BEST MANAGEMENT PRACTICES FOR IRRIGATION SYSTEMS IN ARID AND SEMI-ARID LANDS

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Abstract
The effects of global climate changes are escalating the negative environmental impacts associated with the changes and the worst hit in terms of water scarcity are the arid and semi-arid lands (ASALs) of sub-Saharan Africa such as Kenya, who continuously face adversities resulting from the intensification of climate conditions, that has resulted for the extremities of more rainfall and more dryness in the region. The water scarcity characterized in the region and the need to ensure that more conservative and sustainable ways of the application of water are employed cannot be overemphasized. This paper reviews the Best Management Practices (BMPs) of irrigation systems which have yielded better results in terms of water management and irrigation systems usage. The methodology employed reviewed the use of irrigation systems as reported in various literatures from two key aspects; the management factors of irrigation systems and the technical irrigation design factors. The BMPs scenario considered include tillage (conservation and no-tillage), irrigation systems (surface, sprinkler and drip). The BMPs are not established rules that override manufacturer's guidelines for irrigation practices, but are recommendations for practices that have yielded increased agricultural productivity, crop production and minimized any soil or environmental impacts related to the design and operation of irrigation systems. No-tillage practice was found to be the method with the least negative environmental impact on soils ahead of the conventional ridging practice. Findings also reveal that management roles dependent on technical factors played by the farmers are among the best BMPs. The Irrigation Requirement, systems maintenance and Irrigation Scheduling (IS) are the most important BMPs to consider consequently drip irrigation is the most efficient system to use followed by sprinkler then surface irrigation systems.

Key words: Best management practices, irrigation, water scarcity

1.0 Introduction

Arid and semi-arid lands (ASALs) are characterized by aridity due to shortage of rainfall, dry climate and drought. Rainfall in arid areas ranges between 150 mm and 550 mm per year, and in semi-arid between 550 mm and 850 mm per year, temperatures are high throughout the year with high rates of evaporation (Vision 2030, 2011).The sub-Saharan Africa, particularly the northern part of Kenya experience limited amount of rainfall, harsh drought conditions and a very hot climate. Kenya lies on the equator between latitudes 5°N and 5°S and longitude 34° and 42°E with a land area of 581, 309 km^2 (Kenya, 2013). Kenya's climate varies from tropical along the coast to temperate inland to arid in the north and northeast parts of the country (Kenya, 2013). There is a limited amount of water available for beneficial uses such as domestic and agriculture.The ASALs of Kenya, which form about 89% of the total land mass, has been singled out for special attention for the 2030 development strategy of Kenya. Many, practice irrigation agriculture with the sole objective of providing more water to crops when the rain has stopped, with little or no regard to the Best Management Practices (BMPs) for the systems at the back of their minds.

In early sixties, when evaluation of sprinkler systems, which forms 90% of the irrigation system used in arid and semi-arid Israel was done, it was found out that a lack of accuracy in water application owing to the human factor involved in controlling the taps and a loss of water due to both portable and stationary pipes, a loss due to topography of the irrigated lands was also established, wide pressure differences in the sprinklers cause erratic discharge rates of the individual sprinklers, in addition, the different shapes and sizes of the irrigated plots caused wastage of water in the margins, such as along plots and roads, as a result of inadequate sprinklers (Verbeten, 1998).A quality irrigation system and its proper management are required to distribute supplemental water in a way that adequately maintains plant health while conserving and protecting water resources and the environment (The Irrigation Association, 2005).

The general lack of using BMPs will, without doubt, either make more use of a resource than required or even yield result lesser than what should have been produced. Less meticulous irrigation practices would incur unwanted results for example, there can be non-uniform growth of plants or too much water wasted if irrigation water is not applied uniformly, a part of the farm gets little water and a part gets water that is more than required (Smajstrla *et al*., 2012). A proper water management plan should be done in a whole life cycle analysis, where the water is monitored from the source of the water to its usage at the plant roots (Dukes *et al*., 2013). Irrigation requirements are primarily determined by crop water requirements, but also depend on the characteristics of the irrigation system, management practices and the soil characteristics in the irrigated area (Dukes*et al*., 2013).

