

## Comparative Analysis of Water Saving Techniques for Irrigating More Land with Less Water in Nguruman Scheme, Kenya: Design Principles and Practices

Muya EM<sup>1\*</sup>, Sijali IV<sup>1</sup>, Radiro M<sup>1</sup> and Okoth PFZ<sup>2</sup>

<sup>1</sup>Food Crop Research Institute, KALRO-Kabete, Kenya

<sup>2</sup>International Institute for Rural Technologies, Nairobi, Kenya

### Abstract

A review of the past studies has demonstrated that rehabilitation of an irrigation scheme through infrastructural development and agricultural production value chains alone will not sustain the targeted agricultural production unless scientific principles, aimed at enhanced water use efficiency are incorporated in the development agenda to avoid future water losses and shortages. In Nguruman, the available water supply has the capacity to meet irrigation water requirement of 5,332,809 m<sup>3</sup> to irrigate the targeted 800 ha per year. However, with increasing number of farmers engaging in irrigated agriculture, more area is expected to be brought under irrigation to meet the increasing food demands, thus requiring significant amount of water savings through enhanced water use efficiency. For this reason, analysis and review of the irrigation design challenges, operational realities and technological options for improved water use efficiency was carried out in terms of the quantities of water saved and additional area that can be irrigated by each of the technological options considered in relation to the farmers' irrigation methods. The technological options reviewed were: drip plus digital instruments; drip plus analog instruments; sprinkler plus digital instruments; sprinkler plus analog instruments and farmers' irrigation method. It was deduced from literature review that drip plus digital instruments, drip plus analog instruments, sprinkler plus digital instruments and sprinkler plus analog instruments could save 465,600, 433,132, 365,520 and 323,637 m<sup>3</sup> of irrigation water respectively relative to the farmers' method. The additional area to be irrigated using water saved from drip plus digital instrument, drip plus analog instrument, sprinkler plus digital instrument and sprinkler plus analog instrument was 146.3, 136.7, 115.4 and 104.1 ha respectively. Since drip irrigation plus digital instrument had the highest water saving potential, it was identified as the most appropriate technology to be used tested, validated and applied to irrigate more land with less water in Nguruman Irrigation Scheme.

**Keywords:** Water savings; Irrigation technologies; Efficiency

### Introduction

#### Study background

Nguruman Irrigation Scheme is one of the nine schemes targeted for development by the Small Scale Horticultural Development Project (SHDP), supported by African Development Bank. One of the main objectives of the project is rehabilitation and infrastructural development of the schemes through appropriate design followed by construction [1]. However, design, construction and entire infrastructural development will sustain the agricultural production with the limited water supply in the long-run if important scientific principles are incorporated in the irrigation development agenda [2]. The scientific approach is based on the production objective of optimizing crop yields through improved irrigation efficiency, focusing mainly on efforts to maintain appropriate soil-water-plant relationships [3]. As a result of extensive research into these relationships, water requirements by crops at various stages of growth under different soil and climatic conditions can be determined with great accuracy [4,5]. This development can enable the designers, planners or irrigation development agencies to assess the scheme water supply requirement in relation to available water from the source, the capacities of water distribution systems and design the operation of water supply to the irrigated field, based on accurate information on the field irrigation scheduling, aimed at ensuring the use of limited water with the designed irrigation efficiencies [6]. In order to understand the relationships between the design assumptions, irrigation schedules and operation reality and their effects on water use efficiency, Professional Training Consultants suggested an intimate interactions between all parties involved in irrigation development and identified four main parties, namely: planners/designers (e.g. consultants, donors or development

agencies); technical and operational unit (District Agricultural and/or Irrigation Office); Scientists, equipped with scientific principles (e.g. Kenya Agricultural and Livestock Research Organization) and operational field staff and farmers at tertiary and secondary levels [7]. The study focuses on water savings to irrigate more land with less water through the study of the interactions between these parties during planning, design and operational stage of irrigation development.

#### Study focus

Water saving for irrigating more land is to be achieved by planning, designing and operating an irrigation system using adequate information and data input into each of the three important stages of irrigation development. The underlining objective of sound irrigation development and practices is to attain the quantity and quality of agricultural products desired in the market, while, at the same time, maintaining or enhancing the quality of soils and environment to ensure the biophysical sustainability of the designed system [8]. Planning stage entails determination of seasonal and peak scheme water supply requirements to use in estimating how much actual acreage that can be irrigated by water available from the source

\*Corresponding author: Muya EM, Food Crop Research Institute, KALRO-Kabete, Kenya, Tel: 721904432; E-mail: [edwardmuya2011@gmail.com](mailto:edwardmuya2011@gmail.com)

Received March 17, 2016; Accepted April 01, 2016; Published April 07, 2016

Citation: Muya EM, Sijali IV, Radiro M, Okoth PFZ (2016) Comparative Analysis of Water Saving Techniques for Irrigating More Land with Less Water in Nguruman Scheme, Kenya: Design Principles and Practices. Irrigat Drainage Sys Eng 5: 158. doi:10.4172/2168-9768.1000158

Copyright: © 2016 Muya EM, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

(irrigation potential), followed by determination of the irrigable area to be matched with irrigation potential determined. To derive data for the design and operation of irrigation system, a detailed evaluation of water supply schedules is done, starting from the lowest irrigation unit and subsequently include the block of fields, served by tertiary system, area served by laterals, and eventually the entire project area, served by the sub-mains and mains. Detailed design followed by the construction of an irrigation system is not yet a conclusion of the irrigation development. No irrigation system will function perfectly the day it is commissioned and becomes operational [4]. The operation criteria must be developed immediately after the construction, based on the field irrigation supply schedules, i.e. size, duration and interval of supply, and method of supply (rotation, on demand or continuous). Development of operation criteria considers the supply schedules for individual fields and subsequently blocks of fields, the area served by lateral and the main canals Muchangi et al., [9]. It is a common knowledge that variations may occur in cropping systems and area being served, hence the need for the supply to be regulated accordingly. Therefore, based on the supply schedules, the capacities of water supply and regulating structures should be determined together with organizational framework for operating and maintaining the system through involvement of the key stakeholders, including the Irrigation Water User Association, Extension workers, farmers and Soil and Water Engineers. Against this background, the objective of this paper is to explore ways and techniques for enhanced water savings through examination of the data input, challenges and technological options in different phases of irrigation development, namely: planning, design and operation with specific reference to Nguruman Irrigation Scheme, Kenya.

