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Review Article

Cropping Systems and Agronomic Management Practices in Smallholder Farms in South Africa: Constraints, Challenges and Opportunities

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Abstract

Many studies have been conducted to assess challenges faced by smallholder crop producers in South Africa but few have focused on agronomic constraints. This study is a review of agronomic constraints faced by smallholder farmers under irrigation and dryland farming in South Africa. Constraints include choice of cultivars, planting dates and densities, tillage operations, water and fertilizer management and cropping patterns. Water availability is a major constraint under dryland farming and studies showed that the impacts can be very severe. Interaction of a variety of constraints under irrigation resulted in below average yields. Strategies for increasing productivity in dryland agriculture include capturing more water and allowing it to infiltrate to the root zone and the use of available water more efficiently. Yields under irrigation can improve when micronutrients are blended with macronutrients in relatively affordable blends. Use of green manure as an alternative fertilizer can also improve yields. Soil and water management technologies that improve soil fertility and productivity were as important as those that prevent soil erosion and water loss. It was recommended that practices such as supplementary irrigation and rainwater harvesting technologies take priority in efforts to address dryland water problems. As for farmers with access to irrigation water, practices that deal with improvement in planting dates and populations and water and fertilizer management can have positive impacts on crop yields. Research focused on smallholder agriculture should also start focusing more on water productivity and improving agronomic practices.

Key words: Smallholder farming, crop management practices, agronomic constraints, water and fertilizer management, crop varieties

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INTRODUCTION

The total land area of South Africa is 127 million ha of which 82% (100 million ha) is agricultural land. Only 14% (14 million ha) of the latter receives sufficient rainfall for arable crop production and periodic droughts affect the dryland areas[1]. South Africa is currently facing one of the worst droughts in history. Less than 10% (1.35 million ha) of the arable area is irrigated but the irrigated area accounts for a substantial proportion of the value of the country's total agricultural output[1]. The commercial farming sector produces more than 95% of the total marketed agricultural output, while the smallholder sector produces only 5%.

South African agriculture is dualistic in nature, consisting of the less developed smallholder sector and a well-developed commercial sector. The number of commercial farmers is estimated at between 50,000 and 60,000. The large-scale commercial sector, consisting of mostly white farmers, provide food for the whole nation while the smallholder farmers are characterized by the overwhelming large number of the rural population who play an insignificant role in national food production. Oettle *et al.*[2] reported that 60,000 white commercial farmers occupy 102 million ha while 1.2 million black farmers share about 17 million ha of agricultural land. Recent studies such as Cousins[3] showed however increased figures of people involved in smallholder agriculture to be 4 million and Hart[4] reported a decreased number of commercial farmers by at least 23%. Armour[5] reported that there are 3.3 million smallholder farmers and 30,000 commercial farmers in South Africa. A report produced by World Wide Fund-SA[6] pointed out that a decline in commercial farming is attributed to decreased productivity and drought. Smallholder agriculture is therefore beginning to play a significant role in the country's agriculture economy.

Smallholder agriculture plays an important role in terms of food security, employment creation and income generation in many countries. In Sub-Saharan Africa, over 60% of the rural population depends on dryland agriculture[7] and in South Africa; approximately 1.3 million rural households are involved in dryland agriculture[8]. The majority of smallholder farmers in South Africa are located in the Eastern Cape and Limpopo provinces where 52 and 60% of the households are poor, respectively[9]. Rural livelihoods in most parts of South Africa depend on agriculture and over 30% rural households in Eastern Cape and Limpopo provinces are involved in agriculture[10].

South Africa has incorporated smallholder agriculture into various support and development programs of both the public and private sectors to ensure viability and sustainability in farming practices. The aims of the smallholder agricultural development programs in South Africa include increasing crop productivity, enhancing sustainable resource use and facilitating economic growth in rural communities[11]. The government has created several support programs to improve agricultural productivity of smallholders in rural areas. Programs like the Land Reform for Agricultural Development (LRAD) are specifically meant to empower smallholder farmers. However, as Hart[4] pointed out, some of these programs have tended to make matters worse than improve them.

Despite government efforts, poverty is still pervasive in rural areas, particularly in the former homelands where smallholder farmers are the majority. Problems of unemployment, low income levels and food insecurity continue to be a challenge for the government. Alleviating food insecurity therefore requires more effort to be directed towards developing smallholder agriculture. In contrast to the international scene where irrigated agriculture is recommended as an appropriate way of addressing rural poverty and unemployment in areas where sustained dryland production of crops is limited by water deficits[12], smallholder irrigation schemes in South Africa have not performed optimally to achieve the desired goal of increased crop productivity.

Currently there are 302 smallholder irrigation schemes with 206 still operational and the remainder non-operational[13]. The majority of the schemes are in Limpopo, KwaZulu-Natal and the Eastern Cape provinces. Researchers in smallholder irrigation schemes have found that much of the schemes are operating below their potential[13-16]. An analysis of yields of main crops grown under irrigation in the Eastern Cape indicated that large gaps existed between yields achieved by farmers and those achieved with good management[15]. Yields of maize (*Zea mays*) and butternut (*Cucurbita moschata*) were 24 and 22% of maximum economic yields obtained in on-farm experiments conducted in the scheme during the same period. The fact that the yields from on-farm experiments were comparable to commercial yields suggests that other factors were responsible for the low crop productivity experienced by farmers.

