Ciência Rural, Santa Maria, v.40, n.10, p.2218-2225, out, 2010
ISSN 0103-8478

Irrigation technology in South Africa and Kenya

Tecnologia da irrigação na África do Sul e no Quênia

Rodrigo Otávio Câmara Monteiro[I] Jokastah Wanzuu Kalungu[II] Rubens Duarte Coelho[III]

- REVIEW -

ABSTRACT

This paper reviews various irrigation technologies in both South Africa and Kenya that enable improvements in their socio-economic conditions. The two countries are located in semi-arid areas that experience extreme fluctuations in the availability of rain water for plant growth. Population growth exceeds the ability to produce food in numerous countries around the world and the two countries are not an exception. This experiment examined the constraints that farmers face and the role of government and nongovernmental organization in the uptake of modern technologies for irrigation. Detailed mechanisms and options to secure sustainable irrigation which are economically viable are considered. Despite the higher production of cereals and grains, fruits, and flowers also thrive in the two countries. Total irrigated area, crops grown and irrigation systems used in the two countries are discussed.

Key words: *irrigation dissemination, irrigated arid and semi-arid regions, irrigated agriculture.*

RESUMO

Este trabalho aborda as tecnologias de irrigação utilizadas na África do Sul e no Quênia que possibilitam melhorias nas suas condições sócio-econômicas. Localizados em regiões semiáridas, esses países estão susceptíveis à extrema flutuação na disponibilidade de precipitação pluviométrica para o desenvolvimento das plantas. O crescimento populacional, como em muitos países, excede à capacidade de produção alimentar. Neste trabalho foram levantados as dificuldades que enfrentam os produtores rurais e o papel do governo e das instituições de pesquisa não governamentais na captação de tecnologias modernas para a irrigação. Detalhados mecanismos de execução e opções para garantir a irrigação sustentável e economicamente viável foram considerados. Apesar da maior produção de cereais e grãos, a fruticultura e a floricultura também prosperam nesses países. A área irrigada total, as culturas beneficiadas e os sistemas de irrigação usados nesses países também foram discutidos.

Palavras-chave: *disseminação da irrigação, irrigação em regiões áridas e semiáridas, agricultura irrigada.*

INTRODUCTION

The world's total population is expected to increase by about 35% in the year 2030 (PLAYAN & MATEOS, 2006). The growing population will result in both considerable additional demand for food and water from both agricultural and non agricultural sectors in both developed and developing countries. In most developing countries, agricultural production is expected to increase by 49% by the year 2030 in rain fed systems and by 81% in irrigated systems (BRUINSMA, 2003). Three-quarters of the world's total irrigated area, which is of 260 million hectares is in developing countries where smallholder agriculture predominates. The rural poor are viewed as small-scale

[I]Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul (IFRS), Campus Bento Gonçalves, Avenida Osvaldo Aranha 540, Juventude, 95700-000, Bento Gonçalves, RS, Brasil. E-mail: rodrigo.monteiro@bento.ifrs.edu.br. Autor para correspondência.
[II]University of Nairobi, Nairobi, Kenya.
[III]Departamento de Biosistemas, Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ), Universidade de São Paulo (USP), Piracicaba, SP, Brasil.

Received 02.28.10 Approved 08.23.10 Returned by the author 09.24.10
CR-3212

irrigators, and will continue to be a vital part of future world food security (IPTRID-FAO, 1999).

In Africa, irrigation is the widest form of water management. According to a FAO report, the practice covers 6% of the total cultivated area which is low when compared to 38% in Asia, 27% in Caribbean and 12% in Latin America (FAO, 2005). In Africa, 80% of the most practiced irrigation technique in either full or partial control schemes is surface irrigation. However, more than one million hectares of sprinkler irrigation have been reported, most of it being concentrated in Botswana, Libya, Egypt, Morocco, Tunisia, Zimbabwe, South Africa and to a lesser degree in Kenya and Zambia. In relative terms, sprinkler irrigation system represents the most widely used technique in Botswana, Zimbabwe and South Africa , benefit that comes from a relatively long tradition in this field (FAO, 2005). Micro-irrigation is concentrated in Egypt and South Africa. In the African continent, about 85% of water withdrawals are directed towards agriculture but this figure varies considerably from one region to another. This paper reviewed irrigation systems in South Africa and Kenya, the constraints that rural farmers face and the role of government and nongovernmental organization in the uptake of modern technologies in irrigation.

