

Review

Overview of smallholder irrigation schemes in South Africa: Relationship between farmer crop management practices and performance

M. Fanadzo, C. Chiduza* and P. N. S. Mnkeni

Department of Agronomy, Faculty of Science and Agriculture, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa.

Accepted 26th October, 2010

Irrigated agriculture accounts for almost 30% of total crop production and is the single largest user of water in South Africa. The country is water-scarce, and, although water consumption through irrigation has decreased from 80 to about 50% over the past 25 years, the need to improve water use efficiency in irrigation farming is more imperative than ever. Generally, smallholder irrigation schemes (SIS) in South Africa have performed poorly and have not delivered on their development objectives of increasing crop production and improving rural livelihoods. The poor performance of many SIS in terms of productivity and economic impact has been largely attributed to socio-economic, political, climatic, edaphic and design factors, as well as lack of farmer participation. Research and expenditure has tended to concentrate on rehabilitation of irrigation infrastructure, but evidence indicate low yield levels and limited knowledge of crop production among farmers as probably the main reasons for the failure of many SIS in South Africa. The tendency to focus on infrastructure has often yielded little and proved to be fruitless because the human capital was not developed to effectively utilise and maintain the infrastructure. This indicates that farmer practice may actually be constraining performance in spite of the state of irrigation infrastructure. It is therefore recommended that crop production approaches including farmer training be considered alongside all other issues during revitalisation of SIS to improve on performance.

Key words: Smallholder irrigation schemes, performance, cropping systems, farmer management practices, revitalisation.

INTRODUCTION

Performance of smallholder irrigation schemes

Over the years, many smallholder irrigation schemes (SIS) have been established in South Africa in order to gain accessibility to productive land and increase production in the different regions of the country. The primary goal of establishing these schemes was to improve rural livelihoods through sustainable crop production for food security and poverty alleviation (FAO, 2001). Studies on SIS in South Africa, however, indicate that the development objectives of SIS remain largely

unfulfilled (van Averbek et al., 1998; Bembridge, 2000; Fanadzo et al., 2010). As such, the benefits of irrigation have not been realised in the smallholder sector of South Africa. The inability of these schemes to bring about the expected social and economic development has raised doubts about irrigation being a suitable option for rural development. This is in contrast to the international scene where irrigated agriculture is still recommended as an appropriate way of addressing rural poverty and unemployment in areas where sustained rain-fed production of crops is limited by water deficits (Lipton, 1996).

The poor performance of many SIS in terms of productivity and economic impact has been largely attributed to socio-economic, political, climatic, edaphic

*Corresponding author. E-mail: cchiduza@ufh.ac.za.

and design factors, as well as lack of farmer participation (Bembridge, 2000). However, Crosby et al. (2000) cited low yield levels as probably the main reason for the failure of many SIS in South Africa, indicating that farmer practice may actually be constraining performance in spite of the state of irrigation infrastructure. At the same time, limited knowledge of crop production among farmers has been identified as one constraint to improved crop productivity in SIS (Machethe et al., 2004; Fanadzo et al., 2010). In this regard, Denison and Manona (2007a) recommended that crop production approaches including farmer training be considered alongside all other issues during revitalisation of SIS to improve on performance. However, little research has been carried out to link agronomic practices to productivity in order to establish best management practices. Indeed, De Lange et al. (2000) noted that research and expenditure had tended to focus on infrastructure, and that often this proved to be fruitless because the human capital was not developed to effectively utilize and maintain the infrastructure.

In the former Ciskei for instance, a number of SIS were planned and established following a centralised estate design whereby control over farming activities and decision making was strictly enforced by central management with little or no input from farmers. This created a high level of dependency among farmers in the schemes and poor performance when farmers were left to manage the schemes on their own.

Experience elsewhere in sub-Saharan Africa has shown that SIS can succeed if farmers participate in design and management (FAO, 2000). As a result of these positive African experiences, the South African government policy has gradually moved towards entrusting more responsibilities to smallholder farmers to manage SIS. The objective of this review was therefore to provide an overview of the development of smallholder irrigation schemes in South Africa, with an emphasis on the relationship between management practices and performance.

Definition of smallholder irrigation in the South African context

South Africa has about 1.3 million ha of land under irrigation of which about 0.1 million hectares is in the hands of smallholder farmers (Perret, 2002; Backeberg, 2006; van Averbek, 2008). In order to describe the smallholder irrigation sector, one needs to have a good understanding of who the smallholder farmer is. The term 'smallholder' is widely used on the assumption that there is a common understanding of what it means. Despite widespread reference to smallholder farming in agricultural and rural development literature, few analysts attempt to define or describe the smallholder farmer. Terms used to describe smallholder farmers include small-scale farmers, resource-poor farmers, peasant

farmers, food-deficit farmers, household food security farmers, land-reform beneficiaries and emerging farmers (Machethe et al., 2004).

The main criteria often used to classify farmers as smallholders by various analysts include land size, purpose of production (subsistence or commercial), income level (whether poor or rich), and, in South Africa, racial group (whether one is black or white and, thus, historically disadvantaged or advantaged, respectively). Various definitions have been used to describe smallholder farmers in South Africa (Machethe et al., 2004; Botha and Treurnich, 1997; The Farmer Support Services Working Group, 1997; Catling and Saaiman, 1996; Van Zyl et al., 1991; Eicher, 1990).

