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Adopting deficit irrigation as a strategy to enhance food security in Botswana

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ACH conceived idea, collected data, data analysis, drafted manuscript, edited manuscript. JNA collected data, data analysis, edited manuscript.

ABSTRACT

Food security can be defined as ensuring that all people, at all times, have access to sufficient, safe and nutritious food that meets their dietary needs and preferences for an active and healthy life. Most countries aim to achieve food security by maximising production and thus reducing the reliance on imported food. Botswana is a net food importing developing country (NFIDC). The average annual food import bill over the last three years has been six billion Pula. The value of imported food as a proportion of all merchandise imports fell from 14.2% in 2000 to 8.7% in 2015. This resulted in Botswana's ranking in the world moving from position 63 in 2000 to 100 in 2015.
In this study, data provided by Statistics Botswana were disaggregated to separate foodstuff from beverages and tobacco. Over the last three years, one fifth of imported food valued at just over one billion Pula per year, has been staple cereals (sorghum, maize and wheat). Seventy five per cent of all imports are from South Africa which makes the country's position of food insecurity even more precarious. An argument is presented to encourage the irrigation of staple cereal crops so as to increase production and thus substitute for imports, create employment and improve the food security status of the country. In particular, it is argued that deficit irrigation should be adopted as a matter of policy, allowing the most efficient use of limited water resources and resultant increase in irrigated area and quantities of staple foods produced.

Key words: Botswana, deficit irrigation, food imports, food security

INTRODUCTION

The University of Cambridge defines food security as ensuring that all people, at all times, have access to sufficient, safe and nutritious food that meets their dietary needs and preferences for an active and healthy life (Cambridge Global Food Security, 2017). In 2015 the United Nations (UN) passed a resolution that acts as the post–2015 Development Agenda or successor to the Millennium Development Goals. It is a broad intergovernmental agreement officially known as *Transforming our world: the 2030 Agenda for Sustainable Development*, also dubbed the Sustainable Development Goals (SDGs). It is a set of 17 Global Goals with 169 targets among them.

Goal number 2 simply reads "Zero Hunger" and *aims to end hunger, achieve food security and improved nutrition and promote sustainable agriculture* (UN Sustainable Development Knowledge Platform, 2017). Target number 4 of this goal states *By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*.

Being a member of the UN, Botswana is a signatory to the resolution and the goals referred to above. This is a challenging but noble task that the country has taken on. Considering the arid and semi–arid conditions that typify its climate and thus influence its agricultural production systems, the resolution is a motivating development. The country has plans to increase food production with a relevant objective in the National Water Policy (Ministry of Minerals, Energy and Water Resources [MMEWR], 2012) stating thus: *7.1.2 To improve national food security, contribute to regional food security and promote employment creation in the rural economy through diversification of the national agricultural base, as well as increased agricultural productivity and output*.

To implement this, two strategies are adduced under the same objective: *7.1.6 Support research and development on affordable, appropriate and sustainable techniques for increasing productivity and application of emerging crops, irrigation technologies and livestock to improve water efficiency. 7.1.8 Develop mechanisms and incentives to improve irrigation technologies that will increase water use efficiencies.*

Clearly, it is implicit from the foregoing that for tangible realisation of food security in Botswana, one of the avenues that the country should follow is to explore and implement innovative irrigation technologies that have been proven to be effective in efficient water utilisation. The key strategy is to implement practices that may lead to increased "water productivity". One such technique that has been widely investigated and applied elsewhere is "deficit irrigation".

The aims of this paper were to:

1. Review literature on deficit irrigation
2. Review the state of food supply and related statistics in Botswana
3. Demonstrate how food supply and security could be improved by deficit irrigation.

METHODOLOGY

An extensive literature search on deficit irrigation was carried out. This was followed by gathering and disaggregation of raw data on food imports generated by Statistics Botswana, specifically the International Merchandise Trade Statistics (IMTS) digest for February 2017. More raw data on irrigated crop production was sourced from the Horticulture Unit, Ministry of Agricultural Development and Food Security, and collated.

Deficit irrigation

Deficit irrigation has been defined as an optimization strategy in which irrigation is applied during drought–sensitive growth stages of a crop but less water than the maximum crop water requirement at other stages of growth (FAO, 2002). For most crops flowering is the most drought–sensitive stage. Deficit irrigation aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields per unit of land area. According to the FAO (2002), with increasing scarcity and growing competition for water, there will be more widespread adoption of deficit irrigation, especially in arid and semi–arid regions. This is because it minimizes water demand yet has minimal impacts on yields and crop quality. If the water saved when using deficit irrigation is used to irrigate more land, overall production is increased, leading to improved food security.