Constraints and challenges faced by smallholder dryland farmers include those linked with tillage operations, cropping systems and patterns, cultivar choices, planting populations and times, plant stands, soil nutrients/fertilizer and water management. However, before suggesting solutions to the problems there is need to understand what constitutes smallholder farming and an understanding of the constraints and challenges faced by the farming systems. The main objectives of this study were to (1) Review the constraints and challenges faced by smallholder farmers in South Africa, (2) Assess the impact of the agronomic constraints on smallholder cropping systems, (3) Explore the relationship between agronomic constraints and crop yields and (4) Suggest some of the interventions, options and opportunities that South Africa can utilise to improve productivity in the smallholder farming sector.

There is no standard definition of a smallholder farmer 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[17]. No clear distinctions can be drawn between categories such as smallholder, small-scale, subsistence, communal or emergent or peasant. In the South African context and in this study, smallholder farmers are defined as black farmers most of whom reside in the former homelands. 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[18].

MAJOR AGRONOMIC CONSTRAINTS TO IMPROVED CROP PRODUCTIVITY ON SMALLHOLDER FARMS

Smallholder farmers in South Africa are generally not farming at an optimum level. This is because the constraints and challenges facing smallholder farmers have not been addressed well, hence the persistence of low productivity levels. Challenges encountered by smallholders have been linked to historical, socio-economic, financial, natural and agronomic factors[19,20,15,21]. While challenges such as socio-economic and financial factors have support programs and institutions to assist the farmers, in the case of agronomic constraints there is very little progress on efforts to help farmers. Agronomic constraints that farmers are battling with include tillage practices, nutrient (fertilizer) management, water (irrigation and rainfall) management, cultivar choice, planting dates and planting densities and resultant plant stands[15, 16].

In South Africa, the smallholder crop producer challenges and constraints have been identified and studied but to date not many studies have found real solutions to the constraints. Generally, smallholder farmers are not efficiently producing or at least sustaining the production. Fanadzo *et al.*[15,22] pointed out that limited research has been done to evaluate the relationship between agronomic constraints or farmer management practices and the resulting crop productivity.

Tillage: There is clear evidence on how conventional tillage causes and contributes to soil degradation, erosion and desiccation. Frequent soil disturbance with implements such as ploughs and hoes, which is common in smallholder production in the Southern African region, does more harm than good[7]. One obvious negative effect of tilling the soil is the creation of the restrictive soil layers commonly known as hard pans. The restrictive hard pans created by frequent tillage impede soil infiltration and root penetration and causes accelerated oxidation of organic matter[7]. Conventional tillage is labor demanding in smallholder production and it is associated with poor timing of farming operations[23]. Resource poor farmers who depend on ox-traction, which is not uncommon in many smallholder productions for ploughing operations, are affected.

Kosgei *et al.*[24] reported that dryland smallholders maximised tillage because of perceptions that it resulted in increased yields with results from Potshini Catchment supporting their statement. However, that is untrue according to Rockstrom and Falkenmark[25]. Perennial cultivation of cereals under conventional tillage practices has been linked to yields below 1 t ha^{-1} where otherwise more than 3 t ha^{-1} can be achieved. This is partly because the restrictive layers delay seed emergence and compromise plant growth[25]. Johansen *et al.*[26] noted a reduction in soil particle infiltration and the resulting slow water infiltration as a result of continuous conventional tillage. Aeration is also reduced with increased compaction and the plant's roots are not distributed effectively under such conditions.

Wani *et al.*[27] reported reduced porosity and increased surface runoff with conventional tillage. Rockstrom[23] reported a total runoff of 10-25% in similar conditions. Runoff increases in soils where tillage has excessively destroyed the organic matter status of the soil leading to reduced water holding capacity[26]. In Thukela River Basin, a maize yield increase of more than 5% was achieved when the surface runoff was reduced by more than 80%[28]. In a study of tillage impacts on maize yields, Kosgei *et al.*[24] reported an increase in maize yield of 168, 133 and 120% in no-till plots compared to conventional tillage. Burning or removal of crop residues after tillage leaves the top soil exposed to adverse climatic conditions[23] such as runoff and wind, hence top soil loss which further leads to reduced soil fertility for crop production.

Water management: South Africa has an average annual rainfall of less than 500 mm. According to the United Nations Council on Combating Desertification (UNCCD) system for defining dry lands, more than 80% of South Africa's land surface is classified as semi-arid to arid. Only 18% of is classified as dry sub-humid or subhumid[1]. Rainfed crop production is concentrated in the sub-humid zones as well as in the central and eastern reaches of the semiarid zone, where favourable soil characteristics occur[1].

Unlike farmers who practice irrigation, dryland farmers have to battle drought, which is a huge constraint to resource poor farmers without irrigation. Knowledge of drought incidence is crucial under dryland smallholder agriculture[29]. Such knowledge enables smallholder farmers to be prepared and to commence the necessary measures early to prevent crop failures. Mupangwa *et al.*[30] noted that not only drought and rainfall variability affect plant growth but difficulty in planning the planting dates, crop types and varieties increases under these conditions. Water productivity in smallholder dryland farming is a limiting factor to optimum production in many areas. In addition to drought, the cropping timeliness to coincide with rain, hydrological properties of soils and timely weed control[24] also pose major constraints. The low mean annual rainfall of 450-550 mm and high annual evaporation of 2000-2500 mm in South Africa results in severe crop water stress during most seasons[31]. These conditions were prevalent in semi-arid areas where smallholder farmers are located with little capacity to establish conventional irrigation infrastructure to handle recurring droughts and periods of dry spells[24].