In the South African context, smallholder farmers are defined as black farmers most of whom reside in the former homelands. It is also noted that not every black farmer is a smallholder farmer and smallholder farmers are not a homogenous group (Machethe et al., 2004). The heterogeneous nature of smallholder farmers is apparent from the definitions of farmers given by the various analysts. However, despite the recognition that smallholder farmers in South Africa are heterogeneous, there are no clear criteria for assigning farmers to the different categories of smallholder farmers. Thus, it is not clear why one category of farmers is different from the other. In addition, the number and needs of farmers in the different categories are not known (Machethe et al., 2004). In this review, the term 'smallholder' is used as described by Lahiff and Cousins (2005):

"There is no standard definition of a smallholder, but the term is generally used in the South African context for producers who are black and otherwise distinct from the dominant (and white dominated) large-scale commercial sector. No clear distinctions can be drawn between categories such as smallholder, small-scale, subsistence, communal or emergent ..."

'Smallholder' recognises a characteristic of small farm size and a partially developed link to the larger economic system. Smallholder farmers are usually affected by prices, subsidies and markets, but the input and output markets, which are not fully formed, remain localised to some extent. This distinguishes smallholders from commercial enterprises, both large scale and family farms, which have access to fully formed external markets (Ellis, 1998). Smallholder irrigators in South Africa have been categorised into four groups (Crosby et al., 2000; Du Plessis et al., 2002; van Averbek, 2008), namely (i) farmers on irrigation schemes; (ii) independent irrigation farmers; (iii) community gardeners; and (iv) home gardeners. According to Backeberg (2006), there are 200 000 to 250 000 smallholder irrigators contained in these four groups. This review is concerned with one group of smallholder irrigators, namely those operating on irrigation schemes.

Table 1. Major smallholder irrigation schemes established during the homeland era in the Eastern Cape Province of South Africa.

Irrigation scheme	Irrigated area (ha)	Area per farmer (ha)	Number of farmers	Irrigation system	Year of establishment
Zanyokwe	439	4.2	61	Sprinkler	1984
Tyefu	641	0.4	1678	Sprinkler/drag	1983
Keiskammahoek	744	5.1	147	Sprinkler	1976
Shiloh	455	1.6	278	Centre pivot/sprinkler	1970
Qamata	1959	2.0	1000	Flood	1968
Ncora	2490	9.2	272	Sprinkler/drag	1976

Source: Fanadzo (2010).

Size and distribution of SIS in South Africa

South African SIS can be defined as multi-farmer irrigation projects larger than five ha in size that were established in the former homelands or in the resource-poor areas by black people or agencies assisting their development (van Averbeke, 2008). These schemes are under local responsibility, controlled and operated by the local people in response to their felt needs, and using a level of technology which they can operate and maintain effectively (Underhill, 1984). Such schemes vary in size, both in terms of the number of farmers supported by a particular scheme and the size of the scheme. Examples of such schemes from the Eastern Cape Province are presented in Table 1.

There are more than 330 SIS covering approximately 50 000 ha of land and these are located mainly in the former homelands (Denison and Manona, 2007b). Most of these either have collapsed or are utilised well below their potential (ibid.). Seventy-nine percent of the SIS are located in the Eastern Cape, KwaZulu-Natal and Northern Provinces. Smallholder irrigation in Mpumalanga province largely comprises of emerging commercial farmers, most of who are involved in sugarcane production (Bembridge, 2000). In the Free State province, smallholder irrigation is restricted to small schemes in Qwa Qwa area, as well as a few peri-urban areas near larger towns, which are more in the nature of communal gardens (Mukhela and Groenewald, 1998).

Development of SIS in South Africa: History and current status

Several eras have been identified in South African SIS development (van Averbeke, 2008). These are the peasant and mission diversion scheme era, the smallholder canal scheme era, the homeland era, and the irrigation management transfer (IMT) and revitalization era.

The peasant and mission diversion scheme era

Early smallholder irrigation development, which occurred during the 19th century in the Cape Colony, was the

result of technology transfer from colonists to the local people (van Averbeke, 2008). This era was associated with mission activity and the emergence of African peasantry in the Eastern Cape. Smallholder irrigation developments were private initiatives and the technology used (river diversion) was similar. In terms of area brought under irrigation, the peasant and mission diversion era was not very important and much of what was developed had ceased to function by the end of the 19th century (van Averbeke, 2008).

The smallholder canal scheme era

This second era of the development of canal irrigation schemes lasted from about 1930 until about 1960. The schemes were primarily aimed at providing African families residing in the "Native or Bantu Areas" with a full livelihood based on farming. According to van Averbeke (2008), at least 18 200 ha (37%) of the existing SIS were developed during the smallholder canal scheme era (Table 2).

Typically, the irrigation schemes that were established during this era obtained water from a river by means of concrete weir diversion but schemes using storage dams were also built. The plot size on these schemes was considerably smaller than the 8-20 ha plots that were allocated to white settler farmers during the same period. The difference between the plot size allocated to white and African farmers suggests that irrigation farming proceeded under the assumption that African families required less land (and income) to attain a full livelihood than white farmers did. Trust tenure was imposed on these farmers, and they held their plots by means of permission to occupy. Trust tenure provided the state with the necessary powers to prescribe land use and to expel and replace farmers whose practices did not comply with these prescriptions. In some cases, the state effectively used these powers to enforce the overall objectives of the scheme by evicting poorly performing families (van Averbeke, 2008).

The homeland era

This third era lasted from about 1960 until about 1990

Table 2. Categorisation of existing smallholder irrigation scheme development in South Africa.

