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(REVIEW ARTICLE)

# Improving Sugarcane (*Saccharum officinarum* L.) yields in Sub-Sahara Africa through the use of existing technologies: Sugarcane agronomy

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## Abstract

Sugarcane is an important commercial crop for rural farmers in sub-Sahara Africa. To increase its productivity, farmers need to adopt better agronomic practices at all cane production stages. Proper and timely monitoring of pests and diseases must be done for early detection and control. This work therefore highlights key practices aimed at improving sugarcane production in Sub-Sahara Africa. For sustainable management of pests and diseases, farmers should adopt the use of resistant varieties such as D8484 and KEN 83-737 and environmentally friendly practices such as crop rotation, intercropping and use of less toxic pesticides that enable proliferation of natural enemies. A part from competition with sugarcane for key growth requirements such as light, space, nutrients, and water, weeds act as alternate hosts for major sugarcane pests and diseases hence timely and proper control should be put in place. Healthy sugarcane plants resist better the impacts of pests and diseases and must be maintained through a balanced application of adequate fertilizers and water during growth periods. Storage of harvested canes results in yield reduction. Therefore, harvesting of sugarcane should be done when millers are ready to pick the canes.

**Keywords:** Fertilizer application; Sugarcane pests and diseases; Sugarcane agronomy; Integrated soil fertility management and integrated pest and disease management

## 1. Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the commonly grown commercial crops by small-scale farmers in Africa. Globally, Africa contributes only 5% of sugarcane production, of which 83% is produced in Sub-Saharan Africa (SSA) [1]. In SSA, six countries account for more than half of the total production; with South Africa leading with 23%, followed by Kenya at 8%, Sudan at 7%, Swaziland at 7%, Mauritius at 5%, and Zambia at 5% [1]. Other than employment creation and source of income to various stakeholders along its value chain, the crop provides raw materials for sugar, alcohol used by the pharmaceutical industry and as fuel, bagasse for paper and chipboard production. Despite its importance, sugarcane productivity is still below its potential in the region compared to global average yields of 71 t/ha [1]. For instance, the current yields in Ethiopia, Kenya, Nigeria, Rwanda, Uganda and Tanzania, ranges between 17 and 70 t/ha compared the leading producers such as Brazil (74 t/ha), China (76 t/ha) and USA (82 t/ha) [1]. The low yields could be due to un-optimized agronomic practices currently applied by farmers that do not allow for efficient usage of already limited resources such as labor, nutrients, and water. This work therefore aims at sequentially discussing key production practices with scientific backing recommended for improving sugarcane production in the SSA region. The practices are categorized into key agronomic practices: site selection, variety selection, land preparation and field layout, sett production and treatment, planting, soil fertility management, water requirement, weed management, cropping systems, pest and disease management and harvesting and post-harvest handling practices.

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## 2. Site selection

Site selection is an important practice in healthy cane production however; it is limited and hindered by decreasing arable lands caused by land subdivision in the region. Sugarcane crop can be grown in nearly all soil types as long as the soil supplies adequate water and nutrients whenever required. The crop requires fertile, deep, and well-drained soils with pH ranging between 5.5 and 7.7, though the crop can tolerate lower soil pH. At soil pH below 5.5, the nutrient-supply capacity of the soils begins to decline since most nutrients get adsorbed leading to deficiencies [21]. Saline and salt-affected soils should also be avoided because they greatly affect yields. In terms of rainfall, sugarcane requires about 1000-1500 mm annually followed by dry periods towards the end of the season for ripening of canes and concentration of sucrose [2, 3]. Temperature is an important climatic aspect that greatly influences sprouting, growth and ripening processes. The crop requires temperatures above $18^{0}$C for faster sprouting and up to $38^{0}$C for better growth and cane production [4, 5]. The crop also responds well to a long period of sunlight of about 12 hours and high humidity of 80%. In these conditions, sugarcane has fast growth and elongation of stems.

## 3. Variety selection

The choice of a cane variety depends largely on the farmers' preferences which are always influenced by the market demands. There are three main categories of sugarcane varieties that could be produced in the region:

### 3.1. Chewing cane

These are sweet moist, soft fiber canes that are eaten raw. The local examples are Goa and noble canes.