Water availability in dryland farming can be cited as the single most important challenge to crop growth[23,32-34]. Most of these studies concluded that low productivity in dryland agriculture mainly relates to management practices. According to Rockstrom *et al.*[32], physical potential was the least cause of poor productivity. Improved management practices can increase yields obtained in dryland agriculture. The challenge is to maximize water infiltration, mitigate dry spells and improve primarily soil fertility in order to increase productivity[7]. De Winnaar *et al.*[33] studied the Thukela River Basin where farmers normally grow maize and soya beans (*Glycine max*) to identify potential run-off harvesting in order to capture and efficiently use water to maintain agricultural production in an economic, environmental and sustainable manner. The authors concluded that providing information of runoff that is spatially relevant is a vital step for locating runoff-generating areas and determining areas within a catchment where surface water is generated, which is an important step in promoting runoff-harvesting technologies. Irrigation reduces or removes water deficit as a limiting factor in plant growth and makes it possible to grow crops where the climate is too dry for this purpose and to increase crop yields[13]. However, research also showed that with adequate water but improper management practices yields were likely to remain poor in irrigated agriculture. Generally, infield water management in smallholder irrigation schemes in South Africa is weak. In the Eastern Cape, Fanadzo *et al.*[15] partly attributed this to the infield irrigation equipment that was in a state of dilapidation as many of the sprinkler systems used were very old and were not maintained well. Different standpipe lengths, sprinklers and nozzles were found in single laterals while many connections to the laterals often leaked due to worn-out threads (Table 1).

In KwaZulu-Natal, farmers reported problems with regards to irrigation methods; for example, furrow irrigation was reported as causing erosion and wasting water as it is difficult to measure the exact amount of water to be provided to the crops[16]. In the Eastern Cape, Fanadzo *et al.*[15] reported that farmers did not exercise irrigation scheduling but used a combination of plant observation and the feel method. Sprinkler irrigation schedules of two to four hour stand times every two to three days were common. In extreme cases, farmers irrigated overnight, resulting in over irrigation and wastage of water. Irrigation scheduling was generally constant regardless of crop type and growth stage, usually resulting in over irrigation during early crop growth stages and under-irrigation during the advanced growth stages. Similar

Table 1: Sprinkler system characteristics, uniformity and efficiency parameters at two smallholder farms in the Eastern Cape, South Africa[15]

Parameters	Nofemele farm	Kalawe farm	Norm
Sprinkler type	Rain Bird 30BH	Rain Bird 30BH	-
Nozzle sizes (mm)	3.6 and 4.0	3.6 and 4.0	-
Sprinkler spacing (m)	12	12	-
Lateral spacing (m)	12	18	-
Number of sprinklers per lateral	7	4-8	-
Average application (mm h^{-1})	6.05	2.87	-
Gross application (mm h^{-1})	10.14	5.81	$\geq$5
Christiansen uniformity coefficient (%)	74.3	93.0	$\geq$85
Distribution uniformity (%)	54.9	90.0	>75
Application efficiency (%)	59.6	49.3	>65
System efficiency (%)	32.7	44.4	>48
Pressure variation (%)	20.4	30.3	$\leq$20

results were obtained in the Limpopo province where farmers applied large amounts of water at a time instead of applying reduced amounts of water at intervals that are more frequent. Over irrigation was one of the reasons for reduction in yields in Limpopo[35].

Soil fertility management: Soil fertility is defined as the quality of a soil that enables it to provide nutrients in adequate quantities and in proper balance for the growth of specified plants or crops[36]. A decline in soil fertility implies a decline in the quality of the soil. Soil fertility decline is defined as the decline in chemical soil fertility or a decrease in the levels of soil organic matter, pH, cation exchange capacity and plant nutrients[37]. Soil fertility decline thus includes nutrient depletion or nutrient decline (larger removal than addition of nutrients), nutrient mining (large removal of nutrients and no inputs), acidification (decline in pH and/or an increase in exchangeable Al), the loss of organic matter and an increase in toxic elements[37].

Nutrient removal may result in a decline of the soil fertility if replenishment with inorganic or organic nutrient inputs is inadequate. In many parts where smallholders are operating, declining soil fertility is a major production constraint[23,38]. A lack of fertilizers and manure has not only been identified as a factor contributing to low soil fertility but farmers also explained how soil erosion and poor soil types are also aggravating the situation. Even in areas of adequate rainfall distribution, crop yields remain largely low. Crop management practices and soil fertility were cited by Minde *et al.*[38] as possible contributing factors to low crop productivity by smallholders. In the Olifants River Basin of South Africa, Magombeyi and Taigbenu[39] reported that even with effective management of pests and adequate moisture, yields are expected to decrease by 50% if there is a lack of macronutrients (NPK).