Era	Number of schemes	Area (ha)	Mean area per scheme (ha)	Main irrigation technology used
Smallholder canal scheme (1930-1969)	74	18 226	246	Gravity-fed surface irrigation
Independent homeland (1970-1990)	62	12 994	210	Different forms of overhead irrigation
IMT and revitalization (1990-present)	64	2 383	37	Pump and sprinklers or micro-irrigation
Year of establishment uncertain	117	15 897	136	Mostly overhead irrigation
Total	317	49 505	156	-

Source: van Averbeke (2008).

and was an integral part of the economic development of the homelands, which were all islands of under-development and poverty (Beinart, 2001; van Averbeke, 2008). New irrigation schemes were established with funding from the South African government. The number of existing schemes that date back to this period is probably higher than 64, because much of the 15 897 ha of existing irrigation land that could not be dated (Table 2) was probably developed during this era (van Averbeke, 2008).

Irrigation development during the homeland era was characterized by modernisation, functional diversification and centralisation of scheme management (van Averbeke, 2008). Typical examples of large schemes (> 400 ha) developed during this era were found mainly in the Eastern Cape and included schemes presented in Table 1. With the exception of Qamata, which used canals, the irrigation and farming technology that was implemented on these large schemes was often the most technologically developed available at that time. Even on the smaller schemes established during this era, pressurised overhead irrigation systems were used instead of surface irrigation (van Averbeke, 2008).

On the large schemes, economic viability was pursued by means of a strategy of functional diversity. The schemes were operated as estates with a central unit, a commercial smallholder function in the form of medium sized plots, also called mini-farms (5-12 ha), and a subsistence function in the form of food plots, ranging from 0.1 to 0.25 ha in size (van Averbeke, 2008). The functional diversity provided rural homesteads with different options to benefit from irrigated agriculture, depending on the structure of their existing livelihood. For example, the mini-farms catered specifically for homesteads that sought full land-based livelihoods. The food plots provided homesteads that derived their livelihood from external sources, such as old-age pensions, while the estate component offered opportunities to members of rural homesteads who were searching for employment and monetary income close to home (van Averbeke, 2008). Management of these large schemes was centralized in the hands of specialized parastatals (Lahiff, 2000).

The large schemes established during the independent

homeland era were very complex and proved very costly to maintain. Social unrest and conflict during the late 1980's and early 1990's further affected their sustainability. Following democratisation of South Africa in 1994, provincial governments decided to dismantle the agricultural homeland parastatals they had inherited. This decision particularly affected the large schemes. This was because they were the most complex and had been centrally managed from inception, resulting in exceptionally high levels of dependency among farmers (van Averbeke et al., 1998). Partial or total collapse of production followed this decision almost immediately (Bembridge, 2000; Laker, 2004).

The irrigation management transfer and revitalisation era

The most recent or current era in South African smallholder irrigation development can be referred to as the irrigation management transfer (IMT) and revitalisation era. IMT refers to the transfer of the responsibility of managing, operating and maintaining irrigation schemes from the government to the farmers (van Averbeke, 2008). The process of IMT includes government withdrawal, formation of water users associations, development of local management institutions, and transfer of ownership and management (Perret, 2002). Revitalisation is a holistic development philosophy that aims for socially uplifting, profitable agribusiness on existing irrigation schemes and in the communities surrounding the schemes (Denison and Manona, 2007a). It is characterised by whole enterprise planning, human capital development, access to information, and is underpinned by a financially sustainable development strategy alongside repair and re-design of existing infrastructure (ibid.). South Africa has just cautiously initiated IMT in government SIS in the former homelands, and most transfer operations are still unsure how to design and implement the process.

CROPPING SYSTEMS IN SOUTH AFRICAN SIS

The International Rice Research Institute (IRRI, 1978)

defines a cropping system as the crop production activity of a farm, comprising all cropping patterns and their interaction with farm resources, other household enterprises and the physical, biological, technological and sociological factors or environments. It may comprise a number of cropping patterns and involve the production of several crops with components required for the production of a particular crop and their relationships with the environment. Soil and water management are key elements in the management of irrigated cropping systems, both for sustainability and productivity.

Production is the most obvious output and measure of the performance of a cropping system (FAO, 1995). It can be measured as the biological or economic output from the system either as the yield or income generated. It is a measure of the efficiency of the management of the cropping system and can be related to productivity, measured as output per unit of input (FAO, 1995). Therefore, a sustainable cropping system is one that maintains resources, such as soil and water, while providing an adequate and economic level of production, both now and for future generations (Hoare, 1992).

Cropping patterns

The term, cropping pattern, has been defined in different ways. For example, FAO (1996) defines cropping pattern as the spatial representation of crop rotations. Bontkes and van Keulen (2003) define it as the spatial arrangement of crops in an area as a result of climate, soil, available facilities and socio-economic factors, without including yearly crop sequences in the concept. Other concepts do not include the spatial location in the definition. They consider cropping patterns as a list of crops that are produced in an area and their sequence within a year (Sarker et al., 1997), or just as the list of typical crops without considering their spatial distribution or sequence (Singh et al., 2001, Bigman and Srinivasan, 2002). For purposes of this study, cropping patterns will be taken to include both the spatial distribution of crops as well as their sequence over time.