DEVELOPMENT

Irrigation in South Africa

The Republic of South Africa is located on the southern tip of Africa and covers an area of 122 million hectares where 18 million hectares is considered as arable. Irrigated area is about 1.3 million ha which represents 9% percent of the 14.6 million ha of cultivated area (FAO, 2002). Irrigated agriculture contributes between 25 to 30% of gross agricultural production though its impact in terms of Gross Domestic Product (GDP) (ENCYCLOPEDIA OF THE NATIONS, 2006). Irrigated agriculture is of considerable importance in rural areas where it provides opportunities for employment and food production for many families. Agricultural production under irrigation in South Africa receives water from groundwater and surface water sources. Groundwater irrigates 24% of irrigable area as compared to surface water which irrigates 76% (VAN TONDER & DENNIS, 2000).

The country's population of 45.4 million (FAO, 2004) with estimated annual population growth of 1.7% (CENTER FOR AFRICAN STUDIES, 2009) coupled with urbanization and industrialization has increased pressure on the available water resources. Due to this, the country is expected to face serious water shortages by the year 2030 as 11 of the 19 water management areas in the country are facing water deficit because the water demand exceeds the water available. Water consumption has increased twice the rate of population growth. The threat of water becoming scarce and unevenly distributed in the country was partly due to apartheid and practices of the past political regime which prevented equal access to all. This led to the creation of water resource management units which aim to ensure sustainable water resources to supply all water users.

The largest water consumer in South Africa is the agricultural sector which accounts for nearly half of the water requirement. It consumes $10.7x10^9m^3$ of water each year which represents 54% of currently usable water resources (WRC, 2000) even though the consumption of industries (17%) and urban areas (29%) are also increasing.

Between 40 and 50% of South Africa's population can be classified as living in poverty (TERREBLANCHE, 2002; FAO, 2004) while 25% of the population can be categorized as ultra-poor. Although the country is self sufficient in food production, about 14 million people are said to be vulnerable to food insecurity and 43% of households suffer from food insecurity (MINISTRY OF FINANCE, 2001). In South Africa the highly irregular rainfall favored the irrigation need in the crop production. The average annual rainfall is about 495mm ranging from less than 100mm $year^{-1}$ in the western deserts to about 1200mm $year^{-1}$ in the eastern part of the country. Only 35% of the country has a precipitation of 500mm or more, while 44% has a precipitation of 200-500mm and 21% has a precipitation of less than 200mm (LCCS, 1996).

Smallholder irrigation practice

Modern technologies usually cost much more than traditional methods and rely to a great extent on external specialist support from suppliers and distributors. However, many farmers benefits from such technologies. For instance affordable small motor-driven pumps can greatly reduce the work needed to lift and move water. Modern water distribution technologies such as sprinkle and trickle irrigation are replacing more traditional surface methods. They can help farmers to manage water better as well as reduce wastage, which in turn reduces the amount of water that needs lifting. Engineers and planners often favor the use of these technologies because water savings by some farmers means that more is available for others. South Africa was among the countries which started the use of drip irrigation in the early 1970s along with Australia, Israel, and Mexico (POSTEL, 1997). Drip irrigation is widely recognized as one of the most

efficient methods of watering crops (KELLER & BLIESNER, 1990). It can improve crop yields and significantly reduce water wastage.

Smallholders are able to benefit from drip systems because they can be adapted to small and varied plots of land. Drip and drum kits retain the benefits of conventional drip systems while remove the factors that prevent their uptake by poor farmers such as purchase cost, requirement of a pressurized supply and its associated pumping costs and complexity of operation and maintenance (IPTRID-FAO, 1998).

