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Exploring potentials and constraints of low-cost drip irrigation with saline water in sub-Saharan Africa

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Abstract

Irrigation with saline water could provide an interesting opportunity to meet increasing food demands without competing with other pressing needs for fresh water such as domestic and industrial water use in water scarce regions. In sub-Saharan Africa, saline groundwater could be a plentiful and under-utilised resource; however, there is a lack of data to confirm this assumption. Saline water is deliberately and successfully used for irrigation of field and garden crops in several countries. The water saving characteristics and the distribution patterns of water in the soil under drip irrigation make this water application technique suitable for use in combination with saline water. Low-cost drip irrigation has already been successfully implemented in sub-Saharan Africa. It is suggested that low-cost drip irrigation with saline groundwater for the cultivation of horticultural crops can be a feasible option under conditions of water shortage, and has the potential to contribute to improved and sustainable crop production for smallholder farmers.

Keywords: Saline water; Drip irrigation; Sub-Saharan Africa; South Africa; Small-scale farmers; Horticultural crops

1. Introduction

Approximately 20% of the world's population lacks access to safe drinking water and about a third lives in countries with moderate to high water stress, i.e. in areas where the withdrawal of freshwater exceeds 10% of the renewable storage (UNEP, 1999, 2002a). If the same consumption patterns continue, two out of three people on earth will live under water-stressed conditions by the year 2025. In Africa, at least 13 countries are already subject to water stress or water scarcity, and this figure is likely to increase in the future (UNEP, 2002a). The main factors causing increasing water demand over the last century are population growth, industrial development and expansion of irrigated agriculture. Agriculture accounts for 70% of the total freshwater use globally, mainly for agricultural crops (UNEP, 2002a). For Africa, this figure is nearly 80% (UNEP, 1999).

The United Nations Food and Agricultural Organisation (FAO, 2002) reports that 799 million people, or approximately one out of five in the developing world, are undernourished. Sub-Saharan Africa has the highest prevalence of under-nourishment and also has the largest increase in the number of undernourished. Many of these people are landless labourers or small-scale farmers. It has been estimated that improved access to water could double the crop output and income generated from these smallholder farms (Postel et al., 2001). With a secure water supply, supplementary irrigation can be used to decrease the high risk imposed by erratic rainfall, thereby increasing the incentives for the farmers to invest in higher-yielding seeds, higher-value crops, fertilisation and also to grow an additional crop (Rockström et al., 2002).

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Several studies indicate that there is a large potential for poverty alleviation through increased and improved irrigation in small-scale agriculture in sub-Saharan Africa (e.g. Postel et al., 2001). However, under conditions of water shortage, increased water use for irrigation conflicts with increasing demands for industrial and domestic freshwater use. Using saline water, inappropriate for domestic use, in irrigated agriculture would in this respect be an interesting option. The aim of this publication is to investigate potentials and constraints to using low-cost [1] drip irrigation with saline water in sub-Saharan Africa. Availability of saline water globally and in sub-Saharan Africa, problems related to salinisation and the experiences from previous use of saline water for irrigation are first discussed. Characteristics of drip irrigation and the possibilities and constraints to using low-cost drip irrigation systems in combination with saline water in sub-Saharan Africa are outlined. An in-depth case study on the potential for saline water irrigation with low-cost drip irrigation systems in South Africa is provided as an example.

2. Saline water—a problem or a possibility for irrigated agriculture?

About two billion people depend on groundwater supplies globally (UNEP, 2002a). In Africa, highly variable levels of rainfall have resulted in a large number of people being dependent on groundwater as their primary freshwater source (UNEP, 2002b). Globally, saline or brackish groundwater amounts to a total of 12.87 M km^3, which is slightly higher than the total amount of fresh groundwater of 10.53 M km^3 (Gleick, 1993; Shiklomanov, 1993). In Africa, several countries report high salinities in groundwater and unusable water in boreholes due to high salinities e.g. Tunisia (Söderström, 1992), South Africa (Volschenk and de Villiers, 2000) and Botswana (Machacha et al., 2000). Though studies indicate that saline water is present in several African countries, no data on the exact locations and amounts of saline water for the whole continent or even just sub-regions was found in the literature.