Several other advantages have been attributed to deficit irrigation, which include enabling economic planning and stable income due to a stabilisation of the harvest in comparison with rainfed cultivation. When compared with full irrigation, deficit irrigation decreases the risk of certain diseases linked to high humidity and also reduces nutrient losses as there is minimal leaching of the root zone (English, 1990; Zhang and Oweis, 1999). Despite these, the strategy also presents some constraints such as the need for knowledge of the exact response of the crop to water stress, guarantee of a certain minimum amount of water for crop sustenance, and the possibility of salt accumulation due to minimal leaching.

In essence, deficit irrigation introduces stress to the crop, and when this is done during various stages of crop growth, it is said to be regulated deficit irrigation (RDI). Du et al. (2015) reviewed various studies involving regulated deficit irrigation of different crops and irrigation systems in China. From the study, they concluded that regulated deficit irrigation may be used to tune the physiological processes for various crops, leading to increased water use efficiency (productivity of water), yield and crop quality.

English at al. (2014) also describe deficit irrigation as regulated deficit irrigation or partial irrigation, and observe that it is a profitable strategy when water supplies are limited or expensive or where there is considerable spatial variation in soil water–holding capacities within a field. However, they contend that RDI requires much more sophisticated management, as it entails greater analytical effort.

Kirda (2002) states that with increasing municipal and industrial demands for water, its allocation for agriculture is decreasing steadily. Further, that the major agricultural use of water is for irrigation, which, thus, is affected by decreased supply. Alternative sources of water of a lower quality, for example treated wastewater, are often promoted for irrigated agricultural production.

Kirda and Kanber (1999) argue that with limited water resources available for agriculture, innovations for increasing the efficient use of water have to be developed. They suggest four strategies: (i) adopt new irrigation technologies and innovative irrigation scheduling for rational water management, (ii) augment limited supply through efficient and sparing use, (iii) search for alternative cropping systems with least dependence on irrigation, and (iv) improve the operation and maintenance of irrigation schemes. They also emphasised that management techniques should be acceptable to farmers and also be affordable.

Zhang and Oweis (1999) conducted a 10–year study on supplemental irrigation of wheat in the arid part of northern Syria. Their studies showed that certain stages of growth were most sensitive to water stress, thus affecting the yield of the crop. Targeting a specific yield level, the authors recommended supplementary irrigation scenarios with sustainable water utilization that would lead to maximized net profit and water use efficiency, or productivity.

The results of a number of studies conducted to evaluate the yield response of various field crops to deficit irrigation e.g. Kirda and Kanber (1999), Prieto and Angueira (1999), Kirda (2002), Moutonnet (2002) generally point to the following conclusions: (i) decreases in yields are proportionate to the decreased application of irrigation water; and (ii) the crop water use efficiency (water productivity) is increased even if crop yields fall. It is also reported that the impact of deficit irrigation on crop yield can be insignificant where the water stress is applied to the crop during specific growth stages that are less sensitive to moisture deficiency. These findings suggest that if the water saved were used to increase the overall area irrigated, the extra production would more than compensate for any yield loss, and would increase overall food production and thus improve food security. This scenario will be illustrated by an example given later in this paper. Similar arguments are expounded in an opinion paper by Fereres et al. (2011) who asserted that not only would the area under crop production be increased, but extra labour would also be needed, hence creating employment.

Imports of food to Botswana

Statistics Botswana, a parastatal organisation under the Ministry of Finance and Development Planning, collects, publishes and disseminates all official statistics in the country. A monthly digest summarising statistics on trade (quantities and values of imports and exports) is produced by the IMTS Unit of Statistics Botswana, and provides data which is only three or four months old.

In common with most countries, in the IMTS reports "food" is lumped together with beverages and tobacco products. Apparently "food" is deemed to comprise the commodities in the UN Standard International Trade Classifications (SITC) sections 0 (food and live animals), 1 (beverages and tobacco), 4 (animal and vegetable oils and fats) and SITC division 22 (oilseeds, oil nuts and oil kernels).

