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Sugarcane Production Systems in Small Rural Properties

Mauro Wagner de Oliveira,

Luís Cláudio Inácio da Silveira, Alexandre Bosco de Oliveira,

Márcio Henrique Pereira Barbosa, Manoel Gomes Pereira

and Terezinha Bezerra Albino Oliveira

Abstract

Sugarcane grown in small rural properties of the Zona da Mata region, located in the southeast of the state of Minas Gerais (MG), is generally intended for animal feed and the production of *rapadura*, brown sugar, *cachaça*, and ethanol. This chapter focuses on the authors' experience on technologies recommended to small farmers for the implantation and management of sugarcane plantations. The following issues are addressed and discussed: planning and preparation of the sugarcane plantation; soil sampling and soil fertility assessment; application of lime and gypsum; setting up seedling nurseries; green fertilization in the areas of planting and renewal of sugarcane plantation; soil preparation, planting and chemical fertilization of plant-cane; weed and pest control; chemical fertilization of ratoon; assessment of sugarcane nutritional status; organic fertilization with crop residues and agroindustrial residues; mineralization of sugarcane straw; assessment of broth quality and sugar production; and renewal of the sugarcane plantation.

Keywords: sustainability, nutrient cycling, broth quality of the sugarcane, leaching, organic fertilization

1. Introduction

The sugarcane production systems addressed in this chapter were recommended by the authors for small farms of the Zona da Mata region of the state of Minas Gerais, Brazil. These small rural properties are located at geographical coordinates ranging from 20°45'14" to 21°11'39" South and 42°52'55" and 43°01'04" West. The altitude ranges from 330 to 650 m. The climate of the region is humid subtropical and varies from Aw to Cwa with rainy summers, according to Köppen classification. The average precipitation of the last 30 years is approximately 1200 mm. There is water surplus from November to March, precipitation is below potential evapotranspiration from April to September (causing water deficit), and precipitation is again higher than evapotranspiration in October. Therefore, the dry and rainy seasons are well defined in the region.

The predominant soils in the region are Distrophic Red-Yellow Latossol, Ultisol Red-Yellow Dystrophic and Latossolic Cambisol [1]. Although soils have low fertility, their physical composition allows for agricultural activity provided that

appropriate techniques are used. The main agricultural techniques recommended to these small farmers are aimed at improving the physical and chemical properties of the soil by lime and gypsum application, chemical fertilization, green fertilization, using organic compost, planting of sugarcane varieties with greater yield potential, chemical weed control, and biological pest control. The sugarcane produced in these properties is intended for animal feed and the production of *rapadura*, brown sugar, *cachaça*, and ethanol.

2. Planning and implantation cost of sugarcane plantation

Several technologies can be used in setting up and managing sugarcane plantations in small farms. Those selected and recommended by the authors are focused on maximizing the use of inputs, land and human resources to reduce operating costs and increase crop yields, in addition to helping preserve the environment. The main cost items for setting up 1 ha of sugarcane in the region are shown in **Table 1**.

Cost item	Unit*	Unit price	Quantity	Total price	Participation
		(US\$)		(US\$)	
A) Consumption					
Limestone	t				
Gypsum	t				
Seeds of <i>Crotalaria juncea</i>	kg/ha				
Fertilizer	kg				
Sugarcane seedlings	t				
Chemical insecticide	L or kg				
Herbicide	L or kg				
Formicide	L or kg				
Biological insecticide	L				
Subtotal (A)					
B) Service					
Land rent	ha				
Soil analysis	sample				
Plowing	h/m				
Harrowing	h/m				
Sowing of <i>Crotalaria juncea</i>	h/m				
Incorporation of <i>C. juncea</i> into soil	h/m				
Furrowing for planting sugarcane	h/m				
Fertilizer application in the planting furrow	h/m or d/H				
Seedling distribution and pruning	d/H				
Insecticide application on the seedlings	h/h or d/H				

Cost item	Unit*	Unit price	Quantity	Total price	Participation
		(US\$)		(US\$)	
Covering of seedlings	h/m or d/H				
Herbicide application	h/m or d/H				
Formicide application	d/H				
Insecticide application	d/H				
Subtotal (B)					
C) Total cost for the implantation of a sugarcane plantation (A+B)					

*t: tonne, Kg/ha: kilograms per hectare, L: Liters, Kg: Kilogram, h/m: machine hours, d/H: work days per man, sample.

Table 1.
 Main cost items for the implantation one hectare of sugarcane in small farms of the Zona da Mata region.

Scenarios	Decrease in yield (%)	Cuts							Average	Sugarcane plantation (ha)	Area (%)
		1st	2nd	3rd	4th	5th	6th	7th			
		.----- t of natural matter per hectare -----.									
1	10	150	135	122	109	98	89	80	112	1.63	100
2	15	150	128	108	92	78	67	57	97	1.88	115
3	10	120	108	97	87	79	71	64	89	2.04	125
4	15	120	102	87	74	63	53	45	78	2.35	144
5	17.5	120	99	82	67	56	46	38	72	2.52	154
6	20	120	96	77	61	49	39	31	68	2.69	165
7	10	110	99	89	80	72	65	58	82	2.23	137
8	15	110	94	79	68	57	49	41	71	2.56	157
9	17.5	110	91	75	62	51	42	35	66	2.75	169
10	20	110	88	70	56	45	36	29	62	2.94	180
11	10	100	90	81	73	66	59	53	75	2.45	150
12	15	100	85	72	61	52	44	38	65	2.82	173
13	17.5	100	83	68	56	46	38	32	60	3.02	185
14	20	100	80	64	51	41	33	26	56	3.23	198

Table 2.
 Simulation of a sugarcane plantation area needed to feed 25 dairy cows (20 kg of natural matter per cow/day) for 365 days and plant-cane yield and yield stability in seven succeeding cuts.

