Strategies for cane production in marginal environments and under more environmental scrutiny

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Abstract Climate change is impacting on production conditions and sugarcane producers need to adapt to this challenging environment. Although some places on the globe will receive more rainfall, this paper addresses management strategies to mitigate the likelier scenario of reduced water availability, applied to marginal environments. The objective is to highlight key practices for the sustainable production of sugarcane under water-limiting conditions, with the focus being on soil-related aspects. The condition and properties of the soil have a significant effect on root development. The principle to be applied is to maximise root distribution in order to explore the available soil volume more effectively to improve access to water and nutrients. Problems frequently encountered include compaction, surface crusting, soils that are often shallow with a low water and nutrient retention capacity, salinity, sodicity and acidity issues, and low organic matter content. An important consideration is that new land available for agricultural crop production is frequently marginal due to low soil quality or unfavourable topography, so that sound advice and good management practices become crucial to ensure sustainability. Such practices have received much research attention, and include reduced tillage, correction of in-profile constraints including salinity, acidity and compaction, impact of sugarcane production on a sensitive environment (excess nutrients, i.e. N and P, and quality of irrigation water), maintenance of soil organic matter content, elimination of surface water runoff and residue mulching through green-cane harvesting to improve surface protection and water conservation, and to protect air quality. Two farmers adhering to a number of these BMPs (e.g. controlled traffic, mulching, crop rotation, etc.) based on the North Coast of KwaZulu-Natal, South Africa, maintained crop yields at least to 90 t/ha during the recent drought while the average yields of the remainder of the district dropped to 42 t/ha with an estimated loss of income of ZAR 20,800/ha (USD 1312/ha). The adoption of scientifically-proven best management practices is thus of paramount importance in ensuring the sustainability of grower operations and the well-being of grower communities.

Key words Better management practices, environmental scrutiny, marginal areas, soil health

INTRODUCTION

Climate change exposes people, societies, economic sectors and ecosystems to risk. Indeed, each of the last three decades has been successively warmer than the preceding one, and an evaluation of different studies has demonstrated that the effects of climate change on crop yields tended to be more negative than positive (IPCC 2014). As with other crops, sugarcane is expected to be impacted by climate change, but its effects remain debatable. For instance, a study by Deressa et al. (2005) has indicated that sugarcane production is highly sensitive to climate change in South Africa, and that its effects would be negative in all zones whether irrigated or not. On the other hand, a completely different conclusion has been reached by Marin et al. (2013), who predicted that climate change would have positive effects on sugarcane production in Brazil, with increased stalk fresh mass and water-use efficiency under rainfed production, irrespective of the scenario.

Only the future will tell whether climate change will benefit or harm the industry, but there is consensus that it is causing the environment to change rapidly (IPCC 2014). Sugarcane production around the world is thus subject to increased environmental scrutiny due to pressure from conservationists and local communities, increased regulation and pressures applied through markets (Cheesman 2004). A good example of this type of scrutiny is in the sugarcane-producing region of northern Queensland, where waters drain into the Great Barrier Reef (GBR) lagoon, a World Heritage-listed site that needs to be protected against sediments, nutrients and pesticides (Webster et al. 2009). The concern about the effects of
sugarcane cropping on such a sensitive environment is evidenced by the number of studies in that field (e.g. Thorburn et al. 2011; Joo et al. 2012), which all look into likely environmental degradation to the GBR from sugarcane cultivation. Indeed, sugarcane cultivation can have an impact on water quality and aquatic ecosystems from runoff and leaching, resulting in poor quality water (e.g. Hunter and Armour 2001).

In addition to environmental sustainability, sugarcane production faces the challenge of agronomic sustainability, particularly with respect to the soil resource. As reviewed by Haynes and Hamilton (1999), sugarcane production generally leads to a diminution in soil quality. Indicators that have been identified for this degradation include compaction, acidification, salinisation and loss of soil organic matter (OM). Causes for compaction include, amongst others, overuse of machinery and intensive cropping (Hamza and Anderson 2005), two factors that also affect soils under sugarcane. It is, therefore, not surprising that compaction with sugarcane cropping has been reported in a number of countries (Haynes and Hamilton 1999). Similarly, soils were found to acidify with sugarcane cropping, on account of oxidation of ammoniacal fertilizers, mineralization of OM, leaching of basic cations and removal of nutrients in harvests (Meyer et al. 1998). As ammonium-forming fertilizers such as urea are essential to sustain yields, fertilizer-induced acidification is bound to continue. Issues pertaining to soil salinity and sodicity have also been identified in a number of countries, particularly under irrigated conditions in low-rainfall areas. The main cause for this problem is inadequate drainage (Workman et al. 1986), whereby salts present in the irrigation water are not completely leached out of the soil profile and thus accumulate over time. However, beyond compaction, acidification and salinisation, the loss of soil OM has overarching consequences as it has far reaching effects on soil physical, chemical and biological properties and processes (Umrit et al. 2014). The evidence from several countries clearly shows that OM decreases sharply when virgin soil is put under sugarcane (Haynes and Hamilton 1999). This reduction could be due to a lower return of carbonaceous material, enhanced exposure of hitherto physically-protected OM to microbial action and higher rates of OM decomposition (Dominy et al. 2001).