### 3.2. Crystal canes

These are used to make cane sugar e.g. black Tanna, and stripped Tanna.

### 3.3. Syrup cane

These are used in making syrups for medicines and other food preservatives.

In the region, the chewing canes and crystal canes are the most preferred and grown categories- examples are as shown in Table 1.

**Table 1** Some of the latest crystal cane varieties released in Kenya and their key attributes. Source: KESREF [6]

| Variety | Year of release | Recommende d harvest age (months) | Disease tolerant | Sucrose (Pol% cane) | Expected cane yield (t/ha) |
|---|---|---|---|---|---|
| KEN 00-13 | 2014 | 16-18 | N/A | 12-14 | 92-145 |
| KEN 00-3548 | 2014 | 16-18 | Smut | 12-13 | 77-120 |
| KEN 00-3811 | 2014 | 16-18 | N/A | 13-14 | 90-133 |
| KEN 98-530 | 2014 | 16-18 | N/A | 12-14 | 78-125 |

## 4. Land selection, preparation and field layout

Farmers should avoid water logged areas, and alkaline soils for sugarcane production. The selected fields should not have been planted previously with sugarcane and should be accessible to road for easier transportation. Land preparation should be done early before the onset of rains to ensure proper control of weeds and soil-borne pests. Well prepared lands encourage good soil water-air relations, allow for better root penetration, better incorporation of organic residue and manure, and facilitate proper soil chemical and microbial activities. In SSA, based on our observations, farmers commonly use tractor-drawn or ox-drawn plows for first land opening and subsequent secondary cultivations. The choice of a method of land preparation depends on the land size and financial resource available. About 3 plowings should be considered enough to achieve suitable tilth for cane planting. In areas with hardpan, subsoiling to a depth of about 50 cm may be recommended to break the hardpan for easy water infiltration and root penetration. Use of raised beds with furrow channels is encouraged in areas with relatively flat and heavy soils that are prone to flooding and waterlogging to allow free flow of excess water during heavy rains.

## 5. Seed setts preparation and treatment

The setts or seed cane is of good quality if results in maximum germination. Any planting materials should be sourced from pests and diseases free parents. Common diseases to monitor during the preparation of seed setts include red rot, wilt, smut, ratoon stunting disease (RSD). There are two methods of propagating sugarcane depending on the part of the cane used;

### 5.1. Planting using seed setts

Sugarcane seed setts are sections of cane stalks with buds used for propagation. Setts with 2-3 buds have been found to be the best for planting as they produce better germination and yield than the setts having more or fewer buds [7, 8]. These setts should be from young seed canes of about 8 months old. Alternatively, farmers may use the top 1/3rd portion of the healthy and matured canes as seeds for production.

### 5.2. Planting using bud chip

Bud chips are small portions of cane stalks with one bud. The bud chips must be raised first in the nursery for about 6 weeks before transplanting to the main field. This technology is gaining popularity and has been reported to produce higher bud sprouting, root number, fresh weight of shoots and roots and plant vigor index than using the setts [9]. Before planting, seed setts should be treated to ensure that crops are given protection against common soil-borne diseases. Commonly used treatment methods include hot water treatment where seed setts are put in running cold water for 24 hours followed by hot water at 50°C for 3 hours. The hot water treatment may also contain mercurial fungicide, a process reported to cure smut, RSD and leaf scald [10]. Seed setts can also be treated with chemicals containing 0.1% (at 1g/liter) Carbendazim solution for 15 minutes [8]. Other methods include moist air treatment and aerated steam treatment. High levels of hygiene must also be maintained during the preparation of seed setts by treating cutting equipment e.g. knives with products containing 0.1% benzalkonium chloride to avoid the spread of these diseases.