In sugarcane, it is common to evaluate the results obtained by quantifying the production of culms, sugars, or total shoot biomass. In analyzing the production costs, one can use the exchange ratio, which is an economic indicator that shows the exchange capacity of a certain product in relation to the inputs used in production (product/input).

The great advantage of exchange ratio analysis over price analysis is that agricultural products represent the weighted average of several inputs and goods used by the farmer. Thus, it is easier to calculate the variation in producer purchasing power or production system efficiency. If possible, this analysis should cover a long period of time, so that the extent of the variation in results can be measured.

The use of spreadsheets (e.g., Excel) is helpful in analyzing simulation results, as well as budgeting and managing sugarcane production costs. The authors have guided farmers to adopt practices that recover and maintain soil fertility, recycle nutrients, and reduce compaction and sealing of the topsoil, combined with activities that enable increased yields in plant-cane and small decreases in subsequent cycles. **Table 2** shows a simulation of sugarcane yield in 14 scenarios, which combine high and medium yields in the plant-cane cycle to low, medium, or high decreases in yield over seven cycles (seven cuts).

Table 2 shows that to feed 25 cows for 365 days (20 kg of natural matter per cow/day), an area of 1.63 ha of a sugarcane plantation with high yield in the plant-cane cycle and 10% decrease in subsequent cycles would be necessary (Scenario 1). On the other hand, an area of about 3.3 ha would be needed for a sugarcane plantation with medium yield in the plant-cane cycle and large decreases in subsequent cycles (Scenario 14). In sugarcane plantations with yields of less than 60 tons of natural matter per ha (about 50 tons of industrializable culms), in addition to decreasing the use of land and labor resources, chemical weed control is generally inefficient, as the crop does not completely cover (shade) the soil, allowing the emergence and growth of invasive species (**Figure 1**). Also, in cases where sugarcane is cut by hand, the worker will be more exposed to snakes and scorpions.



Figure 1.
Contrast between a sugarcane plantation with high yields and excellent weed control, and a plantation with low yields and poor weed control.

3. Selecting sugarcane variety

Choosing the right variety is an important and low-cost technology for the producer. Currently, there are several sugarcane cultivars with proper agronomic and zootechnical characteristics, such as high response to improved soil fertility, erect growth, and resistance to falling, which facilitates harvesting, high culm and sucrose yield, regrowth vigor, resistance to pests and diseases, and good dry matter digestibility.

Characteristic	Variety						
	RB835054	RB855536	RB867515	RB928064	RB975201	SP80-1816	SP80-3280
Yield ¹	High	High	High	High	High	High	High
Maturation	Early	Medium	Medium	Late	Late	Medium	Medium
Sucrose content	High	High	High	Medium	Medium	High	High
Harvest ²	Apr-Nov	Jun-Nov	Jun-Sep	Sep-Nov	Ago-Nov	Jun-Sep	Jun-Sep
Soil ³	Medium	Medium	Low	High	Medium	Medium	Medium
Regrowth ⁴	Good	Excellent	Good	Good	Good	Excellent	Good
Tillering ⁵	Average	Excellent	Average	Very good	Average	Very good	Very good
Toppling ⁶	Frequent	Little	Little	Little	Frequent	Little	Rare
Detrashing ⁷	Easy	Medium	Easy	Medium	Easy	Medium	Easy
Pilosity	No	No	No	Yes	No	Yes	No
Flowering	Absent	Absent	Medium	Absent	Absent	Absent	Present
Wilting	No	No	Medium	No	No	Little	Yes
Sensitivity to Herbicides ⁸	High	Medium	Low	Low	Low	Medium	Medium
Coal ⁹	Resistant	Intermediate	Resistant	Resistant	Resistant	Intermediate	Intermediate
Rust ⁹	Resistant	Resistant	Resistant	Resistant	Resistant	Resistant	Resistant
Red Streak ⁹	Resistant	Intermediate	Susceptible	Resistant	Intermediate	Resistant	Resistant
Leaf scalding ⁹	Resistant	Intermediate	Resistant	Resistant	Resistant	Resistant	Resistant

¹Yield: Yield per ha of industrializable culms and biomass (High, Medium or Low)

²Harvest: Recommended months for the harvest of sugarcane for brown sugar and rapadura

³Soils: Soil fertility requirement (High, Medium or Low)

⁴Regrowth: sprout vigor of regrowth under conditions of trampling by machines or animal traction vehicles

⁵Tillering: growth speed and soil shading, thus minimizing weed competition

⁶Toppling: plant growth habit, which varies from erect to decumbent. Even cultivars with upright culms may topple under high-yield conditions

⁷Detrashing: removal of dry leaves or attachment of the sheath to the culm

⁸Sensitivity to certain herbicides

⁹Diseases of the plant shoot.

Source: Silveira, L. C. I. (unpublished data).

Table 3.

Agroindustrial, morphological, and tolerance characteristics of seven varieties of sugarcane recommended for cultivation in the small farms of the Zona da Mata region.