The evidence thus points towards a situation where environmental challenges keep increasing, the more so as new developments for cane production tend to be on marginal lands. Such areas are even more difficult to manage as they usually have low soil quality or are situated in regions with unfavourable topography. These new cane lands could, for instance, have shallow soils and be on sloping or undulating terrain. Under these conditions they would be more susceptible to erosion, sometimes at rates that are unsustainably high (e.g. Prove et al. 1995). The challenge is thus to find ways and means to produce cane in these difficult areas, based on sound technical strategies. We detail some of these approaches in this paper.

MANAGING CANE FIELDS IN MARGINAL ENVIRONMENTS

Many sugar industries have a list of recommended best management practices or BMPs (e.g. Horrigan et al. 2002; Meyer et al. 2013; Gravois et al. 2015), and yet there seems to be a lack of adoption. The reasons for non-adoption are numerous, but those that have adopted the BMPs claim improved crop performance and cash rewards (McElligott et al. 2014; Goble 2015). The following are recognised BMPs with suggested implementation strategies aimed at maximising sugarcane yields sustainably.

Restricted depth

The most common feature of marginal soils is their shallow depth, which can have natural or anthropogenic causes. Natural causes include duplex character (abrupt change of clay content with depth), presence of a hard solid rock layer, shallow water table and layers with chemical imbalances (e.g. acid or saline/sodic subsoils). Anthropogenic activities leading to marginal soils include compaction and over-irrigation. All these conditions result in restricted rooting depth and, therefore, limited amounts of plant available nutrients and water. These factors will be discussed in turn.

The texture of soils with a duplex character often abruptly changes within 0.5 m from the surface. In such soils, depth distribution of roots and water drainage are negative limitations and the solution is then to deep rip to at least 0.5 m to increase rooting depth and possibly drainage in cases where the limiting layer is thin. The alternative is to grow the crop on ridges (Meyer et al. 1988; Van Antwerpen et al. 1991) by moving soil from the interrow area to the row area, thereby creating additional space for root development between the stalk and the restricted layer. Using this method, cane yield response of ratoon crops ranged between 4 and 15 t/ha/yr with an average of 9 t/ha/yr (Meyer et al. 1988; Van Antwerpen et al. 1991). Generally, no yield response was observed for the first crop after converting to ridging because the bottom portion of the stalk was buried in the ridge. The ridging technique can also be used where the restricted layer is a water
table (Van Antwerpen et al. 1991). However, soils with a shallow rock layer should best be left under natural vegetation and sites with a high water table might be a wetland which should also not be cultivated.

As sugarcane fields are replanted only once in 5-10 years, compacted layers may develop at plough depth for that duration. Their effect in restricting root development and drainage of soils and their ability to impact negatively on crop yield are well known (Pérez et al. 2010; Ricaud 1977). Sugarcane is a relatively high yielding crop that requires agricultural machinery at harvest and this inevitably results in compaction close to the soil surface (Van Antwerpen et al. 2007). Thus, at least two compacted layers are often found in fields cultivated with sugarcane – at the surface and at plough depth. The adoption of controlled traffic is the preferred solution to this problem. This approach has the advantage of eliminating traffic-induced compaction in the production area (Garside et al. 2006) while allowing the compacted interrow to be used as a ‘road’, with no further energy requirement for compaction alleviation. The alternative is to rip the compacted field before replanting and again after harvesting in the interrow to reduce runoff and to prevent land erosion. Yield response due to controlled traffic with 1.8 and 2.1 m interrow spacing’s and dual rows spaced 0.5 m apart was 18 and 14 t/ha, respectively, in a manually-harvested field (Garside et al. 2005). An observation from the records of a farmer who has converted a large part of his farm to controlled traffic (1.8 m = 0.65 m tram + 1.15 m interrow) has seen an average yield increase of 21 t/ha (19%) over conventional row spacing (1.2 m). Concurrently, he also showed a 30% reduction in herbicide costs (McElligott et al. 2014).

**Soil fertility**

Balanced fertilisation is of cardinal importance in ensuring the profitability of sugarcane agriculture. Nutrients must be supplied, firstly, to correct any inherent deficiency in soils, and secondly, to compensate for the large amounts of nutrients removed in crop harvests. The nutrition of sugarcane is too broad and complex a topic to be comprehensively covered in this paper; the interested reader is referred to the detailed reviews of Kingston (2000), Fageria (2011) and Gopalasundaram et al. (2011). In this section, several significant developments in cane nutrition are discussed in terms of the future sustainability of sugarcane production.