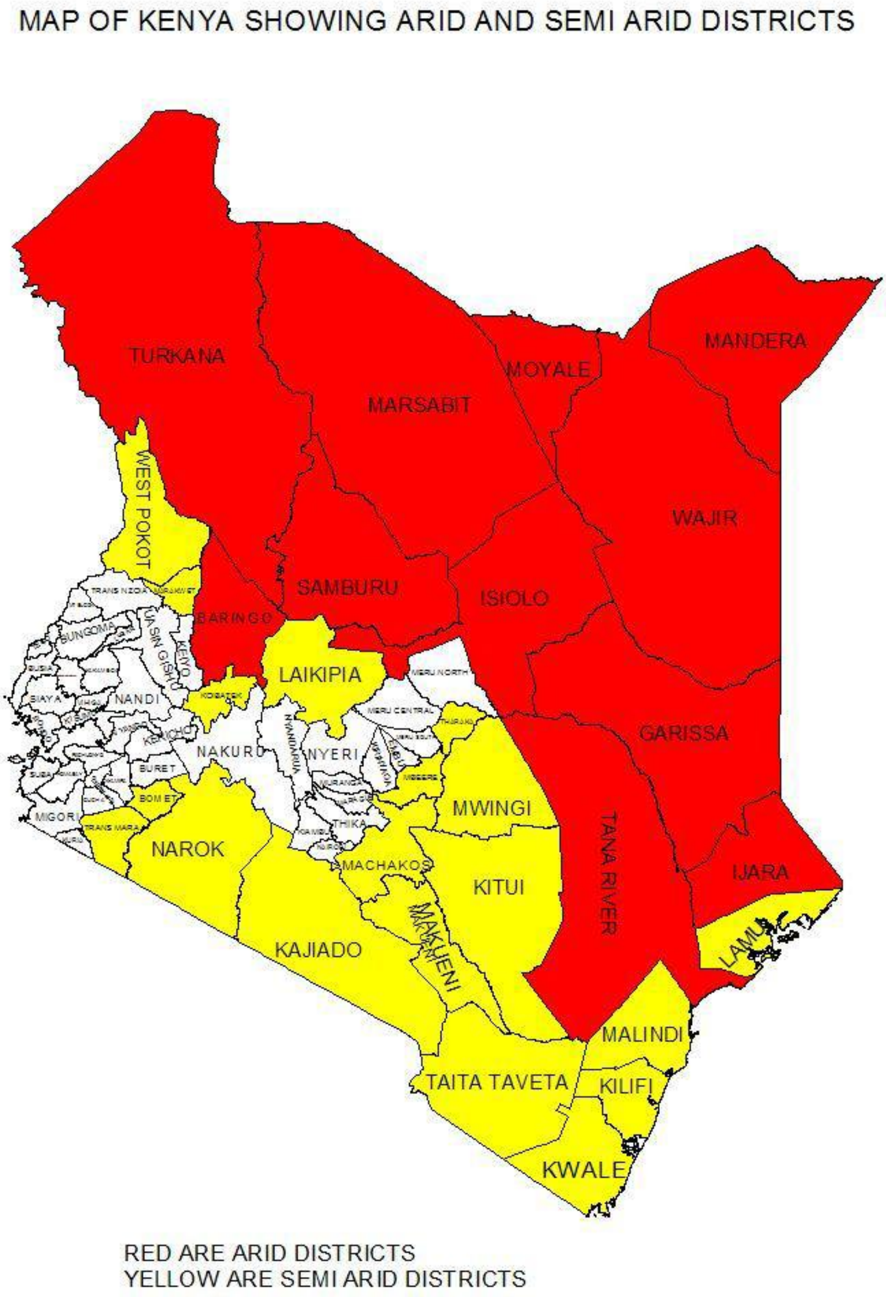

Figure 1: Sourced from Republic of Kenya (2013)

2.0 Methodology

The methodology reviewed the practice of irrigation systems by other farmers in other ASALs of the world from two vantage points; one looked at the management factors and the other considered the technical factors of irrigation systems, becausethe assurance of an overall quality of the system requires attention to irrigation system design, installation, maintenance and management (The Irrigation Association, 2005). Each of them has been shown to be among the best practices in which the maximum potential benefits of irrigation systems can be derived.