The authors of this chapter do not recommend planting one variety of sugarcane in more than 33% of the total area, even if it has a large number of desirable characteristics. This is because sugarcane production will be greatly compromised in cases of possible breakdown of resistance to disease or sudden decline of the cultivar. Thus, in order to obtain a good quality product, ensure vigorous regrowth and consequently increase the longevity of the sugarcane plantation, the authors recommend that farmers use at least four varieties of sugarcane and adopt measures to maintain soil fertility and cut the sugarcane at the most suitable time for each variety. Once the varieties have been selected, it is necessary to check the quality of the seedlings. It is also important to confirm the health of the seedlings in terms of diseases, pests, and mixture of other cultivars. **Table 3** shows characteristics of the varieties currently most planted in small farms of the Zona da Mata region.

RB867515 has been the variety of sugarcane most cultivated by small producers due to its high yield potential in different edaphoclimatic conditions. As mentioned in **Table 3**, RB867515 is a medium maturing variety with high sucrose content in industrializable culms. It has a low requirement for soil fertility, but it is very responsive to fertilization. Its detrashing is easy and it has no pilosity. **Figure 2** shows dry matter accumulation rate in shoots of three sugarcane varieties (RB855536, RB867515, and SP801816). The study was conducted in soil of medium texture in the city of Mercês, state of Minas Gerais (MG) (latitude 21.260232, longitude 43.298827, and altitude 503 m).

Sugarcane was planted in the first half of February. Following the recommendation of Ref. [1], 5.0 t of dolomitic limestone and 1.5 t of gypsum were applied per ha in September of the year prior to the planting of sugarcane. The soil was plowed and harrowed, followed by the sowing of *Crotalaria juncea*. In early February, at the grain filling stage, *Crotalaria juncea* was incorporated into the soil. A week later, the soil was furrowed and sugarcane was planted. The chemical fertilization consisting solely of phosphorus was applied at the bottom of the planting furrow at a dose of 100 kg of phosphorus per ha (equivalent to 229 kg of P_2O_5 per ha). Chemical weed control with pre-emergent herbicide was used. In mid-September, when the rainy season started again, 200 kg of potassium per ha (equivalent to 240 kg of K_2O per ha) was applied between the rows of sugarcane. Assessments of dry matter

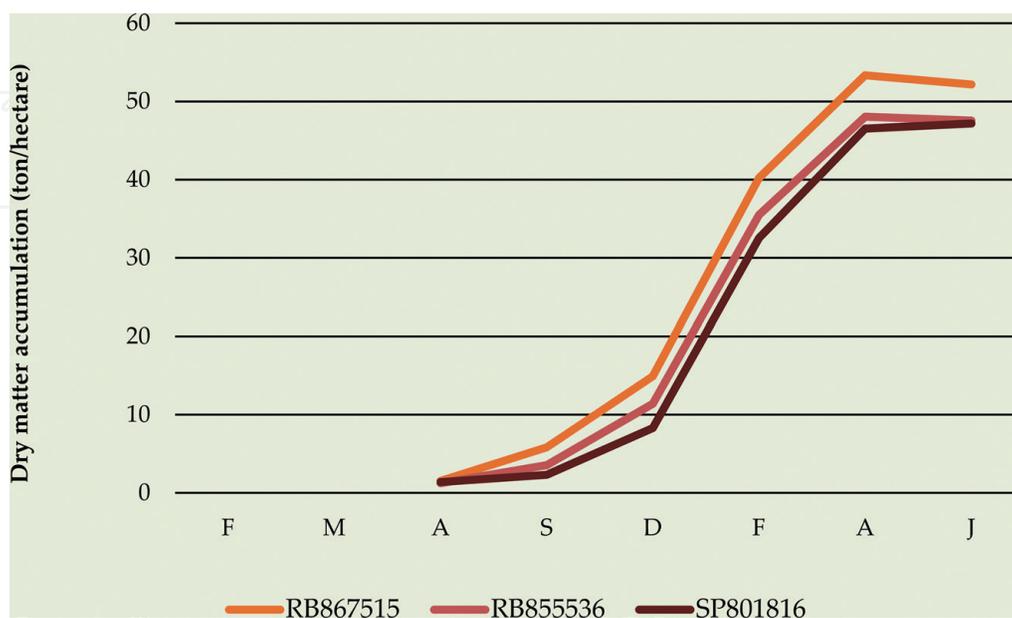


Figure 2. Dry matter accumulation rate in shoots of three sugarcane varieties planted in February and harvested in July of the following year. Study carried out in the city of Mercês, located in the Zona da Mata region. Source: Oliveira MW (unpublished data).

accumulation were held in April, September, and December of the year of planting of sugarcane and in February, April, and July of the following year. As shown in **Figure 2**, RB867515 produced about 5.0 t more dry matter than the other two varieties, which corresponds to approximately 15 t of forage per ha. The average percentage of culms in forage of these varieties is 85%. Thus, RB867515 produced 12 t of industrializable culms more than the other two varieties.

4. Implantation of sugarcane plantation

Similarly to South Central Brazil, the planting of sugarcane without irrigation in small farms of the Zona da Mata region is essentially done at the beginning of the rainy season (September and October) and at end of the rainy season (February to March). The sugarcane planted at the beginning of the rainy season can be harvested from April to May of the following year (known as “one-year sugarcane”). However, for sugarcane planted from February to March, the harvest will take place about 15–18 months after (known as “one-and-a-half-year sugarcane”).