Nitrogen is an important driver of sugarcane yields, and over the years most aspects of N nutrition have received detailed research attention, including application rates, fertiliser sources, placement of fertilisers and the extent of losses from fields. In terms of enhancing N use efficiencies, attention is drawn to the following two promising technologies:

- **Nitrogen fertiliser sources.** Owing to its relatively low cost per unit N, urea remains the source most widely used in sugarcane production, but its efficiency is low on account of its high solubility and its propensity to be lost by volatilization. In recent times, slow-release N sources and urea-based products containing urease and/or denitrification inhibitors are becoming increasingly competitive price-wise (Weigel et al. 2014; Rice et al. 2015). In laboratory simulations of field conditions on an alkaline soil, loss of applied N by volatilization from urease-inhibitor treated urea was 6.9%, whilst that from untreated urea was 26.5% (Weigel et al. 2014). The indication is, therefore, that more widespread adoption of these products could markedly improve efficiencies and reduce the environmental footprint of N.

- **Nitrogen mineralization.** In sugarcane production systems, prediction of the extent of N mineralisation from the soil organic matter introduces major uncertainties in the development of N recommendations. In several countries, N recommendations are modified on the basis of estimated N release from the total organic C reserves in soils (e.g. Rice et al. 2015; Wood et al. 2010). Although this approach has undoubtedly improved the reliability of recommendations, in recent years it has been shown unequivocally that relatively simple soil tests that are based on the labile soil carbon fractions provide far more reliable estimates of N mineralization (Haney et al. 2008; Schomberg et al. 2009). Crop nutrition programs in sugarcane agriculture could undoubtedly benefit from this development.

Next to N, potassium is the nutrient taken up in largest quantities by sugarcane. For high-yielding crops, removals of K in harvested stalks may be in the range of 200 to 560 kg/ha (Kingston 2000). Amounts of K applied often do not match amounts removed by the crop, resulting in yield limitations and increased susceptibility to drought and diseases due to K deficiency. This disparity was highlighted in the studies of Wood and Schroeder (2004) who found that in the Australian industry, mean K application rates were approximately 0.90 kg K/t of harvested cane, while removals were in the range 1.3 to 1.5 kg K/t, thus indicating a continued ‘mining’ of soil K reserves in sugarcane agriculture that threatened its long-term sustainability. In the opposite vein, a failure to take into account non-exchangeable soil K reserves may represent a lost opportunity for significant savings in fertiliser inputs. It would appear that only in the Australian industry is some attempt made to modify K recommendations on the basis of non-exchangeable soil K (Schroeder et al. 2007). Recent investigations conducted on samples from southern and central African countries have shown that large tracts of soils, in particular in the irrigated areas, have massive reserves of K in their mineral fractions, and high levels of production could be sustained.
almost indefinitely with no K fertiliser applications (Miles and Farina 2014). That this aspect has been largely ignored in crop nutrition programs is no doubt due mainly to the difficulties associated with the measurement of non-exchangeable K. A positive development in this respect is the finding that non-exchangeable K levels can be predicted with reasonable accuracy by mid-infrared spectrophotometry (MIR) (Miles and Farina 2014).

Indications are that micronutrients remain the forgotten aspect of crop nutrition programs in all too many sugar industries. Yet ensuring an adequate supply of all micronutrients is a critical aspect of sustainable crop production (Kingston 2000). A particular problem with respect to managing micronutrients, and the metals (zinc, copper, manganese and iron) in particular, is the uncertainty surrounding relevant soil test thresholds. This uncertainty is likely to persist, since for economic reasons field calibration trials are becoming increasingly impracticable. The solution would appear to be an increased reliance on leaf sample analyses, for which thresholds appear to be more reliable (Reuter and Robinson 1997).

As a final thought in the context of crop nutrition, we draw attention to the amazing advances in the past two decades in the use of MIR for soil testing. This technique involves the focusing of radiation in the mid-infrared range on milled air-dried soil samples, and the interpretation of the reflected spectra by statistical software. Once calibrated (using soil samples of known properties), the instrumentation can be used to reliably predict a wide range of soil properties in less than 2 minutes. The range of parameters that can be successfully predicted with MIR is increasing continually, and currently includes pH, soil organic carbon, nitrogen and sulphur, microbial biomass, clay, silt and sand, exchangeable cations, electrical conductivity, sodium adsorption ratio, lime requirement, P fixation, CEC and non-exchangeable K reserves (Janik et al. 1998; Terhoeven-Urselmans et al. 2010; Mathadeen et al. 2013; Rasche et al. 2013; Miles and Farina 2014). For routine growers’ soil testing, MIR-based analysis offers the potential of decreased turnaround times and analytical costs. It is worth noting that MIR testing is a particularly exciting development in the context of precision in-field nutrient management. It has long been recognized that the analytical costs arising from the large volumes of samples necessary for a precision-farming approach to nutrient management render this technology a non-starter in terms of its widespread adoption. The MIR technique has the potential to reverse this situation, thereby introducing vast improvements in sugarcane nutrient management.