The cropping pattern generally employed in SIS in South Africa is alternate summer and winter cropping for both field and vegetable crops. A wide range of field and vegetable crops are grown in South African SIS. Field crops include maize, wheat (*Triticum aestivum*), cotton (*Gossypium hirsutum*), sugarcane (*Saccharum officinarum*), sugar bean (*Phaseolus vulgaris*), sweet potato (*Ipomoea batatas*), and Irish potato (*Solanum tuberosum*). Vegetable crops include cabbage (*Brassica oleracea* var. *capitata*), tomato (*Lycopersicon esculentum*), carrot (*Daucus carota*), beetroot (*Beta vulgaris*), onion (*Allium fistulosum*), pumpkin (*Cucurbita mixta*), butternut (*Cucurbita moschata*) and spinach (*Ipomoea oleracea*). Maize is the most important summer crop in terms of the area devoted to the crop and number

of growers (Perret et al., 2003; Machethe et al., 2004; Monde et al., 2005), while cabbage and/or wheat are the dominant winter crops, depending on province. Maize is grown for utilisation as green cobs (table maize), grain or both.

In a study of six SIS in the Eastern Cape, van Averbeke et al. (1998) observed that in schemes with standard food plots, farmers either practiced a rotation of maize and cabbage or maize and potato, or monoculture maize on part of the land and a rotation of cabbage and potatoes on the rest. In general, yields tended to be higher in newer than old schemes. Inappropriate farming practices such as poor weed control, low plant populations and inadequate pest control generally contributed to low yields (Bembridge, 2000).

FARMER CROP PRODUCTION PRACTICES IN RELATION TO PRODUCTIVITY

Planting density and crop mix

Achieving optimum plant population for a given set of environmental conditions is an important management factor to be considered in order to achieve optimum crop yields. Taking maize for instance, optimum population is known to vary according to level of soil fertility, moisture status, cultivar grown and planting time (Sangoi, 2000). Generally, under irrigation, the practice in South Africa is to grow short-season cultivars at a population of 80 000 to 90 000 plants ha⁻¹ and 40 000 to 60 000 plants ha⁻¹ for medium to long-season cultivars. However, observations in Zanyokwe irrigation scheme (Fanadzo et al., 2010) indicated that farmers used a standard population of 40 000 plants per hectare for all their maize production and were as a result be compromising on yield and income. In a study of SIS in the Northern Province, Bembridge (2000) reported that the low yields obtained by farmers were partly as a result of inappropriate cultural practices, with low planting populations being one of them. However, the report did not quantify the achieved plant stands, making it difficult to relate seed rates to crop productivity.

The higher yield potential made possible by the favourable water regime provided by irrigation, the high soil fertility levels resulting from heavy application of fertilisers, and the genetic potential of new varieties and hybrids can be achieved only with appropriate adjustments to plant population.

Plant density has a direct effect on yield, capture of photosynthetically active radiation, evaporation and shading of weeds (Murphy et al., 1996; Zimdahl, 2007; Sangoi, 2000), and thus an indirect effect on water use efficiency (WUE). Plant population and planting pattern influence WUE indirectly by influencing the interception and utilisation of incident solar energy that in turn influences crop yields.

Nutrient management

Irrigation imposes a great demand for fertiliser nutrients and most crops grown in SIS are high value vegetable crops that take large quantities of nutrients from soils. Nutrient management becomes very important given that soils in the Eastern Cape are already highly impoverished (Mandiringana et al., 2005). Cabbage for instance, which is one of the most common vegetable crop under smallholder irrigation in South Africa, is a heavy feeder on fertiliser nutrients, except phosphorus and heads will not form unless adequate nitrogen (N) is applied. The recommended total amount of N for cabbage is 160 to 260 kg ha⁻¹ (FSSA, 2007). Provision therefore must be made to replace nutrients removed by these heavy feeders for farmers to continue realizing profitable yields. Incorporation of leguminous crops in rotation would help add N to the soil and this may result in increases in crop productivity and production.

The study by Monde et al. (2005) showed that some farmers in Zanyokwe irrigation scheme applied fertiliser once in two or three years due to lack of cash. The same study indicated that at Tugela Ferry irrigation scheme in KwaZulu-Natal, most farmers tended to apply unspecified amounts of basal fertilisers and very few applied topdressing fertiliser. In the Limpopo province, Machete et al. (2004) noted that farmers applied blanket amounts of inorganic fertilisers and these were usually marginal, especially for the field crops, but no quantification of the rates used was given.

The application rates were usually not based on soil fertility analysis and recommendations. Farmers cited lack of information on fertility recommendations and funds as the main reasons for resorting to low blanket applications. The analysis of soil fertility status at the schemes, however, indicated that the soils were adequate in phosphorus and potassium but low in nitrogen (Machete et al., 2004).

A study of Zanyokwe irrigation scheme in the Eastern Cape Province indicated that farmers generally applied low amounts of fertilisers in all crops, resulting in low yields. Poor timing of application was another major cause of low productivity, particularly in butternut (Fanadzo et al., 2010). The same study indicated significant decreases in maize and butternut yields with poor fertility management. For irrigation to be profitable yields must be high and this would translate to greater nutrient uptake by crops. According to Crosby et al. (2000), the interaction of moisture supply and nutrient supply is reciprocal: "if the farmer cannot irrigate, it is a waste to fertilise; if a farmer cannot fertilise, it is a waste to irrigate." Thus, if small-scale irrigation farmers are to realise higher yields, there should be a balance between water application and fertiliser management. Therefore, for cropping systems to remain productive and sustainable, it is necessary to replenish the nutrients removed from the soil.