The authors have recommended the planting of “one-year sugarcane” in more fertile soils with smoother and less erosive relief, because there is heavy rainfall during this period. Because sugarcane starts the maximum growth phase in January (when water and thermal availability begin to decrease), nutrient supply should not be a limiting factor to plant development. Therefore, biomass yields exceeding 120 t of natural matter per ha should be reached. However, planting “one-and-a-half-year sugarcane” has been recommended for the more rugged and less fertile soils, since sugarcane will continue to grow in the field for a longer period. Also, the maximum growth phase (**Figure 2**) coincides with the times of greater water and light availability, which results in higher vegetation cover by sugarcane foliage as well as in higher photosynthetic rate and dry matter accumulation. One other great advantage of planting the “one-and-a-half-year sugarcane” is the possibility of growing *Crotalaria juncea* prior to the planting of sugarcane.

5. Evaluation of soil fertility and lime and gypsum application

Sugarcane extracts and accumulates large amounts of nutrients from the soil because it produces large amounts of biomass. In evaluations carried out in small properties of the Zona da Mata region, the authors found that to produce 120 tons of natural matter per ha (about 100 t of industrializable culms), the accumulation of nutrients in shoots is approximately 150, 40, 180, 90, 50, and 40 kg of N, P, K, Ca, Mg, and S, respectively. In the case of iron, manganese, zinc, copper, and boron, accumulation in shoot biomass for a production of 120 t is around 8.0, 3.0, 0.6, 0.4, and, 0.3 kg, respectively [1]. Because of this high nutrient removal, it is necessary to know the nutrient supply capacity of the soil to complement it with fertilization if necessary. On the other hand, if toxic levels are found, the concentration of these elements is reduced by applying limestone and gypsum. The availability and presence of toxic levels of nutrients in soil are typically evaluated by chemical analysis of the topsoil. Knowledge of the history of the area is also of great value, especially fertilization and whether or not there were symptoms of deficiency or toxicity in previous crops.

Soil samples are typically collected at depths of 0–20 and 20–40 cm. The results of the analysis at 0–20 cm have been used to calculate the need for fertilization and liming, while those at 20–40 cm to calculate the need for gypsum. Because these are small areas, the authors have advised producers to collect soil samples using a hole

digger and straight shovel, as the use of a straight shovel decreases the variability of soil fertility indexes. Further details on sampling procedures, sample variability, sample drying, and comparison between chemical extractors can be found in Ref. [1]. As previously mentioned, most of the soils of the region are naturally acidic and present low saturation by basic cations such as calcium, magnesium, and potassium. Deficiency of these basic cations combined with high levels of aluminum, iron, and manganese has been detrimental to the growth of the root system and the entire plant. For these reasons, limestone and gypsum applications are recommended by the authors. Several materials have been used as soil acidity correctors, of which the most commonly used is dolomitic limestone. However, calcitic and magnesium limestone, as well as calcium and magnesium silicates (referred to as steel slags) are also used. Magnesium oxide content is around 8% in steel slag, while it is less than 5% in calcitic limestone, between 6 and 12% in magnesium limestone, and above 12% in dolomitic limestone. The efficiency of these products in correcting soil acidity depends on particle size, uniform distribution in the field, and soil water availability.

The most used soil analysis method in the region is the one that uses calcium acetate to determine $H^+ + Al^{+3}$. This extractor greatly underestimates the amount of $H^+ + Al^{+3}$, and results in underestimating the cation exchange capacity at pH 7.0 and the limestone dose. For these reasons, the authors have recommended raising the dose of limestone by 1.5–2.0 times. For sugarcane grown in small farms, the recommendation is to increase base saturation (V) to 60%. The limestone dose (LD) when using the base saturation method is calculated by the following equation (Eq. (1)):

$$LD (t ha^{-1}) = [(60-V) \times T] \div RTNP \quad (1)$$

where V is the current base saturation of the soil, T is the cation exchange capacity at pH 7.0, and RTNP is the relative total neutralizing power of the corrective used.

Dolomitic limestone is recommended when magnesium content at 0–20 cm is less than 0.40 $cmol_c/dm^3$ of soil. On the other hand, if magnesium content at 0–20 cm is greater than 0.40 $cmol_c/dm^3$ of soil, the recommendation is to use the corrective that has the lowest price per ton of RTNP in the crop. Thus, an economic factor is included in the decision making regarding the type of limestone to be used. The use of gypsum has been recommended based on the results of chemical analysis of the 20–40 cm layer. Gypsum has been applied when calcium content is less than 0.40 $cmol_c/dm^3$ of soil or aluminum saturation (m%) is higher than 20%. The usual recommended dose is one-third of the limestone dose (e.g., assuming that the limestone dose is 4.5 t per ha, then gypsum will be 1.5 t per ha). Limestone and gypsum are mixed for subsequent application to the soil. The application of gypsum will lead to the improvement of the root environment of the layers below the topsoil. This effect lasts for several years, which is the reason annual gypsum application is not necessary [1].

In small properties, the application of limestone + gypsum is typically done by hand. A recommended method for these small producers has been to delimit a square or rectangle with the mixture of limestone + gypsum and apply a volume corresponding to the recommended dose in the area. For instance, if the recommended dose was 6000 kg (4500 kg of limestone + 1500 kg of gypsum per ha) and the density of the limestone + gypsum mixture is 1.25 kg/L, then 4800 L per ha or 0.48 L per m^2 should be applied. Another alternative for small producers to apply limestone + gypsum by hand would be to demarcate areas of 25 m^2 with the mixture itself and apply 12.0 L of limestone + gypsum.

