

## OPTIONS FOR IMPROVING AGRICULTURAL WATER PRODUCTIVITY UNDER INCREASING WATER SCARCITY IN SOUTH AFRICA

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### ABSTRACT

South Africa is ranked among the thirty driest countries in the world, a challenge that is negatively affecting agricultural production. Other challenges such as population growth, rural-urban migration, changing food preferences and drought exacerbate pressure on agricultural water productivity. The review critically assessed the different considerations for increasing agricultural water productivity under water scarce conditions in South Africa. While under these conditions, irrigation may seem an obvious solution to increasing agricultural water productivity as a response to frequent droughts and mid-season dry spells. However, considerations on the availability of water and energy for irrigation expansion and the accessibility of irrigation services to different farming groups in the country. It is generally argued that irrigation is an expensive option and not necessarily readily accessible to most farmers.

There are prospects for tapping into South Africa's groundwater resources but the extent to which they can contribute to expanding area under irrigation is contested given the challenges of quantifying and pumping the water. Most smallholder farmers currently lack access to water, energy, infrastructure and technical skills to irrigate thus making irrigation a challenging option in this sector. An alternative would be to explore rainwater harvesting and soil water conservation technologies, which involve inducing, collecting, storing and conserving runoff water for agriculture. The drawbacks to this are that, apart from scale issues, rainfall is becoming more erratic and droughts more frequent and hence the feasibility of this approach under frequent drought could be challenged.

**Keywords** : Climate risks, Drought, Management, Rainwater harvesting, Smallholder

### 1. INTRODUCTION

South Africa is a semi-arid country whose water profile is rapidly moving from water scarce to water stressed (Singels et al., 2010). The country's annual average rainfall fluctuates around 500 mm, which is far below the world's average of 860 mm per annum (Hardy et al., 2011). Rainfall is unevenly distributed, with about 50% of the rain falling on 15% of the land (Hardy et al., 2011). It is in most of the remaining 85% of the country where rural population is concentrated (Hardy et al., 2011). While South Africa may be considered as food secure, either in relation to producing sufficient staple food or in its ability to import sufficient and nutritional food for its populace (Masipa, 2017), about 28.3% of its population remain at risk of hunger and 26% are actually food insecure (SADHS, 2017). The country's National Development Plan (NDP) recognises agricultural productivity and rural development among the essential priorities for

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employment creation, economic growth, reducing poverty and addressing food security in South Africa (National Planning Commission, 2012). Agriculture in SA, therefore, faces complex challenges where it needs to produce more nutritious food while using less water per unit of output, provide rural communities with resources and opportunities to live a healthier and more productive life, adopt sustainable technologies that ensure environmental sustainability and contribute to the country's GDP.

Consequently, meeting water and food challenges will require dynamic institutions and actions that can balance soil-water productivity for increased crop productivity while decreasing environmental externalities. There is need to provide relevant information to enable both public and private sector decision makers to accurately assess and respond to the growing water and food risks (Masipa, 2017). Agriculture requires large quantities of water and is the biggest user of water in South Africa and the world. Agricultural production and livelihoods in water scarce regions, like SA, can be sustained, only if priority is given to improving water productivity and enhancing the efficiency of water procurement (Cai et al., 2011). Technologies and strategies to improve water productivity and the management of scarce water resources are available.

This paper addresses the options for improving agricultural water productivity under increasing water scarcity in South Africa. Water productivity is considered in the context of both rain-dependent and irrigated agricultural production systems. We outline the meaning and implications of increased water productivity and then systematically consider the limits and opportunities for its improvement.

## 2. TERMINOLOGY

While the terms WUE and WP seek to address the notion of “more crop per drop”, they are now being used interchangeably and seemingly lack common definition. Irrigation engineers, crop physiologists and water managers hold different perspectives on the correct terminology. Molden et al. (2003) proposed a common conceptual framework for communicating water productivity. The indices water use efficiency (WUE) and water productivity (WP) in an agronomic sense have been used widely to quantify the notion “more crop per drop” (Molden, 2007; Zhou et al., 2012). Although these terms have been used interchangeably in some instances, WUE and WP are different. Water use efficiency is the ratio of biomass or yield to water applied (Equation 1) while WP is defined as the ratio of biomass or yield to actual water used (Equation 2).