Subsoil acidity

Sugarcane is a remarkably resilient crop that is able to produce economically sustainable yields under harsh soil conditions, where other crops such as maize or beans would fail to produce a yield. Whilst being advantageous from an economic perspective, this attribute of sugarcane has allowed growers to often exploit the soil resource by not addressing associated acidity build-ups in top- and sub-soils. Sumner (2012) commented that relatively infertile soils, with acid subsoils, are a feature of sugarcane-producing areas throughout the world.

Major limiting factors in acid subsoils are aluminium toxicities and deficiencies of calcium, both of which restrict root development and functionality. Yield reductions due these problems have been reported in many sugarcane-growing areas of the world, with field trials showing that applications of lime and gypsum are highly effective in addressing this condition (Nixon et al. 2003; Sumner 2012). Data presented in Table 1 provide evidence of the significant benefits in terms of cane yields of a very modest application of gypsum to a highly acidic soil.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th>Base saturation* (%)</th>
<th>Cane yield** (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0-20</td>
<td>60</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Gypsum (2 t/ha)</td>
<td>0-20</td>
<td>64</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40-60</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

* three years after application  
** mean of plant and four ratoons

Table 1. Effect of phosphogypsum on soil base saturation and yield of sugarcane grown on a sandy Oxisol in Brazil (Sumner 2012, citing the data of Dematté 1986).
In terms of the practical management of subsoil acidity, a particular concern is that this problem often goes undetected since soil sampling and testing is restricted to the top 20 or 25 cm layer in most sugar-producing countries. In South Africa a BMP introduced in 2011 involved taking deeper soil samples (at increments of 20 cm, to a depth of 60 or 80 cm) prior to replanting sugarcane in all rainfed areas of the industry. The benefits of this initiative have exceeded all expectations, with profile samples being taken from thousands of fields during a 3-year period. As a result of this sampling initiative, severe subsoil acidity was detected across wide areas of the industry, and grower observations suggest that the resultant use of lime and gypsum has greatly improved yields, in particular under drought conditions.

Environmental scrutiny

There is an ever-increasing focus on the environmental impact of agricultural operations. In terms of fertiliser use in sugarcane production, the focus is on the ‘leakage’ of nutrients, in particular N and P, to water bodies. Sugarcane production areas where there is intense scrutiny of this problem are the GBR and the Florida Everglades.

Nitrogen management

With respect to the GBR, nutrient pollution concerns relate mainly to elevated levels of dissolved inorganic nitrogen (DIN) detected in rivers draining into the sea. The load of N from these river catchments is estimated to be up to 6 times greater now than during pre-European settlement (Hunter and Walton 2008). Losses in coral cover and coral biodiversity are attributed to the increased DIN loads being transported to the Reef. Sugarcane is by far the dominant crop in catchments draining into the GBR, and, not surprisingly, production practices relating to this crop have in recent years come under intense scrutiny.

With N being the most important nutrient for optimizing sugarcane yields, the conundrum having to be dealt with by scientists is that of maintaining economic levels of production while simultaneously minimizing the environmental footprint of N. As is the case with most other crops, N utilization efficiency in sugarcane is poor. Regghenzani and Armour (2002) in budgeting N inputs and outputs for a first-ratoon crop at South Johnstone (Queensland) found that only 33.2% of total N inputs were contained in the millable cane stalks.

Two divergent approaches have emerged in scientific studies aimed at containing N losses from cane lands. Wood et al. (2010) and Schroeder et al. (2010) have focused on improving N utilization through the adoption of best agronomic management practices (the ‘Six Easy Steps’ program). This approach has been vigorously promoted in Queensland for the past 15 years, and there is convincing evidence of continuous improvements in N-use efficiency in sugarcane production since its adoption: N-use efficiency increased from about 0.34 t cane/kg N in 2001 to 0.5 t cane/kg N in the 2006 to 2009 period (Wood et al. 2010). The second and more drastic approach involves simply applying rates of N fertiliser that are equivalent to the amounts of N exported in the previous crop (Thorburn et al. 2010; Webster et al. 2012). Over a 3-year trial period, this strategy resulted in reduced DIN loses to surface waters, while yields did not differ significantly from those obtained with the conventional N fertilisation rates. As this approach involves greatly reduced fertiliser N doses, its impact on crop production needs to be evaluated over longer periods.