Plowing and harrowing is typically done after the application of limestone + gypsum to incorporate the products into the soil. In most small farms, subsoiling (decompacting soils or breaking compacted layers) has been recommended after

plowing and harrowing. This recommendation is based on the land use history of the area, the traffic of machines, implements and animals, the presence of crusts on the surface of the land, and the shallow root system of the natural vegetation. Although it may be an additional burden for the producer, the presence of densified or compacted layers has harmful consequences on water absorption, mineral nutrition, crop development, and longevity of the sugarcane plantation.

6. Green fertilization in “one-and-a-half-year sugarcane”

As previously mentioned in item 4 (implantation of sugarcane plantation), one of the advantages of planting the “one-and-a-half-year sugarcane” is the possibility of a green fertilization prior to the planting of sugarcane. Among the main desirable characteristics of plants used for green fertilization are the following: the possibility of using mechanization from sowing to the harvesting of seeds, the ability to associate with nitrogen-fixing bacteria, rapid growth to control weeds, having mechanisms, or being able to synthesize compounds that help control pests (e.g., nematodes) and diseases, no dormant seeds, and a vigorous and deep root system that assists in the recycling of nutrients from the deepest layers and in soil decompaction. Another aspect to be considered is the supply of organic and mineral substrate to soil microorganisms. Thus, green fertilization also contributes to the improvement of the biological quality of the soil [2–4]. Several legumes have these characteristics, but there is generally a preference for *Crotalaria juncea* in South Central Brazil [1].

In the studies conducted by the authors of this chapter in the Zona da Mata region, green fertilization with *Crotalaria juncea* prior to planting the “one-and-a-half-year sugarcane” resulted in increased yield in the plant-cane and first regrowth cycles, which together ranged from 20 to 26 t of culms per ha. In a multiyear analysis, the costs of green fertilization corresponded to 6–12 t of industrializable culms per ha. Thus, the increase in yields covered the costs of growing the legume. Furthermore, there are studies in which increased yields of sugarcane as a result of green fertilization with *Crotalaria juncea* were higher. For instance, in studies conducted over several years in the city of Sales Oliveira, state of São Paulo, Ref. [5] reported increased yields of industrializable culms ranging from 26 to 40 t per ha.

Crotalaria juncea exhibits high growth rates, which result in increased plant height, as shown in **Table 4**. High growth rate associated with increased plant

DAE	Plant height	LAI	DM accumulation	DM accumulation rate
	(cm)	m ² /m ²	(t/ha)	(kg/ha/day)
30	84	2.1	2.2	73
45	178	3.6	4.1	127
60	192	6.5	7.8	247
75	247	8.3	11.9	273
90	313	9.4	14.2	153
105	328	11.3	15.5	87
120	342	8.9	16.2	47

Table 4. Plant height, leaf area index (LAI), dry matter accumulation (DM accumulation), and dry matter accumulation rate (DM accumulation rate) in shoot biomass of *Crotalaria juncea* at 30, 45, 60, 75, 90, 105, and 120 days after plant emergence (DAE).

height causes shading of the soil and affects other plants, especially weeds. This is one of the reasons it is used in weed control [1, 4]. Cultural methods are practices that aim to make the crop more competitive than weeds and include reducing planting space, intercropping or rotation with green manure.

Ref. [6] reported excellent results with the use of *Crotalaria juncea*, with weed control percentages greater than 90% in areas with a predominance of grasses, competitive plants, and high nutritional and photosynthetic efficiency. These results were confirmed by Ref. [3], who found that *Crotalaria juncea* was outstanding in terms of soil cover. Plants covered 100% of the soil 50 days after emergence, contributing to the control of erosion and weeds. In addition to the physical effect of shading, *Crotalaria juncea* releases organic compounds from its secondary metabolism (allelopathic compounds), which inhibit weed seed germination or slow down its development [2, 5–7]. Field observations by the authors confirm this allelopathic effect on weeds, verified by the absence of weeds between the planting rows (**Figure 3**). The sowing of *Crotalaria juncea* was carried out in an area adjacent to *Brachiaria* pasture. Therefore, the seed bank of this area should be large.

Crotalaria juncea is extremely sensitive to the length of night (nictoperiod), flowering early under increasing long nights and hence interrupting growth and reducing dry matter accumulation and nutrient cycling, especially of nitrogen [1, 7].

Table 5 shows the accumulation of dry matter and nitrogen in shoot biomass of *Crotalaria juncea*, as well as plant height was statistically similar for the first three sowing times (beginning of October to beginning of November). For sowing times of mid-November, early and mid-December, there was an average percentage reduction in dry matter accumulation of around 20, 35, and 40% in comparison with the beginning of October.

These reductions were around 6, 13, and 24% for plant height in comparison with that of the first sowing times (**Table 5**). The study was conducted in a Latossolo vermelho amarelo distrófico, which exhibited the following chemical characteristics at 0–20 cm: pH in H₂O = 6.2; 6.0 mg/dm³ of phosphorus and 59 mg/dm³ of potassium, (extracted with Mehlich), no exchangeable aluminum and 45% of base saturation. *Crotalaria juncea* is very sensitive to aluminum toxicity and when the soil has exchangeable aluminum, liming should be done prior to sowing [1, 4].

Due to the sensitivity of *Crotalaria juncea* to nictoperiod, the delay in sowing results in early flowering. The authors of this chapter have observed in crops of *Crotalaria juncea* of the Zona da Mata region that plants are able to receive the stimulus for floral induction around 40 days after emergence. Thus, for sowing times



Figure 3. *Crotalaria juncea* at the early growth stage and its allelopathic effect on weeds confirmed by the absence of weeds between the planting rows (photo on the right).