The IMTS digest for February 2017 was used for this study, which summarises imports and exports for each month from January 2014 to February 2017. Data for the top four categories of imports (principal commodity groups) were used to produce Figure 1, which indicates that during this period spending on food, beverages and tobacco ranks fourth, after imported diamonds, fuel and machinery and electrical equipment. While diamonds account for an average of 36% of imports, food, beverages and tobacco accounts for an average of 9.9%. The cost of food, beverages and tobacco imports averages almost 576 million pula per month over the 38 months to February 2017.

As shown in Figure 2, spending on food, beverages and tobacco as a proportion of total merchandise imports has fallen over the 15 years from 2000. It stood at 14.2% in 2000 and at only 8.7% in 2015. This statistic is used to rank countries and thus indicates those that import large quantities of food and those with a low proportion of food imports. Botswana was at position 63 in the world in 2000 and at a lower position (100) in 2015.

Raw data from Statistics Botswana for imported food, beverages and tobacco for the period January 2014 to December 2016 was disaggregated by the authors to obtain information on Botswana's actual monthly food import bill over the last three years. The mean annual total value of the 19 categories of foodstuffs which remained after removing beverages, tobacco and some animal feeds which were discovered to be included in the data are presented in Figure 3, which shows that cereals are the most significant food import, representing 20.3%, 21.65% and 20.0% of all food imports in the years 2014, 2015 and 2016, respectively. The quantity of cereals imported was 356 395, 386 138 and 332 385 tonnes in 2014, 2015 and 2016, respectively. The overall value of food imports has been steadily increasing from P5 253 827 139 in 2014 to P6 086 634 328 in 2016.

Botswana's main import partners are South Africa, China, Israel, Namibia and Zimbabwe (tradingeconomics.com). Seventy five per cent of all imports are from South Africa which makes the country's position of food insecurity even more precarious.

Irrigated crop production in Botswana

Crop production in Botswana is mainly practised under rainfed conditions. Of the estimated 200 000 ha planted annually, only 1 200 ha (0.6%) are under irrigation (policy brief produced by the Department of Water Affairs and Centre for Applied Research, 2014). This figure is only about 25% of the land allocated for irrigation, and approximately 50% of the area serviced for this purpose. This means that the water allocated for irrigation is underutilised.

According to the same report, existing irrigation schemes comprise individual farmers whose holdings average 2 ha in area, and a few commercial farms such as Talana Farms with about 380 ha, and government–sponsored schemes such as Glen Valley with 200 ha and Dikabeya having some 60 ha. The main crops grown in these irrigation schemes are horticultural crops, which include various types of vegetables and some fruits. Cereals, mainly sorghum and maize, as well as various kinds of pulses, mainly beans and cowpeas and some oilseeds e.g. sunflower are produced predominantly by the rainfed sector. Table 1 shows the national production of irrigated horticultural crops in 2015–16 by district; most production was in the Central District (58%), followed by Kgatleng (15%) and South–East and North–East (7% each).

Table 1. Horticultural production by district, 2015–16

District	Total production (tonnes)
Central	28 751
Kgatleng	7 216
South–East	3 590
North–East	3 578
2Kweneng	2 322
North–West	1 657
Ghanzi	972
Chobe	466
Southern	379
Kgalagadi	25
Total	**49 568**

Source: Ministry of Agricultural Development and Food Security, Horticulture Unit

Table 2 shows the national production of irrigated vegetable crops for the last two years (2014–15 and 2015–16). A total of 46 182 tonnes of vegetables were produced in 2015–16; an increase of 10% on the previous year. The most important crops are cabbage, potatoes, tomato, onion and butternut, which together account for 80% of production in both years. Total irrigated areas are also shown, and the area planted in 2015–16 was lower than in the previous year. Between 2014 and 2016 there was an average total of 2 249 ha of crops under irrigation,