2.1 Best Management Practices

Generally, irrigation BMPs are but not limited to; monitoring of soil moisture before and after irrigation; irrigation scheduling according to crop needs, water availability and soil water depletion rather than following design recommendations; occasional evaluation of the efficiencies of IS; monitoring of irrigation application; and finally contacting qualified and experienced professionals to help schedule irrigation and determine efficiency of irrigation systems, if need be (Department of Agriculture, 1998). The sole aim of using BMPs in ASALs is to efficiently use the limited amount of water most especially during non raining season. Theses BMPs have been specifically developed for agriculturists of many different regions in ASALs all over the world. Some are targeted towards reduction of water pollution because water quality impacts crop productivity more than soil fertility, pest and weed control, variety and other factors (Dukes et al.,2013), others towards conservation and efficient use of water resourcesand the efficient utilization of precipitation and irrigation for profitable crop production (Department of Agriculture, 1998; Waskom, 1994).

2.2 Irrigation Scheduling

This BMP is used to determine when to irrigate a crop. Irrigation scheduling (IS) is a generic term for the act of scheduling the time and amount ofwater applied to a crop based on the amount of water present in the crop root zone, theamount of water consumed by the crop since the last irrigation, and other managementconsiderations such as salt leaching requirements, deficit irrigation, and crop yieldrelationships(TWDB, 2005). Dukes *et al.* (2012) and Department of Agriculture (1998) considered IS importantbecause the whole effort is geared towards the reduction of water wasting, either applying too much or too less, hence, the reason why it is among the most important BMPs to consider. FAO (2002) considers 3 major parameters in preparing irrigation schedules; daily crop water requirements, the water holding capacity (WHC) of the soil and the effective rooting zone depth. Most importantly, the determination of the WHC soil should be determined from time to time to fit actual soil conditions as the capacity can vary from time to time due to number of tillage operations, tillage equipment, farm type, residue management and type of crop and water quality (FAO, 2002 and NHDA, 1998). Untimely application of water to crops would have two consequences, either stunted growth of plants or wastage of water, hence, a timely application of water will prevent these problems (Dukes *et al*., 2012). Appropriate IS and matching irrigation amounts with the water holding capacity of the effective root zone may help minimize the incidence of excess leaching associated with over-irrigation (Dukes *et al*., 2012).

To effectively carry out this BMP, a determination of soil water content should be carried out first using direct soil measuring or estimation techniques of soil water budget. Soil water can be estimated by hand probing, where one feels the soil in his hand to feel and see any visible amount of moisture available in the soil, or use other more accurate methods such as tensiometers, gypsum blocks, neutron probes, time domain reflectometers (TDR) and phene cells. Apart from determining IS through soil water measurements, it can also be determined using manual and computerized techniques using crop water requirements (FAO, 2002). Whatever the method of determining IS, either manual or computerized, these parameters; cropping programme, daily water requirements of different crops at different stages of their growth, root zone depth at the different growth stages of each crop, total available soil moisture, allowable soil moisture depletion level and on site rainfall data (TWDB, 2005) should be determined.