Crop protection

Weeds, insect pests and diseases are the main biological constraints faced by smallholder farmers. In the Eastern Cape, van Averbeke et al. (1998) established that insects and fungal diseases were the major pests responsible for reductions in crop yields, but the type of pests were not specified and yield reductions were not quantified. However, on two of the schemes studied, small birds feeding on maize were reported to be the main pest problem. Bembridge (2000) also cited inadequate pest control as a factor contributing to low yields in several SIS in South Africa, but again did not quantify the resultant losses.

In Limpopo province, Machete et al. (2004) noted that insect pests faced by farmers in vegetable production included black cutworms (*Agrotis ipsilon*), aphids (*Aphis gossypii*), diamond back moth (*Plutella xylostella*), bagrada bugs (*Bagrada hilaris*) and red spider mites (*Tetranychus urticae*). The report seems to suggest that farmers had the chemicals to control all these pests, but does not clarify how effective the control was, in terms of application time and effectiveness. In addition, it is not clear whether farmers scouted their fields or what determined the need for chemical spraying, that is, whether the pests caused economic damage. The report also states that farmers sprayed butternut with malasol (active ingredient: Malathion) once in two weeks, from transplanting until harvest, without specifying what they were spraying against. Like in many other schemes, weed control on vegetables was exclusively by hand hoeing.

The inability of farmers to control weeds effectively, particularly nutsedge (*Cyperus* spp.) and star grass (*Cynodon dactylon*), was responsible for lower yields at one of the schemes studied by Machete et al. (2004). Studies conducted at Zanyokwe irrigation scheme revealed that inadequate weed control was among the major causes of poor yields (Fanadzo et al., 2010). Weeding was also identified as the activity demanding most labour by 88% of farmers in the six SIS in the Eastern Cape studied by van Averbeke et al. (1998).

Marais (1992), singled out poor weed control as the major cause of poor yields on small farms in the Eastern Cape and this was similarly cited by Bembridge (2000) as one of the main production problems in SIS in KwaZulu-Natal. Most smallholder farmers are aware of the detrimental effects of weeds, but do not have the time or the means to control them especially where tractor mechanisation has resulted in an increased area of land being cultivated (Steyn, 1988). Under such circumstances weeds can rapidly get out of control, especially given that the most commonly used weed control method by smallholder farmers is hand weeding (pulling or hoeing), a method which was described by Chivinge (1990) as slow, labour-intensive, cumbersome and inefficient.

Water use and management

An important aspect of irrigation water management in crop production is to improve water productivity by increasing crop yield per unit of irrigation water applied. Knowledge on irrigation water management and practical irrigation scheduling at scheme level in South Africa is weak (FAO, 2000; Fanadzo et al., 2010). The result is low field irrigation efficiencies irrespective of the irrigation technology in place (surface or sprinkler). Fanadzo et al. (2010) reported that farmers at Zanyokwe irrigation scheme did not practice any irrigation scheduling and they seemed to be ignorant of the dangers of over-irrigation. Farmers irrigated haphazardly with sprinklers running in some cases for more than 24 hours per setting. At Tugela Ferry irrigation scheme in KwaZulu-Natal (furrow irrigation), it was observed that there was high competition for water within and among blocks such that some blocks did not receive water at certain times when they needed it (Monde et al., 2005). The other problems reported by most farmers at Tugela Ferry were that the method of irrigation used (furrow) causes soil erosion and uses a lot of water as it is difficult to measure the exact amount of water to be provided to the crops (Monde et al., 2005).

In Limpopo province, Machethe et al. (2004) showed that low crop productivity was usually attributed to inadequate amounts of water applied to crops. Responses of wetting front detectors (devices used to observe how deep the wetting front has moved) showed that the applied irrigation water in wheat and maize drained up to 30 cm down the soil profile but not at 60 cm when 23 mm of irrigation water was applied. The implication is that the soil profile around the 30 cm depth was well watered but the application rate was not adequate to reach the 60 cm depth. Wheat roots can extract water beyond the 60 cm depth and maize up to 100 cm, indicating that farmers could increase the amount of irrigation water applied.

In the same study by Machethe et al. (2004), farmers tended to apply the same amount of irrigation water regardless of plant growth stage. This could result in over-irrigation during early crop growth stages and under-irrigation during advanced growth stages as the crop water requirements increase. The relatively higher yields at some schemes were attributed to better irrigation facilities and consistency in water application to the crops throughout the growing season. The lowest maize productivity of 1.6 t ha⁻¹ was largely because of the persistent breakdown of the irrigation pump and excessive leakages of the pipelines. The same problem of continuous breakdown of pumps adversely affecting crop growth was reported of Setsipi irrigation scheme in the Northern Province (Mpahlele et al., 2000). However, in the Limpopo Province, excessive irrigation water application was also a factor contributing to poor yields on some of the farmer's fields (Machethe et al., 2004).

Crop cultivars and yields

Higher-yielding cultivars are a pre-requisite to achieving high maize yields as noted by USDA (2003), and the same applies to all other crops. The main explanation for the difference in yield between improved high-yielding and traditional cultivars is the increased rate in which primary plant production is redirected to harvestable products, such as grains (Anonymous, 2009). There is very limited information available from literature on the specific cultivars grown by farmers for the various crops in SIS in South Africa. However, at Zanyokwe irrigation scheme it was found that the most popular varieties traditionally grown by the farmers were open-pollinated varieties (OPVs) amongst a few other recent hybrids (Fanadzo et al., 2009). OPVs are known to perform better than hybrids in below optimum conditions of low rainfall (moisture), but they cannot compete with hybrid maize in performance under irrigation (Belsitio, 2004). This brings into question farmer knowledge and choice of varieties, particularly to suit irrigated farming.