## 6. Planting

Generally, the spacing of sugarcane crop varies across different countries in the region depending on the variety, climate, machine technology used and soil fertility. A wide inter-row spacing of 1-2 m is commonly recommended and practiced among farmers [8]. Although narrow rows can be practiced without yield penalty depending on general agronomic practices carried out, soil fertility and prevailing weather conditions. In terms of intra-row spacing, there is not much distinct spacing practiced in the region. Traditionally, seed setts are placed in the furrows with about 10% overlap. Despite the high labor requirement, this method has been hailed for high yields [10]. Ayele et al. [11] improved this practice and recommended a 10 cm gap between setts. The researchers found the method economical and adaptable. On average, about 16,187 (≈ 4.45 tons) three-bud or 20,243 two-bud setts per acre are required for cane production [8]. The planting depth should not be too deep as it would lead to delayed or failed sprouting-approximately, 5-10 cm planting depth is recommended.

## 7. Fertilizer application and soil fertility management

Sugarcane is one of those crops that accumulate a lot of nutrients per unit aboveground body mass. It is reported that for every 1 ton of aboveground biomass, the crop accumulates 1500, 400, 1800, 900, 500, 400, 66.7, 25, 5, 3.3, and 2.5 grams of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B nutrients respectively [12]. The peak requirement levels of these nutrients vary depending on the growth stage. For instance, consumption of N, P and K increase steadily from sprouting with N and P nutrients reaching their peaks at the tillering stage while K nutrient reaching its peak at the grand growth phase (Figure 1). These rates of nutrient removal are high and should be replaced seasonally for sustainable production. Assessment of soil fertility status is one of the initial important practices that need to be carried out to ascertain the capacity of the soils to supply these nutrients and to decide on how much of fertilizer is needed for optimum production.

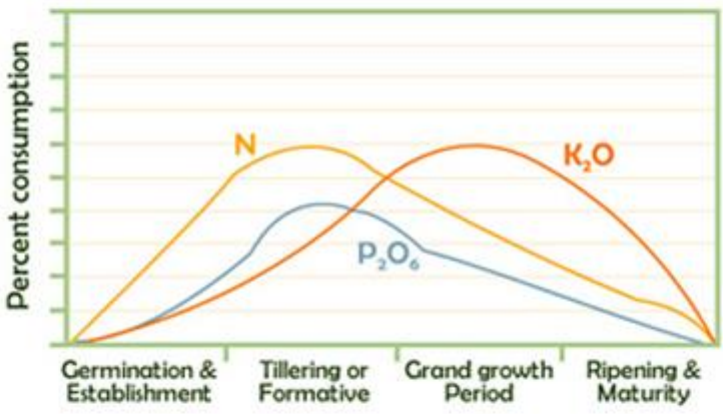


**Figure 1** Relative requirement of NPK at different crop growth stages of sugarcane. Source: Bachchhav [13]

Nitrogen is a very important nutrient during sugarcane germination and growth and is always demanded in large quantities. However, one must be careful by avoiding excess application to reduce risks of lodging. The N application rates vary widely depending on the availability, cost, soil fertility and technology used with up to 400 kg N /ha used in the USA [14] (Table 4). In SSA, researchers have recommended much lower rates: 90 kg N/ha in Nigeria [15], 147 kg N/ha in Kenya [16] and up to 200 kg N/ha in Uganda [17]. Apart from the rates, timing of N fertilizer application is another important practice ensuring better final juice quality. According to Haifa [18], N fertilizers should be applied at an early stage of growth and is essential to complete the application at least 5 months before the intended date of harvest. Wayagari *et al*., [15] further suggested that about 50% of recommended N rate should be applied at planting while the remaining 50% applied in two splits at 5-6 and 10-12 weeks after the first application for better efficiencies and quality sucrose content.

**Table 2** Phosphorus doses suggested for sugarcane fertilization based on the availability of phosphorus extracted with Mehlich and on the expectation of natural matter production. Adapted from de Oliveira *et al.,* [12]

| **Production expectation in the cane plant cycle (t/ha)** | **Soil fertility class** | | |
|---|---|---|---|
| | Low | Medium | High |
| | Dose of P (kg/ha) * | | |
| Less than 100 | 70 | - | - |
| 100-150 | 80 | 60 | 40 |
| 150-180 | 90 | 70 | 50 |
| Above 180 | 100 | 80 | 60 |

*To convert P into P2O5, multiply the desired value by 2.29.