The other problem is to know the amount of water to add, just to fill the effective root zone and prevent deep percolation and runoff. A reduction of number of irrigations can be achieved thereby conserving labour and plant nutrient if proper scheduling is done. The final irrigation is particularly important to be left out in order to go into off-season with a depleted soil profile, so that a storage space available for precipitation in the crop root zone without unnecessary leaching or runoff (Department of Agriculture, 1998). Reliability of estimates of climatic parameters such as rainfall and ET would have to be based on the weather station of the locality. Inaccurate measurements of these values will completely undermine the whole BMP exercise, since values that will be determined will mean they are not coherent with the region's climate hence, estimates of water requirements and deficit would be wrong. IS can start during anytime of the plantation but normal practice is usually before the first irrigation of the crop. Ideally, irrigation is done when there is water deficit in the soil. Therefore, IS should be done based on the amount of water available, the demand for water by the crop and the labour. Integrating labour considerations should be part and parcel of IS. The BMP guide of TWDB reported that yield or quality of many irrigated crops can be very dependent on adequate soil moisture at one or more critical periods in growth which can happen due to choice of farmers to choose to irrigate without any irrigation scheduling because of the economics of scheduling. For proper BMPs, documentation has to be done on parameters. Records of the amount of rainfall, irrigation depths, and volumes of water applied during each irrigation and the method, records of the location and information collected from direct measurement of soil moisture and copies of irrigation scheduling program reports (TWDB, 2005).

2.3 Volumetric Measurement of Irrigation Water Use

The determination of irrigation water use is important as it informs the farmer of the amount of irrigated water, hence the performance of the irrigation system. Either direct or indirect measurements can be done to estimate the amount of the irrigated water used. Direct methods may include either the installation of flow meter or a periodic manual measurement of flow. Indirect measurements are secondary ways in which these estimates can be arrived at from determining the amount of energy used, irrigation equipment operating or design information, irrigation water pressure, or other information. A correlation of energy use, water pressure and other parameters related to water used during irrigation is required.

The implementation of this BMP requires careful adherence to manufacturer's specifications for direct measurements and determination of the correlation of energy usage and the volume of water used for indirect measurement (TWDB, 2005). Both direct and indirect measurement methods should be evaluated periodically for the accuracy of volume or flow rate of the water being measured. It is important to be aware that both measurement methods vary significantly with each site, type of measurement being made, desired accuracy of the measurement, and the volume of flow rate of the water used (TWDB, 2005). As for when the volumetric measurement should take place, according to the BMP guide by TWDB report, for the indirect measurement, once the correlation of energy usage and water used is established, only periodic evaluation needs to be done to verify pumping capabilities that may change due to normal wear on irrigation equipment. For direct measurement, the installation of a flow meter is typically little, an hour or two for a saddle mount or insertion meter to several days for the construction of a metering vault and fabrication of associated piping or open channel metering station or the construction of a weir or a flume.

However, according to the BMP guide of TWDB, this report varies from site to site, and each method may have its limitations and requirements. From a simple recording of the amount of energy used per month from an energy bill to a complex installation and measurement of a large open flow management, so also do these metering requirements vary by geographic region and political subdivision (TWDB, 2005). A proper documentation of the total water used per field or system should be recorded on a periodic basis as this is necessary for implementation of other BMP practices, because this BMP does not directly reduce water usage, however, the information obtained helps inform the user of the cost associated with water use and will trigger the impetus to integrate water conservation measures in a bid to reduce the cost. Indirect measurement such as energy usage are easy to retrieve as they are documented as electricity bill by the power provider or in cases where power is generated on site by the user, documentation should be done on the amount of fuel used. The cost and benefit of implementing this BMP on a large scale will be very significant.

2.3 On-farm Irrigation Audit

This BMP is done in order to account for the total amount of water used in on-farm irrigation and to identify opportunities to improve water use efficiency. According to TWDB (2005), it can be thought of as the initial BMP for irrigation farmers to increase water efficiency in irrigation, because it will identify potential water efficiency measures that will form the basis on which additional BMPs will be implemented. The water audit will gather information on the following; field size(s) and shape, obstructions, topography, flood vulnerability, water table and access for operation and maintenance; type of pump equipment and energy source and pumping efficiency, if any; type of irrigation equipment, age and general state of repair; records of previous and current crops and water use and human assets-available technical ability and language skills of labourers, time and skill level of management personnel (NRSC, 1999).