Yields obtained in SIS have generally been observed to be below optimum due to an interaction of factors. Crosby et al. (2000) cite low yield levels as probably the main reason for the failure of many SIS in South Africa. Van Averbeke et al. (1998) reported average maize grain yields of 3.7 t ha⁻¹ in six irrigation schemes in the Eastern Cape. The low yields were attributed by farmers to insect pests and fungal diseases. Birds feeding on vegetables and maize grain were identified as presenting a problem at three of the six irrigation schemes studied. In the Limpopo Province, Machethe et al. (2004) reported maize grain yields ranging 1.6 to 4.2 t ha⁻¹ while wheat yields averaged 4.1 t ha⁻¹. The low yields were attributed to the inability of farmers to effectively control weeds, particularly nutsedge (*Cyperus* spp) and star grass (*Cynodon dactylon*), as well as low fertiliser application levels. In the same study (Machethe et al., 2004) attributed low maize vegetable productivity levels to unreliable water supply caused by persistent breakdown of the irrigation pump and excessive leakages in pipes, and low soil depth, poor soil structure and fertility. Additional constraints to higher productivity levels in some vegetables, notably tomatoes, were diseases and pests that limited the production of good quality products for the market. For example, 30% of the 24 tonne yield of tomato at one of the schemes was considered sub-standard in terms of quality (Machethe et al., 2004).

In the Eastern Cape, KwaZulu-Natal and Northern Provinces, Bembridge (2000) reported that crop yields were extremely variable, with reasonable yields on newly established smaller schemes while on similar early established and larger schemes, yields were extremely poor. Major constraints to improved crop productivity included poor weed management and the general lack of technical skills and experience in the management of crops by the farmers. Few farmers, and for that matter,

extension officers, had an understanding of irrigation scheduling and management, as well as in-field water-use efficiency. In KwaZulu-Natal, poor weed management was the main cause of uneconomic yields (Bembridge, 2000). Other constraining factors included lack of inputs, inefficient irrigation, inadequate draught power and lack of knowledge among other factors.

Information on yields obtained from vegetable crops in smallholder irrigation in South Africa is limited. However, van Averbeke et al. (1998) reported cabbage and potato yields averaging 30 and 9.6 t ha⁻¹ in the Eastern Cape, respectively. With the exception of cabbage with yields, approaching what could be considered as on-farm potential of 40 t ha⁻¹ and the overall mean being about 75% of on-farm potential, the mean yields were relatively low for irrigated conditions (*ibid.*). Potato yields were found to be well below the achievable yield, probably due to low nutrient input and the use of inferior seed at some schemes (van Averbeke et al., 1998). The overall mean of 9.6 t ha⁻¹ for potato is about 25% of what can be realised on-farm. In the Limpopo province, Machethe et al. (2004) reported that vegetable productivity levels in two of the three schemes studied were satisfactory, but no quantification of yield was given.

Land use intensity

Land-use, as expressed in terms of the number of crops that are cultivated on a particular surface area per year or season is termed cropping intensity. Cropping intensity has also been defined as the fraction of the total available land cropped in any given year (Noordwijk, 2002) or the fraction of the arable area that is harvested (Bouwman, 1997). Under irrigated conditions in most parts of South Africa, it is possible to grow two crops per year, which would translate into a cropping intensity of 200% (van Averbeke et al., 1998). However, the study by van Averbeke et al. (1998) showed that the average cropping intensity in six schemes in the Eastern Cape was 113%, which is nearly half of the potential. At Zanyokwe irrigation scheme, farmers achieved an average cropping intensity of 48% (Fanadzo et al., 2010). These results show that the land is not used as intensively as it could be. The same study showed that cropping intensity was related to plot size, with higher intensities at smaller plots than at larger plots (more than one ha). This would suggest that larger plots are too large to handle within the constraints of the smallholder farmers' current farming system noted earlier in this review.

A study of the Bululwane and Thukela irrigation schemes in KwaZulu-Natal (Bembridge, 2000) revealed that approximately 80 and 70% of the 345 and 550 ha schemes, respectively, was not being utilised due to lack of motivation and resources. In the Northern Province, Mphahlele et al. (2000) noted that only about 300 ha out of a total of 2 012 ha (a mere 15%) in the Arabie-Olifants

River irrigation scheme were cultivated. Agricultural and Rural Development Corporation's inability to provide credit for inputs and maintenance for pumping equipment due to significant budget cuts was cited as the major reason for this. In Thabina irrigation scheme, Perret et al. (2003) observed that 42% of the total land area was unused because the plot holders were not interested in farming. Also evident from the study was the fact that, despite the small average plot size, even active farmers did not crop their whole land, hence additional land was left unused in the scheme.

Conclusions

This review has demonstrated that the poor performance of SIS in South Africa is largely related to poor crop production practices (soft components) at the plot level. It is evident that farmer management with regards to crop production falls far short of expectations, and poor performance can be related to poor crop yields caused by inappropriate management of basic cultural practices such as planting density, nutrient and water management, and inadequate crop protection. In addition, whilst one of the objectives of irrigated farming is to increase cropping intensity from the levels attained under rain-fed conditions, the review has indicated that irrigation has regrettably not translated to higher land use intensities. There is need to conduct situation analyses of individual SIS in order to come up with major themes in terms of constraints, and then address the specific problems with the participation of resident farmers.

ACKNOWLEDGEMENTS

This review was carried out as part of research work funded by the Water Research Commission through WRC Project No. K5/1477//4.