$$WUE = \frac{Y_a \text{ or } B_a}{\text{water applied}} \text{ kg m}^{-3} \quad \text{Equation 1}$$

$$WP = \frac{Y_a}{ET_a} \text{ kg m}^{-3} \text{ or } \text{kg ha}^{-1}\text{mm}^{-1} \quad \text{Equation 2}$$

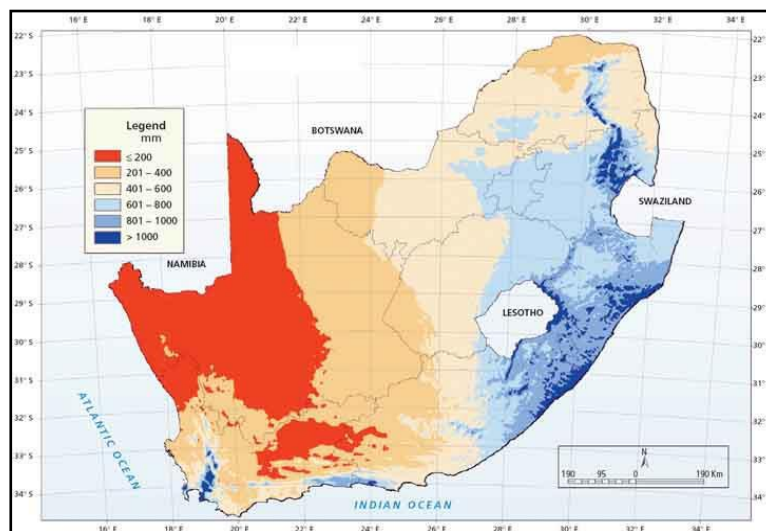
Ya and Ba is the actual yield and biomass (kg), respectively and ETa is the actual evapotranspiration (mm ha<sup>-1</sup> or m<sup>-3</sup>) or water consumed. For the calculation of WUE, water applied suggests water entering the systems and is silent on the unproductive loss of water such as runoff, deep percolation, capillary rise and changes in subsurface flow since it is challenging to quantify these.

### 2.1 Spatial Variability of Water and Water Productivity

South Africa's land area is huge and diverse, with a highly variable rainfall regime, which is characterised by a semi-arid climate (Botai et al., 2018). South Africa is the 30<sup>th</sup> driest country in the world with low and highly variable rainfall (both inter- and intra-annually), erratic runoff, high evaporation and shallow dam basins (Department of Water Affairs, 2013). The historical annual rainfall varies from less than 100 mm per

annum in the west to over 1500 mm in the east; the average rainfall is 450 mm per annum (Figure 1). More than 60% of its river flow arises from only 20% of the land area requiring large-scale inter-basin transfers (Department of Water Affairs, 2013). In terms of surface runoff, which contributes to the flow of rivers, and the recharge of wetlands, lakes, dams and aquifers, only about 8% of South Africa's land produces about 50% of the total surface runoff. This inherent variability characterises the country's annual rainfall distribution patterns, concentration and intensity.

Spatial information on water use, crop production and water productivity plays a vital role in water management, especially where scarce water resources can be improved. Reported data on water productivity with respect to evapotranspiration (ET) show considerable variation e.g., maize, 18 - 29 kg ha<sup>-1</sup> mm<sup>-1</sup> and wheat 15 - 24 kg ha<sup>-1</sup> mm<sup>-1</sup>. The variability differs because of variety, crop management conditions and environmental conditions. Furthermore, it is often difficult to determine the real crop yield over a large area, e.g. the size of a large irrigation system. However, with advancements in technology we can now assess variations in water use and water productivity over large spatial scale. With the advent of satellite sensors and multispectral imagery of the earth's surface, remote sensing has evolved as a technique that allows ET to be measured more efficiently and economically on a large spatial scale or field scale using the shortened energy balance equation. Remote-sensing and geographic information system (GIS) tools can help in assessing water productivity and how productivity varies with spatial scale



**Figure 1:** Average annual rainfall across South Africa Source: ARC-ISCW, 2004

## 2.2 Considerations in Improving Water Productivity

The key principles for improving water productivity at field, farm and basin level include (i) increase the marketable yield of the crop for each unit of water transpired by it, (ii) reduce field related outflows (runoff, drainage, seepage, percolation and evaporative), and (iii) increasing the effective use of rainfall, stored water, and water of marginal quality (Kijne, 2003). These apply regardless of whether the crop is grown under rainfed or irrigated conditions and at all scales. However, options and practices associated with these principles require different approaches and technologies at different spatial scales.