The guidelines to follow in conducting the water audit should also follow NRCS (1999) procedures, however, other methods can also be used. Before begining the audit, the first thing to do is to gather and prepare some information that consists of map of the agricultural operation with field sizes and locations of main water supply, meters or measuring points, inventories or irrigation equipment and irrigation schedules, crop types, field slopes, soil types and textures amnd infiltration rates should be collected, as well as water use data for the previus year. Information on any previous water audit should be sourced as it will be relevant in identification of water saving measures. When the prilimanry information gathering is done, the next is on-farm irrigation physical wand water use audit. Water usage for each major water usage should be determined. Cost-effective analysis should be done to determine the implementable water use efficiency, however, even if a water efficient strategy is not cost-effective, it may be implemented if it is due to general goodwill, ease of implementation or high-visibility.

Furthermore, an action plan detailing conservation goals and recommended technology or actions to be implemented should be prepared. Other things to include in the proposed action plan should include estimates of time required to implemet technology or action. Finally, an on-farm irrigation audit report that includes an updated set of field diagrams and water flow charts broken down by water use areas, a current list of all water using equipments including actual and recommended flow rates, a current schedule or irrigation for all areas and equipment and an analysis of water costs by each field and for the entire farm and calculations of difference between water coming into the agricultural operation and a list of identified water uses throughout the operation. A timetable of when to implement the strategy should be added to the report.

The BMP should be implemented and continued till the targeted efficiency is reached. Documenting the progress of this report should record information pertaining to the audit report, cost-effectiveness analysis, action plan, schedule for implementing the action plan, the documentation of actual implementation of water efficiency measures contained in the action plan and the estimated water savings and actual water savings for each item implemented.

2.4 Conservation Tillage and Crop Residue Management

Tilling of lands has been a conventional practice of farming from antiquity. Conservation tillage improves the ability of the soil to hold moisture, reduces the amount of water that runs off the field and reduces the amount of water that runs of the field, and reduces evaporation of water from the soil surface. Conservation tillage and crop residue management allows for the management, orientation and distribution is of crop and other plant residue on the soil surface year-round on crops and grown where the entire field surface is tilled prior to planting (TWDB, 2005). The BMP of conservation tillage includes no till, strip till, mulch tillage and ridge till. The number, sequence and timing of tillage and planting operations and the selection of ground-engaging components shall be managed to achieve the planned amount, distribution and orientation of the residue after planting or at other essential time periods (TWDB, 2005). Undercutting or mixing will be used to maintain plant residue on or near the soil as tillage implementation. This BMP can be practiced throughout the whole cropping sequence or used as a residue management strategy that will include other tillage methods such as no till. It should be noted that not all irrigation systems can incorporate conservation tillage, surface irrigation system like furrow irrigation will not achieve its maximum possible efficiency and application uniformity as residue may impede water flow as well as prevent water from passing through it. Conservation tillage works well enough with low pressure centre pivot irrigation and subsurface drip irrigation (TWDB, 2005). Benefits will vary with climate and irrigation method practiced.

2.4.1 Land Levelling

This is the mechanized grading of farmlands based on a topographic survey. This BMP is used to increase the uniformity with which water is applied to an irrigated field that use furrow, border or basin irrigation. The land levelling is done according to the topography of the land and according to the irrigation or crop requirement. In cases where there are more than one irrigation method or crop, levelling should be done according to the most restrictive method and crop(TWDB, 2005). Levelling should be incorporated according to slope limits of water application method and should provide for removal of excess surface water and control erosion caused by rainfall. For best results, use a laser controlled scraper pulled by a tractor. The laser is set to predetermined cross and run slopes and the scraper automatically adjusts the cut of filled land over the plane of the field as the tractor moves. Levelling can be done to lands that have not been graded before or a land prior to preparation of seed beds. It is typically applied to mildly sloping lands, modest and steeply sloping lands require contour and terrace farming respectively. Documenting this BMP includes copies of the topographic survey of the land prior to land levelling, drawings that show design slopes and field layout after the land levelling work is complete and annual records of “touch-up” land levelling work by field.