## Conceptual Framework

How efficient an irrigation system would be or how much water is saved by improving the irrigation efficiency depends not only on the type and sufficiency of the data collected at each stage of development, but also the accuracy and timeliness of the collected data [10]. The data collected and put into each stage of development are mainly on water, soils and crops. Based on these data, average and peak water supply, field irrigation schedules and field water budgets and balances are derived for the planning, designing and operation stage respectively [4]. This involves analysis of climatic data, water availability at the proposed intake and soil quality at planning stage (National Irrigation Board of Kenya, field water balance and permissible soil water deficit at design stage and operational parameters at the implementation level [3,11].

## Stages of Irrigation Development, Challenges and their Redress

### Planning stage, requirements and constraints

At the planning stage, a comprehensive inventory of available resources is done, involving the determination of the physical, chemical, hydrological characteristics of soils as well as climatic attributes and preliminary cropping patterns for the estimation of the irrigation potential of the project area. Two important results of these studies as far as water saving is concerned is how much acreage can be irrigated by the available water and how much is the irrigable area [8]. Crop water requirement is an essential component of planning and developing an irrigation system because of its application in the preliminary, design and operation stage [12]. At the preliminary planning stage, the crop water requirement is applied to calculate seasonal and peak water demands for a given cropping pattern which are needed to provide

the basis of determining the total acreage that can be irrigated by the available water supply from the source.

In Nguruman Irrigation Scheme, Small Scale Horticultural Development Project targets 800 ha (40% of total irrigable land) to be irrigated [13]. The annual water requirement for irrigating 800 ha is 5,333,809 m<sup>3</sup>, which can be met by the available water from the source (28 million m<sup>3</sup>) for the proposed cropping pattern comprising pasture, beans, maize, onions, water melon, and banana in phase one [14]. However, more area is likely to be brought under irrigation in the near future, considering the growing population, and the fact that 60% of the area is still available for irrigation. This would lead to a serious water deficit unless appropriate water saving techniques are identified to improve the irrigation efficiency from 55% to over 95% [15]. According to Muya et al. low irrigation efficiency of the current system, determination of net irrigation requirements without measured data on field water balance, and using climatic data derived from meteorological station which is Fourty kilometer away from the scheme, resulted into erroneous calculation of the irrigation water supply requirement, thereby, causing, not only reduction in the quantity and quality of agricultural products (Box 1), but also degraded soil and environment (Plate 4) [8]. The quantity and the quality of agricultural products are determined by the capacity of the system not only to meet the required agricultural inputs, but also to control pests, diseases and adverse interactions between the applied inputs and environments [16]. In principle, precision agriculture tries to fine-tune land management practices with an objective of maximizing agricultural production and its quality, while minimizing the environmental side effects. This is to be achieved by satisfying the immediate plant needs such that, what is good for business is also good for environment. For instance, accurate measurements of the exact levels of water and nutrients required at a given stage of growth is need to determine the quantities of inputs that would interact optimally to give the right size, appearance and taste of the products required in the market. For example, too much water would result into production of okra which is too long and rough textured, while too little would give small and coiled products, which are thrown away during the sorting out processes, hence a lot waste to the farmers [3]. Accurate measurements would also result into improved environmental quality and sustainability and reduced land degradation [16]. Low irrigation efficiency, not only results into excess capillary rise of the ground, salty water to the root zone, but also causes increased volume of drainage water (agricultural waste water) that finds its way into Ewaso Ngiro River water (Plate 5) [8]. In 1993, the Independent Board of Consultants cautioned that irrigation in the vicinity of Ewaso Ngiro river should be accompanied by appropriate mechanisms that limit the excess irrigation water into the river. This is because the degrading buffer zones are continually losing their capacity to filter the water flowing from the scheme, with increased movement of unfiltered drainage water into the river water [17]. The consequence of this contamination would be the extinction of the flamingos in Lake Natron where the river ends, hence loss of tourist attraction. Therefore, appropriate instruments, irrigation methods and practices must carefully be considered at the preliminary stage to ensure enhanced environmental quality and sustainable agricultural production [17].

### The design stage: data required and challenges

In Nguruman Irrigation Scheme 800 ha is targeted (in three phases) under the assumed cropping patterns indicated in Table 1 to be irrigated using annual water supply of 5,299,479 m<sup>3</sup>. The discharge of water from the headworks through mains, sub-mains and laterals into tertiary system and irrigated fields, are manually operated and

Phase I		Phase II		Phase III	
Crops	Area (ha)	Crops	Area (ha)	Crops	Area (ha)
Beans	40	Soybeans	65	Green grams	30
Onions	40	Ravaya	80	Okra	20
Water melon	40	Tomatoes	20	Karella	80
Pasture	40	Pasture	40	Pasture	40
Bananas	40	Mangoes	30	Lemons	40
Maize	65	Sorghum	35	Sweet potatoes	55
Total acreage	265		270		265

**Table 1:** Assumed cropping patterns, based on the farmers' preference.  
**Source:** Muya et al. [14].

hardly any measurement is done [8]. According to Shanan [10], irrigation system is designed to facilitate regulation and measurement of water flows from the point of abstraction through the distribution system into the irrigated field units. To derive the data for design and operation of the irrigation distribution system, a detailed evaluation of the supply schedules is made [4]. This should start from the lowest and furthest irrigation field, through blocks of field, served by the tertiary, sub-areas, served by the laterals and the entire project area, served by the mains [6]. The detailed design should be followed by putting down the operation criteria of the system which are based on the irrigation supply schedules, i.e. size, duration and interval of the supply as well as the method of application (rotation, on demand or continuous supply) as is demonstrated by Withers and Vipond [18]. Rehabilitation, infrastructural improvement and completion of the construction of any irrigation scheme will have positive impacts in terms of enhanced water savings and irrigation efficiency if the system design is done in consideration of soil-water-plant-relationships and subsequent irrigation scheduling [7]. Determination of these relationships will result into appropriate system design that not only sustains the reasonable irrigation efficiency, but also the infrastructural stability including water distribution structures [19]. Hillel indicated that the soil aggregate stability can be sustained through appropriate soil water management strategies that must be put in place prior to any agricultural development [20].