Phosphorus management

Phosphorus is the most limiting nutrient in terms of the eutrophication of most stream and dam waters. The potential for P removal in percolating or runoff waters is closely related to P fertiliser application practices, soil properties and labile P levels (Vadas et al. 2005; Lang et al. 2005).

The Everglades Agricultural Area (EAA) in South Florida presents a particularly interesting case study in terms of P management. The EAA is an artificially drained area of some 200,000 ha of mainly organic soils, with 80% planted to sugarcane. Undesirable changes in the vegetation communities of the Everglades have been linked to elevated P levels in drainage waters from agricultural operations (Rice et al. 2013). Legislation promulgated in 1994 required that surface runoff P levels be reduced by at least 25% relative to historic trends. BMPs introduced to address this requirement proved highly successful, with 100% grower participation and P load reductions averaging 55% annually. The program has prevented a cumulative 2,600 t of P from entering the Everglades from 1996 to 2013 (Rice et al. 2013). Specific on-farm interventions included (Lang et al. 2005):

- Reducing P fertilization rates based on improved soil-test calibrations;
• Focusing on correct placement of fertiliser to ensure optimum nutrient uptake and reducing losses by banding of P fertiliser in close proximity to plant roots, rather than broadcasting across the entire field surface;
• Paying particular attention to maintenance and calibration of fertiliser application equipment.

The potential for P losses from sugarcane agriculture is by no means limited to the Florida Everglades. The widespread practice of surface applications to ratoon crops of fertilisers, manures and mill by-products renders the P in these products highly vulnerable to removal in runoff waters, while there is also mounting evidence of ‘overloading’ of sugarcane topsoils with P (e.g. Barry et al. 2000; Miles and van Antwerpen 2015). Of particular concern is that mill by-products and manures are often disposed of at high rates in sugarcane fields, leading to a situation where acid-extractable P levels were as high as 1000 mg/kg in Queensland (Rayment et al. 1998). In South African studies, Miles and van Antwerpen (2015) found that soil test P levels in many sugarcane fields were well above established threshold levels for optimum growth, often because of long-term use of poultry manure. Relationships developed between soluble P (i.e. the P potentially removable in percolating or runoff waters) and P extracted with the Truog and resin tests reflected an exponential increase in P solubility with rising P test levels above the crop requirements for this nutrient. A model using resin P/oxalate Al was found to provide a useful prediction of soluble P levels for a wide range of southern African soils (Fig. 1a). These workers also found that soil samples taken to a depth of 20 cm for routine soil fertility evaluations in most cases grossly underestimate the P environmental hazard, since P levels are highest at the immediate soil surface (top 2-5 cm soil layer; Fig. 1b).

![Figure 1a](image1a.png)

*Fig. 1. (a) Relationship between resin P/oxalate Al and calcium chloride soluble P for 163 soils from southern African sugar producing fields, and (b) relationships between resin P soil tests for 0-2 and 0-10 cm soil sampling depths from treatments in the long-term BT1 trial. (Treatments in the BT1 trial; BtFo, burned, tops not spread, no fertiliser; BtF, burned, tops retained and spread, no fertiliser; TFo, residues retained and spread, no fertiliser; TF, residues retained and spread, plus fertiliser) (Miles and van Antwerpen 2015).*

Such observations underline the need for more rigorous management of crop P nutrition in sugarcane. Indeed, the successes achieved in Florida serve as an encouraging example of what may be accomplished through the adoption of improved technologies and BMPs.

**Salinity and sodicity**

Marginal soils cleared for agricultural production are occasionally saline or sodic by nature. In contrast, some soils that were initially in very good condition may become saline/sodic due to inappropriate irrigation management practices, particularly if the irrigation water is loaded with salts. It is unlikely that naturally well-drained soils will develop salinity/sodicity problems. Saline soils are characterised by electrical conductivity (EC) values greater than 400 mS/m, saturated paste (sp) pH values less than 8.2 and exchangeable sodium percentage (ESP) values less than 15%. Sodic soils typically will have EC values less than 400 mS/m, pH values greater than 8.2 and ESP values greater than 15% (Robbins and Meyer 1990). In South Africa the critical EC value for sugarcane where yield is not affected is below 200
mS/m. With EC values between 200 and 400 mS/m cane yield is affected and at values >400 mS/m cane yield is seriously affected (Von der Meden 1966). The latter author also reported that cane growth is regarded as good, fair, very poor and dead at exchangeable sodium percentages (ESP) of 9.3, 11.6, 32.4 and 44.5, respectively. In Australia it was found that sugarcane yield is reduced by between 1.5 and 2.4 t/ha for every 1% increase in ESP (Ham 1997; Nelson and Ham 1998).