REFERENCES

- Anonymous (2009). High yielding varieties versus traditional cultivars. [Online]. Available at http://en.wikipedia.org/wiki/High-yielding_varieties. [Date of access: 22/05/2009].
- Backeberg GR (2006). Reform of user charges, market pricing and management of water: problem or opportunity for irrigated agriculture. *Irrigation and Drainage* 55 (1), 1-12.
- Beinart W (2001). *Twentieth century South Africa*. Oxford University Press, New York, USA.
- Belsitio AM (2004). Open pollinated corn cultivar trials and a discussion of the practical implications for open pollinated corn in small-scale whiskey Production. MSc thesis, Cornell University, p. 44.
- Bembridge TJ (2000). Guidelines for rehabilitation of small-scale farmer irrigation schemes in South Africa. WRC Report 891/1/00. Water Research Commission, Pretoria, South Africa.
- Bigman D, Srinivasan PV (2002). Geographical targeting of poverty alleviation programs: Methodology and applications in rural India. *J. Policy Modelling* 24: 237-255.
- Bontkes TS, van Keulen H (2003). Modelling the dynamics of agricultural development at farm and regional level. *Agric. Syst.*

- 76: 379–396.
- Bouwman AF (1997). Long-term scenarios of livestock cropland use interactions for the assessment of environmental indicators in developing countries. In: Land and Water Bulletin No. 5. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Botha CAJ, Treurnicht S (1997). Converting South African state extension services: a sustainable development framework. South Afr. J. Agric. Exten., 26: 31-52.
- Catling D, Saaiman B (1996). Small-scale farmers and growers in the Western Cape: the challenge of providing appropriate extension services. In: L. Lipton, M. de Klerk, M. Lipton (Eds.). Land, labour and livelihoods in rural South Africa, Volume 1 (pp 159-176). Durban: Indicator Press, University of KwaZulu-Natal, South Africa.
- Chivinge OA (1990). Weed science technological needs of the communal areas of Zimbabwe. *Zambezia* xv (ii), pp.133-143.
- Crosby CT, De Lange M, Stimie, CM, Van der Stoep I (2000). A review of planning and design procedures applicable to small-scale farmer irrigation projects. WRC Report 578/2/00. Water Research Commission, Pretoria, South Africa.
- De Lange M, Adendorff J, Crosby CT (2000). Developing sustainable small-scale farmer irrigation in poor rural communities: guidelines and checklists for trainers and development facilitators. WRC Report 774/1/00. Water Research Commission, Pretoria, South Africa.
- Denison J, Manona S (2007a). Principles, approaches and guidelines for the participatory revitalisation of smallholder irrigation schemes. Volume 1 – A rough guide for irrigation development practitioners. WRC Report TT 308/07. Water Research Commission, Pretoria, South Africa.
- Denison J, Manona S (2007b). Principles, approaches and guidelines for the participatory revitalisation of smallholder irrigation scheme. Volume 2 – concepts and cases. WRC Report TT 308/07. Water Research Commission Pretoria, South Africa.
- Du Plessis FJ, Van der Stoep I, Van Averbek W (2002). Micro-irrigation for smallholders: guidelines for funders, planners, designers and support staff in South Africa. WRC Report TT 164/01. Water Research Commission Pretoria, South Africa.
- Eicher CK (1990). Africa's food battles. In: C.K. Eicher, J.M. Staatz (Eds.). *Agricultural development in the third world*. Baltimore: The Johns Hopkins University Press, pp. 503-530.
- Ellis F (1998). Household strategies and rural livelihood diversification. *J. Develop. Studies* 35 (1): 1-38.
- Fanadzo M (2010). Improving productivity of maize-based smallholder irrigated cropping systems, a case study of Zanyokwe irrigation scheme, Eastern Cape, South Africa. PhD Thesis, University of Fort Hare, South Africa, pp. 385
- Fanadzo M, Chiduzo C, Mnkeni PNS (2009). Investigation of agronomic factors constraining productivity of grain maize (*Zea mays* L.) at Zanyokwe irrigation scheme, Eastern Cape, South Africa. *J. Appl. Biosci.*, 17: 948-958
- Fanadzo M, Chiduzo C, Mnkeni PNS, Van der Stoep I, Stevens J (2010). Crop production management practices as a cause for low water productivity at Zanyokwe irrigation scheme. *Water SA* 36(1): 27-36.
- FAO (1995). Sustainable dryland cropping in relation to soil productivity – FAO soils bulletin 72. Food and Agricultural Organisation of the United Nations, Rome, Italy.
- FAO (1996). Agro-ecological zoning guidelines. FAO Soils Bulletin 73. Food and Agricultural Organisation of the United Nations, Rome, Italy.
- FAO (2000). South Africa: Affordable irrigation technologies for smallholders: Opportunities for technology adaptation and capacity building. Programme formulation Report No. 6 – December (2000). IPTRID Secretariat, Food and Agricultural Organisation of the United Nations, Rome, Italy.
- FAO (2001). Smallholder irrigation technology: prospects for sub-Saharan Africa. International program for technology and research in irrigation and drainage knowledge synthesis report No. 3. IPTRID Secretariat, Food and Agriculture Organization of the United Nations, Rome, Italy.
- Farmer Support Services Working Group (1997). Discussion groups' notes from plenary session of the workshop held on 8-9 July 1997, Pretoria, South Africa.
- FSSA (2007). Fertilizer Handbook, Sixth Revised Edition. The Fertilizer Society of South Africa. Hennopsmere, South Africa.
- Hoare J (1992). Sustainable dryland cropping in Southern Australia: A Review. *Agriculture, Ecosyst. Environ.*, 38: 193-204.
- IRRI (1978). Annual Report for 1978. International Rice Research Institute, Los Baños, Philippines.
- Lahiff E (2000). An apartheid oasis? Agricultural and rural livelihoods in Venda. Frank Cass Publishers, London, UK.
- Lahiff E, Cousins B (2005). Smallholder agriculture and land reform in South Africa. *IDS Bulletin* Volume 36 No. 2, June 2005. Institute of Development Studies, South Africa.
- Laker MC (2004). Development of a general strategy for optimising the efficient use of primary water resources for effective alleviation of rural poverty. WRC Report KV149/04. Water Research Commission, Pretoria, South Africa.
- Lipton M (1996). Rural reforms and rural livelihoods: The context of international experience. In: M. Lipton, M. de Klerk, M. Lipton (Eds.). Land, labour and livelihoods in rural South Africa. One: Western Cape. Indicator Press, Durban, South Africa.
- Machethe CL, Mollé NM, Ayisi K, Mashatola MB, Anim FDK, Vanasche F (2004). Smallholder irrigation and agricultural development in the Olifants river basin of Limpopo province: management, transfer, productivity, profitability and food security issues. WRC Report 1050/1/04. Water Research Commission, Pretoria, South Africa.
- Mandiringana OT, Mnkeni PNS, Mkile Z, Van Averbek W, Ranst EV, Verplanke H (2005). Mineralogy and fertility status of selected soils of the Eastern Cape Province, South Africa. *Commun. Soil Plant Anal.* 36: 2431-2446.
- Marais JN (1992). FSR-E Newsletter No. 4, November 1992. Southern African association for farming systems research-extension, Development Bank of Southern Africa, Halfway House, South Africa.
- Monde N, Mtshali S, Mnkeni PNS, Chiduzo C, Modi AT, Brusch MO, Dladla R, Mthembu BE (2005). A situation analysis report on the Zanyokwe and Tugela Ferry irrigation schemes. Water Research Commission Project K5/1477 Deliverable 2 report. Pretoria, South Africa.
- Mphahlele RE, Malakalaka TM, Hedden-Dunkhorst B (2000). Characteristics of smallholder irrigation farming in South Africa: A Case Study of the Arabie-Olifants River irrigation scheme. South Africa working paper number 3. University of the North and International Water Management Institute, South Africa.
- Mukhela E, Groenewald DC (1998). Experiences and perceptions of black small-scale irrigation farmers in the Free State. *South Afr. J. Agric. Exten.*, 27: 1-18.
- Murphy SD, Yakubu Y, Weise SF, Swanton CJ (1996). Effect of planting patterns and inter-row cultivation on competition between corn (*Zea mays*) and late emerging weeds. *Weed Sci.* 44: 856-870.
- Noordwijk M (2002). Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the Fallow Model. *Ecol. Modeling* 149, 113–126.
- Perret S (2002). Water policies and smallholding irrigation schemes in South Africa: A history and new institutional changes. *Water Pol.* 4(3): 283-300.
- Perret S, Lavigne M, Stirer N, Yokwe S, Dikgale S (2003). The Thabina irrigation scheme in a context of rehabilitation and management transfer: prospective analysis and local empowerment. Final Report: DWAF, CIRAD-IWMI-UP, Pretoria, South Africa.
- Sangoi L (2000). Understanding plant density effects on maize growth and development: an important issue to maximise grain yield. *Cencia Rural* 31(1):159-168.
- Sarker RA, Talukdar S, Haque AFMA (1997). Determination of optimum crop mix for crop cultivation in Bangladesh. *Appl. Math. Modeling* 21: 621 – 623.
- Singh DK, Jaiswal CS, Reddy KS, Singh RM, Bhandarkar DM (2001). Optimal cropping pattern in a canal command area. *Agric. Water Manage.* 50: 1-8.
- Steyn GJ (1988). A farming systems study of two rural areas in Peddie district of Ciskei. PhD thesis, University of Fort Hare, Alice, South Africa.
- Underhill HW (1984). The Role of governmental and non-governmental organizations and international agencies in smallholder irrigation