Knowledge of land conditions and soil health constraints is necessary to plan management options and to apply necessary soil fertility enhancements[40]. Soil health is a huge research topic under smallholder irrigation[35, 41, 42]. Research also indicated that dryland smallholder farmers tend not to apply fertilizer, fearing risks of crop failures caused by dry spells and drought[43] and at times, the low availability and the high cost of fertilizer is an impediment[44]. Soil fertility is reported to be very low in much of the Sub-Saharan Africa region and Rockstrom[23] added that farmers in Africa generally apply 11 kg of fertilizer per every harvestable hectare, while in developed countries the average fertilizer applied for every hectare is 62 kg. Soil fertility constraints often constitute the primary limiting factor to crop growth in both irrigated and dryland agriculture. Andersson *et al.*[45] identified nitrogen as the main constraint to crop growth in the Thukela river basin.

There is a considerable relationship between water usage and fertilizer applications in crop production. A combination of supplementary irrigation and fertilizer applications leaded to improvements in yields in drylands[7,43]. However, fertilizer application alone resulted in higher yields than supplementary irrigation alone. It is not uncommon in South Africa where smallholder farmers generally use low inputs to use kraal manure as a source of fertilizer. Smallholder farmers resort to manure and other non-synthetic fertilizers due to lack of capacity to buy commercial fertilizers.

Research indicated that soils under smallholder irrigation lacks the essential nutrients and farmers tend to ignore the detrimental effects of soils cultivated without replenished fertilizers. For instance, farmers in the Eastern Cape applied fertilizers at random and the applications were only made once in two to three years[16]. Mandiringana *et al.*[46] reported that soils under irrigation schemes in the Eastern Cape are already nutrient depleted. In Limpopo province, Machethe *et al.*[35] found that the soils at some irrigation schemes had accumulated salts to toxic levels due to poor water management.

Fanadzo *et al.*[47] identified poor timing and low amounts of fertilizer application as the major causes of low productivity in maize and butternut production under irrigation in the Eastern Cape (Table 2). In the same province, fertilizer application rates were usually not based on soil fertility analysis and recommendations[15]. In Limpopo province, Machethe *et al.*[35] reported that farmers applied blanket amounts of inorganic fertilizers and the rates were mainly marginal, especially for the field crops. Farmers cited a lack of information on fertilizer recommendations and funds as the main reasons for resorting to low blanket applications. A study conducted in the Limpopo province showed that 5% of the farmers lacked knowledge of fertilizer use while 48% had insufficient financial power to purchase the fertilizers[41]. Farmers are not only unable to obtain appropriate fertilizers but they are also unaware of the correct fertilizers for usage in already depleted soils[38,48]. Farmers need to know the recommended fertilizer application rates and Odhiambo and Magandini[41] stressed that while that may seem obvious, inappropriate applications of fertilizer or soil amendments can waste resources, cause water pollution and damage soils.

Table 2: Fertility management and yields of grain maize, green maize and butternut at Zanyokwe irrigation scheme, Eastern Cape, South Africa[15]

	Seasons			
Variable (kg ha^{-1})	2005/06	2006/07	2007/08	Mean
Grain maize				
Basal N	13.2	13.2	13.2	13.2
Top-dress N	28.0	37.8	46.1	37.3
Total N	41.2	51.0	50.5	47.6
Grain yield	2266	1417	3489	2391
Green maize				
Basal N	-	9.7	11.9	10.8
Top-dress N	-	52.5	45.7	49.1
Total N	-	60.6	57.6	59.1
Percent cob sales	-	42.6	49.1	45.9
Butternut				
Basal N	13.2	10.9	11.9	12.0
Top-dress N	48.8	58.2	52.4	53.1
Total N	62.0	68.7	50.6	60.4
Total yield	6800	8100	3200	6000

Farmers do not have knowledge of nutrient requirements of the crops that they plant, which can increasingly overuse the nutrient reserves. Irrigation imposes a great demand for nutrients and most crops grown under irrigation are high value vegetable crops that take up large quantities of nutrients from soils. Provision should therefore, be made to replace nutrients removed by these heavy feeders for farmers to continue realizing profitable yields. The interaction of moisture supply and nutrient supply is reciprocal such that if the farmer cannot irrigate, it is a waste to fertilize and if a farmer cannot fertilize, it is a waste to irrigate[49]. Therefore, with inadequate fertilizer management under the smallholder sector, farmers are not getting the potential yields.

Cropping patterns: Cropping patterns (yearly sequence and spatial arrangement of crops or of crops and fallow on a given area) present an advantage and opportunity to farmers, allowing them to sow crop after a crop and increase cropping intensity[26]. Research indicated that most smallholder farmers in South Africa practice monoculture of maize and this is practiced by 88% of farmers in Limpopo dryland production[38]. However, Van Duivenbooden *et al.*[34] reported intercropping with leguminous crops at low densities. Snapp *et al.*[50] explained the importance of legumes for both food and feed nutrition and their contribution to subsequent cereal productivity through biologically fixed nitrogen[44], pest build-ups/cycles breakdowns, conservation and sustainable agriculture promotion. Furthermore, Ogindo and Walker[31] found out a low surface evaporation rate in a maize-bean intercrop in the Free State province. However, the transpiration rate also amounted to 5-6% higher than a sole maize and bean. A high leaf area of the intercrop can suppress weeds and provide soil moisture retention.