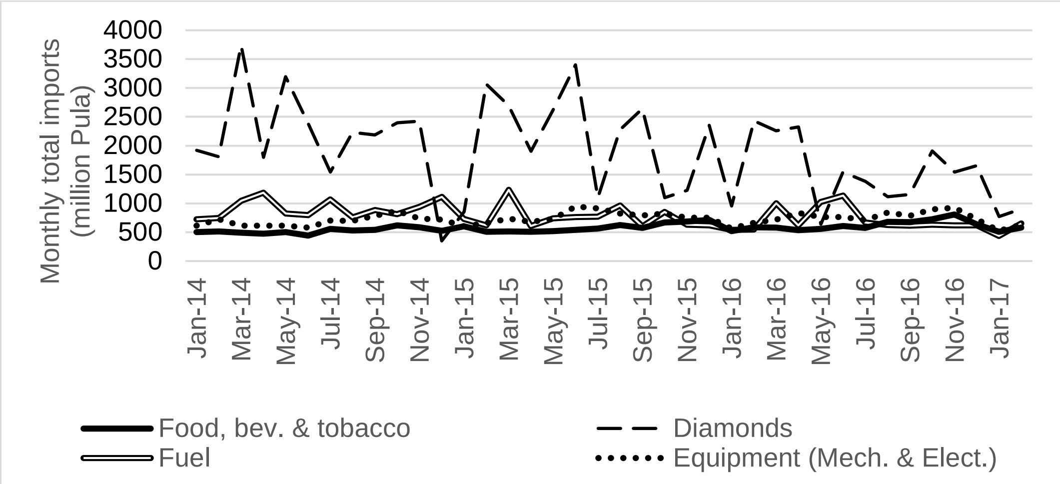

Figure 1. Top four categories of imports to Botswana, (January 2014 – February 2017)
Source of raw data: Statistics Botswana (2017)

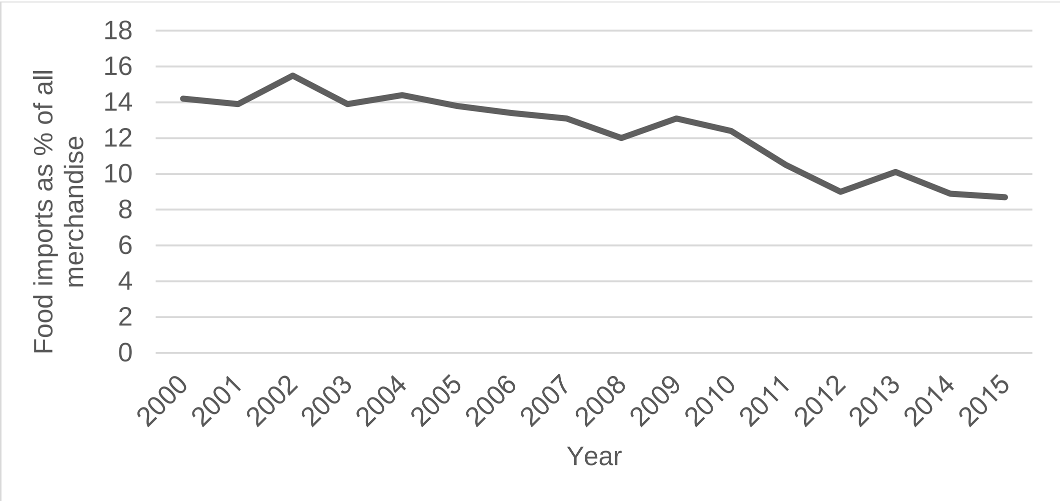

Figure 2. Food imports to Botswana as a percentage of total merchandise imports, 2000–2015
Source: Knoema, an internet search engine