It is estimated that approximately one-third of the irrigated land in the major irrigation counties is badly affected by salinity or is expected to become so in the near future (Gleick, 1993). Fig. 1 shows the distribution of salt affected soils in Africa. Arid and semi-arid regions are the most affected. In these areas the lack of fresh-water often forces farmers to use water of lower quality for irrigation. As water evaporates from the soil surface, salts are left behind in the upper soil profile, causing salinisation and subsequent crop growth reductions. In addition, since insufficient irrigation causes immediate effects on crop growth, there is a tendency to over-irrigate, aggravating the problem further. As a matter of fact, the most serious salinity problems in irrigated agriculture results from over irrigation (Suarez, 1992). Salinisation is also commonly caused by insufficient drainage, causing capillary rising of water from shallow groundwater tables to the root zone, with soil evaporation and salinisation occurring as a result. Recently sub-Saharan farmers have been reported to abandon their rice fields due to the incidence of salinity (Kijne et al., 1998). Studies on salinisation problems related to irrigation have been conducted in many countries e.g. Australia (Termaat et al., 1985), Bangladesh (Mondal et al., 2001), China (Liang et al., 2002), India (Chaudhuri and Choudhuri, 1998), Israel (Meiri et al., 1992), Italy (Katerji et al., 1997), Germany (Läuchli and Wieneke, 1979), Saudi Arabia (Hussain et al., 1997), South Africa (Volschenk and de Villiers, 2000), the Netherlands (Marcelis and van Hooijdonk, 1999) and the United States (Hoffman et al., 1983).

Fig. 1. Salt affected soils in Africa.

However, saline water should not only be seen as a problem but also as an under-utilised resource. Saline water is deliberately used for irrigation in a number of countries, due to a lack of freshwater. Hoffman et al. (1990) and Rhoades et al. (1992) list a number of examples of successful commercial irrigation with saline water (Table 1). In these examples careful irrigation management is carried out to avoid detrimental salinity levels in the root zone. Crop tolerance to salinity stress varies between species. The limits to categorise crops according to salinity tolerance are shown in Fig. 2. Commonly grown horticultural crops grown in sub-Saharan Africa includes maize (MS), tomato (MS), spinach (Ms [2]), potato (MS), cabbage (MS), carrot (S [3]) and onion (S). No information on the extent to which saline water is used in agriculture in sub-Saharan Africa today

[1] Even though the cost per unit area of these systems is high in comparison with conventional irrigation systems in rural sub-Saharan Africa (e.g. furrow irrigation), the cost is low in relation to commercial drip irrigation systems.

[2] MS = moderately sensitive (see Fig. 2).

[3] S = sensitive (see Fig. 2).

Table 1
Successful irrigation projects with saline water

Country	Crop	Soil salinity ($dS\,m^{-1}$)
China	Wheat, corn, cotton	3–8
Egypt	Clover, rice, wheat, barley, beet, cotton	2–3
India	Wheat	16
Iraq	Wheat, pears	6
Israel	Cotton, sugarbeet	2–8
Tunisia	Sorghum, date palms, barley, alfalfa, rye grass, artichokes	3
US (Arizona)	Cotton	3–11
US (Colorado)	Alfalfa, sorghum, wheat	2–8
US (Texas)	Cotton, sorghum, alfalfa, small grains, tomatoes	4–9
Uzbekistan	–	8–9

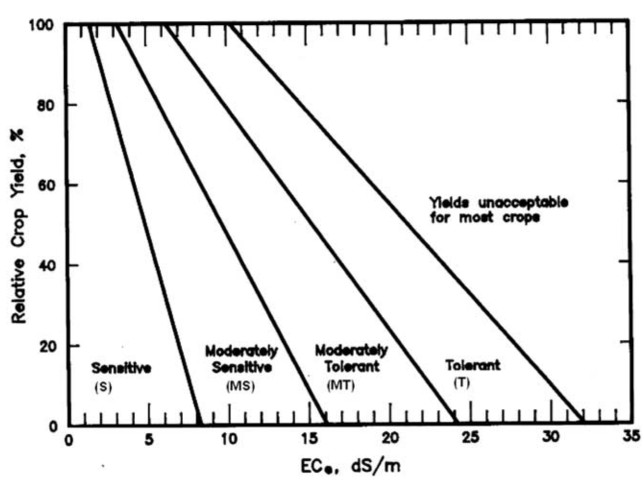

Fig. 2. Classification of crop tolerance to soil salinity. From: Maas and Hoffman (1977).