### 2.3 Enhancing Water Productivity at Plant Level

Plant-level options have been reviewed extensively and these rely mainly on germplasm improvements (Condon, 2004; Morison et al., 2008; R. Richards et al., 2002; Richards, 2006; Richards et al., 2010; Zobel, 2006). Such improvements include early seedling establishment, improving seedling vigour, increasing rooting depth, increasing the harvest index (the marketable part of the plant as part of its total biomass), and enhancing photosynthetic efficiency (Table 1). Through the efforts of breeding, modern sorghum varieties have about a threefold increase in water productivity compared with traditional varieties (Xin et al., 2009). Breeders have also developed a range of crop varieties that match growth cycles with the expected water supply or with the absence of crop hazards (Richards et al., 2010). Short to medium duration varieties can also increase water productivity by escaping late-season drought that adversely affects flowering and grain development (Kijne, 2003). Breeding for and selecting crop species with enhance architecture can also aid in enhancing water productivity. Deep root systems increase water uptake in deeper horizons and while increasing adventitious roots will allow more water to be capture in the top layer before evaporative losses (Kell, 2011; Richards et al., 2002). Progress in extending these achievements to other crops has been considerable and will probably accelerate following the recent identification of the underlying genes (Bennett, 2003). Drought escape and increasing drought tolerance are also important strategies for increasing water productivity (Araus et al., 2002; Kulathunga, 2013).

### 2.4 Improving Water Productivity at a Field Level

Improved practices at field level related to changes in crop, soil and water management can increase water productivity under irrigated and rainfed growing conditions. These practices include selecting appropriate crops and cultivars; planting methods (e.g. on raised beds); minimum tillage; timely irrigation to synchronize water application with the most sensitive growing periods; nutrient management; drip irrigation; and improved drainage for water table control (Table 1). Under rainfed conditions, farmers face a risk due to rainfall variability, the risk increases when the amount of rainfall is usually low relative to crop water requirements. Opportunities for improving crop water productivity mainly lie in choosing adapted water efficient crops, reducing unproductive water losses and ensuring optimum agronomic conditions for crop production such as optimum fertiliser, and good pest and disease management practices (see, for example, Chimonyo et al., 2016; Kijne, 2003; Mabhaudhi et al., 2018; Rockström et al., 2003 and Table 1). In general, agronomic measures directed at healthy, vigorously growing crops favour transpiration and productive water losses over unproductive losses (Table 1). Rainwater harvesting (RWH) can also be a solution to increasing water productivity of dryland agriculture.

*Rainwater harvesting* implies collection and storage of precipitation that would have seeped into soil or run off into stream channels (Kahinda et al., 2011). When RWH is coupled with soil conservation practices increases in simultaneous increases in crop and water productivity have been observed (Mupangwa et al., 2006). Based on catchment surfaces the main RWH techniques are micro- and macro-catchment. Micro-catchment techniques can be subdivided in to *in situ* RWH and rooftop. *In situ* RWH techniques such as deep ploughing, contouring, ridging, pitting, conservation agriculture techniques (e.g. permanent soil cover) (Table 2). Macro-catchment RWH comprises a group or techniques for harvesting runoff from a catchment area and delivering it to a cropped area. In some areas where large volume of runoff takes a longer time flowing and it is utilized for crop production is referred to as supplementary or spate irrigation

In South Africa, RWH has been investigated by several researchers (Botha et al., 2014; Kahinda et al., 2007; Mzezewa et al., 2011) Rainwater harvesting techniques are used

for variety of purposes with the main being for agricultural and domestic use. While reports show significant and positive influences of RWH in agriculture, its uptake in rural communities has been slow. Kahinda et al, (2010) stated that high labour requirements in constructing and maintenance of RWH structures is a major constraint, and has created a negative outlook amongst marginalised farmers. In addition, literature shows that there has been little consideration on human capacity and economic aspects during the implementation of RWH technologies. The introduction of RWH techniques needs to be complemented by a combination of extension support, inputs, collective action and skills development. To ensure the sustainability of RWH a combination of farmer training, water conservation, supplementary irrigation, better crop selection, improved agronomic practices, and political and institutional interventions also need to be used. At a catchment level, planning and socio-economic assessment should consider and the short-term effect and longer-term implications of hydrological changes brought about by water harvesting on downstream water users closely monitored (Mwenge Kahinda et al., 2008).