The water supply requirements at field level are determined by the depth and interval of irrigation, where the supply requirements of the individual fields have to be expressed in flow rates or stream size, shown in the following equation that determines the quantitative aspects of soil-water-plant relationships:

$$\text{Where: } qt = 10 \frac{P.Sa.D.A}{Ea}$$

q=Stream size in m<sup>3</sup>/s

t=Supply duration in seconds

P=Fraction of the available water permitting unrestricted evapotranspiration

Sa=Total available soil water in mm/m soil depth

A=Acreage of a specified crop in the assumed cropping patterns

The relative values of q and t in the in the soil-water-plant relationships have to be determined as a measure of water uptake and retention capacities and should be the basis of designing the stream size such that it may, not only be easily handled by the irrigators, but also causing no water wastage through high volume of run-off into the drainage system, deep percolation and surface ponding with eventual losses through evaporation and non-destructive to the soil.

The biggest challenge that requires redress is the fact that the actual

water distribution to the groups of farmers in most irrigation scheme deviates from the irrigation supply schedules designed, based on the soil-water-plant relationships and efficiency considerations [10]. This means that the procedures on the regulation, measurement and monitoring of the water flows are either not provided as guidelines after the design and construction of the scheme or provided in the design report but ignored by the field extension staff and farmers. This discrepancy has a serious implication on the amount of water saved or lost measured by the quality of agricultural product and water use efficiency [21]. In Nguruman Irrigation Scheme, the irrigation methods currently practiced are not based on the design arrangement. The irrigation interval is once a week and water application duration ranges from 4 to 12 hours. These irrigation practices are based on the rule of thumb rather than soil and crop water demands [8]. Therefore, the main cause of low irrigation efficiency is uniform application of irrigation water, using the same irrigation methods and scheduling, throughout the scheme by most farmers, disregarding the differences in physical, hydraulic and chemical properties of soils that influence the choice of irrigation methods and scheduling [8]. Horst claims that one of the factors contributing to this problem is that the irrigation schedules, based on soil-water-plant relationships hardly feature in the design report, thereby, deliberately, assuming the farmers' practices, and how the irrigation manager, agencies or Water User Association will operate the irrigation system after the design and construction of the irrigation infrastructure [2,3]. It is normally taken for granted the irrigation operators have the necessary skill to manage the scheme as per the design. This problem may be solved by understanding the relationships between these design assumptions, irrigation schedules and the operation reality. This can be achieved by bringing out clearly the picture of what happens to the four important parties engaged in irrigation design, development and practices as well as their role and challenges (Table 2).

### Design assumption and their consequences from long-term perspectives

The systematic design procedures given by FAO were aim at translating the production objectives into adequate technical planning criteria [4]. This involves collection of the required information on water, soils, climate and crops. Based on the collected data, tentative plan is prepared, followed by the search for optimal plan through systematic analysis of the serial modifications of the tentative plan. In summary, FAO [4], describes the design procedures as comprising the following stages: (1) project identification and preliminary stage; (2) project design and (3) project operation. In practice, the design and construction of irrigation systems are normally contractual undertakings which are pressured by limited time, financial resources and timely availability of relevant technical expertise in diversified fields [2]. This often leads to deliberate assumption of important input-

Parties involved and challenges	Their role and problems
Research scientists	Delineate the extent and distribution of soil types together with their physical and chemical characteristics, particularly water-related properties including the fraction of the available water that permits unrestricted evapotranspiration; identify irrigable areas and clusters of production units in terms of their constraints/potentials/limitation to be superimposed on the detailed irrigation system design.
Planners, designers, or development agencies and projects (e.g. Small Scale Horticultural development Project)	Design the irrigation system on irrigation areas to facilitate regulation and measurement from the intake to the irrigated fields, based on soil-water-plant relationships and efficiency; and ensure that the supply system is at permissible level and satisfying the momentary irrigation requirements of each crop and area in terms of stream size, duration and interval of supply.
Operational staff (e.g. District Agricultural Officer or Irrigation Engineer).	Mainly concerned with water allocation and distribution scheduling.
Field staff, Irrigation Water User Association and farmers	Determine how the water is distributed in reality. The actual water distributed is the product of interactions between the field staff and farmers.
Challenges	Often there is no effective communication between the research scientists and the designers, who develop the detailed layout design without regards to the soil investigation and clustering results; designing irrigation schedules, based on soil-plant-water relationships requires enormous amount of data collection, processing and dissemination to arrive at stepwise-procedures and manual on the guidelines on the operation of the irrigation systems, based on the appropriate water supply scheduling.

**Table 2:** The important parties involved in irrigation development.  
**Source:** Horst and Muya et al. [2,14].

variables required in each stage of design [3]. One of the most severely affected areas is soil resource inventory, hydraulic characterization, and clustering production/land units, required for preliminary, design and operation stage respectively. For example, lack of adequate soil resources inventory at the planning stage would lead to unclear boundary between irrigable and non-irrigable areas, and consequently, the design capacities of the water distribution and control structures would be based on the assumption that all the project area will be irrigated [21]. This is particularly the case if the preliminary irrigation layout was not superimposed (during design) on delineated clusters of soil units, with each cluster having well defined irrigation potentials, limitations, productivity index for envisaged crops and detailed hydraulic characterization. The detailed hydraulic characterization is required for the determination of the field irrigation schedules, field irrigation supply calendar, and field irrigation layout and water distribution plan [4]. According to Muchangi et al. lack of these important soil data would lead to the design of the capacity of water supply structure without considering the soil and soil-related variables that influence the operation of an irrigation system [9]. These include: the (net and gross) depth of water application, available soil moisture, allowable soil water depletion level, effective rootzone depth, irrigation cycles, number of irrigation shifts per day and irrigation time per shift. This may lead to over or under irrigation in the long-run.