Planting densities of the intercropping system depends on both rainfall and soil type. A common rotational practice involves maize with either a legume crop or vegetable. In the case of vegetables, farmers are mainly using them for local market income. Magombeyi and Taigbenu[39] in a study of the Olifants River basin found the same results where farmers generally planted maize in the area for approximately 121 days and after harvest, farmers prepare their fields for winter vegetables. In addition, in many parts of Sub-Saharan Africa, the inclusion of cereal-legume such as millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*) is common[34].

Cropping patterns generally used in many smallholder-irrigated areas involve alternating summer and winter crops, field crops and vegetables[20,35]. Depending on province, the type of crops grown under irrigation differs. Of all the crops, maize is the most common and important summer crop grown in terms of the areas devoted to crop type and number of growers[20,41,38]. In Limpopo, Machethe *et al.*[35] reported maize or cotton followed by winter wheat as the dominant rotation system, while in the Eastern Cape, Fanadzo *et al.*[15] reported dominant cropping patterns of maize monoculture, butternut-cabbage and maize-cabbage rotations. Under irrigation in KwaZulu-Natal, it is possible to cultivate three crops a year on a single plot but many farmers leave at least some plots fallow in the winter months[51].

The use of arable land is not optimum in smallholder cropping, both under irrigation and under dryland. 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. Whilst cropping intensities of 200% are possible under irrigation in the Eastern Cape[14], a study by Fanadzo *et al.*[15] indicated low cropping intensities averaging

Table 3: Cropping patterns at Zanyokwe irrigation scheme, Eastern Cape, South Africa (Modified from Fanadzo *et al.*[15])

	Seasons			
Parameters	2005/06	2006/07	2007/08	Mean
Number of crops				
Summer	1.70	2.70	2.13	2.18
Winter	0.73	0.70	0.40	0.61
Total	2.43	3.40	2.53	2.79
Cropped area				
Summer	41.57	43.20	39.33	41.37
Winter	7.97	6.53	5.33	6.61
Cropping intensity	49.54	49.73	44.66	47.98

48% from 2006 to 2008 (Table 3). Similar low cropping intensity levels have been reported in smallholder irrigation schemes in other provinces[14,52,53]. Increased crop productivity with higher cropping intensities is well documented[54-56].

Lack of motivation and resources were identified as the two main factors responsible for the underutilization of land in the Eastern Cape[15]. The low cropping intensities were attributed to minimal winter cropping because of limited markets for most winter vegetables such as cabbage (*Brassica oleracea* var. *capitata*), spinach (*Spinacea oleracea*), beetroot (*Beta vulgaris*) and carrots (*Daucus carota*). Farmers relied on customers who came to buy the vegetables from the field. Thus, even at the low winter cropping intensities, some of the cabbage was observed to rot in the field after farmers failed to secure customers on time.

Cultivar choice: Literature available on crop cultivars does not give specific details of the varieties of crops used by smallholder farmers in South Africa based on their farming systems. However, Fanadzo *et al.*[15] reported that irrigation farmers in the Eastern Cape used a combination of hybrid seeds and Open Pollinated Varieties (OPVs). Van Averbeke *et al.*[13] reported that hybrid maize yielded 50% more than the OPVs commonly grown by farmers in the same irrigation scheme. With timely planting and optimum fertilizer application, long season maize cultivars were favoured over short season cultivars, while the latter was a better option with delayed planting as long as the cultivars were grown at higher densities and well fertilized under irrigation in the Eastern Cape[22].

At Tugela Ferry irrigation scheme in KwaZulu-Natal, Cousins[51] reported that almost all farmers planted early green maize to benefit from the crop's comparative market advantage. Gouse[57] surveyed the Hlabisa district of KwaZulu-Natal and found out that at the end of the 2009/2010 season none of the farmers planted *Bacillus thuringiensis* (Bt) maize and few still planted conventional maize and the rest planted Herbicide Tolerant (HT) or BR (a stacked traits of Bt and HT combination) maize[57]. Farmers seemed to be willing to pay for weed-control and labour-saving benefits of HT maize than the borer-control insurance of the Bt maize.

Although literature lacks details on cultivars grown by smallholder farmers, especially under dryland, specifics are available for the type of cultivars that farmers can utilize. According to Van Duivenbooden *et al.*[34], the short-period growth varieties that can withstand the effects of drought periods were recommended for dryland drought prone environments. Ogindo and Walker[31] gave an indication of cultivars which form base for the recommended varieties in which a short season PAN 6804 [PANNAR (Pty) Ltd., South Africa] maize cultivar maturing in 121 days was used in relation to soil moisture content. When cultivar PAN 148 was grown together with dry bean in intercropping system, the recorded advantages were water conservation and high biomass creation due to increased transpiration. The fertilizer application rate, planting density per hectare and cultivar choice forms a link when deciding on appropriate cultivars for dryland production[31].