could be found in the literature. Nor was it possible to find data on the location and salinity level of saline surface and subsurface water in the region. However, it has been stated that saline water is generally greatly underutilised and will be used to a greater extent in the future as the competition for water continues to increase (Suarez, 1992). Generally, there seems to be a lack of research on the present irrigation practices with saline water in sub-Saharan Africa. An urgent initiation of a research programme that should focus on management solutions to salinity problems in irrigated agriculture in developing countries was called for in a publication by Kijne et al. (1998).

3. Drip irrigation

With the development of the plastic industry after the Second World War, inexpensive, water-resistant plastic was available also for the agricultural industry. Perforated tubes were used to irrigate individual plants under low pressure with water almost directly emitted to the root zone. The technology was further refined in Israel during the 1970s. In the 1990s the technology was being introduced to smallholder farmers as an efficient and easy-to-operate method (Or, 2000). Drip irrigation is one of the most efficient methods of watering crops. Its field application efficiency can be as high as 90% compared to 60–80% for sprinkler and 50–60% for surface irrigation (Dasberg and Or, 1999). Studies have compared furrow, sprinkler and drip irrigation with saline water, with the result that presently drip irrigation is widely regarded as the most promising irrigation system in combination with saline water (e.g. Meiri et al., 1992; Suarez, 1992).

There are several factors that contribute to favourable results obtained with saline water when using drip irrigation (Dasberg and Or, 1999). Lower water use because of high application efficiency in comparison to other irrigation systems, results in less salt accumulation in the soil. Soil evaporation under a fully wetted row crop has been estimated to be about 30% of total evapotranspiration, whereas for drip irrigation the corresponding value is only 7–10% of total water loss (Dasberg and Or, 1999). Secondly, since the irrigation water is applied under the plant canopies, problems with foliar absorption and leaf burn are avoided. In addition, the high frequency drip irrigation prevents the soil from drying out between irrigation events, which results in a more even salt concentration and thus less salinity stress compared to low frequency irrigation systems. Finally, salts are continuously leached out from the wetted section and accumulate at the wetting front away from the active root zone.

4. Low-cost drip irrigation for smallholder farmers

Recently low-cost drip irrigation has been implemented for small-scale farmers in sub-Saharan Africa. For a long time drip-irrigation was perceived as technique too advanced to be operated and managed by small-scale farmers (Chitsiko and Mudima, 2002). Several studies in which low-cost drip irrigation was successfully implemented in sub-Saharan Africa have since proved the opposite. du Plessis and van der Stoep (2000) report on partly successful implementation in South Africa. In Zimbabwe the technique is recently being implemented (Chitsiko and Mudima, 2002), whereas in Kenya it was rapidly spread between 1996 and 1999 (Kabutha et al., 2000). The potential for low-cost drip irrigation systems in sub-Saharan Africa has been emphasized in several publications (Musonda, 2000; van Leeuwen, 2002).

One of the most common low-cost drip irrigation systems used in sub-Saharan Africa consists of a 20-l bucket mounted one meter above ground. The water passes through a simple filter located under the bucket and enters a main lateral connected to several sub-laterals. These are normally between 10 and 15 m long, and irrigate the crop either through emitters located directly on the lateral (so called in-line systems) or through micro tubes attached perpendicular on the laterals. In Kenya, 70–80% of the drip kit users are women (Kabutha et al., 2000). The drip kits are commonly used to irrigate vegetable gardens and can provide a family with fresh vegetables for their own consumption as well as for selling the produce at the market. Provided there is a market for the produce, the potential returns for horticultural crops are good (Freeman and Silim, 2000).