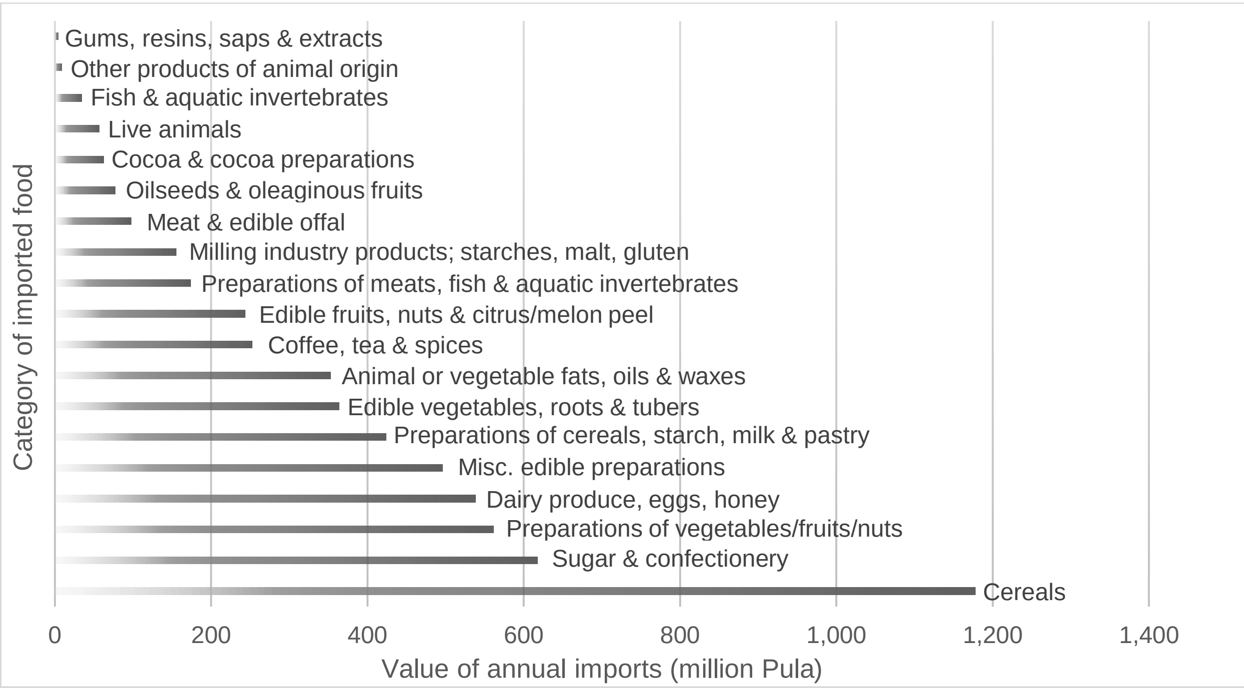

Figure 3. Mean annual food import bill, 2014–2016, by food category

Source of raw data: Statistics Botswana (2017)

Table 2. Area planted to vegetables and total production, 2014–16

Crop	April 2014 – March 2015		April 2015 – March 2016	
	Total area (ha)	**Total production (t)**	**Total area (ha)**	**Total production (t)**
Cabbage	421.6	10 300.4	388.6	13 636.0
Potatoes	195.8	5 810.6	206.7	8 765.2
Tomato	225.2	9 046.8	236.2	5 790.9
Onion	156.6	4 743.9	171.6	4 944.7
Butternut	467.1	3 638.9	325.3	3 716.3
Carrots	123.2	1 336.1	96.9	2 317.3
Rape	143.9	1 521.4	125.3	1 628.0
Beetroot	122.2	2 605.0	99.1	1 251.8
Sweet pepper	91.4	1 067.1	84.7	1 011.5
Sum for other vegetables	379.4	1 928.2	437.7	3 120.8
Total	**2 326.0**	**41 998.0**	**2 172.0**	**46 182.0**

Source: Ministry of Agricultural Development and Food Security, Horticulture Unit

although this was likely produced on ±1 200 ha, when taking double cropping (irrigation intensity) into account.

The difference between vegetable production for 2015–16 (46 182 tonnes, Table 2) and total horticultural production in the same year (49 568 tonnes, Table 1), is accounted for by 3 386 tonnes of fruits which were produced in the country. In 2014–15, the figure was 3 164 tonnes. Almost all of the fruit produced is oranges (>98%) but there are also small quantities of mango, grapes and strawberries.

Example of deficit irrigation, Maun Botswana

The crop water requirement is determined as the product of a crop coefficient, Kc, and the reference evapotranspiration, ETo. The latter represents the rate at which water would be used (lost) by an extensive area of short, healthy grass, which is actively growing, completely shading the soil *and not short of water*. Thus the rate of crop water use represents a maximum value, ETm and

ETm = Kc*ETo (Equation 1)

The net irrigation requirement, I, can be calculated over any given period of time as

I = ETm – Pe (Equation 2)

where Pe is the depth of *effective rainfall* received over the given interval of time.

When deficit irrigation is practised, the actual rate of water use, ETa, is less than ETm and consequently yield is usually reduced. The relative yield decrease can be related to the relative evapotranspiration deficit by the crop yield response factor, Ky:

[**1 – (Ya/Ym)] = Ky*[1 – (ETa/ETm)]** (Equation 3)

where Ya is the actual yield to be expected, Ym is the maximum potential yield and ETa is the actual seasonal crop evapotranspiration. This methodology was first published by FAO in 1979 (Doorenbos and Kassam) and has since been widely used on different scales (at field, scheme, regional and national level) throughout the world, as reported by Smith and Steduto (2012).