Irrespective of the causes of salinity/sodicity, similar reclamation steps are needed. Key in the reclamation of these soils is the leaching of excess salts, which requires large amounts of good quality water and an internal drainage system. Reclamation of both saline and sodic soils are summarised in Table 2.

**Table 2.** Basic steps to follow in the reclamation of saline or sodic soils.

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Ensure the soil is sufficiently drained to facilitate leaching of excess salts.</td>
</tr>
<tr>
<td>2</td>
<td>Sodic soils: Apply the recommended amount of organic matter and gypsum and mix thoroughly as deep as possible with the soil. Thorough mixing is especially important if the soil was dispersed to depth. Saline soils: This step is not required.</td>
</tr>
<tr>
<td>3</td>
<td>Apply the recommended amount of best quality water available in typical irrigation scheduled amounts (e.g. 40 mm/irrigation) in order to leach the excess salts. For budget purposes at least 100 mm water needs to be applied for every ton of gypsum applied.</td>
</tr>
<tr>
<td>4</td>
<td>After reclamation, embark on a maintenance irrigation programme which should make provision for the occasional leaching of salts.</td>
</tr>
</tbody>
</table>

Reclamation methods include continuous ponding, intermittent ponding and sprinkler irrigation (Hanson et al. 2006). However, the method to be used is determined by local factors such as soil type, infiltration rate, drainage capacity, water delivering system and quality of the water to be used for leaching. Calculation of the amounts of water to be used with each application method (taking into account the initial salt load of the soil and the desired salt load after reclamation), as well as quality of irrigation water, drainage requirements and appropriate ameliorants to be used are discussed in Hanson et al. (2006).

In addition to leaching, halophytes (salt tolerant crops) can be used to remove salts (e.g. Qadir et al. 2007; Ravindran 2007) in a process termed phytoremediation. Salt tolerant agricultural crops to be used in phytoremediation were listed by Qadir (2007). Those most commonly used in the reclamation of both saline and sodic soils are barley (Hordeum vulgare) and wheat (Triticum aestivum) while sugar beet (Beta vulgaris) is used in the reclamation of saline soils only.

Preventing the development of saline/sodic conditions is a different strategy that can be achieved by analysing soils before planting for salt contents, infiltration rate, water-holding capacity and internal-drainage capacity, in fields that are to be irrigated. This information should be used in the decision to install subsurface draining systems, their design and in the planning of an appropriate irrigation system and water application schedule. The irrigation schedule should make provision for controlled over irrigation, or leaching requirement, at predetermined intervals to prevent the build-up of salts in the soil (Hanson et al. 2006).

**Irrigation and water quality**

The maximum amount of water available for plant growth is determined by the capacity of the soil to store water. Many new land expansions are into areas with marginal soils that are either sandy or shallow. Water-holding capacity is often between 80 and 100 mm/m and, if the depth limitation is factored in, total plant available water (TAW) is often less than 60 mm. Thus, if crop water use is around 4 mm/day, then there is enough water for only about 7 days before the stress point is reached. After that point, if there is no rainfall or irrigation, the crop will be under increasing water stress, resulting in reduced growth and hence lower yield. These soils therefore require greater management skills to minimise water stress and to grow a profitable crop.

One effective way to increase water availability is to reduce direct soil evaporation. This can be achieved with a mulched layer following green cane harvesting. If the crop is burnt before harvest, an attempt should be made to facilitate a ‘cool’ burn (such as early in the morning when the crop is covered with dew) in order to maximise the amount of residue available to cover the soil surface when spread.
Quality of water available for irrigation is a growing problem (Van der Laan et al. 2012) and farmers often do not possess sufficient knowledge to mitigate this condition. The adoption of management strategies is poor due to a lack of knowledge (Pannell 1999). A concerted effort from scientists, consultants and extension specialists is required to equip farmers to better understand principles in the use of water with a lower quality. The following are options in the management of poor quality water.

- Dilute poor quality water with water of better quality. This is an on-farm activity and the advice from a specialist should be sought to assist with the quantities to be mixed and possible adjustment of the prescribed irrigation scheduling programme (Hanson et al. 2006; Copeland 2013).
- The quality of river water is normally poorer in drier periods with low flow compared to high rainfall periods. Occasionally, the local authorities can release water from upstream holding dams to dilute downstream saline problems (Van der Laan et al. 2012).
- Determine the leaching requirement and apply as prescribed (Hanson et al. 2006; Copeland 2013).