### Water saving through redress of the discrepancy between the designed irrigation schedules and operational realities

The problem of incompatibility between the designed irrigation schedules and operational reality can be addressed by sticking to the principle that irrigation practices imply optimization of production. By keeping the soil-water-plant relationships and water use efficiency as the main focus of the design, water saving can be achieved, based on measurement by newly developed techniques (Horst, 1996). The accurately measured data will facilitate the use of water stress indicators, water-yield functions and simulation models, aimed at achieving economic yield of high quality product [22]. The techniques include automation of the irrigation system. Automatically controlled irrigation system, either hydraulically, electronically or electro-magnetically by micro-processors or computers will be more efficient with less labour inputs [23]. For determination and monitoring soil water balance, web based controlled instruments remotely operate the irrigation system with chain interface on board, allowing connections

soil moisture sensors [24,25]. Application of these techniques can result into increased water saving and improved irrigation efficiency if they are developed through multi-level stakeholders' platforms including the irrigators. Stakeholders on the ground, especially farmers, would adopt the recommended practices if they are demonstrated as addressing practical problem issues. For example, in Nguruman Irrigation Scheme, one of the most critical problem is low product quality associated with non-optimal interactions between the applied irrigation water and available nutrients. Okra is one of the most commonly grown vegetable for direct export market, and has, since suffered massive rejection due to low quality (Box 1).

The design of water supply structures and schedules without considering soil and soil-related variables may have adverse consequences in the long-run, particularly in Nguruman Irrigation Scheme, if not addressed immediately after commissioning the project. This is a justified course of action because no irrigation system worked perfectly the day it was commissioned. According to FAO, the function of an irrigation system is to satisfy as much as possible, the momentary irrigation requirements of each crop and each area in terms of stream size (Q), duration (T) and the interval of supply (I) and expressed in the following equation after [4,9]:

$$\text{Where: } Q = 10 \frac{A.d_{gross}}{I.Ns.T}$$

Q = System capacity (m<sup>3</sup>/hr)

A = Design area (Ha)

D<sub>gross</sub>=Gross depth of water application (mm)

NS=Number of shifts per day

T=Irrigation time per shift

For the quality and quantity of the agricultural products to be maintained at the required level without huge losses, a combination of appropriate irrigation water application method, appropriate water measuring techniques and reasonable level of irrigation efficiency is required. Since field irrigation requirements will vary for each crop during the growing season, water supply should follow these changes over area and time, based on the analysis and evaluation of the field variables that include water supply requirement factor, irrigation system design factor, supply duration factor and supply factor [4].



## Analysis of Water Savings through Different Technologies

### Need for irrigators to have designed irrigation scheduling

Critical to any irrigation system is an accurate estimate of the amount of water to be applied from the water source into an irrigated field to meet the crop water requirements over the growing season [9]. Within the growing season, the amount of water required by a given crop varies with the growth stages, thereby requiring appropriate irrigation schedules to meet the changing water needs [12]. In many cases, farmers continue irrigating as long as water is available for irrigation without taking into consideration their system's efficiency [8]. Since irrigation has a major impact on both cost and yields, one must install an irrigation system that will deliver sufficient amount of water at minimum cost without compromising on the yields predicted [9]. Mike and Lynne emphasizes that a basic understanding of an irrigation system's capacity to deliver water is a very powerful piece of knowledge since it allows one to take a more scientific approach to irrigation process, greater control and conservation of water without compromising the crop yields. For this to be achieved, Muchangi et al. suggested an application of appropriate irrigation methods and schedules that indicate when to irrigate, how to irrigate, how much water to apply and how deep the water penetrates into the soil after irrigating [9]. In this regards, all the irrigators need to know their system's net water application rate and the methods applied in their determination as well as guidelines on measurement and monitoring soil moisture level. Against this background, detailed analysis of the performance of different technological options is carried out in terms of their efficiency, how much water is saved and additional acreage. The three technologies examined in relation to the farmers' methods are: drip plus digital instruments, drip plus analog instruments, sprinkler plus digital instruments, and sprinkler plus analog instruments.

**Drip and sprinkler plus digital instruments:** Overhead irrigation methods (drip and sprinkler) are away of applying irrigation water with reasonably high efficiencies (75-90%). This can be further improved when accompanied by advanced digital instruments [9]. When combined with digital measuring instruments, these technologies can relax constraints on irrigation rates and timing by permitting better adjustments of irrigation scheduling to varying crop water needs within the growing period [24]. The advanced brands of instruments are currently available and offering a range of wireless solar-powered measuring and monitoring systems with web based software for improved irrigation scheduling [25]. According to Babajimopoulos et al. optimal irrigation water management and scheduling take into account the effectiveness of the irrigation water use in crop production, which is attainable through the use of improved measuring instruments [22]. The web based instruments remotely operate the irrigation system through instruments chain interface on board that allows the wireless intelligent sensor mesh network to connect all the sensors for various soil and climatic attributes from the field to mobile that signals the irrigators to irrigate as per the pre-determined irrigation schedules. Because of limited and controlled loss of irrigation water through the use of these instruments, the efficiency of both drip and sprinkler will step up significantly.