The following procedure enables Equation 3 to be used to determine the actual yield expected with any given deficit irrigation regime (Smith and Steduto, 2012):
(i) Establish maximum potential yield (Ym) of an adapted crop variety, as determined by its genetic makeup and climate, assuming agronomic factors such as water, nutrients, pest and diseases are not limiting.
(ii) Calculate maximum evapotranspiration (ETm) according to established methodologies and assuming that crop water requirements are fully met.
(iii) Determine actual crop evapotranspiration (ETa) under the specific deficit irrigation regime to be followed.
(iv) Evaluate actual yield (Ya) through the selection of the yield response factor (Ky) for the full growing season or over different growth stages.

For the purposes of this example, it is assumed that the maximum potential grain yield with a moisture content of 12 to 15%, of MR–Buster, a hybrid sorghum variety, grown in Maun (latitude 22º00'S, longitude 23º25'E) is 3 t/ha (personal communication, Seed Co, Botswana). In step (ii), it is presumed that the crop is planted on January 1, with a total growing season of 105 days, and values of ETo in Maun for the months of January to April are those published by Tahal (2000). Crop coefficient (Kc) values for different growth stages of sorghum are those given by FAO (Doorenbos and Kassam, 1979). These inputs are shown in Table 3, where monthly values of ETm are derived.

With planting in January, some of the crop water requirement is met by rainfall, so certain values of Pe have been assumed for the months of January to March. In the scenario where irrigation is used to supplement the effective rainfall and fully meet the crop water requirement, the net irrigation requirement (I~FULL) is determined, over monthly periods, using Equation 2. The total amount of water received by the crop during the growing season is the sum of seasonal water applied (I~FULL) and seasonal Pe, i.e. 290 mm + 150 mm = 440 mm (Table 3).

The deficit irrigation strategy to be followed is to meet 60% of the crop water requirement throughout the growing season. However, effective rainfall in January meets the full crop water requirement (Table 3). In the months of February to mid–April the net irrigation requirement (I~DI) has been determined as

I~DI = 0.6*ETm – Pe (Equation 4)

Then actual evapotranspiration over the growing season, seasonal ETa, is calculated as the sum of seasonal I~DI and seasonal Pe, i.e. 144 mm + 150 mm = 294 mm (Table 3). Finally, a value of 0.9 has been used as the crop yield response factor, as given by Doorenbos and Kassam (1979), for sorghum, where the water deficit occurs over the full growing season. Values of Ym, Ky, seasonal ETa and seasonal ETm can be substituted into Equation 3, giving [1 – (Ya/3)] = 0.9*[1 – (294/440)]. Rearranging, the expected sorghum grain yield with this deficit irrigation regime is 2.1 t/ha.

Table 3. Depths of water required by a sorghum crop grown in Maun with irrigation either meeting the full crop water requirement or providing 60% of the crop water requirement

	Month				Seasonal total (mm)
	January	February	March	April	
ETo (mm/day)	6.0	5.8	5.7	5.3	
Kc	0.4	0.7	1.1	0.7	
ETm (mm/day)	2.4	4.0	6.3	3.7	
ETm (mm/month)	**74**	**114**	**195**	**56**	**439**
Pe (mm/month)	75	60	15	0	150
I~FULL (mm/month)	**0**	**54**	**180**	**56**	**290**
I~DI (mm/month)	**0**	**8**	**102**	**34**	**144**

Water productivity, WP, is computed as the ratio of yield obtained to depth of water received by the crop. With full irrigation this is 3 000 $kg.ha^{-1}/440\ mm.ha^{-1}$ = 6.82 kg per mm of water. With the deficit irrigation regime WP is 2 100 $kg.ha^{-1}/294\ mm.ha^{-1}$ = 7.14 kg per mm of water. Although less water has been applied with the deficit regime, the amount of grain produced per unit of water has increased. The *use* of water has improved with the deficit regime.

Taking into consideration the area of land under production, these figures can be converted to volumes of water, since one millimetre of water applied over one hectare is equivalent to 10 cubic metres of water. Assuming one hectare under production, with full irrigation, seasonal ETm would be 4 400 m^3, while with the deficit regime, seasonal ETa is 2 940 m^3. The difference represents a *saving* of water, of 1 460 m^3. If this water is used to irrigate more land under the same deficit irrigation regime, with the seasonal net irrigation requirement (I~DI) being 1 440 m^3/ha, another hectare of land could be irrigated. Thus the area under production would be doubled and the overall production from two hectares under this deficit regime would now be 4.2 tonnes of grain and not the 3.0 tonnes that would have been obtained from one hectare of sorghum supplied with the full crop water requirement. The overall production of grain would potentially increase by 40%.