Planting time and densities: Research showed significant relationships between moisture, fertilizer applications, planting populations and planting dates. In a study by Fanadzo *et al.*[22], planting time and plant population interaction showed that increasing plant population from 40,000 maize plants ha^{-1} resulted in higher yields when planting was done early but significantly lower yields when planted late under irrigation. Late planting was identified by Van Averbeke *et al.*[13] as one of the major causes for low productivity in many smallholder farms. In the Eastern Cape, maize grain yield decreased by 38% when planting was delayed[15]. Results from the dry parts of South Africa showed that optimum population of maize for best yields decreased from 60,000 plants ha^{-1} with 650 mm water supply to 10,000 plants ha^{-1} with 240 mm water availability[58].

Economic crop yields arise from plant densities that minimize inter and intra-row competition, which widely depends on environmental conditions, while cereal grain yield is the product of heads per unit area, kernels per head and kernel weight[34]. Factors that influence these components are seeding density, plant distribution and genotype for a given area. For grain legumes, which form part of most rotational and intercropping in many smallholders[48], an optimum seeding rate depends on the delicate balance between seedling death by fungal pathogens, extent of infestation by foliar diseases and insect pests, soil moisture status throughout the crop cycle and production of sufficient vegetative growth for supporting yield formation[26]. The recommended planting density of maize and *Sorghum* grains under dryland in southern Africa is 10,000-32,000 and 50,000-80,000 plants ha^{-1}, respectively[34]. Plant population is influenced by other prevailing conditions in achieving an optimum population. Soil fertility and moisture are known to be playing a fundamental role. In conditions where soil fertility and moisture are low, planting density is likely to be affected and dryland farmers are already facing that problem.

Planting population management is generally poor in many smallholder areas under irrigation with most studies showing results of under population. Higher yielding cultivars at optimum planting densities are important if higher yields are to be achieved. However, plant populations interact with other factors such as fertilizers particularly nitrogen, cultivar selection and planting time. With nutrients and season length non-limiting, the higher plant populations will yield more for short season cultivars and long season cultivars would yield more at low planting populations in maize[22].

Machethe *et al*.[35] reported maize planting densities of 55,000-80,000 plants ha^{-1} under irrigation in Limpopo province. However, densities were relatively high taking into consideration the fact that fertilizer especially nitrogen was marginal[35]. Fanadzo *et al*.[59] showed that the standard planting population of 40,000 plants ha^{-1} which is a norm amongst smallholder irrigation farmers in the Eastern Cape is not enough to optimize on both green and grain maize production under irrigation. As supported by various studies[60-65], for example, knowledge of optimum planting populations and determinants of the choice of planting density is crucial for achieving high yields. Manipulation of planting densities and row spaces play a vital role in grain production. Maize is the agronomic species that is most sensitive to changes in planting density, such that for each production system, there is a population that maximizes the utilization of available resources allowing for the expression of maximum attainable yield in the environment[63].

OPPORTUNITIES FOR IMPROVED PRODUCTIVITY

Research showed that water is the main constraining factor to productivity under dryland agriculture and other factors such as nutrient and pest management techniques play a lesser role[66]. Rockstrom[23] identified two broad strategies for increasing yields in dryland farming when water availability in the root zone constrains crop growth: (1) Capturing more water and allowing it to infiltrate into the root zone and (2) Using the available water more efficiently (increasing water productivity) by increasing the plant water uptake capacity and/or reducing non-productive soil evaporation. Results by Rockstrom *et al*.[67] correlated with what they had reported earlier[32] on how to mitigate periods of dry-spells in semi-arid rainfed environment:

- Maximise plant water availability (maximise infiltration of rainfall, minimise unproductive water losses, increase soil water holding capacity and maximise root depth)
- Maximise plant water uptake capacity (timelines of operations, crop management and soil fertility management)
- Bridge crop water deficits during dry-spells through supplementary irrigation

The challenge in dryland farming is to maximise infiltration, mitigate dry-spells and to improve primarily soil fertility management in order to increase water productivity. Approaches such as rainwater harvesting techniques are argued as means to manage drought and dry spells in dryland agriculture[33,45]. Biazin *et al*.[43] stated that the techniques for enhancing infiltration, reducing runoff and evaporation or improving soil moisture storage in the crop rooting zone are known as *in situ* rainwater harvesting. These techniques are aimed at enhancing rainfall infiltration ad reducing soil evaporation. The most commonly applied *in situ* rainwater harvesting and management practices include ridging, mulching, various types of furrowing and hoeing and conservation tillage[43].

In the Free State province, intercropping was identified as one option to maximise water usage by reducing the rate of soil water evaporation on smallholder farms[31]. The maize-bean intercrop had the lowest soil surface evaporation as a percentage of precipitation and evapotranspiration. This confirmed what has been already discussed in many studies that intercrop systems, due to an early and higher leaf area index, are able to reduce the amount of energy available for soil surface evaporation. In addition to reduction in evaporation, Nyakudya and Stroosnijder[68] reported that the use of mulch protects the soil from raindrop impact and thus reduces soil surface crusting and encourages infiltration and moderates the high temperatures in the upper root zone. In a study by Mutiro *et al.*[66], it was reported that conservation agriculture improved root penetration and infiltration. The yields of plots that received supplementary irrigation coupled with ripping were higher than supplementary irrigation with no ripping. The study further concluded that ripping increases water availability in the root zone. In addition to intercropping for coping in drought periods, farmers in the Olifants River basin used technology driven efforts such as a new short-duration and drought tolerant crop varieties[39]. Integrated Soil Fertility Management (ISFM) is another concept developed since the 1990s, which focuses on application of soil fertility management practices and the knowledge to adapt these to local conditions, thereby maximising fertilizer and organic resource use efficiency and crop productivity[40]. These practices include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm[69]. Techniques like seed priming (soaking seeds in water before sowing, for 24 h in case of maize) which enhances crop water use efficiency by hastening germination and emergence should be promoted[70].