Phosphorus is also an important fertilizer required for proper root development, stalk elongation and enlargement and production of many stalks per stool. The rates of P vary widely from one country to the other with up to 280 kg $P_2O_5$ /ha reported in the USA [14] (Table 4). The recommended rates are low in Africa: 50 kg $P_2O_5$/ha in Nigeria [15], up to 79 kg $P_2O_5$/ha in Kenya [16, 19]; and up to 100 kg $P_2O_5$/ha in Uganda [17]. The low rates used in SSA could be linked to the prevailing economic and edaphic factors in the region. Comprehensive research by de Oliveira *et al.,* [12] has narrowed down the application rates based on targeted yields and prevailing soil fertility status. This tool is important when making P fertilizer application decisions (Table 2). All P-based fertilizers should be applied at planting by putting in the rows. The basal application ensures an adequate supply of P required for better rooting and growth early in the season.

**Table 3** Potassium doses suggested for sugarcane fertilization based on the availability of potassium extracted with Mehlich and on the expectation of natural matter production. Adapted from de Oliveira *et al.,* [12]

| Production expectation in the cane plant cycle (t/ha) | Soil fertility class | | |
|---|---|---|---|
| | Low | Medium | High |
| | Dose of K (kg/ha) * | | |
| Less than 90 | 100 | - | - |
| 90-120 | 120 | 100 | 80 |
| 120-150 | 140 | 120 | 100 |
| 150-180 | 160 | 140 | 120 |
| Above 180 | 180 | 160 | 140 |

*To convert K into K2O, multiply the desired value by 1.20. When sugarcane is harvested for animal feed, it is suggested to raise the recommended K dose by 25%.

Potassium is another important nutrient playing crucial roles in sugarcane metabolisms such as photosynthesis, protein synthesis, starch formation, and translocation of proteins and sugars. It enables the crops to take up balanced nutrients and is better able to withstand the drought conditions [15]. Different countries recommend different rates of K with up to 450 kg $K_2O$/ha reported in the USA [14] (Table 4). In Nigeria, a rate of about 40kg $K_2O$ /ha was found economical [15] while in Uganda, the National Agricultural Research Organization (NARO) recommended about 100kg $K_2O$/ha for sugarcane production [17]. No K application is currently recommended for use in Kenyan soils despite its heavy mining that has been reported by Stoorvogel *et al.,* [20], Otieno *et al.,* [21] and Otieno [22]. Comprehensive research by de Oliveira *et al.,* [12] has narrowed down the application rates based on targeted yields and prevailing soil fertility status that could be used when making K fertilizer application decisions (Table 3). Proper timing of K application is important and greatly influenced by the soil type and crop growth stage. In heavy soils, all the recommended rates could be applied once at planting [15, 18]. However, in lighter soils, application in two splits (50% of the recommended rate at planting and the remaining 50% at 6 months after basal application) is recommended [18].

**Table 4** Sugarcane: Recommended nutrient doses in different countries. Adapted from Netafim [14]

| Country | Crop | Nutrient application rates (kg/ha) | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| Australia | Plant cane | 56 | 25-80 | 75-150 |
| | Ratoon | 78 | --- | --- |
| Brazil | Plant cane | 30-90 | 0-180 | 20-120 |
| | Ratoon | 20-90 | 15-100 | 10-140 |
| Colombia | Plant cane | 50-70 | 50-100 | 60-150 |
| | Ratoon | 50-100 | 60-120 | 60-150 |
| Cuba | Plant cane | 0 | 0-50 | 0-120 |
| | Ratoon | 35-150 | 0-50 | 0-150 |
| South Africa | Plant cane | 80-120 | 30-60 | 100-125 |
| | Ratoon | 100-140 | 10-40 | 150-175 |
| USA | Plant cane | 300-400 | 280 | 400-450 |