**Drip and sprinkler plus analog instrument:** Drip irrigation, accompanied by analog instruments, involves measurement, laboratory determinations and synthesis of all the water-related properties of soils and climatic characteristics, using of analog instruments. Determination and monitoring of the hydraulic properties of soils

and climatic variables required for designing the irrigation schedules may result into huge water losses, hence relatively low water use efficiency because of the reasons demonstrated by Muya et al. [21]. Determination of the available soil water for a given crop in a given field and soil, involves laborious exercise of digging the soil profiles, wetting all the horizons to be sampled, taking the disturbed and undisturbed samples and transporting them to laboratory, where they are subjected to stepwise incremental suctions and determination of the equilibrium moisture content for each suction. One of the biggest challenges is that the access roads from the field to the main roads may be rough with potholes such that the samples reach laboratories after undergoing considerable disturbance, so that they no longer represent the structure of undisturbed soils in-situ. Therefore, the soil moisture retention characteristics determined from the laboratory usually give wrong results in the system design [21]. The second challenge is that the samples have to be saturated before being closed into the pressure chamber, which may take several days, depending on the structure, degree of compaction, quantity and type of clay. The third challenge is the line between the air entry point that indicates equilibrium moisture content is so thin that values of soil moisture at each suction is a mere approximation, and the time taken to reach equilibrium is more than two weeks.

In Nguruman Irrigation Scheme, the planned sprinkler irrigation system design require accurate measurements of hydraulic properties of soil so as to give the farmers irrigation calendar that deviates from the traditional schedules, based on the rule of thumb. The types of data on the hydraulic properties of soil required for accurate design of irrigation schedules or cycles in this scheme are those that reflect the spatial and temporal variations in the rate and level of capillary rise of ground water, salinity and sodicity, available soil moisture holding capacity, the water uptake capacity, allowable soil water depletion level for various crops under different clusters of soil units identified [8]. Collecting these data for the determination of irrigation cycles, using analog instruments, is constrained by the magnitude of time and personnel required since their collection involves in-situ determinations and monitoring, which can only be achieved successfully using digital instruments [8,24]. This explains why the design of sprinkler irrigation systems in Nguruman Irrigation Scheme, was not based on these measurements. According to Muchangi et al. calculation of the irrigation cycle, based on these hydraulic properties is a must because it would lead to the determination of the parameters required for the design of the field layout for water application [9]. To obtain the highest yields, it is important to treat each field separately as one irrigation unit with specified dimensions, so each irrigation unit is irrigated according to its soil and crop water requirements [8].

To achieve the maximum yield from each irrigation unit Withers and vipond suggested booking methods to be applied in determining the permissible water depletion level by making observations of yields under various irrigation regimes, using instruments with reasonable level of accuracy [18].

For the determination of the net irrigation requirements, reference crop water requirements (ET<sub>o</sub>) are needed. For this purpose, prediction methods for ET<sub>o</sub> have been developed owing to the difficulty of obtaining accurate field measurements of the necessary climatic variables. These methods are Blaney-Criddle, Radiation, Penman and Pan Evaporation [8]. However, advances in research and more accurate assessment of crop water use have revealed weaknesses in these methods that include: need for local calibration to achieve satisfactory results with Penman method; erratic performance of the

Radiation method in arid conditions; and shortcomings in predicting crop evaporation [8]. The relatively accurate and consistent method is FAO Penman-Monteith which is recommended as the sole standard method with strong likelihood of predicting ETo with reasonable accuracy as was applied by Zoratelli.

### Irrigation water supply requirements under different technologies

The monthly net irrigation requirements for different crops are the starting point for the determination of the water supply requirements. The water supply requirements of different crops depend on the efficiency of different irrigation techniques, assuming other factors are under control [4]. Therefore, determination of the irrigation water requirements for the selected cropping patterns in Nguruman includes the net irrigation requirements, irrigation efficiency of water distribution system that depends on the irrigation technology applied and other water needs such as leaching requirements (LR) of the excess salts that depend on the soil and crop types [13]. Table 3 shows different technologies and their efficiencies. Determination of irrigation water supply requirement in m<sup>3</sup>/ha/month is used to determine the acreage that can be irrigated from the available water supply, depending on the irrigation technique in question as is given by the following equation:

$$\text{Where: } V_c = 10 \frac{\sum A \cdot I_n}{E_a(1 - LR)}$$

V<sub>c</sub>=Volume of water required for a specified crop

E<sub>a</sub>=Project irrigation efficiency (55% for Nguruman after Knight Piesold)

A=Area under a specified crop, ha

I<sub>n</sub>=Net water requirement of a given crop, mm/month

LR=Leaching requirement, fraction (assumed to be 20% for Nguruman)

As is shown in the equation, the amount of water required to irrigate a given crop depends on the efficiency of the irrigation

technique applied, acreage to be irrigated, net irrigation and leaching requirements [4]. Therefore, holding other factors constant, different irrigation techniques can be compared in terms of water saving, the additional area that can be irrigated with the amount of water saved [26]. The first step to determine the water savings from different techniques is to define the cropping patterns for a given irrigation scheme or system. Table 4 gives the cropping patterns selected for Nguruman Irrigation Scheme by Muya et al. [13]. For comparative analysis of the water savings from different irrigation techniques, pasture, beans, onions and maize were selected which fall in phase of the cropping systems.

The total water supply requirement to irrigate 800 ha with efficiency of 55% reported by Muya et al. is 5,333,809 m<sup>3</sup>/year, which is only 19% of the available water supply. This amount is required to irrigate all the crops in three crop phases given in Table 4 [13]. However, the amount of water required to irrigate pasture, beans, onions, and maize for which different water saving techniques are compared, using the farmer's method is shown in Table 5.

Based on the proposed cropping patterns for Nguruman Irrigation Scheme, the crop water requirements in different months can be used as guide for the scheme in planning the irrigation schedules. The total irrigation water supply requirements may be matched with the water supply from the source, and the result of matching is the basis of making adjustment in cropping patterns in both spatial and temporal terms [9].