There is considerable scope for improving water productivity of crop, livestock and fisheries from field through to basin scale. Practices used to achieve this include water harvesting, supplemental irrigation, deficit irrigation, precision irrigation techniques and soil–water conservation practices. Practices not directly related to water management impact water productivity because of interactive effects such as those derived from improvements in soil fertility, pest control, crop selection or access to better markets. However, there are several reasons to be cautious about the scope and ease of achieving water productivity gains. Crop water productivity is already quite high in highly productive regions and gains in yield (per unit of land area) do not necessarily translate into gains in water productivity. Reuse of water that takes place within an irrigated area or a basin can compensate for the perceived losses at the field-scale in terms of water quantity, though the water quality is likely to be affected. While crop breeding has played an important role in increasing water productivity in the past, especially by improving the harvest index, such large gains are not easily foreseen in the future. More importantly, enabling conditions for farmers and water managers are not in place to enhance water productivity. Improving water productivity will therefore require an understanding of the biophysical as well as the socioeconomic environments crossing scales between field, farm and basin.

Supplementary irrigation: Supplementary irrigation can mitigate the dry spells in dryland agriculture and this can be achieved through water harvesting systems that collect local surface runoff in small storage structures[7]. It is a key strategy, still underused for achieving rainfed yield potential and water productivity. Supplementary irrigation systems can also be used in small vegetable gardens during dry seasons to produce fully irrigated cash crops[67]. According to Rockstrom[23], water-harvesting systems with storage for supplementary irrigation were not very common in Eastern and Southern Africa. In the Olifants River basin, rainwater harvesting tanks for supplementary irrigation were used to irrigate maize crop in bridging the intra-seasonal dry-spells and in irrigation of winter vegetables to improve family food security[39].

Rainwater harvesting: Faures and Santini[71] defined water harvesting as a process of collecting and concentrating rainfall as runoff from a catchment area to be used in a smaller area, either for agriculture or other purposes. The purpose of rainwater harvesting was to make more efficient use of rainwater that would otherwise be lost as runoff or through evaporation[72]. Footpaths, dirt roads and compounds consist of compacted soil, often with heavy erosion crusts that produce high volumes of runoff. Road runoff can vary from a simple diversion structure directing surface water into crop fields, to deep trenches with check-dams in order to enable both flood and subsurface irrigation[73]. The available means of water harvesting include micro-catchment systems, basins, pitting systems and water storage systems. The latter can also serve domestic purposes, watering livestock and supplementary irrigation[73].

As part of water management practices under dryland crop production, the Agriculture Research Council's Institute for Soil, Climate and Water (ISCW) developed what is called the in-field rainwater harvesting (IRWH) technology in South Africa with the objective of harnessing rainwater for crop production[74]. This technique (Fig. 1) has resulted in a significant increase in crop yield compared to conventional practices[74]. According to Sullivan *et al.*[75], with this technology, rainfall runned off compacted strips or bunds and was collected in rectangular basins running along crop rows and infiltrating deep into the soil beneath the surface evaporation zone. The basin areas are covered with locally available mulch to further retain soil moisture. The technique is specifically suited to smallholder farmers who farm on soils with high clay content.

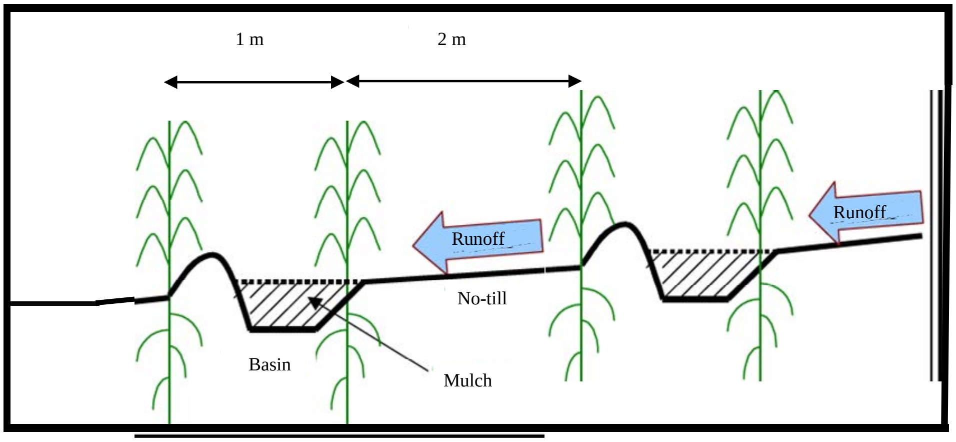

Fig. 1: Infield Rain Water Harvesting (IRWH) technique[74]

Conservation agriculture: Tillage operations and the management of crop residues are important in water conservation, particularly in dry areas[34]. In semi-arid regions, conventional tillage has mainly four purposes: To prepare the seedbed, promote infiltration, water conservation within the soil profile and to prevent wind and water erosion. According to Rockstrom *et al.*[67], a change from conventional to conservation agriculture will increase crop productivity by 20-120% and water productivity by 10-40%. However, potential disadvantages include higher costs of pest control, the cost of acquiring new management skills and investments in new ploughing equipment. Conservation agriculture covers a spectrum of non-soil-inversion practices, from zero tillage to reduced tillage, aiming at maximizing infiltration and soil productivity and minimizing water losses while simultaneously conserving energy and labour[43].

