

Kshs 233 405 and Kshs 313 305 per acre with irrigation (GoK, 2014). The highest gross income with respect to irrigation was obtained from both motor and manual pumps rather than from gravity. The difference appears to be because of the amount of water supplied to the crop. Pumps can supply unconstrained water to the crop at any given time whereas for farmers using gravity, there tends to be water rationing by the National Irrigation Board (Mambala, 2007; GoK, 2015).

The major constraint in crop production in the ASALs has been found to be the irregular occurrence of rainfall during critical growing stages (Fox and Rockstrom, 2003; Valipour, 2015). By supplying water during these critical growing stages when rain is unavailable, irrigation ensures that plants obtain this all important nutrient at all times, which explains why irrigation was found to improve the output of tomatoes in this study. The finding of a positive correlation between irrigation and crop yield in this study is in line with findings by among others Mutabazi *et al.*, (2005), Origa (2011), Tan *et al.*, (2009), and Al-Omran *et al.*, (2010). The percentage increase in tomato yield when irrigated in this study ranged between 7% and 15%, which was comparable to the finding of 15.1% increase in total yield of tomatoes in Ontario, Canada by Tan *et al.*, (2009). However, they were low compared with the recorded increase in marketable yields of tomatoes and onions by between 63.14 % and 78.91% and by 137.97% and 153.16%, respectively in a study carried out by Origa (2011) in Makueni County. However, the latter was an experimental study whereas this study measured yields in a natural setting. Since the amount, frequency and time of application of irrigated water in the two studies were not similar; it might not be completely justifiable to make proper comparisons. It is also important to note that other factors could be responsible. For instance, because of differences in soil type, vegetation cover and topography of the land, there could have been differential leaching, runoff, water retention and evaporation (Kim & Schaible, 2000). Hence, it might be germane to design studies that measure consumptive irrigation water use rather than the amount of irrigation water supplied. The  $\beta$  coefficients in the study all exhibited diminishing returns to scale, which indicated that an increase in a variable would likely result in a less than proportional increase in the yield of tomatoes. The diminishing returns to scale are similar to findings by Nimoh *et al.* (2012) and Gani & Omonona (2009). The diminishing returns to scale found in this study suggested that farmers in the study area could be in the second stage of production and are in agreement with many production functions, in which inputs are required to have decreasing returns to scale (Schoengold and Zilberman, 2007).

## CONCLUSION AND RECOMMENDATIONS

The study concluded that tomatoes in the study area were grown predominantly using irrigation (36%, 27% and 13% for manual pump, gravity and motor pump irrigation, respectively) whereas only a small proportion of farmers grew the crop under the rain fed system (23%). Farmers who practiced rain fed agriculture were found to be significantly older and had less formal education compared to farmers who used gravity or lift systems. The gross tomato income was highest in both motor and manual pump systems, followed by gravity system and was lowest in rain fed agriculture, indicating that overall, irrigation improved the gross production of tomato, and therefore revenue from the crop. The elasticities of all variables in the study (lift, gravity, DAP, CAN, labour and seeds) were all found to have decreasing returns to scale, suggesting that farmers still have some idle capacity and can increase production by increasing the quantity and quality of inputs.

Therefore, small-scale farmers should, adopt the use of irrigation, since all types of irrigation were found to be profitable if inputs are optimized. Since manual pumps are relatively cheap, farmers could invest in them to increase crop productivity. However, if they can afford, farmers should buy motorized pumps, which have the highest returns. Given that the main sources of water for irrigation were found to be rivers, streams, wells and boreholes, small-scale farmers should aggressively harvest rainwater and store it properly with a view of using it in irrigation because bigger parts of the county are described as water-scarce regions.

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