As was shown by Muya et al. (Table 6), drip plus digital instruments had the highest water saving potential of 465,600 m<sup>3</sup>/year for irrigating additional area of 146.3 ha under the four crops (pasture, beans, onions and maize) [21]. This is followed by drip plus analog instruments which can save 433,132 m<sup>3</sup> with the potential of irrigating additional area of 136.7 ha. Sprinkler plus digital and sprinkler plus analog can save 365,520 m<sup>3</sup> and 323,637 m<sup>3</sup> that can irrigate additional area of 115.4 and 104.1 ha respectively. Promotion of the precision agriculture in Nguruman scheme was proposed by the LOG ASSOCIATES to improve the production efficiencies through the design and application of the sprinkler irrigation system, using efficient water measuring

Description of technologies	Efficiency (%)	Remarks
Drip irrigation plus digital instruments	97	The instruments to monitor soil water balanced and weather conditions can either be analog or digital with the later being more efficient
Drip irrigation plus analog instruments	90	
Sprinkler plus analog instruments	85	
Sprinkler plus digital instruments	80	
Farmers irrigation methods and practices	55	Farmers' method is surface irrigation and water supply and distribution are manually operated with no measurements throughout the system.

**Table 3:** Different technologies and their efficiencies.  
Source: Muya et al. [21].

Cropping systems		Cropping phases and proposed acreage		
Option No	Classification of crops	I	II	III
1	Legumes	Beans (40 ha)	Soybeans (65 ha)	G/grams (30 ha)
2	Vegetables	Onions (40 ha) Melon (40 ha)	Ravaya (80 ha) Tomatoes (20 ha)	Okra (20 ha) Karella (80 ha)
3	Pasture	Pasture (40 ha)	Pasture (40 ha)	Pasture (40 ha)
4	Fruit trees	Bananas (40 ha)	Mangoes (30 ha)	Lemons (40 ha)
5	Food security	Maize (65 ha)	Sorghum (35 ha)	Sweet potatoes (55 ha)
	Total acreage (800 ha for the three phases)	265 ha	270 ha	265 ha

**Table 4:** Proposed cropping patterns and cycles for Nguruman irrigation scheme.  
Source: Muya et al. [13].

Crop	Net irrigation requirements of different crops and technological options	Crop water requirements in different months (m <sup>3</sup> ) for different crops under different technological options				Total water requirements
		January	February	March	April	
Pasture	Net irrigation requirements for pasture in different months	13.7	139.4	85.6	12.0	
	Farmers' practices with 55% efficiency	9,963	101,381	62,254	87,27	182,325
	Drip irrigation plus digital instruments with 97% efficiency	5,649	57,484	35,298	4,948	103,379
	Drip irrigation plus analog instruments with Efficiency 90%	6,088	61,955	38,044	5,333	111,420
	Sprinkler irrigation plus digital instruments with efficiency 85%	6,447	65,600	40,282	5,647	117,976
	Sprinkler irrigation plus analog instruments with efficiency 80%	6,850	69,700	42,800	6,000	125,350
Beans		<b>May</b>	<b>June</b>	<b>July</b>	<b>August</b>	
	Net irrigation requirements for beans in different months	46.3	100.8	109	74.8	331
	Farmers' practices with 55% efficiency	33,672	73,309	79,272	54,400	240,653
	Drip irrigation plus digital instruments with 97% efficiency	19,092	41,567	44,948	30,845	119,280
	Drip irrigation plus analog instruments with Efficiency 90%	20,578	44,800	48,444	33,244	147,066
	Sprinkler irrigation plus digital instruments with efficiency 85%	21,788	47,435	51,294	35,200	15,5717
Sprinkler irrigation plus analog instruments with efficiency 80%	23150	50,400	54,500	37,400	165,450	
Onions		<b>September</b>	<b>October</b>	<b>November</b>	<b>December</b>	
	Net irrigation requirements for onions in different months	89.8	110.8	123.9	63.9	388.4
	Farmers' irrigation methods with 55% efficiency	65,309	80,582	90,109	46,473	282,473
	Drip irrigation plus digital instruments with 97% efficiency	37,031	45,691	51,092	26,351	160,165
	Drip irrigation plus analog instruments with Efficiency 90%	39,911	49,36	55,067	28,400	128,314
	Sprinkler irrigation plus digital instruments with efficiency 85%	42,259	52,142	58,306	30,071	182,778
Sprinkler irrigation plus analog instruments with efficiency 80%	44,900	55,400	61,950	31,950	19,4200	
Maize		<b>September</b>	<b>October</b>	<b>November</b>	<b>December</b>	
	Net irrigation requirements for maize in different months	21.8	84.8	148.9	23.9	279
	Farmers' practices with 55% efficiency	25,763	100,218	175,972	28,245	330,198
	Drip irrigation plus digital instruments with 97% efficiency	14,608	56,824	99,778	16,015	187,225
	Drip irrigation plus analog instruments with Efficiency 90%	15,744	61,244	107,538	17,261	201,787
	Sprinkler irrigation plus digital instruments with efficiency 85%	16,671	64,847	113,864	18,276	213,658
Sprinkler irrigation plus analog instruments with efficiency 80%	17,713	68,900	120,981	19,419	227,012	

**Table 5:** Crop water requirements.  
Source: Muya et al. [21].

Irrigation techniques as compared to farmers method	The impacts of different techniques	Water supply requirements (m <sup>3</sup> ), savings and additional area to be irrigated using different techniques for the following crops:				Totals
		Pasture	Beans	Onions	Maize	Four crops
Farmers' method	Water supply requirements	182,325	240,653	282,473	330,198	1,035,649
	Water saving	0	0	0	0	0
	Additional area to be irrigated	0	0	0	0	0
Drip plus digital instruments	Water supply requirements	103,379	119,280	160,165	187,225	570,049
	Water saving	78,946	121373	122,308	142,973	465,600
	Additional area (ha) to be irrigated	24.5	38.3	38.6	45.1	146.3
Drip plus analog	Water supply requirements	111,420	147,066	128,314	201,787	588,587
	Water saving	56,975	93,587	154,159	128,411	433,132
	Additional area (ha) to be irrigated	17.9	29.6	48.7	40.5	136.7
Sprinkler plus digital instruments	Water supply requirements	117,976	155,717	182,778	213,658	670,129
	Water saving	64,349	84,936	99,695	116,540	365,520
	Additional area to be irrigated (ha)	20.3	26.8	31.5	36.8	115.4
Sprinkler plus analog instruments	Water supply requirements	125,350	165,450	194,200	227,012	712,012
	Water saving	56,975	75,203	88,273	103,186	323,637
	Additional area to be irrigated (ha)	17.9	23.7	27.9	32.6	104.1

**Table 6:** Water savings from different techniques relative to farmer's method.  
Source: Muya et al. [13].

and monitoring instruments [1]. Therefore, since drip irrigation plus digital instruments is the most efficient technological option, it is recommended for the scheme. Regarding the farmers' irrigation methods and practices, no water saving is realized; hence no additional area may be irrigated.