Several experiences from the implementation of low-cost drip irrigation are common to many countries. One main advantage of drip irrigation is the reduction in water use for growing crops (e.g. Ngigi et al., 2001). In addition, the technique is labour saving since the irrigation process involves simply filling up the bucket (e.g. van Leeuwen, 2002). Fewer disease problems are encountered with drip irrigation. Since the techniques is implemented in dry land farming regions, where a good yield is associated with lots of rain, there is a general tendency to over-irrigate with the drip irrigation system in the beginning (e.g. du Plessis and van der Stoep, 2000). For the same reason, many farmers do not perceive drip irrigation to be a promising technique since the soil is kept dry in some areas. Thus, there is a need for a deepened understanding of drip systems in communities through training and information. One study showed that farmers with experience and/or training in irrigation are more likely to succeed with the system (du Plessis and van der Stoep, 2000). The same study also concluded that the farmers' initial attitude towards the new equipment is very important. Many studies showed that the access to support services such as spare parts and extension officers is of importance (e.g. Ngigi et al., 2001). Technically related issues such as breakage of plastic items, puncturing of drip tapes, breakage of the filter housing and general leakage sometimes causes problems (e.g. Kabutha et al., 2000). Due to the very low pressure used to force water out through the laterals, the systems are sensitive to ground elevation differences, causing non-uniformity of the emitter discharge (Ngigi et al., 2001). Water supply to the farm plays a major role in the successful operation and management of an irrigation scheme (e.g. Shah and Keller, 2002). Theft of irrigation equipment is further perceived as a threat by the farmers (Ngigi et al., 2001). An interesting finding of the study by du Plessis and van der Stoep (2000) was that only little or no labour and time savings were reported by the majority of the farmers. Nor was the concept of water saving familiar to them, and few of the farmers were concerned about the cost of water.

On the regional level, several characteristics of sub-Saharan Africa constrain the implementation and spread of low-cost drip irrigation, such as the lack of basic infrastructure, the absence of developed markets, and legal and cultural biases against women (Postel et al., 2001). One study emphasised the importance of farmers contact with markets (Merrey et al., 2002). In addition, factors like limited market information, low access to credit, insufficient number of middlemen and high costs for them in collection of small, dispersed quantities pose constraints to irrigated horticultural cultivation (Freeman and Silim, 2000).

There are several management techniques that can be used in combination with drip irrigation to improve system performance. Mulching has been used successfully in combination with drip irrigation in several countries (e.g. Tiwari et al., 1998). Where ground or surface water is available, low-cost drip irrigation can be used in combination with treadle pumps to facilitate the supply of water to the buckets. Treadle pumps are human-powered water-lifting devices that are operated by stepping on two treadles, thereby sucking up the water into two cylinders and transporting it further into its final destination. The potential for using treadle pumps in low-cost drip irrigation systems has been emphasised in other studies (e.g. Postel et al., 2001).

5. Combining saline water with low-cost drip irrigation in sub-Saharan Africa

In order for drip irrigation with saline water to be an interesting option to the farmers, there has to be apparent benefits with adopting the technology to overcome the disadvantages of soil salinisation and high installation costs. When water is scarce and/or highly priced, the reallocation of fresh water from irrigation to domestic use is an obvious incentive. In case saline water is already being used for irrigation, the adoption of low-cost drip irrigation can alleviate present salinisation problems. Saline water can also be used for supplementary irrigation and mitigation of drought spells in rain-fed system, where the reduced risk of crop failure could encourage investments in fertiliser etc. Labour saving involved in the drip irrigation technique is also often an attractive gain.

Saline water irrigation systems require careful management to prevent escalating soil salinisation. Several management issues should be considered in order to develop sustainable saline water irrigation systems with low-cost drip irrigation. Low-cost drip systems utilise gravity as the force to push water through the pipes. Normally a head between 1 and 1.5 m is used, resulting in an average emitter discharge of approximately 0.2–3.0 $l\,h^{-1}$, depending on the drip system. These figures can be compared with flow rates of approximately 2.0–8.0 $l\,h^{-1}$ for conventional drip systems (Dasberg and

Or, 1999). A lower emitter discharge results in longer application irrigation periods, and potentially higher soil evaporation. However, a lower discharge rate creates a more vertical wetting pattern than a high discharge rate, which results in a smaller wetted soil surface area and thus less soil evaporation (Dasberg and Or, 1999). A study on tomatoes showed a 15% water loss in a drip irrigation system with a discharge rate of $2\,l\,h^{-1}$ and an emitter spacing of 70 cm due to the long duration of the irrigation event (8 h) (Ould Mohamed El-Hafedh et al., 2001). Depending on the relative importance of these two processes affecting soil evaporation, it could be necessary to apply mulch at high salinities in order to prevent soil evaporation and produce a good yield.