Sowing times	DM accumulation		N accumulation		Plant height	
	(kg/ha)		(kg/ha)		(cm)	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Early October	14,135 a	14,789 a	273 a	284 a	293 a	305 a
Mid-October	14,768 a	14,845 a	297 a	275 a	311 a	298 a
Early November	14,235 a	13,785 a	268 a	279 a	287a	293 a
Mid-November	11,985 b	11,178 b	220 b	226 b	267 b	256 b
Early December	9,123 c	9,545 c	198 bc	203 c	247 c	236 c
Mid-December	8,523 d	8,037 d	174 c	168 d	217 d	208 d

Means followed by the same letter in the column do not differ statistically from one another other by the Tukey test at 5%.

Table 5.

Accumulation of dry matter (DM accumulation) and nitrogen (N accumulation) in shoot biomass of *Crotalaria juncea*, and plant height at the grain formation stage according to the sowing time in a study conducted during two agricultural years on a dystrophic red-yellow Latosol (Oxisol).

starting in mid-November, the nights will be increasing in length and early flowering will occur at around 40 days after emergence. The results of studies on sowing times carried out by the authors of this chapter and those found in literature allow us to conclude that to obtain high biomass production in shoots of *Crotalaria juncea*, the sowing of the legume in South Central Brazil should be done from the beginning from October to early November. The incorporation of *Crotalaria juncea* to the soil should be done when the first pods are in the phenological stage of grain filling, at which time the accumulation of dry matter and nitrogen in shoots is the highest [1, 4, 7].

The accumulation of nitrogen in the shoot biomass of *Crotalaria juncea* has also varied according to sowing time. **Table 5** shows that for sowing times from the beginning of October to the beginning of November, nitrogen accumulation in the shoot biomass of *Crotalaria juncea* oscillates around 300 kg/ha. Of the total nitrogen accumulated in the shoot biomass of *Crotalaria juncea*, about 60% originated from the symbiotic associations of the roots with N₂ fixing bacteria, resulting in the contribution of significant amounts of N to the soil-plant system [4, 8] and greater sustainability of the subsequent crop. For comparative purposes, let us consider ammonium sulfate, which is one of the most commonly used nitrogen fertilizers. In 100 kg of ammonium sulfate, there is 20 kg of N. Therefore, it would be necessary to use 1000 kg of ammonium sulfate to obtain 200 kg of N.

The inoculation of *Crotalaria juncea* seeds with nitrogen-fixing bacteria could be a way to increase N₂ biological fixation and nitrogen supply in the soil-plant system. However, research conducted by the authors of this chapter in small farms located in the Zona da Mata region and at sugarcane mills showed that the inoculation of *Crotalaria juncea* seeds with nitrogen-fixing bacteria did not increase N supply in the soil-plant system. Similar results were obtained at EMBRAPA Agrobiologia by Ref. [9], who also found that the inoculants used were not more efficient than the native strains. There was no difference in dry matter and nitrogen accumulation among the treatments with and without inoculation. One of the possible causes could be the high native population of these bacteria in the soils. However, as mentioned by Ref. [10], the fact that the legumes present high nodulation with native strains does not mean that those bacteria have maximum efficiency, since many of these strains have a high competitive capacity, making it difficult to introduce other strains through seed inoculation. Thus, the authors believe that until more efficient and competitive strains are obtained, the

inoculation of the seeds of *Crotalaria juncea* will not result in increased nitrogen biological fixation and accumulation by the plant.

7. Furrowing, fertilization, and planting of sugarcane

Furrowing the soil for the planting of sugarcane is done after plowing and harrowing the land for the incorporation of limestone and gypsum or, after the incorporation of *Crotalaria juncea* in “one-and-a-half-year sugarcane”. Furrowing is typically done with fertilizer furrowers that simultaneously open furrows and fertilize. When this implement is not available, it is possible to use a plow with moldboards or discs, using a single disc (straight furrowing if possible). Furrowing should be carried out as close as possible to the distribution of seedlings and planting rows to conserve soil moisture on dry days or avoid the silting of the furrows on rainy days. The spacing between furrows has varied from 0.90 to 1.40 m depending on the distance between the tires of the implement used in the crop fields, on topography, on soil fertility, and on the type of crop. In more fertile areas, wider spacing is used to prevent the sugarcane from tapering and future toppling by the wind. On the other hand, in soils with lower fertility, less fertilized, and on sloped relief, or when cultivars with lower tillering capacity are used, narrower spacing should be used to allow better spatial distribution of plants, more uniform soil cover and increased yields.

The recommended fertilization of the plant-cane is based on the results of the soil analysis at 0–20 cm and the expected yield of the sugarcane plantation. For plant-cane, only phosphate and potassium fertilization are recommended, because studies conducted by the authors of the chapter showed a lack of response to nitrogen fertilization. This low or absent response of the plant-cane to fertilization is widespread for soils grown with sugarcane in Brazil [4]. For the typically low fertile soils of the Zona da Mata region, the recommendation is 100 kg of phosphorus and 200 kg of potassium per ha (equivalent to 229 of P_2O_5 and 240 kg of K_2O per ha). If gypsum is applied to the soil, triple superphosphate should be used to reduce the planting costs, as it is less expensive. More information on fertilizer doses and soil fertility, as well as losses by leaching of both nitrogen and potassium can be found in Ref. [1].