Green-cane harvesting

The most common method used in sugar industries worldwide to reduce soil water losses due to runoff and evaporation is mulching (soil surface covered with residue). The amount of material available is about 16% of the fresh mass of cane stalks delivered at the mill (e.g. Donaldson et al. 2008; Romero et al. 2009). Cane yield of 70 t/ha would thus yield an estimated 11 t residue/ha which is sufficient for a 100% cover of the soil surface. Mulching can reduce evaporation by about 90 mm/year under dryland conditions in South Africa, resulting in a mean increased crop yield of some 8 t/ha compared to a bare soil due to cane burning, and a water productivity of 9 t/100 mm (Thompson 1966). In more recent work, it was reported that mulching increased the yields of sugarcane produced under dryland conditions by between 16% and 85% (Nxumalo 2015).

Compared to the bare surface under irrigation, Olivier and Singles (2012), reported reduced evaporation of 21% and 12% for mulched plant and ratoon crops, respectively. This reduced evaporation with trash blanketing could lead to savings in irrigation water of the order of 54-72 mm per cropping season (Ng Cheong and Teeluck 2016). However, this saving in irrigation water will not necessarily culminate into an increased crop yield (e.g. De Beer et al. 1995; Olivier and Singles 2012).

The growth stage where a reduction in evaporation is most significant is before canopy closure (Olivier and Singels 2012; Van Antwerpen et al. 2006). After canopy closure, evaporation losses from bare and mulched covered soil surfaces are similar (Olivier and Singels 2012).

The change from burn at harvest to green-cane harvesting is met with a fair amount of resistance and an encouragement is often required. A common method is through legislation as found in many sugarcane countries (e.g. De Moraes and De Oliveira 2016; McCarty 2014) and is currently proposed by others, e.g. South Africa (Puckree and Mtembu 2016). In Queensland, green-cane harvesting has risen from nil in 1980 to over 75% in 2005. Some areas, such as North Queensland, have achieved almost 100% adoption. Green-cane harvesting is the preferred option in nearly all sugar-producing countries as it reaps benefits such as reduced yield variability between seasons and improved yields that culminate into increased income under dryland conditions (McElligott et al. 2014). Barbados converted to burning at harvest (not a BMP) in the 1960s but, due to heavy yield losses as a result of moisture loss and erosion, it readopted green-cane harvesting (Weeks 2004). In some parts of the world, sugarcane producers are awaiting the implementation of co-generation with the expectation that delivering also dry leaf material to the mill will result in an additional income. The removal of dead leaves only from the field and retention and spread of green leaves reduce cane yield by about 2% while covering 70% of the soil surface for cane yield of about 70 t/ha (Van Antwerpen et al. 2006).

Green-cane harvesting and mulch blanketing is a recognised BMP worldwide, but there are areas where residue retention will result in yield losses. These include poorly drained areas such as valley bottoms, where a mulch layer might keep the soil almost permanently waterlogged, leading to yield losses. Similarly, areas that experience a ‘wet’ season in the period from harvest and till canopy closure are likely to suffer yield losses (Van Antwerpen et al. 2006; Viator et al. 2005). Another negative situation occurs in areas prone to frost such as Louisiana in the USA and the high-altitude areas of the Midlands in South Africa. In both areas, the presence of a mulch blanket will worsen the situation leading to even lower temperatures above the residue layer and consequently yield losses (Viator et al. 2005).
CONCLUSIONS

The improved sustainability of farmers through the adoption of BMPs can be valued under adverse environmental conditions such as droughts. Two farmers practicing a number of BMPs (e.g. controlled traffic, mulching, nutrition, etc.) based on the North Coast of KwaZulu-Natal, South Africa, maintained dryland crop yields at least to 90 t/ha during the recent drought while the average yields for the district dropped to 42 t/ha. A similar trend for the South Coast was reported by McElligott et al. (2014).

The profitable production of sugarcane on marginal soils is a challenge that can be overcome with the adoption of BMPs. These include:

- Use of tillage techniques to increase rooting depth of shallow or compacted soils.
- Awareness of subsoil acidity and of options available to managers for mitigating this adverse condition.
- Application of the correct strategy when irrigating marginal soils that are very susceptible to the development of saline/sodic conditions.
- Selection of the correct option in the management of irrigation with sub-optimal water quality.
- Use of a mulch layer to increase plant available water and protect the soil against erosion.
- Practicing green manuring and crop rotation.
- Regular (annual) soil/leaf testing and the application of recommended nutrient amounts.