In developing countries where small scale farmers use drip irrigation, surface irrigation changed to drip irrigation , bypassing sprinkle irrigation because it is considered an inflexible system for use in small plots. A further advantage of drip irrigation is the ease with which it can be operated. The major technical problem with drip irrigation is emitter and lateral line clogging from sand and silt, chemical precipitation from groundwater and algae from surface water. Each of the problems takes the use of trickle into a level of technology and support that can be difficult to sustain in the country. However, on a small scale the farmer can simply go around and clean the system regularly, which can overcome these problems. On a larger scale this would not be practicable. In addition the system costs can range from US$ 1,000.00-3,000.00 per ha (CORNISH, 1998) which makes it uncomfortable to many farmers. In addition the systems require skilled management for effective operation and maintenance. Some of the low cost technologies are the treadle pump, which was developed especially as a low-cost pump for smallholders. It has been particularly successful in South Africa replacing the manual lifting and carrying of water (IPTRID-FAO, 2000).

In South Africa sprinkler irrigation system covers about 33%, drip irrigation system 11% and surface irrigation dominates with about 56% (FAO, 2005). Sprinkle irrigation is mainly developed for larger farms and is not very flexible and adaptable to the multitude of small plots usually found on small farms. To solve this problem the equipment is used with drag-hose sprinklers (International Program for Technology and Research in Irrigation and DrainageIPTRID-FAO, 2000). Experience in South Africa to date has been that short furrow flood irrigation is more sustainable than equivalent irrigation using sprinklers (IPTRID-FAO, 2000).

Crop production

Cereals and grains are South Africa's most important crops, occupying more than 60% of area under cultivation especially corn (FAO, 2005). Both irrigated corn area and yields have increased in South Africa since the year 2002. Irrigated corn area expanded from approximately 120,000 hectares in 1997 to 220,000 hectares in the year 2003 (FAO, 2005). The combination of improved irrigated yields and increased irrigated corn area translates to approximately 2 million tons of corn produced by irrigation. This has also led to increased sales of irrigation equipment especially center pivot systems. High corn prices during the year of 2002 motivated potato farmers and other irrigators to switch crops and plant more corn than usual from the other years (FAO, 2005). Apart from corn, mainly irrigated crops are fodder crops, wheat, sugarcane, vegetables and pulses. Some areas of corn and wheat are irrigated but they are not significant in respect to the areas planted, crop production or fertilizer used.

Sugarcane is an important export crop and South Africa is the world's tenth largest sugar producer. There are about 49,000 sugarcane producers in South Africa and the cultivated area is about 321,000ha to 20.6 millions tons per year (FAO, 2005), where 2,000 farms account for 70% of this area. Of this amount, 80% approximately of this area is irrigated. The sugarcane yield in non-irrigated areas is around 70tons ha^{-1} $year^{-1}$, while in the irrigated areas is around 120t ha^{-1} $year^{-1}$ to 14 years (13 cuts). It was also reported that with drip irrigation yield has increased around 26t ha^{-1} $year^{-1}$ compared to others irrigation systems used. The implementation of drip irrigation and fertigation in sugar cane has proved to be technically feasible and economically viable. In many diverse agro-ecological situations, drip irrigation registered higher yields (50 to 90t ha^{-1}), conservation of water (30 to 45%) and fertilizers (25 to 30%). Furthermore, drip irrigation accounts for the improvement in sucrose content compared to conventional furrow, overhead, dragline and center pivot sprinkler irrigation methods (LECLER et al., 2007).

Fruit and vegetable production

Citrus and subtropical fruits, vines, deciduous fruits and most vegetables are grown under irrigation. The crops grown under more intensive irrigated conditions include paprika, citrus, tobacco, and citrus as well as a range of vegetables such as potatoes, cabbage, peppers, beans and tomatoes. There are also several large undertakings producing vegetables and flowers in tunnels in the Ventersdorp-Potchefstroom area and towards Carletonville. Fertigation either via drip or microjet is a common practice.

The official statistics produced by the Department of Agriculture do not differentiate between irrigated and rain fed areas. Estimates of the horticultural proportions and fruit crops that are irrigated in some provinces are as follows: Citrus - mostly irrigated in Mpumalanga, Western Cape, Eastern Cape and Limpopo; Subtropical fruits and nuts - mostly irrigated in Mpumalanga, Limpopo and Kwazulu-Natal; Vines - mostly irrigated in Western Cape and Northern Cape; Deciduous fruits - mostly irrigated in Western Cape; Potatoes - irrigated and rain fed in most regions. These estimates are reliable for some crops, for others they are part estimated. For example, citrus orchards are cultivated exclusively under irrigation.