Like integrated soil fertility management, a combination of conservation agriculture with other associated technologies like the use of manure, green manure cover crops, the use of drought-tolerant and low nitrogen requiring cultivars and agro-forestry are common successful attempts to adapt the system to the local farming systems[40]. No-till is a powerful point of entry to solve the problems of soil erosion, soil fertility and soils with low water holding capacity[34]. Crop yields from no-tillage agriculture are usually as high as or higher than yields produced by conventional tillage. Rockstrom and Barron[76] supported these findings in that tillage influences both soil conditions at the surface, i.e. infiltration capacity and the structure in the top soil, which will affect the plant water availability and crop productivity[34].

Land and soil fertility management: Use of crop residues by farmers as fodder and none or shorter fallow periods due to a shrinking land resource base, should be balanced by the addition of chemical fertilizers and organic manure, which most smallholder farmers cannot afford. Therefore there is need to develop appropriate soil nutrient and cropping systems that minimize the need for chemical fertilizers and also find ways to integrate livestock into the farming systems[73]. In the deficient soils of smallholders in Zimbabwe, Kumwenda *et al.*[48] reported that additions of micronutrients improved the yield response to nitrogen and phosphorus. Nutrients such as zinc, boron, sulphur and magnesium can often be included relatively cheap in existing fertilizer blends and when targeted to deficient soils, these nutrients can dramatically improve fertilizer use efficiency and crop profitability.

Alternative sources of nutrients are needed in situations where soil fertility needs to be rebuilt and high costs and quantities limit inorganic fertilizer applications. Use of green manure cover crops has been suggested as one viable option because of their ability to regulate soil surface temperatures, improve soil organic matter, conserve soil moisture and suppression of weeds. High-quality organic manures provide readily available N, energy (carbon) and nutrients to the soil ecosystem and they build soil fertility and structure over the long term[48]. Research by Ncube *et al.*[77] showed evidence that there is potential to improve livelihoods of smallholder farmers through the use of small rates of manure and N under semi-arid conditions in Zimbabwe. However, while some research studies recommend that organic fertilizers are possible and convenient way resource-poor farmers can improve their soil fertility, Minde *et al.*[38] suggested that the use of chemical fertilizers is the surest way of restoring soil fertility in the Limpopo province.

To prevent erosion, farmers in KwaZulu-Natal dug furrows by hand or opened with ploughs and then shaped by hand

and placed upslope the field to re-direct water from the fields during heavy rains[78]. Physical structures (for example contour ditches, mulching and windbreaks) reduce soil erosion, especially on sloping land[77]. Technologies that improve soil fertility and productivity are as important as those that reduce soil erosion and water loss[73]. These include practices such as residue mulching, contour tillage and tied ridging, minimum tillage, sub-soiling, crop rotation, cover cropping, rotational grazing, contour ripping and direct applications of organic matter, farmyard manure and inorganic fertilizers.

Other possible opportunities: Assisting smallholders to pursue sustainable intensification of production through adoption of better seeds, technologies and other improved inputs and assisting them to use them more effectively is expected to result in improved crop productivity[79]. Transplanting is one strategy that is commonly used to establish crops when conditions are less favourable for direct seeding, such as when birds pose a threat to emerging seedlings[15]. In the Eastern Cape, Fanadzo *et al.*[59] reported that farmers would obtain higher yields and profits by increasing plant populations to 60,000 plants per hectare without necessarily having to change their inter-row spacing, although narrow rows would result in slightly higher yields and would help in weed suppression. Ensuring that farmers select the appropriate combination of crops could contribute to increased production and productivity[35], for example, incorporation of leguminous crops into the rotation would raise the nitrogen level of in the soil.

CONCLUSION AND RECOMMENDATIONS

Current agronomic practices make the problems already faced by the farmers even worse. Because the gap between farmer yields and the biophysical potential is very large, greater and easier gains are possible through better agronomic management practices. Programs that target emerging smallholder black farmers who in most cases have been found to possess limited farming skills will enable them to improve food security. Practices like rainwater harvesting are relatively new and farmers who are unfamiliar with the practices will need training and mentorship. All relevant stakeholders, including policy makers, private corporations and extension should assist farmers to alleviate crop production problems.

Smallholder farmers should not only be given priority in land and water provision programs but they should also be actively involved in the development of the programs that are meant for them. Training farmers and extension staff in irrigation water and crop management practices and ensuring a reliable supply of irrigation water should receive urgent attention. Sustainable technologies of improving soil fertility such as inclusion of nitrogen fixing species should be encouraged since inorganic fertilizers are expensive and organic sources often inadequate and of poor quality. Enabling policies and strategies need to be formulated to support smallholder farmers to increase productivity by providing the necessary infrastructure and support services, while at the same time fostering self-sustenance and sustainability.

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