The lack of response of the plant-cane to nitrogen fertilization is due to the mineralization of soil organic matter and the greater nutritional efficiency of the plant-cane root system, compared to the regrowth [1, 4]. Studies conducted by Ref. [11] in the coastal plains of Pernambuco (Northeast Brazil) provide more information regarding the mineralization of soil organic matter. These authors measured carbon and nitrogen mineralization in a Red Yellow Podzolic during the plant-cane cycle. The soil was sampled at 0–20, 20–40, and 40–60 cm prior to planting and 3, 6, 11, and 16 months after planting. Total carbon contents were 6.7, 4.1, and 3.4 $g\ kg^{-1}$, while total N contents were 0.7, 0.4, and 0.3 $g\ kg^{-1}$ at 0–20, 20–40, and 40–60 cm, respectively. The estimated amounts of potentially mineralizable N were 139 and 132 kg per ha at 0–20 and 20–60 cm, respectively, with a mineralization constant of 0.074 per week. Ref. [11] also report that although the soil is considered of low fertility based on the results, the amounts of mineralized organic N would be enough to satisfy the needs of the plant-cane.

Nitrogen uptake and metabolism are strongly influenced by the endogenous availability of phosphorus [1, 12, 13]. In plants with adequate P supply, there is an increase in nitrate uptake from the soil solution and greater nitrate translocation from roots to shoots, increasing the accumulation of amino acids in leaves and roots [4, 12, 14]. Ref. [4] reported research conducted in the state of Minas Gerais, in which the increase of the dose of phosphate fertilization applied in the planting furrow resulted in higher N accumulation in the biomass of the plant-cane. In this

case, for each kg of P applied, there was an increase of about 1 kg of N in biomass. These results are caused by changes in N uptake and metabolism, as reported by Refs. [1, 12, 14].

In relation to the planting of sugarcane, an average bud density of 12–15 per meter of furrow is recommended, which is approximately 12–14 t of seedlings per ha. As mentioned previously, one should select good quality sugarcane seedlings (preferably from healthy nurseries) and of first or second cutting at most. It is also important to confirm seedling health in terms of diseases, pests and mixture of other cultivars. The arrangement of the sugarcane within the furrow should preferably be upright with one culm next to the other. The culms are then cut into billets with two or three side branches, which are subsequently covered with soil layer ranging from 5.0 to 8.0 cm and should not exceed 10 cm in thickness. Then, the herbicide application for weed control typically follows the planting of sugarcane.

8. Weed control

Weeds compete with sugarcane during the growth phase for water, light, nutrients, and may exude phytotoxic compounds (allelopathy) and host pests and diseases [4, 15]. Sugarcane exhibits C₄ metabolism, which makes it relatively more competitive in CO₂ assimilation and nutrient use. However, several weeds are from the same family as is sugarcane and therefore have the same metabolism. At the time of harvest, the presence of weeds continues to cause damage, because when sugarcane is cut by hand and without previous burning, the presence of weeds decreases the workers' efficiency and makes them more vulnerable to snake and scorpion bites. The longevity of the sugarcane plantation also decreases when weed control is not effective. In most cases, keeping the crop free from competition with weeds until the vegetation closes the spacing between the rows ensures the harvest of sugarcane without the presence of weeds.

There are several techniques used for weed management. However, the combined use of cultural, mechanical, and chemical methods is the most common [4, 15]. Cultural methods are practices that aim to make sugarcane crop more competitive in relation to weeds and include reducing planting space, intercropping or crop rotation with soybean, peanut, corn, and green manure, as well as the use of high-tillering varieties for faster shading of the soil [4, 15]. In research conducted by the authors in areas heavily infested with *Brachiaria*, the sowing of *Crotalaria juncea* at the time of the renewal of the sugarcane plantation had a great suppressive effect (due to shading) and reduced the number of seeds produced by the grass.

Plows and harrows are used in the mechanical control during the renewal of the sugarcane plantation. This method is highly efficient, but depends on soil moisture, solar radiation and the predominant species in the area. For weed control between the rows of sugarcane, animal traction plows can be used. Manual weeding, once used, has now been restricted to experimental areas. Mechanical cultivation has limitations, especially because it does not control the weeds of crop rows. Its efficiency in controlling weeds between crop rows may also be greatly reduced depending on the climatic conditions and species, such as some grasses of the *Brachiaria* genus, which reproduce vegetatively. The chemical method has been the most used by small producers (**Figure 4**), with herbicides being used in preemergence or postemergence of weeds and with those in early or developed stages (**Table 6**).

Below are some considerations about herbicides commonly used in sugarcane cultivation.



Figure 4.
The use of herbicides to maintain the crop free from weed competition until the space between rows is closed generally guarantees sugarcane harvest without the presence of weeds.

Ametryn: recommended in pre- or early postemergence application, alone or mixed with other herbicides (diuron, 2,4-D, Tebuthiuron, Clomazone, Monosodium methyl arsenate (MSMA), and others). This herbicide causes little toxicity to the sugarcane crop. The effective control period or residual effect is about 70–100 days. It is effective in controlling *Digitaria horizontalis*, *Brachiaria plantaginea*, *Eleusine indica*, *Portulaca oleracea*, *Amaranthus spp*, *Bidens pilosa* and *Acanthospermum hispidum*. Doses vary from 3.0 to 5.0 L/ha. The smaller doses are recommended for lighter soils or application in moist soil, while higher doses should be used in heavy soils or application in dry soils.

2,4-D: recommended for post-emergence application, alone or mixed with other herbicides (Diuron, MSMA, Tebuthiuron, Ametryn, and others). The effective control period is 25–40 days. It is effective only in the control of dicotyledons. Doses vary from 0.8 to 1.5 l per ha.