According to the water requirement for avocado, banana and mango, the annual rainfall should range from 300-2500mm per year. Due to the fact that the rainfall in the major of South Africa areas is low during the winter months, irrigation needs to be applied to supplement rainfall. When looking at the rainfall distribution over the South Africa, the supplemental water demand is very low in winter and therefore the amount of water in the dams and rivers should be adequate for profitable production of tropical/ subtropical fruit.

Fruit farms owners use buckets and hosepipes for irrigation and their main water source is tap water. Irrigation farmers use drip and microjet systems with rivers and dams as the main water. Furthermore, it's important to note that farmers under fruit irrigation production largely depend upon extension officers.

South Africa is self-sufficient as concerns to vegetable production and also exports both fresh and processed vegetables. Tomatoes are the most important vegetable crop, followed by onions. At present, it is estimated that 150ha of greenhouses are in use in South Africa, in which mainly English cucumbers and tomatoes are produced by localized irrigation system. Hydroponics' vegetable production is also firmly established.

Irrigation in Kenya

The republic of Kenya is located in Eastern Africa between Somalia and Tanzania and borders the Indian Ocean. The country's total area is 582,650 square kilometers (58 million ha) with estimated population of 32.4 million (FAO, 2005) of which 80% lives in rural areas (MOSE, 1998). The average annual rainfall is of 630mm with variation from less than 200 mm in Northern Kenya to over 1800mm on the slopes of Mt Kenya (KARANJA & MUTUA, 2004).

Agricultural production is mostly rain fed and this leads to food deficit and insecure food supply as a result of periodic droughts and low access to production resources. According to the 2002-2008 National Development plan Kenya is classified as a water scarce country with water demand exceeding renewable freshwater sources. Agriculture water consumes about 79.1% of the total water withdraws with industry using 3.7% and domestic purposes consuming 17.2%. The total water withdraw by 2003 was $2,735x10^6m^3\ year^{-1}$ for irrigation, livestock and domestic use $470x10^6m^3\ year^{-1}$ and industry $100x10^6m^3\ year^{-1}$. The irrigation supply is from groundwater and surface supplies that are estimated to 1 and 99%, respectively (FAO, 2005).

The irrigation potential area is estimated to be of 540,000ha out of which 87,000ha are currently developed and represents about 16% of the potential irrigable area and 2.5% of 3.7 million ha of cultivated area (KARANJA & MUTUA, 2004). There are several irrigation systems currently in use. These include conventional sprinkler irrigation, sprinkler using motorized hose-pipe by pinching, low-cost drip irrigation and furrow irrigation. Low cost drip irrigation kit in Kenya is gravity fed, and comprises a bucket or drum, a manifold with varying lengths and number of drip lines. Surface irrigation has an irrigated area of about 58,290ha representing 67% of irrigated area while drip irrigated area is 2,000ha representing about 2% of irrigated area. Sprinkle irrigated area is 26,970ha representing 31% of irrigated area (FAO, 2004).

Smallholder irrigation practice

Most smallholder farmers in Kenya are individual owners of the irrigated area. They hold small irrigation area generally of 0.1ha to medium scale of 1.0ha. The most common irrigated crops are vegetables such as kale, spinach, tomatoes, cabbages, onions and peppers. In addition, fruits such as citrus, bananas, mangoes, passion, papaya are also irrigated. The crops are irrigated for both commercial and subsistence purposes (KULECHO, 2006).

The most commonly used smallholder irrigation system in small farms is drip kit system (Figure 1) which has been promoted energetically by government and non governmental organization. This is because they are flexible for irrigating small portions of land and has high irrigation efficiency (POSTEL, 2001). Drip kit irrigates about 100 individual plants over a $25m^2$ area. These systems resemble more conventional drip systems, but have much lower capital costs because they are designed to be shift table instead of stationary. Whereas conventional systems require a