2.4.2 Furrow Dikes

These are a type of surface irrigation method where small earthen dams are constructed at some intervals along the furrows in order to reduce runoff from the soil surface and increase infiltration of water- either rain or that applied through sprinklers. Euroconsult (1989) defines surface irrigation as a technique whereby water is applied on to the field to form a water layer that infiltrates into the ground. Their use however is limited to only gently sloping lands in ASALs (TWDB, 2005). Khatri & Smith (2007) noted that furrow irrigation is mostly inefficient with highly variable and poor application efficiencies, not because of the method, but due to lack of proper management.Furrow dikes are mostly used in fields for row crops to capture rainfall, reduce runoff from fields and improve uniformity of low pressure sprinkler irrigation applications. They are typically installed in non-wheeled traffic rows, require re-instalment or maintained as necessary. Furrow dikes can be implemented with either conservation tillage or conventional tillage. In the former case, they are implemented when the crop bedding is prepared to facilitate capture of rainwater or water from pre-plant low sprinkler irrigation and may remain in place during the entire growing season. For the latter tillage, they can be installed when the crop bed is prepared prior to planting or after the planting but before the crop height could reach one that could be damaged due to the process of installation of dikes (TWDB, 2005). However, furrow dikes can be removed when additional moisture from rainfall would be detrimental to production or harvest of the crop. Tracking of progress is usually done by either water measurement records from both the periods before and after conversion to the water efficient irrigation system or photographs of the furrow dikes installed and other evaluation and assistance reports that may relate to the project. Other innovations recorded by researchers that have proved to save water a lot is the introduction of gated pipes, that are coupled with control valves that allow full control over discharges into furrows, borders and even basins (Hamdy *et al*., 2003).

2.4.3 Drip Irrigation

Drip, micro or localized irrigation is the slow application of water directly to the plant root zone by means of special types of delivery equipment called emitters, surface or subsurface emitters (FAO, 2002). This localized type of irrigation is advantageous as there is increased application uniformity, soil structure is preserved, water is save from because of reduced evaporation and a correct control of water quantities and nutrients reaching plants is possible (Verbeten, 1998). Depending on the type of applicator or emitter used, there can be different things to consider when using this type of system for optimum results. A generic BMP will be used here to cater for all. Considerations should be made for situations where natural precipitation or stored soil water is not sufficient for germination and systems must have the ability to provide enough water to properly germinate seeds (TWDB, 2005). According to the TWDB (2005) BMP guide, maintenance and monitoring issues must be addressed frequently regarding clogging and back flushing of emitters; flushing lateral lines; measurement of applicator discharge and replacement of applicators as necessary; monitoring of operating pressures; injection of chemicals to prevent biological growth; and injection of chemicals to prevent precipitation of salts. Typically, cleaning agents are injected weekly, but in some instances more frequent injections are needed (Dukes et al., 2012). For proper documentation, copies of design layout and specifications of the drip irrigation system should be kept. The use of drip irrigation has been shown to be the most effective type of irrigation system; however, choice of use of the system is not primarily to reduce water usage but rather to increase crop yield and crop quality.