Other management techniques that need to be developed, and that will vary between regions and crops, are for example irrigation scheduling, emitter spacing and irrigation water amounts (leaching fraction). In addition, problems related to the equipment, such as the risk for clogging of the emitters, the effectiveness of simple filters, in-line drip emitter systems performance versus micro-tube systems, and the rusting of the equipment from the saline water remain to be evaluated for low-cost dripper systems. These issues indicate that there is a need for further research on the water and salt balances in low-cost drip irrigation with saline water. In addition, field experiments with different drip irrigation systems and management techniques, such as mulching, should be carried out firstly on-station. A multi-disciplinary feasibility study to determine the conditions for success, such as economic loss due to reductions in yield versus economical benefits of decreased risk of crop failure due to drought and lower water costs, should be conducted followed by an on-farm field trial to obtain feedback from farmers.

6. South Africa—a case study

South Africa is a water scarce country with an annual average precipitation of less than 500 mm, and an uneven distribution of water as a result of geology and climate. With 1.2 ml fresh-water per person per year (1997), South Africa is on the threshold of the internationally used definition of water stress (DWAF, 1997). Today, 96% of the total available amount of water is needed to supply the total demand (DWAF, 2002). This figure will be approximately 99.5% by the year 2025. Even though agriculture represents less than 4% of GDP and only 14% of the labour force, irrigated agriculture and stock watering comprise about 50% of total water usage (Perret, 2002). Thus, South Africa is on the margin of being able to supply its population with the required water and the agricultural sector will in all likelihood have to start reducing its water use in the near future. Since 1998, the management and distribution of South Africa's scarce water resources is governed by the highly commendable National Water Act (DWAF, 1998), resulting in registration and licensing of water users, and subsequent water charges.

Because of its well developed infrastructure and new water policy, South Africa has been targeted as the logical place to demonstrate the potential of low-cost drip irrigation in sub-Saharan Africa (Postel et al., 2001). However, irrigation technologies available on the market in South Africa are still mainly directed to the large-scale commercial farmers, whereas affordable technologies for small-scale farmers are less prevalent. Nevertheless, there are small-scale farmers who practice low-cost drip irrigation to save water and labour costs (Kgole and Walker, 2000). In South Africa's rural areas, up to 60% of the population are landless. Many of them are so called vegetable garden- or backyard farmers, farming small plots (e.g. 10 m × 10 m). In both cases, high-value crops can compensate for small plots.

As can be seen in Fig. 3, South Africa's groundwater resources are partly saline and the salinity levels vary throughout the country. There are two possible areas where irrigation with saline water could be of interest. The dry Karoo semi-desert in the western part of the country adjacent to Namibia has an annual average rainfall below 300 mm and salinity levels in the groundwater are high. This region is predominantly used for extensive sheep farming and the saline groundwater is a largely untapped resource. There are therefore interesting possibilities to utilise this resource in order to produce high-value crops, such as squash (MT [4]), artichoke (MT) or asparagus (T [5]), using low-cost drip irrigation. The Limpopo Province in the northern part of the country receives more rainfall than the Karoo (500–650 mm per year) and the groundwater salinity rarely exceeds $4\,dS\,m^{-1}$. However, the province is affected by dry spells that can be detrimental for the economy of this agricultural region. Supplementary irrigation with saline water has the potential of reducing the risk of crop failure due to prolonged drought. Secondly, the use of saline water in agriculture means that fresh water can be re-allocated from the agricultural sector to other water uses. High-value crops, such as tomatoes (MS) and spinach (MS), could be grown with supplementary low-cost drip irrigation using saline water in the Limpopo Province.