Under irrigated conditions, improving crop water productivity relies mostly on water management and these strategies have been summarised by Ali and Talukder (2008). Strategies such as deficit irrigation, supplementary irrigation, increasing soil fertility, improving harvest index, manipulation of seedling age, priming or soaking of seed, application of organic matter, tillage and sub-soiling, water harvesting, minimising the transpiration, crop selection, modernisation of irrigation system and integrating agriculture-aquaculture. As it is Irrigation currently uses more water than all other users and agriculture faces competing demands for water from other sectors. At present, about 1.3 million hectares, or under 10 per cent of all arable land, is under irrigation (Cousins, 2007; Nhamo et al., 2016). Irrigation supports 25-30% of our national agricultural production. It is estimated that irrigation is responsible for up to 90% of the production of high-value crops (including potatoes, vegetables and fruit) and 25-40% of the production of industrial crops (including sugarcane and cotton). The distribution of irrigation water is as inequitable as the distribution of land, with white commercial farmers holding rights to over 90% of the water supply, supported by massive state investment in irrigation infrastructure (Lahiff and Cousins, 2005). Smallholder farmers, mostly in the former Bantustans (Van Averbek and Khosa, 2007), use around 7.7% of irrigated land, or 100,000 hectares (Hardy et al., 2011).

**Table 1:** Principles, strategies, options and practices for enhancing crop water productivity at a plant, field and basin scale. Adapted from Kijne et al. (2003)

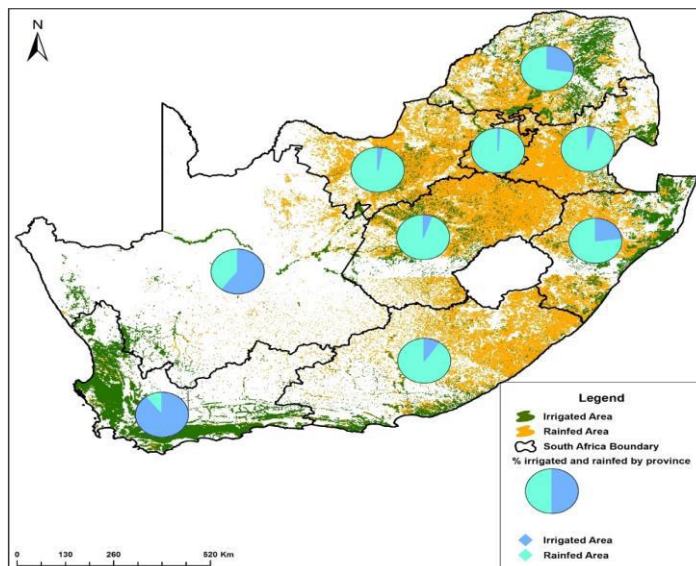
Principal	Strategy	Scale		
		Plant	Field	Basin
Enhancing marketable yield of crops for each unit of crop transpiration	Increasing yield or value of the product	Increasing harvest index, Increasing photosynthesis, Increasing sink strength	Crop and resource management for enhancing yield, Synchronizing water application with crop water demand, Changing to high value crops	Improving water management to synchronize system water supply and field-level water demand, Reallocating water from-value to higher-value uses, Spatial analyses for maximum production and minimum transpiration
	Reducing Transpiration	Reducing non stomatal transpiration, Reducing stomatal transpiration,	Crop scheduling to match season with low evaporative demand, Deficit irrigation	