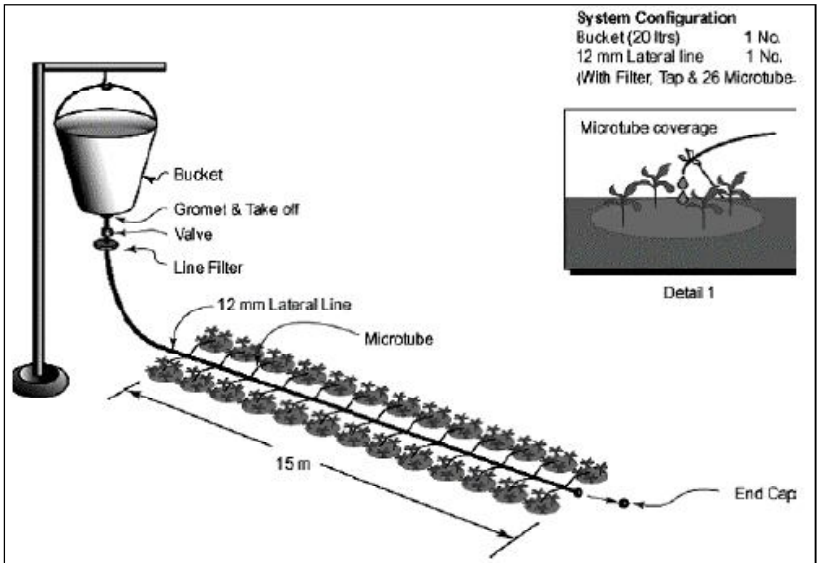

Figure 1 - Bucket kit setup (KARI, 1998).

plastic lateral line for each row of crops, these systems consist of movable lateral lines, each of which irrigates ten rows.

Drip kit system can be used with a bucket or a drum (Figure 1). The drum or bucket is placed at least 1 meter above the ground so that water flows by gravity. They are simple, inexpensive and make a big difference in the lives of many families in Kenya (KARI, 1998). Water flows down from the bucket through the filter lines then drips into the soil next to the plants. This system makes efficient use of precious water. The kit also comes with instructions on how to make raised beds that contain local materials such as green manure and animal manure to provide cheap sources of plant nutrition.

Crop production

Rice is the third most important staple food in Kenya after maize and wheat. It forms part of the larger diet for urban population. About 95% of the rice in Kenya is grown under irrigation in paddy schemes managed by the National Irrigation Board (NIB). The remaining 5% of the rice is rain fed. The average unit production under irrigation is 5.5t ha^{-1} for the aromatic variety, and 7t ha^{-1} for the non-aromatic varieties. Unit yield for rain fed is slightly below 2t ha^{-1}.

For the rice grown under irrigation, three major types of irrigation are practiced, which include smallholder, private commercial and government management schemes. Smallholder schemes grow mainly food crops and vegetables. The government-managed schemes grow mainly rice with tenant plot holders on 1.6ha plots. In addition, one of the areas in the country with the greatest potential for irrigation is the Lake Victoria basin although it is currently restricted by the Nile Treaty, signed in the 1920s between the British and Egyptian Governments, from engaging in any major irrigation activity. If properly used the Lake Victoria basin has the potential to feed the East and Central Africa region (EXPORT PROCESSING ZONES AUTHORITY, 2005).

Sugarcane production in Kenya is heavily dependent on rainfall, a fact that exposes the industry to vagaries of weather. Consequently, there is over production of cane in years after heavy rainfall and shortage in years after drought. The most obvious response to drought is irrigation and this has been tried out in the past in the Nyando Region. The National Irrigation Board had over 1000ha of furrow-irrigated cane in Ahero and West Kano Irrigation Schemes in the 70's but sugarcane production was terminated in 1980 due to marketing problems. According to available unpublished reports, yields of 260t ha^{-1} were obtained for a variety called NCO 293. The other sugarcane irrigation worth mentioning is the Chemelil Sugar Company, which has 500ha of irrigated cane. From these, 400ha are sprinkler-irrigated while 100ha is furrow-irrigated. According to National Irrigation Board irrigation is an essential commodity in humid areas such as the Nyando Region, in which cane yields have to be increased or at least maintained.

A field coffee irrigation study was conducted to investigate 25 trees and to verify the feasibility of developing irrigation methods for smallholder coffee farms using basins and readily available packaging materials such as polythene bags,

bottles and plastic containers. All treatments, except the polythene bag, resulted in significant yield increases. The best overall treatment (0.5x0.5x0.2m basin supplying water to four trees) resulted in 4672kg clean coffee per ha equivalent to 6.3kg cherry per tree. The non irrigated control resulted in 1003kg clean coffee per ha (2.4kg cherry per tree). The results are discussed. It is concluded that the smallholder yields can be substantially increased by using materials that are readily available in their homes (GATHAARA, 2007).