Two factors emerge as crucial in order to achieve an efficient use of saline groundwater for irrigation of vegetable crops in South Africa. The most obvious one is the management of these systems in order to avoid long-term soil degradation due to salinisation, and subsequent crop failure. There is a need for studies focusing on management techniques available for the small-scale

[4] MT = moderately tolerant (see Fig. 2).
[5] T = tolerant (see Fig. 2).

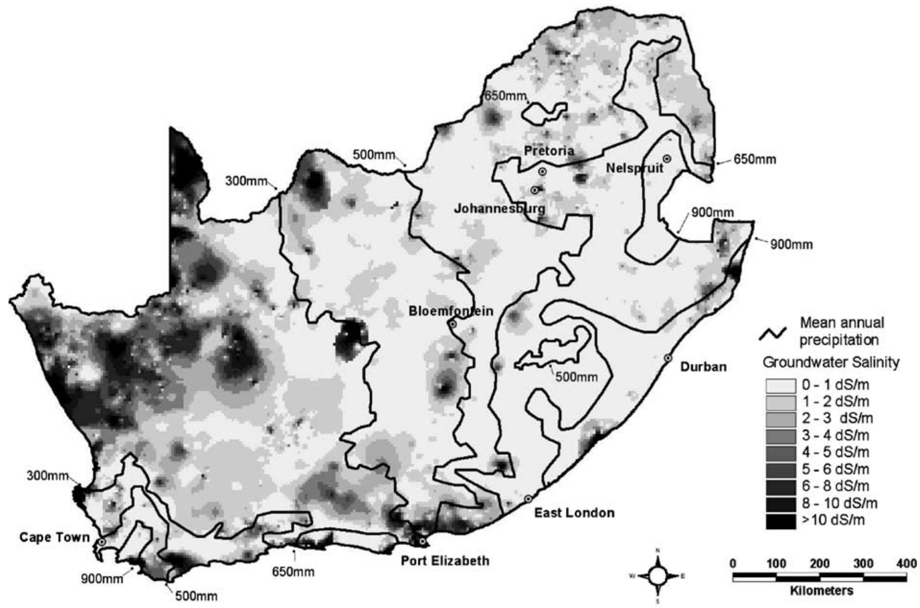

Fig. 3. Groundwater salinity in the uppermost aquifer measured as electrical conductivity (EC), South Africa. Data from 1995–2003, DWAF, South Africa.

farmer in saline water irrigation. Secondly, the water supply has to be secured. Contrary to what was initially believed, there seems to many applications for the treadle pump in South Africa (Kedge, 2000). Initial investigations showed good potential for the successful implementation of the pumps. The water shortage and the economical incentives to save water as dictated by the new water legislation, in combination with the relative abundance of saline groundwater, makes low-cost drip irrigation of vegetables an interesting alternative for small-scale farmers in South Africa.

7. Conclusion

In order to meet increasing food demands, irrigated agriculture has to expand. This could conflict with increasing demands on water for domestic and industrial purposes in regions of water scarcity. In this respect, the use of saline water becomes interesting, since the resource promises an increase in agricultural production without competing with other water users. A lot of research on salinity problems in irrigated agriculture has been carried out globally. Saline water is used successfully to irrigate field and garden crops in a sustainable way. Groundwater, unsuitable for human consumption due to high salinity, could be seen as an under-utilised, potential water resource for agriculture in sub-Saharan Africa. Even though figures on the amount of easily accessible saline water in the region is lacking, the distribution of salinised soils in sub-Saharan Africa indicates that saline water is prevalent in the region. Alternatively, the salinisation problems could be interpreted as an indication of unsustainable use of saline water for irrigation purposes. Successful and sustainable irrigation with saline water requires appropriate management. Drip irrigation has been proven superior to many other irrigation techniques in combination with saline water for a number of reasons. The recent implementation of low-cost drip irrigation kits for small-scale farmers in several countries in sub-Saharan Africa has been successful. In areas where water causes limitations for irrigation, drip irrigation with saline water is a promising option provided the implementation is combined with appropriate management and training of the farmers. There seems to be a lack of research on the use of low-cost drip irrigation systems in combination with saline water in general, and of suitable management techniques in particular. A multi-disciplinary feasibility study to determine the constraints to successful implementation of low-cost drip irrigation with saline water is also needed.

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