Also, sugarcane could benefit from the application of trace elements such as S, Mg, Ca, B and Fe which are current reported to be getting low in the region [21, 22]. Upon the detection of iron (Fe) deficiency symptoms, foliar application of ferrous sulfate ($FeSO_4$) at the rate of 30 kg/ha is recommended [11]. In the event of toxic levels of Fe, Al, and Mn elements as commonly experienced under low soil pH levels, application of lime and manure should be practiced [21]. Use of organic manure is very important and has been shown to increase yields when applied at rates of 2-4 t/acre together with inorganic fertilizers [23]. Amelioration of soil acidity is important in ensuring that the applied nutrients are made available and utilized efficiently. Hence, soil pH test is important when determining lime requirement. According to Netafim [14], the general lime requirement for sugarcane production should be about 450 - 675 kg/ha every 2 years for sandy soils, 1800 - 2250 kg/ha every 3 - 4 years for clay-loams and 2700 - 3600 kg/ha every 4 - 5 years in clay soils.

## 8. Water stress and water requirement

Naturally, sugarcane crop is drought tolerant. However, extreme levels could result in significant yield losses. For instance, Ramesh [24] reported a reduction in dry matter content by 25-60.8, 52.4 and 25.9% in severe drought and 46.3, 36.3 and 15.1% in moderate drought at the ends of the formative, grand growth and maturity phases, respectively. Sugarcane requires high water supply during its entire growth periods for higher cane yields. It is estimated that between 89-118 litres of water is required to produce 1 kg of sugarcane [25]. This water can come from rainfall or irrigation depending on the system of production. The impact of irrigation has been modeled and proved that cane yields can increase by 3 t/ha if about 500 mm of water is provided constantly [26]. This is the response expected when water is not a limiting factor.

Another important aspect of water stress is waterlogging. The impact of waterlogging on cane production depends on the stage of growth and height of stalks- young and short canes are more affected compared to old and tall canes. In general, yield loss of 15-20% after 5 days submergence, 30-60% after 10 days and 37-100% after 15 days of emergence have been reported [27]. To manage flooding and waterlogging stress, farmers should use dikes and ditches around the farm and plant on raised beds separated with furrows in in such areas.

## 9. Weed management

Proper weed control should be done during the critical periods between 90-120 days after sprouting to avoid potential 12-72% yield loss [7, 14, 28, and 29]. Manual weed control is applicable and commonly practiced in SSA due to relatively small farm sizes and poor knowledge on the use of herbicide among farmers. For better weed control, tillering and yield production, about 3-4 weeding is enough to keep weeds below economic threshold levels. Another strategy lowly gaining popularity in the region is the use of the herbicide. Examples of herbicides commonly used in sugarcane production include asulam, atrazine, metribuzin, glyphosate, pendimethalin, terbacil, diuron and hexazinone, etc. The use of herbicide is time-saving and economical compared to hand weeding and should, therefore, be encouraged among farmers as long as safety measures are considered. It is important to use less toxic herbicide products and have personal protective equipment whenever handling these chemicals to avoid human and ecological risks [30].

## 10. Cropping system

Most sugarcane varieties take about 17 months to the first harvest and about 4-5 years from planting to harvesting of the third ratoon in the region. This period is long and makes it impossible to rotate sugarcane with other crops every year. The extensive rooting system and high nutrient demands make intercropping difficult especially past 8th month after planting. This means that farmers are left with about 6-8 months' window period to carry out any intercropping with annual crops like maize, sorghum, soybean, grams, beans and potatoes. In the first season (about 3-4 months) the yields of intercrops are less affected compared to the second season. The effects of annual intercrops on sugarcane yield have shown mixed impacts. For instance, in India, Mauritius, and Egypt, researchers have reported increased cane yields and general monetary returns when intercropped with rice, potatoes and soybeans [31, 32]. However, depressed yields have been reported with other crops such as wheat, lentils, onion, mustard and safflower [33, 34]. Therefore, care must be taken to avoid yield depression of both crops- proper spacing and timing are very important. To avoid high nutrient mining and competition for other growth factors, farmers should adopt a 1:1 (with all crops) or 1:2 (with legumes and short statures cereals) sugarcane-intercrop planting configuration [31]. The main reason for intercropping sugarcane with other food crops is to reduce over-dependence on sugarcane as a source of family livelihood. The practice also helps to maximize on the use of land and labor. By default, intercropping sugarcane with annual crops ensures weed-free fields during the critical cane production periods. Annual legume crops such as beans, grams and cowpea increase soil fertility through biological nitrogen fixation and production of high quality residue.