Fruit and vegetable production

Horticultural Crops Development Authority (HCDA) playssmallholder in the export market, which share 40% of fruit and 70% of vegetables. Fresh produce accounted for about 30% of horticultural exports, and included green beans, onions, cabbages, snow peas, avocados, mangoes, and passion fruit. Flowers exported include roses, carnations, statice, astromeria, and lilies (ENCYCLOPEDIA OF THE NATIONS, 2006). Most producers are small scale farmers which represent 90% of the total production. They are usually located in arid regions of Kenya and produce mostly for domestic market (BAWDEN et al., 2002). Kenya has a well developed policy whose overall objectives are to accelerate the rate of horticultural growth. One of these policies is to promote development in arid and semi-arid areas through horticultural production under irrigation, but the supply of electricity is inadequate. There are frequents power rationing and blackouts, which adversely affects horticultural production in areas of irrigation, cold storage and processing. Water for irrigation and processing is a limiting factor in horticulture, because the quantity supplied is insufficient and the quality is not assured. The availability and supply of water is a major constraint. According to the Ministry of Agriculture the top seven fruits in Kenya in terms of area and total production are bananas, citrus fruits, mangoes, avocados, passion fruits, pineapples and papaws. Rain fed production is available in a small portion of the country – this leads to low and seasonal production. Almost all horticultural production, especially for export is done by some method of irrigation and in addition to drip (for large/medium farms) there exists simple technologies which are: furrow and basin irrigation; flooding; overhead; watering cans and simple drips.

Water is usually diverted from small perennial streams by gravity up to the plots. Farmers are generally organized to implement such scheme, and they pay some money for water permit, which cover the construction and/maintenance costs of it. Government policy exists to encourage water supply schemes; monitor and protect water supply sources against pollution; make better use of the water available ; improve and encourage water harvesting; construct rivers dam for irrigation; and preserve water for catchment areas.

Vegetable production

When compared to other countries, vegetable production in Kenya is still very low. This is because in the developed countries, production of vegetables is usually characterized by use of newly developed technologies such as fertigation in greenhouses e.g. in Israel (MUENDO & TSCHIRLEY, 2004). Hence most weather factors are controllable, production is evened out through the year and output per unit of land is relatively high. This is in contrast with production conditions in Kenya where it is usually rain-fed and takes place at almost one point in time. Most farmers doesn´t have knowledge about skills on production techniques. This has resulted in low yields compared to other world producers as well as frequently low quality produce.

Flower farming

Kenya's flower industry is the oldest and largest in Africa. Kenya is the world's largest producer and exporter of pyrethrum, a flower that contains a substance used in pesticides. (ENCYCLOPEDIA OF THE NATIONS, 2006).The success of cut flower is attributed to a combination of factors including Kenya's natural advantages related to its location on the equator, in which the ideal agro-climatic conditions associated with localized irrigation systems can favors production of flowers during the whole year. There is also active participation of a robust private sector and favorable government policies (BOLO, 2007).

Lake Naivasha is the only fresh water lake in the whole Rift Valley region. Flower growing requires a lot of water for irrigation and the presence of Lake Naivasha attracted many farmers to this region. Besides the lake, there are lots of underground water resources (aquifers) which the farms drill to use for localized irrigation systems (BOLO, 2007). There is also availability of large farm for large scale commercial production with suitable soils as well as proximity to Jomo Kenyatta International Airport (JKIA), Nairobi.

Opportunities and constraints for adoption of affordable irrigation technology

Sustainability of irrigation systems has been discouraged in both countries especially those funded through the government. This has been attributed to

negative political influence, poor water management, low priorities in irrigation, inadequate credit and financing to irrigation projects, lack of markets for the products as well as, unclear government policies. These constraints have led to collapse of projects, under utilization of resources, illegal water abstraction, little involvement of stake holders especially women as well as financial mismanagement (SHAH et al., 2000). In addition to farmers negative attitude of not being willing to share costs hence, the project performance is poor. To address the constraints there is a need to adopt participatory and implementory approaches through consulting, coordinating and collaborating with all stake holders. Farmers are sensitized to enhance participation through leadership training and project management. They are encouraged to establish revolving funds and integration of women in making decisions (IPTRID-FAO 2000).