REFERENCES


Stratégies pour la production cannoìère dans des régions marginales et sous une surveillance environnementale accrue

**Résumé.** Les effets du changement climatique se font sentir sur les conditions de production et les producteurs de canne à sucre doivent s’adapter aux défis de ce nouvel environnement difficile. Même s’il y aura probablement une plus grande pluviométrie dans certaines régions du monde, ce présent article s’intéresse au scénario plus probable d’un approvisionnement réduit en eau et aux stratégies de gestion à adopter dans cette optique pour les régions marginales. L’objectif est de mettre en lumière des pratiques essentielles pour une production durable de la canne à sucre quand l’eau est le facteur limitant, en se concentrant sur les aspects liés au sol. L’état et les propriétés du sol ont un effet crucial sur le développement racinaire. Le principe à appliquer consiste à maximiser l’extension des racines pour mieux exploiter l’eau et les nutriments dans le sol. Les problèmes qui sont fréquemment rencontrés incluent le compactage, les croûtes de surface, les sols superficiels avec de faibles capacités de rétention d’eau et de nutriments, la salinité, la sodicité, l’acidité et une faible teneur en matière organique. Un point important à considérer est que les nouvelles terres disponibles pour l’agriculture sont souvent marginales, en raison d’une mauvaise qualité du sol ou d’une topographie défavorable, ce qui fait que des conseils avisés et de bonnes pratiques de gestion sont cruciaux pour en assurer la durabilité. De telles pratiques ont fait l’objet de nombreuses recherches, telles que le travail du sol réduit, les amendements aux contraintes pédologiques telles que la salinité, l’acidité et le compactage, l’impact de la production cannoìère sur un environnement sensible (l’excès de nutriments, à savoir N et P, et la qualité de l’eau d’irrigation), la stabilisation de la teneur en matière organique dans le sol, l’élimination du ruissellement, et le paillis à travers la récolte en vert pour une meilleure protection du sol et de la qualité de l’air, ainsi qu’une meilleure conservation de l’eau. Deux fermiers qui ont adopté un certain nombre de ces pratiques (par exemple le trafic contrôlé, le paillis, la rotation des cultures, etc.) dans la région du North Coast en Afrique du Sud ont ainsi pu maintenir leurs rendements autour de 90 t/ha durant la récente sécheresse alors que le rendement moyen dans le reste du district chutait à 42 t/ha, avec une perte de revenus de l’ordre de ZAR 20,800/ha (USD 1312/ha). L’adoption des meilleures pratiques de gestion qui ont fait leurs preuves scientifiquement est ainsi d’une importance capitale pour assurer la pérennité des opérations de culture et le bien-être de la communauté des planteurs.

**Mots clés:** Meilleures pratiques de gestion, surveillance environnementale, zones marginales, santé du sol

**Estrategias para la producción de caña en ambientes marginales, bajo un escrutinio ambiental mayor**

**Resumen.** El cambio climático está impactando en las condiciones de producción y los productores de caña deben adaptarse a este ambiente de retos. Aunque algunos lugares del planeta recibirán más lluvia, este trabajo se trata de las estrategias de manejo para mitigar el escenario muy probable de reducida disponibilidad de agua, aplicada a ambientes marginales. El objetivo es resaltar las prácticas clave para la producción sostenible de caña en condiciones limitantes de agua, enfocado en aspectos relacionados con el suelo. Las condiciones y propiedades del suelo tienen un efecto significativo en el desarrollo de las raíces. El principio que se debe aplicar es maximizar la distribución de la raíz para promover la exploración del volumen del suelo de una forma más efectiva y mejorar el acceso al agua y los nutrientes. Los problemas más frecuentes incluyen compactación del suelo, incrustaciones en la superficie, suelos superficiales con poca capacidad de retención de agua y nutrientes, problemas de salinidad, sodicidad y acidez y bajo contenido de materia orgánica. Una consideración importante es que los nuevos suelos disponibles para producción agrícola son marginales con frecuencia, debido a la baja calidad del suelo, topografía no favorable, por lo tanto, buenas prácticas de manejo y buena asesoría son indispensables para asegurar la sostenibilidad. Estas prácticas han recibido mucha atención de los investigadores e incluyen labranza mínima, corrección de problemas como salinidad, acidez y compactación, impacto en el cultivo de caña en un ambiente sensible (exceso de nutrientes como N y P y calidad del agua de riego), mantenimiento del contenido de materia orgánica, eliminación de la escorrentía superficial y dejar residuos del cultivo en el campo después de la cosecha en verde para mejorar la protección de la superficie y conservar el agua y proteger la calidad del aire. Se presenta el caso de dos productores de caña de la Costa Norte de KwaZulu-Natal, Sudáfrica, que se adhirieron a varias de estas buenas prácticas de manejo (ej. Control de tráfico, mulching, rotación de cultivos, etc.) y que mantuvieron la producción de sus campos en al menos 90 t/ha durante la reciente sequía, mientras la producción promedio del distrito bajó a 42 t/ha con una pérdida estimada de ZAR 20,800/ha (USD 1312/ha). La adopción de las mejores prácticas que han sido probadas científicamente es de vital importancia para asegurar la sostenibilidad en las operaciones de los productores y el bienestar de las comunidades agrícolas.

**Palabras clave:** Mejores prácticas de manejo, escrutinio ambiental, áreas marginales, salud del suelo