- development. In: M.J. Blackie (ed.). Proceedings of the African Regional Symposium on smallholder Irrigation, Harare, Zimbabwe, 5 September 1984.
- USDA (2003). Irrigated corn increases in South Africa. Production estimates and crop assessment division, foreign agricultural service, May 27, 2003. [Online]. Available at <http://www.fas.usda.gov/pecad2/highlights/2003/05/southafrica/index.htm>. [Date of access: 3/10/2006].
- Van Averbeké W (2008). Best management practices for small-scale subsistence farming on selected irrigation schemes and surrounding areas through participatory adaptive research in Limpopo Province. WRC report TT 344/08. Water Research Commission, Pretoria, South Africa.
- Van Averbeké W, M'marete CK, Igodan CO, Belete A (1998). An investigation into food plot production at irrigation schemes in central Eastern Cape. WRC report 719/1/98. Water Research Commission, Pretoria, South Africa.
- Van Zyl J, Vink N, Van Rooyen CJ (1991). Proposals for an agricultural operation system in South Africa: uitdangings and adjustments for landbouvoor ligting in response to the realities of the nineties. Paper presented at the annual conference of the South African Society for Agricultural Extension
- Zimdahl RL (2007). Fundamentals of weed science. Third Edition. Academic Press, San Diego, California, USA.