### **Efficient irrigation technologies involving digital instruments in Nguruman**

Although Nguruman scheme is graduating into a commercial farming enterprise where measurements of economic water use efficiency is extremely necessary, no single measurement has been done to determine and monitor soil water balance in relation to nutrient dynamics and solute transport within the soil profiles. This concern has been expressed by Muya et al., in response to the sentiments of many workers, that increased application of nutrient inputs into the irrigated soils without getting watering and irrigation scheduling right through accurate measurements of water and solute levels in the soils (using digital instruments) may lead not only to the decline of soil and environmental quality in the long-run, but also huge losses of resources [13]. Odongo indicated that improved irrigation scheduling based on measurement of soil-plant-water interactions, using accurate digital instruments, resulted into reduced production costs, controlled accumulation of unwanted salts, conservation of limited water resources and increased quality of agricultural products. Wilk et al. emphasized that a careful management of irrigation water through appropriate irrigation scheduling is a key factor in good yields and plant performance which can be attained through detailed assessment of hydraulic functions in relation to crop performance. Assessment of hydraulic functions for practical irrigation scheduling requires information on soil water/tension readings transferred from the irrigated fields to irrigation operator, farmer or irrigator who uses the information to decide on when, where and how much to apply irrigation water [9]. There are a number of digital instruments including wireless sensor networks now available to provide accurate information on when to irrigate and how much water to apply. Drip and sprinkler irrigation methods, accompanied by sensor and wireless transmission system can provide web-based irrigation scheduling through timely and accurately monitored field soil moisture balance in relation to crop performance and yields [21]. The wireless sensor network can be used to monitor various environmental parameters related to agriculture that are input variables into models developed to estimate the crop water requirements, field water supply requirements and irrigation scheduling. Monitoring of these parameters using these digital instruments results into significant minimization of time and costs; maximization of the quantity and quality of agricultural products; and increased economic water use efficiency [24].

### **Striking the balance between science and the reality on the ground**

Many workers have demonstrated that rehabilitation of an irrigation scheme through infrastructural development and proper placement in agricultural production value chains without incorporating scientific principles in the implementation framework will not sustain the targeted production however efficient the planning, design and construction works was. Scientific principles required in the implementation of the designed irrigation scheme aim at achieving the enhanced soil-water-plant relationships for sustained irrigation efficiency. As reported by Muya *et al.* the main cause of low irrigation efficiency in Nguruman Scheme is uniform application of irrigation water, using the same irrigation methods and scheduling, throughout

the scheme by most farmers, disregarding the differences in physical, hydraulic and chemical properties of soils that influence the choice of irrigation methods and scheduling [8]. The cropping patterns, their acreage and the shape of the farms in relation to the designed layout are not yet defined by the irrigators. The proposed irrigation technology aim at maximizing the productivity on water through improved efficiency of its use by providing information, data, irrigation method and water measuring instruments that will assist farmers to decide how much acreage to irrigate, when to irrigate, how to irrigate and how much water to apply and the depth of water penetration in the soil after irrigation, and total production per unit of water consumed by the desired crops. For this to be achieved, farmers and the members of Water User Association (IWUA) should be equipped with data, instruments and capacity building that enable them to know how much water to supply individual farmers' fields, irrigation blocks and the entire scheme through the designed water distribution networks. Table 7 shows how to apply scientific principles in implementing the scheme. For Nguruman irrigation scheme, sprinkler irrigation method has been decided and designed. Therefore, a reasonable compromise must be arrived at between the recommended technologies (drip plus digital instruments) and those on the ground (sprinklers) to ensure sustainable use of limited water and nutrient resources. The guiding factors are the clusters arrived at, in which the use of sprinkler in certain area should be accompanied by the implementation of the recommended practices to reduce risks of land degradation associated with the use of the sprinkler technology. For example, one of the clusters identified in the scheme is relatively steep and extremely compact with potential of generating run-off under sprinkler irrigation which imitates the rain falling on steep and low-permeable soils. Increased land degradation under this method can be alleviated by selecting the sprinkler with discharge rates that are commensurate with water uptake characteristics and capacity of the soil. However, sprinkler method is ideally suitable for clusters with highly permeable soils which have been subjected to excessively nutrient leaching through basin irrigation. Therefore, the best approach would be to select and implement an irrigation practice for each cluster so that cluster-specific irrigation technologies are developed for the scheme. In this context, clusters which are highly degraded with compact surface and saline-sodic soils would certainly not benefit much from sprinkler because of the negative impacts this type of irrigation on soil structure stability [20]. In order to achieve the targeted crop production on long-term basis, the layout map of entire irrigation scheme, consisting production systems and Irrigation Water User Association, should be superimposed on the clusters of soils delineated to guide the irrigators on the management required and application of scientific inputs in order to sustain the irrigation and water use efficiency desired (Table 7).

### **Conclusion**

Water saving for irrigating more land with less water can be achieved by planning, designing and operating an irrigation system by timely information and data inputs into the three stages of irrigation development. Planning stage requires data on seasonal and peak water supply requirements on the basis of which to determine the actual acreage that can be irrigated by the available water supply. For the design stage, water supply scheduling is designed, based on data timely collected on the hydraulic characteristics of soils.