Principal	Strategy	Scale		
		Plant	Field	Basin
		Shortening crop growth duration		
Reducing non-beneficial atmospheric depletions and the outflows from the domain of interest	Reducing evaporation from soil and water	Early shading, Seedling vigour	Crop scheduling to reduce evaporation during fallow period, Plant spacing and row orientation, Tillage and soil management (e.g., minimum tillage, mulching) to reduce evaporation, Irrigation techniques (e.g., drip, subsurface irrigation), Saturated culture with rice on bed	Land use planning over the whole domain of interest to reduce evaporation from fallow land, decrease free water surfacing.
	Reducing transpiration from weeds	Increasing weed competitiveness	Weed management, Levelling and precision irrigation, Water-saving irrigation in rice	Land use planning to reduce weeds and other non-beneficial vegetation,
	Reducing percolation	Seedling vigour, Deep roots Aerobic rice	Levelling and precision irrigation, Water-saving irrigation in rice	Reducing percolation and runoff into sinks, Water reuse
	Reducing runoff		Water harvesting, Tillage to increase infiltration	
Enhancing the effective-use of rainfall, water with marginal quality and water stored in the domain of interest	Effective use of rainfall	Drought escape, Drought tolerance, Submergence tolerance	Risk management in rain-fed agriculture, Synchronizing crop demand and rainfall, Nutrient management to reduce drought effects, Drainage	Irrigation scheduling to account for rainfall variability, Utilization of medium and long-term weather forecasts for reducing risk
	Effective use of water storage	Deep rooting for drought avoidance	Water harvesting and supplementary irrigation	Conjunctive use of surface water and groundwater, Increasing water storage within the domain to capture runoff
	Effective use of water with marginal water quality	Salinity stress tolerance	Mixing marginal water with water of good quality, Crop management to reduce salinity effects	Land management to reduce salinization hazard

While the National Development Plan's intention to increase area under smallholder irrigation to about 200 000 ha this may place further strain on already scarce water resources, as well as energy that will be needed for pumping the water (Cai et al., 2017). Increasing the number of dams to capture and store water that flows in to oceans can create plausible opportunities for promoting programmes for irrigation expansion (Mabhaudhi et al., 2018). However, South Africa is almost at the limit of feasible dam construction. Mabhaudhi et al. (2018) states that the use of technologies that enhance water productivity can lessen the pressure of increasing water availability in irrigated agriculture. Therefore, improving efficiencies within irrigation can go a long way in improving water productivity and sustainable food production. This can be achieved through irrigation systems such as drip, deficit and supplementary irrigation.

*Deficit irrigation* involves the application of water of predetermined percentage of a calculated potential water use. The prescribed water deficit should result in a small yield reduction that is less than the concomitant reduction in transpiration. Therefore, it causes a gain in water productivity per unit of water transpired (FAO, 2003). Deficit

irrigation reduces the amount of water used by the plant and has the potential to increase water productivity by reducing unproductive water use. For deficit irrigation to be successful, farmers need to know the deficit that can be allowed at each of the growth stages and the level of water stress that already exists in the root zone (FAO, 2003). Deficit irrigation carries considerable risk for the farmers where water supplies are uncertain, as is the case with rainfall or unreliable irrigation supplies. Considerable knowledge on crop water thresholds and soil water properties are required (FAO, 2003).



**Figure 2.** Comparison of rainfed and irrigated areas in South Africa. Pie charts represents percentage of irrigated and rainfed land by province.

*Drip irrigation* is most efficient among all the irrigation methods and yield gains of up to 100% and water savings of up to 40-80% have been reported (Rao et al., 2016). Drip irrigation is a type of micro-irrigation system that can reduce unproductive water and nutrients losses as it allows water to drip slowly to the roots of plants (FAO, 2003). This is from above the soil surface or buried below the surface. Drip irrigation improved the aerobic rice yield and water savings by 29 and 50%, respectively, and increased water productivity by 200% (Rao et al., 2016). Huge improvements in water productivity have also been noted by Ali and Talukder (2008) and Zwart and Bastiaanssen (2004)

*Supplementary irrigation (SI)* can be defined as the addition of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields. According to ICID (2012) SI is the opposite of full or conventional irrigation (FI). In the latter, the principal source of moisture is fully controlled irrigation water, and highly variable limited precipitation is only supplementary (ICID, 2012). Supplementary irrigation is dependent on the precipitation of a basic source of water for the crop (Grafton et al., 2018; Guendouz et al., 2016; Li and Sun, 2016; H. Zhang et al., 2017; Y. Zhang et al., 2017). If applied during critical crop growth stages, SI can result in substantial improvement in yield and water productivity. Shortage of soil moisture in the dry rainfed areas occurs during the most sensitive growth stages (flowering and grain filling) of cereal and legume crops (Steduto et al., 2012). Bridging crop water deficits during dry spells through supplementary irrigation stabilizes production and increases both production and water productivity dramatically if water is applied at the moisture-sensitive stages of plant growth. According to Oweis and Hachum, (2006) applying 212, 150, and 75 mm of additional water to rain-fed wheat crop increased yields by 350, 140, and 30% over that

of rain-fed receiving annual rainfall of 234, 316, and 504 mm, respectively. This increases water productivity by 80, 75 and 55%, respectively (Oweis and Hachum, 2006).