Irrigation practices in Botswana and the place for deficit irrigation

Rainfed agricultural practices in Botswana are constrained by the arid and semi–arid climatic conditions of the country. Severe droughts have often been experienced, a scenario that threatens the nation's desire to attain food security. Where conditions of water availability and suitable soils allow, it would be prudent to utilize suitable irrigation techniques in crop production. This is in keeping with the plans and policies of the Government of Botswana (MMEWR, 2012; Ministry of Finance and Economic Development, 2016).

From the foregoing discussion on the state of the art in deficit irrigation, it is arguable that the practice could be implemented in Botswana with expected positive results. Several factors would support this assertion: (i) the country has a semi–arid to arid environment; (ii) increasing demand for water, especially in the domestic and commercial sectors; (iii) frequent droughts; (iv) diminishing water resources; and (v) a high rate of population growth. The water resources allocated to irrigation – although not yet fully utilised – are meagre in relation to the available land that is considered suitable for irrigation and thus increasing water productivity should be a goal of agricultural development. Moreover, any steps taken towards improving the food security of the country should reduce the large food import bill, thus releasing funds for other development objectives. The drive towards food security can be realised through irrigation technologies. Incorporation of proven efficient practices that feature high water productivity should be encouraged.

It is likely that horticultural crop production will grow considerably in coming years, given the government plans for treated wastewater reuse in irrigated agriculture (Ministry of Environment, Wildlife and Tourism, 2003). Suitable land that is in close proximity to urban areas and large villages is already being allocated for horticultural production, especially to young farmers under 35 years of age. The concentration of consumers close to these sites should allow for significant growth in the horticultural sector.

Drip irrigation is promoted in Botswana, especially when water of poor or marginal quality, for example treated wastewater is used (Ministry of Agriculture, undated). However, there has been a sharp increase in the number of centre pivot irrigating machines in the country over the last few years. For example, at Pandamatenga a total of six farmers, with 12 – 14 pivots are now irrigating 230 ha; in Ghanzi one farmer with four pivots irrigates 64 ha and there are another five farmers who have recently installed an unknown number of pivots. In the Tuli Block four farmers irrigate with 17 pivots and Talana Farms is planning to increase their pivots from 15 to 32.

More information needs to be obtained on the number of pivots and the total irrigated areas, as well as the crops being grown, but centre pivots can certainly be used for the irrigation of field crops such as cereals and perhaps these farmers will do so. With the exception of Ghanzi, the areas where pivots have been recently installed are not close to sources of treated wastewater; instead groundwater and water from the Limpopo River is being used for irrigation.

On the website of the Botswana Investment and Trade Centre (BITC) is the following statement: *Botswana is a Net Food Importing Developing country (NFIDC) [with] the opportunity to increase domestic production of basic foodstuffs particularly cereals (grain sorghum and maize) and pulses. National demand for cereal stands at 200 000 tonnes per year, of which only 17% is supplied through local production. Investments in arable agriculture will stimulate private sector development, create employment and value–addition opportunities, and enhance food security and ultimately exports*. BITC also notes that the agricultural sector's contribution to GDP has declined and there is a need to diversify agricultural production and promote the potential for investment in agro–industrial and supply–chain development. It can also be seen that the political will to grow the arable sector is a fact, demonstrated by the recent change in name from Ministry of Agriculture to Ministry of Agricultural Development and Food Security.

Although an annual demand for cereals of 200 000 tonnes sounds large, the authors believe the true figure is much higher since over the last three years, the quantity of cereals imported averaged 358 339 tonnes per annum; 79% more than the demand stated by BITC. The difference may be accounted for by the production of animal feeds within Botswana, using imported grain, or perhaps some grain or the milled products thereof are exported.

CONCLUSION

In order to achieve the second SDG and move towards improving food security in Botswana, there should be a greater effort to produce staple food crops under irrigation. Water is available for irrigation – especially treated wastewater – yet it is being underutilised. It has been demonstrated and argued that using deficit irrigation will maximise water productivity (yield per unit of water used), and allow for larger areas of irrigated production, which would result in higher overall food production, create employment and also reduce the huge food import bill. This would liberate capital for investment in other areas of the economy such as agricultural processing and value–addition industries, thus creating further employment. This move to use deficit irrigation needs to be included in the country's agricultural policies, and be considered alongside climate–smart agriculture, to ensure a more food secure country in the future.