## 11. Management of field pests and diseases

This section provides a summary of important pests (Table 5) and diseases (Table 6) that affect sugarcane in the SSA region. It also looks at possible yield losses and management strategies for better recommendation.

**Table 5** Summary of common sugarcane pests and their management options

| Pests and their impacts on cane yields | Management strategies |
|---|---|
| **Cane grub**<br>These grubs could cause 39-80% yield loss if left uncontrolled under heavy infestation [35]. | • Practice intercropping or rotation with legume crops.<br>• Practice deep plowing during dry seasons.<br>• Destroy adult beetles physically.<br>• Apply biological agents such as *Metarhizium anisopliae* soon after planting. |
| **Nematode**<br>Yield loss of up to 50% has been reported [36, 37]. The losses are higher on sugarcanes grown on sandy soils. | • Maintain weed-free cane fields.<br>• Rotate sugarcane with legumes crops.<br>• Practice trash mulching or green manuring to promote the establishment of beneficial organisms (e.g. Metarhizium anisopliae and Paecilomyces lilacinus [38].<br>• Apply nematicides such as organophosphates and carbamates at planting [39]. |
| **Termites (*Macrotermes natalensis*)**<br>Termites lower germination by up to 60% if left uncontrolled [14]. On canes, the pest could cause up to 33% yield loss under serious attack [35]. | • Practice deep plowing and dig out termite mounds and kill the queen termite.<br>• Apply chemicals: bio-termicides, synthetic chemicals and termite baits (e.g. Bio Blast or hexaflumuron baits).<br>• For comprehensive termite management, refer to Otieno [40]. |
| ***Chilo infescatellus***<br>Yield losses due to *C. infescatellus* vary across the region and could be as high as 33% in cane yield [35]. | • Plant early when the infestations are low.<br>• Practice earthing-up during early sugarcane stages.<br>• Intercrop sugarcane with legumes such as cowpea.<br>• Adopt push-pull technology. |
| ***Chilo saccharifugus***<br>The pest attacks sugarcane from internode formation stage. Yield losses of up to 35% in cane yield have been reported [35]. The effect is favoured by plant lodging and waterlogging conditions. | • Plant self dethrashing varieties such as D8484.<br>• Supply crops with adequate fertilizers and avoid excess N application that could cause lodging. |