Water productivity of irrigated agricultural production is surprisingly low in many parts of the world. At present, engineering technologies for water-saving agriculture, such as prevention of channel leakage (through channel lining), water-saving irrigation scheduling, water delivery with low-pressure pipe, sprinkler and drip irrigation systems, and optimized water allocation strategies in irrigation areas have not been advocated or adopted in most parts of the world except in research or field experiments. Most of the irrigation channels are substandard which causes a considerable water loss in the conveyance system (about 30–50%) (Ali and Talukder, 2008) which indicate that there is a considerable potential for improvement in agricultural water productivity.

## 2.5 System and Basin Level Water Productivity

The management of water as a resource is under immense pressure to support both ecological and human services under a changing political and physical climate (Rockström et al., 2010). There is need to increase reliability and deliveries of surface water to maintain the co-equal goals of human and ecosystem water needs. Difficulties in providing demanded quantities of water may be further exacerbated under a changing climate, especially in systems with strongly seasonal precipitation, thus affecting water productivity of the system (Menéndez et al., 2016). Collectively, agricultural water users need to look beyond their farm gate to the state of water resources at a wider catchment level. At the larger scale, gains in water productivity are possible by providing better land-use planning; better use of short and medium-term climate forecasts; better understanding eco-hydrological characteristics of a landscape, improved irrigation scheduling to account for rainfall variability; and conjunctive management of various sources of water, including water of poorer quality where appropriate (Faurès et al., 2003; Kijne, 2003). At a catchment level increasing water productivity lies at strategic management options where environmental, social, economic and policy issues should be considered.

Water security can be improved by tackling shared water risks upstream, such as removing water-thirsty alien invasive vegetation (Blignaut et al., 2007), combined with doing education drives with the surrounding communities downstream. Active engagement with farmers in water stewardship initiatives facilitated through their local agency can result in fuller dams and a decrease in water shortages during the drier summer seasons. Therefore, understanding the systems from an eco-hydrologic framework can provide insight into feedbacks between ecological and hydrologic processes and help improve water productivity Griggs and Golet (2002). However, an increase in water productivity may or may not result in greater economic or social benefits. When considering the socioeconomic aspects of adoption of enhancing water productivity across basins, the benefits and the costs need to be ascertained for all end users. There is need to reconcile with the concept of water as a social good, i.e., a basic human need that should be exempt from competitive pricing and allocation.

According to Molden et al. (2010) four key strategies for improving water productivity in a basin context include (i) increasing water productivity at a plant and field level which should have a far reaching effect on catchment as a whole, (ii) minimising non-productive losses of water flows by reducing water runoffs to sinks, (iii) improving management of existing irrigation facilities and reusing return flows by controlling, diverting and storing drainage flows; and (iv) identifying water users and, relocate and allocate water among uses based on value of use, e.g. relocating lower value to higher value uses within and between sectors.

### 3. POLICY AND WATER PRODUCTIVITY

Due to the deteriorating water scarcity situation and the subsequent water allocation problems, the water management focus has seen a paradigm shift from supply management (mainly through the increase of water availability via water supply infrastructure and other technical solutions) to demand management (through improved technologies, incentives, re-design of tariffs) (Department of Water Affairs, 2013; Hedden and Cilliers, 2014). The National Water Resources Strategy (NWRS) takes on board a range of options for balancing the supply and demand of water. These options have implications in agriculture and on socio-ecological domains. The strategy notes the impact of future technology, increase in human population and increase severity of climate change induced droughts on water resources. Challenges related to how to achieve efficient use, equity and redistribution, ensuring water security for the future and water availability for economic growth and development are dealt with in this strategy (Department of Water Affairs, 2013). Accordingly, the NWRS2 defines 'developmental water management' as water management "which takes, as a central premise, that water plays a critical role in equitable social and economic development, and that the developmental state has a critical role in ensuring that this takes place". For the achievement of an improved water demand management, the South African Government has so far addressed important administrative approaches like water user registration and licensing processes. A market-driven approach with the aim of benefit maximization from water use, based on the economic valuation of water, would further support more efficient and sustainable water use. Trying to achieve increased productivity of water through pricing mechanisms has faced problems from the long held belief that water is a public property and entitles everybody to have access to it to meet livelihood needs.