CONFLICT OF INTEREST

None.

REFERENCES

Botswana Investment and Trade Centre (BITC) (2017). http://www.bitc.co.bw/sector/agriculture?page=1 (accessed 20 August 2017).

Department of Water Affairs and Centre for Applied Research (2014). Policy Brief: Irrigation and water resources in Botswana, September 2014. http://www.water.gov.bw/images/Reports/DWA Website/Policy%20Brief%20WR.pdf (accessed 25 July 2017).

Du, T., Kang, S., Zhang, J. and Davies, W. J. (2015). Deficit irrigation and sustainable water–resource strategies in agriculture for China's food security. *Journal of Experimental Botany* 66 (8): 2253–2269.

Cambridge Global Food Security (2017). A strategic research initiative of the University of Cambridge. http://www.globalfood.cam.ac.uk/ (accessed 20 August 2017).

Doorenbos, J. and Kassam, A. H. (1979). Yield response to water. FAO Irrigation and Drainage Paper No. 33. FAO, Rome, Italy.

English, M. (1990). Deficit irrigation. I: Analytical framework. *Journal of Irrigation and Drainage Engineering* 116 (3): 399–412.

English, M., Hillyer, M., El Khoury, L. and English, C. (2014). Managing Deficit Irrigation. California Water Plan Update 2013. Vol. 4 Reference Guide.

Fereres, E., Orgaz, F. and Gonzalez–Dugo, V. (2011). Reflections on food security under water scarcity. *Journal of Experimental Botany* 62: 4079–4086.

Kirda, C. (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. In:

Deficit Irrigation Practices. FAO Water Report No. 22. FAO, Rome, Italy.

Kirda, C. and Kanber R. (1999). Water, no longer a plentiful resource, should be used sparingly in irrigated agriculture. In: Crop yield response to deficit irrigation. pp 1–20. Kirda, C., Moutonnet, P., Hera C. and Nielsen, D.R. (Eds.). Kluwer Academic Publishers, The Netherlands.

Knoema, a data search engine (2017). https://knoema.com/atlas/Botswana/Food-imports (accessed 8 August 2017).

Ministry of Agriculture (undated). NAMPAADD Guidelines. Republic of Botswana. https://www.africaportal.org/documents/5144/NAMPAADD_GUIDELINES.pdf (accessed 15 August 2017).

Ministry of Environment, Wildlife and Tourism (2003). Botswana National Master Plan for Wastewater and Sanitation, Vol. 1: Executive Summary. Republic of Botswana.

Ministry of Finance and Economic Development (2016). National Development Plan 11, Volume 1, April 2017 – March 2023. Republic of Botswana. http://www.ncongo.info/wp-content/uploads/2017/02/NDP-11.pdf (accessed 28 August 2017).

Ministry of Minerals, Energy and Water Resources (2012). Botswana National Water Policy. Republic of Botswana. http://www.water.gov.bw/images/Water%20Pitso/Water_Policy November_2012.pdf (accessed 15 August 2017).

Moutonnet, P. (2002). Yield response factors of field crops to deficit irrigation. In: Deficit Irrigation Practices. FAO Water Report No. 22. FAO, Rome, Italy.

Prieto, D. and Angueira C. (1999). Water stress effect on different growing stages for cotton and its influence on yield reduction. In: Crop yield response to deficit irrigation. pp 161–179. Kirda, C., Moutonnet, P., Hera C. and Nielsen, D.R. (Eds.). Kluwer Academic Publishers, The Netherlands.

Smith, M. and Steduto, P. (2012). Yield response to water: the original FAO water production function. https://www.researchgate.net/.../285749830

Statistics Botswana (2017). International Merchandise Trade Statistics, Monthly Digest, February 2017. http://www.statsbots.org.bw/

Tahal Consulting Engineers (2000). National Master Plan for Agricultural Development, Final Report. Ministry of Agriculture, Botswana.

tradingeconomics.com https://ieconomics.com/botswana-imports (accessed 4 August 2017).

United Nations Sustainable Development Knowledge Platform (2017). https://sustainabledevelopment.un.org/sdg2 (accessed 20 August 2017).

Zhang, H. and Oweis, T. (1999). Water–yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. *Agricultural Water Management* 38: 195–211.