2.4.4 Linear Move Sprinkler Irrigation System

Linear move irrigation system is composed of a series of towers that suspend the irrigation system and move along in the direction of the rows of the farm, supplied water from a source adjacent to the first tower and parallel to the direction of move by a flexible hose, which is in turn supplied through a series of risers connected to a buried pipeline. It is an arrangement made to fit where a centre pivot irrigation system cannot be used due to shape or elevation changes. However, all BMPs discussed here under can be applied to the centre pivot irrigation system. Its use is normally limited to rectangular fields with minimal or flat slopes, however to many soil types and for a wide variety of crops. In general, smaller basins and higher water delivery rates are best for very permeable soils while short, wide basins tend to be more efficient than long, narrow ones(Waskom, 1994). There can be low pressure and high pressure systems. The BMPs suggested here are for low pressure only because they have a higher water application efficiency compared to high pressure systems (TWDB, 2005). High or medium pressure systems can be converted to low pressure to achieve better results. It can be implementable on multiple growing fields according to the growing seasons. When using full automation equipment the moment of irrigation and the quantity of water to be applied are determined automatically, without human intervention (Verbeten, 1998). The use of full automated irrigated systems is done in Israel, Gaza strip among others as this removes the human/management effort that often defaults in proper control of the sprinklers. To track progress of this BMP, water records before and after installation of the system should be kept. TWDB (2005) BMP guide recommends application of this system must be incorporated with other farm cultural practices to prevent runoff during irrigation or rainfall event.Waskom (1994)suggested that the soil moisture monitoring and IS are essential BMPs for managing water application on sprinkler irrigation. Understanding which practices are most important for your farm will depend on your individual situation and location, your current practices and your desired future (NRCS, 1999).

3.0 Results

The practice of the aforementioned BMPs has shown estimates of water use reduction achieved through better efficiency. Even though determination of these water savings could be very difficult at times to determine as for the case of IS but the Pacific Northwest Laboratory (1994) attempted to verify the potential savings resulting from using IS in a particular place, and estimated about 0.3 to 0.5 litres acre-feet per acre is saved, but the real actual savings could not be confirmed or disproved by the Lab's review, others measured showed considerable increase in efficiency of water usage.

On-farm irrigation BMP does not directly save water but helps in identification of conservation BMPs that may be implemented. Water savings from land levelling BMP is also difficult to determine but it generally improves irrigation uniformity and water application efficiency. Considering conservation tillage, a farmer can conserve 0.25 to 0.50 acre-feet per acre if increased soil moisture content is enhanced. Another difficult place to estimate the amount of water savings is from the furrow dikes as it depends on factors like soil infiltration rate, slope of furrow, amount and intensity of rainfall, however, according to TWDB (2005) from a certain plantation of a row crop, it showed 12% of gross quantity of water applied through sprinkler irrigation, and when the dikes were installed, the total runoff was eliminated. In acreage, about 0.25 acre-feet per acre quantity of water would be saved, but this also varies from field to field. For drip irrigation, as water is directly applied to the root zone, it is obviously easy to say that little or amount of water is lost. Water saved through sprinkler irrigation can be easily determined through a mathematical formula that takes effect of the amount of water pumped to the non BMP linear move system and the efficiencies of the non BMP system with that of the BMP system gotten from a table of estimated efficiencies. However, environmental conditions during irrigation also play a role in the amount of water saved. Hamdy *et al.* (2003) reported there is a soil reduction in soil infiltration rate of one-third to two-thirds have been reported under surge irrigation when compared to continuous flow, thus encouraging a more rapid advance and a more uniform application of water.

4.0 Discussion and Conclusions

A checklist provided by NRCS (1999) will help you determine where you are in terms of irrigation best practice; viz. know your farm water and soil resources, know your infrastructure, know your crop water needs, monitor your irrigation use and procedures and finally understand your impact on the environment. BMPs can be implemented at anytime of cropping season but it is best before the begining of the cropping, rainfall or irrigation season. Water savings are largest when they are conveyed through closed pipes and with proximity with the rooting zone as seen with drip irrigation where little water is lost. Human managment factors play a huge role in the management of irrigation water use, also, IS should be done taking consideration of local conditions, management skills and should incorporate farmer participation. This will ensure a clear understanding of the design specifications. According to Morales and Mongcopa (2008), flexibility in designing projects to reflect local conditions and avoid negative environmental impacts is also good practice, thus, the participation of farmers/local communities from project inception contributes to project success. There are other aspects of irrigation systems that BMPs can be incorporated such as water conveyance pipes from source to the pipes, in-farm drainage methods and countour farming. Considerable savings can be made from incorporating BMPs in this aspect.

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