**Table 6** Summary of common sugarcane diseases and their management options

| Diseases and their impacts on cane yield | Management strategies |
|---|---|
| **Brown rust (*Puccinia melanocephala*)**<br>Yield losses due to Brown rust vary depending on the environmental conditions, severity and tolerance level of the variety planted. Losses of 20 to 50% have been recorded under severe infestation [27, 41]. | • Diversify varietal composition and plant resistant varieties.<br>• Apply pre-plant fungicide and rogue off infected plants [42]. |
| **Red rot (*Colletotrichum falcatum*)**<br>The disease reduces cane yields, juice quantity and quality- up to 29% reduction in cane weight and 31% reduction in sugar recovery have been reported [43]. | • Use healthy cane seeds from certified suppliers.<br>• Treat seed setts with hot water and apply fungicides (Carbendazim) before planting.<br>• Practice field hygiene: proper weeding and burning residue from infected crops after harvest.<br>• Rotate sugarcane with green manure crops such as desmodium.<br>• Avoid ratooning on fields with high incidences of the disease. |
| **Pineapple disease (*Ceratocystis paradoxa*)**<br>The typical symptoms *Ceratocystis paradoxa* are detected in setts after 2 - 3 weeks of planting. The disease prevents the sets from rooting leading to germination failure. Stalk damages due to rats and borers provide route entry for the pathogen leading to 85-90% germination failure [35]. | • Plant resistant varieties.<br>• Practice proper field drainage.<br>• Avoid causing injuries and treat seed setts with fungicides e.g. propiconazole before planting.<br>• Practice sugarcane-legume rotation.<br>• Treat seed setts with bio-chemicals (e.g. use of Trichoderma harzianum) or synthetic fungicide (e.g. Carbendazim 50WP) before planting [44]. |
| **Sugarcane smut (*Ustilago scitaminea*)**<br>Losses could range between 21 - 40% in fresh plant crops and up to 70% in ratoons while sucrose content is reduced by 3 - 7% [14, 35]. | • Plant resistant varieties like D8484 and KEN 83-737 [35].<br>• Treat seed setts in running cold water for 24 hours followed by hot water at 50°C for 3 hours before planting [10].<br>• Apply fungicides (e.g. pyroquilon, carbendazim+maneb and metalaxyl+ carboxin+furathiocarb [45]. |
| **Brown spot (*Cercospora longipes*)**<br>Losses of about 14% on canes and 18% on sugar production have been reported [46]. | • Plant resistant variety.<br>• Apply fungicides such as mancozeb and carbendazim+maneb [47]. |
| **Ratoon stunting disease (RSD)**<br>The disease reduces germination, causes stunted growth and thin stalks with short internodes leading to about 5 to 30% yield loss depending on variety and environmental conditions [35]. | • Plant disease-free seed setts.<br>• Maintain hygiene by treating cutting equipment with products containing 0.1% benzalkonium chloride during harvesting and preparation of seed setts.<br>• Treat seed setts in running cold water for 24 hours followed by hot water at 50°C for 3 hours before planting [10]. |

## 12. Harvesting and postharvest handling of canes

Canes are ready for harvesting after 14-22 months depending on the variety. For instance, in Uganda and Kenya, 15 and 19 months after planting are recommended for harvesting, respectively [48]. The commonly recommended practice is to harvest canes before flowering. This is because flowering process uses both energy and sucrose and may lead to pithy islands in the stems thereby reducing yields [2]. The yield loss of about 20% due to flowering has been reported by Bakker [49]. To inhibit flowering, large commercial farmers apply chemicals (e.g. ethrel (ethephon or 2-chloroethanephosphonic acid) at rates of 0.56-0.84 kg/ha a.i.) before flowering [49, 50]. Under small-scale farms, farmers may control flowering by stopping irrigation a month before flower induction.

Mature canes can be harvested green or burnt. Controlled burning helps to clear the fields, drive away dangerous reptiles and reduce the level of foreign materials. This practice is common in large farms in Africa. However, burning should be discouraged to enable build-up of residues that act as mulch thereby increasing soil organic matter, helping in weed control and conservation of soil and water resource. In large scale farming especially in countries with well-developed technologies, farmers use herbicides to defoliate their farms before cutting. The use of glyphosate at 351 to 430 g/ha applied 35 to 40 days before harvest has been reported to produce better defoliation than the recommended 630 g/ha [10]. Harvesting is usually done manually using machetes. At the harvesting stage, care must be taken to maintain cleanliness and hygiene by disinfecting cutting equipment with products containing 1% benzalkonium chloride to avoid the spread of diseases when harvesting different farms. Harvested canes should be milled within 24 hours after harvesting to avoid quality and quantity losses. This implies that farmers should only harvest when millers are ready to collect the canes. Any form of storage of already cut canes automatically leads to high losses especially when canes are left on hot sunny environments.

## 13. Conclusion

Adoption of better agronomic practices could significantly improve sugarcane yields thereby increasing farmers' income in the region. These practices are affordable and available for adoption. Farmers need to start by selection of better varieties that are adapted to the prevailing biotic and abiotic factors. Field activities such as planting, weeding, fertilizer application and pests and diseases management must be timely and properly executed for better growth and cane production. To ensure sustainability, integrated pest and disease management must be followed at all time- avoid as much as possible the use of farm chemicals. Any delayed harvesting significantly reduces cane yields and therefore must be monitored and carried out within the maturity periods. Any form of storage of already cut canes automatically leads to high losses especially when canes are left on hot sunny environments.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The authors declare no conflict of interest.

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