Despite of having well trained and competent technical officers and extension workers there is need for continual professional upgrading and updating. The lack of motivation due to large work-loads and insufficient financial resources is compounded by the lack of professional in-service training. Technical officers and extension workers are often not able to apply what they know due to a lack of resources nor are they able to keep up-to-date with ideas and field-on technology applications. Appropriate training and awareness building at all levels are being programmed and implemented (NGIGI et al., 2005).

CONCLUSION

Republic of South Africa and Kenya still have few irrigated areas of 9% and 3% of total cultivated area, respectively. The challenge of realizing food security is still far from reality. However Kenya has a higher potential of rain fed production as it has an average annual rainfall of 630mm as compared to South Africa which has 495mm. In both countries, grain and cereals are main crops with maize as the staple food. While there are several efficient water irrigation systems, those used in the two countries are mainly traditional furrow and overhead sprinkler systems, which use too much of the limited water resources. The irrigation sector has focused on large scale canal projects that deliver large quantities of water, large groundwater projects and high pressurized sprinkler and drip systems that are too expensive for small holders. The missing piece in global irrigation is systems designed for poor farmers and for small plot farms.

REFERENCES

BRUINSMA, J.E. **World agriculture: towards 2015/2030**. London: Earthscan, 2003. 432p.

BAWDEN, R. et al. **Increasing rural household incomes in Kenya through horticulture - A design proposal.** Washington DC.: A report prepared for USAID, 2002. 67p.

BOLO, M. **The case of Lake Naivasha cut flower cluster in Kenya.** Washington DC.: The World Bank, Washington DC, 2007. 16p.

CENTER FOR AFRICAN STUDIES. Country information**. University of Illinois Site**, Champaign, 2009. Available at: <http://www.afrst.illinois.edu/abroad/index.html>. Access: Nov. 30, 2009.

CORNISH, G.A. **Modern irrigation technologies for smallholders in developing countries.** Wallingford: ITDG, 1998. 96p.

ENCYCLOPEDIA OF THE NATIONS. **South Africa**, Pretoria, 2006. Available at: <http://www.nationsencyclopedia.com/Africa/South-Africa.html>. Access: Oct. 22, 2009.

EXPORT PROCESSING ZONES AUTHORITY. **Grain production in Kenya**. Nairobi, 2005. Available at: http://www.epzakenya.com/UserFiles/File/GrainReport.pdf. Access: Apr. 22, 2010.

FAO. **Socio-economic analysis and policy implications of the roles of agriculture in developing countries**. Rome, 2004. 12p. (Research Programme Summary Report).

FAO. **Food security in Africa**. Rome, 2002. 51p. (Water Reports, n.7).

FAO. **Irrigation in Africa in figures: aquastat survey 2005**. Rome, 2005. 89p. (FAO Water Report n. 29).

GATHAARA, M.P.H. **Smallholder coffee irrigation research in Kenya**. Ruiru: Coffee Research Station, 2007. Available at: <http://www.asic-cafe.org/pdf/abstract/18_064.pdf>. Access: Apr. 22, 2010.

IPTRID-FAO. **Low cost drip and sprinkler irrigation for small farmers: a briefing note on micro irrigation.** Pretoria: International Programme for Technology and Research in Irrigation and Drainage, 1998. Available at: <http://www.fao.org/landandwater/iptrid/en/Involvement.html>. Access: Nov. 28, 2009.

IPTRID-FAO. **Affordable irrigation technologies for smallholders: opportunities for technology adaptation and capacity building in south Africa**. Pretoria: International Programme for Technology and Research in Irrigation and Drainage, 2000. Available at: <http://www.fao.org/landandwater/iptrid/en/Involvement.html>. Access: Nov. 28, 2009.

IPTRID-FAO. **Poverty reduction and irrigated agriculture**. Rome, 1999. 22p. (FAO Water Reports n.01).

KARANJA, F.K, MUTUA, F.M. **Reducing the impact of environmental emergencies through early warning and**

preparedness: impacts of the 1997–98 El Niño events in Kenya. Nairobi, 2004. Available at: <www.unu.edu/env/govern/elnino/countryreports/pdf/kenya.pdf>. Access in: Oct. 21, 2009.