Muchara et al. (2016) noted that the value of water is often unknown by many smallholder farmers leading to unequal distribution, poor management and inefficient use of water. A paradigm shift toward cost recovery mechanisms to encourage effective irrigation water management and water-use efficiency might need to be considered for smallholder farmers (Muchara et al., 2016). Aiming for the highest economic productivity of water in agriculture may conflict with the political desire for national food security. More often than not, the economic productivity of water in growing staple crops is less than that for growing vegetables or flowers for export markets. Crop substitution involves switching high water-consuming crops for less water-consuming crops or for crops with higher economic productivity. The approach provides a strategy for increasing crop water productivity at the agro-ecological system level as well as at the global level. Policies and incentives are important in the adoption of changes from traditional agronomic and cultural practices. However, it is necessary to identify the types of policies and incentives that will work best.

As human populations and economies grow, the demand for water across different sectors has increased rapidly (Tuong and Bouman, 2003). However, the efficiency of water resources management varies across and within different domains and this can result in synergies or trade-offs on water productivity. Water management is complicated, further, by the fact that water use or misuse in one domain, in this case agriculture, affects other domains such as energy and environment. The water–energy–food nexus (WEF nexus) concept is a novel approach that considers the interactions, synergies, harmonisation, and trade-offs between water, energy, and food when undertaking the management of these resources (Bizikova et al., 2013; Mabhaudhi et al., 2018; Mpandeli et al., 2018). Several scholarly articles have demonstrated the need to adopt a WEF nexus approach to managing and improving efficiencies of natural resources within the region. Mpandeli et al. (2018) assessed the regional and international literature on climate change adaptation opportunities and challenges applicable to southern Africa from a WEF nexus perspective. Nhamo et al. (2018)

explored opportunities for the WEF nexus in promoting cross-sectoral policy linkages among water, energy, and food sectors achieve regional integration and sustainable development. The main recommendations were on transboundary water management for improved resource use efficiency. Mabhaudhi et al., (2018a) assessed the status of irrigated agriculture in southern Africa from a water–energy–food (WEF) nexus perspective and emphasized the need to increase water storage, human capacity, and broaden the energy base to support efforts to increase the area under irrigation. This WEF nexus approach thus addresses the multifaceted and interrelated nature of resource systems for any intended outcome or impact. It is because of its cross-sectoral approach to resource planning and management that the WEF nexus is an important tool in water management in irrigation and across catchments (Bizikova et al., 2013; Entholzner and Reeve, 2016; Mpandeli et al., 2018). Therefore, any intervention to increase area under irrigated should be done in the context of a WEF nexus analytical framework.

#### **4. RECOMMENDATIONS**

Under water scarcity, the success of agriculture lies in increasing water productivity. Whilst food security is a priority, an integrated approach to addressing water productivity will ensure the trade-offs with the environment and socio-economic constructs. The following recommendations are suggested:

- There is need to ensure that the policy landscape in South Africa is conducive to supporting water efficiency initiatives, with stakeholder such as scientists, farmers and industry informing and guiding agricultural water management;
- There is need to invest in the development of infrastructure and adoption of relevant technologies that are water efficient
- There is need to develop human capacity with relevant skills to support the implementation of strategies aimed at improving water productivity at different scales. It involves training a foundation of field experts who can promote greater awareness of initiatives aimed at efficient use of water and ensure these are successfully integrated into agriculture, and
- Promote the use of better agronomic practices: currently, which includes the use of climate-smart agriculture techniques that increase crop production and enhance efficient resource use under rainfed and irrigated conditions

#### **5. CONCLUSIONS**

Increasing water productivity in South Africa for sustainable increases in food production requires a multicentre approach, which includes considerations from a plant, field and basin level. Climate-smart agriculture practices that (i) promote rainwater harvesting and soil water conservation, (ii) the use of improved crop varieties with high water productivity, and (iii) improved agronomic practices and alternative practices such as intercropping, mulching and rotations that contribute to increased water productivity should be strengthened. There is a need to strengthen human capacity to ensure that smallholder farmers are equipped to take advantage of the investments in irrigation. This will sustain gains achieved from increasing the area under irrigation and may enable farm management to shift towards climate-smart agriculture. The inclusion of smallholder farmers through investments in small-scale irrigation schemes will assist in the development of resilient food systems and strengthening their capacity to adapt to climate variability and change.

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