In Nguruman Irrigation Scheme, the targeted 800 ha of land for irrigation, using farmers' method with efficiency of 55%, is only 40% of the total irrigable area, and the annual water supply requirement of 5,333,809 m<sup>3</sup> for irrigating the targeted area can be met by the water



Components	Management implications	Scientific inputs
Entire Irrigation Scheme	Physical infrastructure to deliver water to irrigated land.	<ul style="list-style-type: none"> <li>• Determination of the irrigable area.</li> <li>• Calculation of seasonal and peak water supply required for the selected cropping pattern and intensity.</li> <li>• Calculation of the total irrigable area that can be irrigated by the available water from the source</li> </ul>
Production system (plot use or farm enterprises)	Irrigation blocks with organized and input specific production systems with known water supply requirements, identified with irrigators, IWUA and other stakeholders.	<ul style="list-style-type: none"> <li>• Organization of production systems into logical patterns in terms of acreage, temporal and spatial arrangements of the envisaged crops in each cluster identified.</li> <li>• Determination of the crop water requirements and water duties for the selected patterns.</li> <li>• Determination of the irrigation schedules/cycle for each cluster.</li> </ul>
Organization (IWUA)	Group based irrigation systems imply an organization in charge of operation and management. Organizational performance is an important factor of productivity and sustainability of irrigation system.	<ul style="list-style-type: none"> <li>• Development of the organizational structure that tallies with the layout of water distribution networks in relation to the irrigation blocks or clusters.</li> <li>• Development of irrigation calendar for efficient supply and management of irrigation water.</li> <li>• Installation of appropriate water control and monitoring structures/instruments.</li> </ul>

**Table 7:** Application of scientific principles to various components of irrigation.  
**Source:** Muchangi *et al.* with modification to suit the research area [9].

supply from the source, which is about, five times the current water requirements. However, with current increase in food demand, the remaining 60% of the total irrigable area will soon be brought under irrigated agriculture, hence potential water shortage.

The result of the review indicated that the highest potential water saving for Nguruman Scheme was reportedly 465,600 m<sup>3</sup> with drip plus digital instrument, including wireless sensor networks, resulting in additional area to be irrigated of 146.3 ha. This was followed by 433,132 m<sup>3</sup> saved by drip plus analog instrument. Sprinkler plus digital instrument and sprinkler plus analog instrument saved 365,520 and 323,637 m<sup>3</sup> respectively. The additional area to be irrigated by sprinkler plus digital instrument and sprinkler plus analog instrument was reported to be 115.4 and 104.1 ha respectively.

#### Acknowledgement

Funding from African Development Bank for feasibility study for situational analysis of Nguruman Irrigation Scheme as well as timely facilitation by the Project Coordination Unit are highly appreciated as well as the logistic support provided by J. Gathoni, L. Wasilwa, V. Kirigua, V. Wasike and H. Goro.

#### References

- LOG ASSOCIATES (2011) Mid-Term Review of Small Scale Horticultural Development Project.
- Horst L (1996) Irrigation water divisional structures in Indonesia. Liquid Gold Special Report.
- Muya EM, Jura MO, Mati BM (2009) Water management in irrigated agriculture: A training manual for technical staff.
- FAO (1977) Crop water requirements. FAO Irrigation and Drainage paper, Rome.
- FAO (1979) Yield response to water. FAO Irrigation and Drainage paper, Rome.
- World Bank (1990) Discussion paper on operational issues at the scheme level.
- Professional Training Consultants (2011) Training Curriculum for Extension Staff.
- Muya EM, Obanyi S, Owenga PO (2012) Watershed characterization and analysis of water-related constraints of Mountains and Oasis areas of KASALS.
- Muchangi P, Sijali IV, Wendot H, Lemperiere P (2005) Irrigation systems, their operation and maintenance.
- Shanan L (1992) Planning and management of irrigation systems in developing countries. *Agricultural Water Management Journal*.
- National Irrigation Board of Kenya (2013) Approaches for feasibility study for irrigation development.
- FAO (1976) A framework for land evaluation.
- Muya EM, Maingi PM, Kirigua V, Owenga PO (2014) Assessment of cluster-specific constraints and irrigation suitability of the degraded soils: A basis for formulating technological interventions for improved soil quality and productivity in Nguruman.
- Muya EM, Owenga PO, Kahiga P, Kirigua V, Goro H, et al., (2013) A review of crop water requirements determination methods and their application in water supply scheduling: The blue print for Nguruman Irrigation Scheme.
- Muya EM, Owenga PO, Kirigua V, Goro H, Atonya B, et al., (2013) Determination of crop water requirements for Nguruman Irrigation Scheme, Kenya Soil Survey.
- Wanjogu SN, Gicheru PT, Maingi PM, Tanui K (2006) Land degradation and management in the river Yala catchments, Western Kenya.
- Knight P (1999) Pre-feasibility study of Irrigating rangeland in Olkirimantian and Shompole Group Ranches for Ewaso Ngiro South Hydro-Electric Power Development.
- Withers B, Vipond S (1974) Irrigation design and practice.
- Muya EM, Maingi PM, Chek AL, Gachini GN, Otipa M, et al., (2011) Analysis of soil quality, irrigation system and cluster-specific interventions for improved production of high value vegetables.
- Hillel D (1982) Introduction to soil physics. Academic Press, California.
- Muya EM, Owenga PO, Kirigua V, Goro H, Atonya B, et al., (2014) Determination of crop water requirements for Nguruman Irrigation Scheme. Kenya Soil Survey.
- Babajimopoulos C, Panoras A, Geogoussis H, Arampatzis G, Hatzigiannakis E, et al., (2007) Contributing to irrigation from shallow water table under field conditions. *Agricultural water management* 92: 205-210.
- Shasbank K (2014) Micro-controller-based automated irrigation system.
- Okoth PFZ (2014) The use of mobile phones to access irrigation and weather information: Data collection and maintenance.
- Pessl GJ (2013) Turning information into a profit through metos digital irrigation instruments.
- Shani U, Tsur Y, Zemel A, Zilberman D (2007) Irrigation production functions with water capital substitution.