KELLER, J., BLIESNER, R. **Sprinkle and trickle irrigation**. New York: Van Nostrand Reinhold, 1990. 652p.

KARI - KENYAN AGRICULTURAL RESEARCH INSTITUTE. 1998. **Simple drip irrigation makes a big difference on small farms**. Kenya National Research Report, Nairobi. Available at: <http://www.kari.org/index.php?q=content/irrigation-and-drainage-research-program>. Access: Oct. 21, 2009.

KULECHO, I.K. Issues of irrigation of horticultural crops by smallholder farmers in Kenya. **Irrigation and Drainage System**, v.20, n.2-3, p.259-266, 2006. Avaiable at: <http://www.springerlink.com/content/a9158547393834u3/>. Access: Nov. 12, 2009. doi: 10.1007/s10795-006-9006-y.

LCCS - LIBRARY OF CONGRESS COUNTRY STUDIES. 1996. **World fact book South Africa climate and rainfall**. Available at: <http://www.photius.com/countries/south_africa/climate/south_africa_climate_climate_and_rainfall.html>. Access: Nov. 08**,** 2009.

LECLER, N.L. et al. **Performance of irrigation systems and water use of sugarcane: a field to catchment scale perspective**. Durban: Congress of the South African Sugar Technologists Association, 2007. Available at: <http://issct.intnet.mu/ComAgric2007.htm>. Access: Apr. 21**,** 2010.

MINISTRY OF FINANCE. **Intergovernmenta8l fiscal review 2001.** Pretoria: National Treasury, 2001. Available at: <http://www.hst.org.za/indicators/Finance/FiscalReview_2001.pdf>. Access: Nov. 09, 2009.

MOSE, L.O. **Factors affecting the distribution and use of fertilizer in Kenya: a preliminary assessment**. Egerton: Edgerton University, Tegemeo Institute of Agricultural Policy and Development, 1998. Avaiable at: <http://www.aec.msu.edu/fs2/kenya/Dist_use_fert.pdf> 1998. Access in: Nov. 12**,** 2009.

MUENDO, K.M.; TSCHIRLEY, D. **Improving Kenya's domestic horticultural production and marketing system: Horticultural production**. Egerton: Egerton University, 2004. V.1, p.1-24. (Working Paper n.08/A).

NGIGI, S.N. et al. Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia District, Kenya. **Agricultural Water Management**, v.73, n.1, p.21-41, 2005.

PLAYAN, E.; MATEOS, L. Modernization and optimization of irrigation systems to increase water productivity. **Agricultural Water Management**, v.80, p.100-106, 2006.

POSTEL, S. et al. **Drip irrigation for small farmers.** Avaiable at: <http://www.informaworld.com/smpp content~content=a908074571&db=all>. Access: Nov. 5. 2009. doi: 10.1080/02508060108686882.

POSTEL, S. **Last Oasis: facing water scarcity.** The Worldwatch Environmental Alert Series. New York: Norton & Company, 1997. Avaiable at: <http://books.wwnorton.com/books/Last-Oasis/>. Access: Nov. 5, 2009.

SHAH, T. et al. **Pedaling out of poverty: social impact of a manual irrigation technology in South Asia**. New Delhi**:** International Development Enterprises (IDE), 2000. 46p. Avaiable at: <http://www.ideorg.org/OurStory/Pedaling_Out_of_Poverty.pdf>. Access: Out. 15, 2009.

TERREBLANCHE, S. **A history of inequality in South Africa 1652-2002.** Pietermaritzburg: University of Natal Press & K M Publishing, 2002. 527p.

VAN TONDER, G.; DENNIS, I. **Catchment, aquifer and groundwater balance**. Bloemfontein: Course on groundwater and the National Water and Water Services Acts. Institute for. Groundwater Studies, University of the Free State, 2000. Avaiable at: <http://www.uovs.ac.za/faculties/content.php?id=6951&FCode=04&DCode=109>. Access: Out. 15, 2009.

WATER RESEARCH COMMISSION (WRC). **Making the difference: Improving Agricultural Water Management**. Pretoria, 2000. 7p. (Water Research Commission Report n.127/00).