Diuron: Recommended in pre- or early postemergence application, alone or mixed with other herbicides (2,4-D, Tebuthiuron, MSMA, and others). It has a residual effect of 150 to 180 days. It is effective in the control of *Digitaria horizontalis*, *Brachiaria plantaginea*, *Eleusine indica*, *Portulaca oleracea*, *Amaranthus spp*, *Bidens pilosa*, *Bidens pilosa* and *Acanthospermum hispidum*. Doses range from 1.8 L/ha (Diuron 500) to 3.2 L/ha (Karmex GRDA).

Diuron + Hexazinone: sold under the names Advance and Velpar K. Advance is mostly used in plant-cane and Velpar K in regrowth. Both are applied in pre- or early postemergence in moist soil. They may cause toxicity to the crop, especially in sandy soils and in conditions of high moisture content. It has broad spectrum of control and residual effect of 90–120 days. It is efficient in controlling *Panicum maximum* jacq. Cv.Colonião, this is a very present and competitive species in the cultivation of sugar cane. The doses of Advance and Velpar K vary from 2.2 to 2.8 and 1.5 to 2.7 kg/ha, respectively.

Action mechanism	Application time	Herbicide (Brand)
<i>Membrane disrupters</i>		
Oxyfluorfen	Pre- or postemergence	Goal
Sulfentrazone	Preemergence	Boral and Solara
<i>Inhibitors of photosynthesis</i>		
Ametryn	Pre- or postemergence	Ametryn, Gesapax, Herbipax, and Metrimex
Atrazine	Pre- or post-emergence	Atrazinex, Gesaprim, Atrazine, and Nortox
Atrazine + Simazine	Pre- or postemergence	Extrazin, Triamex, Primatop, and Herbimix
Diuron	Pre- or postemergence	Karmex, Diuron Nortox
Ametryn + Diuron	Pre- or postemergence	Ametron
Hexazinone + Diuron	Pre- or postemergence	Velpar K and Advance
Metribuzin	Pre- or postemergence	Sencor
Simazine	Preemergence	Gesatop
Tebuthiuron	Preemergence	Combine, Tebuthiuron
<i>Inhibitors of mitosis and early growth</i>		
Alachlor	Preemergence	Laço
Pendimethalin	Preemergence	Herbadox
Trifluralin	Preemergence	Trifluralina Nortox, Treflan, and Premerlin
<i>Inhibitor of respiration</i>		
MSMA	Postemergence	Daconate, Dessecan
<i>Inhibitors of amino acid synthesis</i>		
Flazasulfuron	Pre- or postemergence	Katana
Glyphosate	Postemergence	Glifosato, Roundup, and Trop
Halosulfuron	Postemergence	Sempre
Imazapic	Pre- or postemergence	Plateau
Imazapyr	Pre- or postemergence	Arsenal, Contain e Chopper
Trifloxysulfuron + Ametryn	Postemergence	Krismar
<i>Inhibitors of pigment synthesis</i>		
Clomazone	Preemergence	Gamit
Isoxaflutole	Preemergence	Provence
Clomazone + Ametryn	Preemergence	Sinerge, Ranger
<i>Growth regulators</i>		
2,4-D	Pre- or postemergence	DMA
Dicamba	Pre- or postemergence	Banvel 480
Picloram +2,4-D	Pre- or postemergence	Dontor

Table 6.
 Main herbicides used in sugarcane and application times in relation to weed emergence.

MSMA: recommended for late postemergence in direct spray application. It causes high toxicity to the sugarcane crop. It has been widely used in mixtures with other herbicides (Diuron, 2,4-D, Tebuthiuron, Ametryn, Velpar K, and others). It is effective in the control of several annual and perennial grasses, as well as nutsedge when it has about 4–8 leaves. Doses of 0.5–0.87 L/ha are recommended for MSMA 790.

Tebuthiuron: recommended for preemergence, including application to dry soils. It is not efficient in postemergence application. It persists in soil for a longer period, with residual effect of 12–15 months. It should not be used in areas intended for future renewal of the sugarcane plantation and should use crop rotation with soybean, peanut, and bean. It has a broad spectrum of control, and it is efficient in controlling several dicotyledons and grasses, including *Panicum maximum* Jacq. Cv. Colônia, but not efficient for *Digitaria horizontalis*.

9. Chemical and organic fertilization of regrowth

The fertilization of the regrowth of sugarcane recommended for small farmers is based on the recovery of nitrogen and potassium removed by harvesting the previous cut. In one ton of natural matter of sugarcane biomass (industrializable culms + dry leaves + green leaves + buds), there is 850 kg of industrializable culms on average. Thus, the average index of industrializable culms in biomass is 0.85. For each ton of sugarcane biomass exported from the plantation, 1.2 kg of nitrogen and 1.5 kg of potassium are removed [1, 4]. Assuming that the yield of the plant-cane was 150 t of biomass (about 120 t of industrializable culms), the application of 180 kg of nitrogen and 225 kg of potassium is recommended. There is no need to split fertilization for fear of leaching losses of both nitrogen and potassium [1].

If sugarcane has been harvested for animal feed, the amount of dry leaves on the soil is small. Thus, burying the fertilizer between the crop rows is recommended. Urea can be used as the source of nitrogen in this case. If the fertilizer cannot be buried between the crop rows, ammoniacal or nitric sources should be used to fertilize the regrowth, because volatilization losses are very high when urea is applied over the straw. More detailed information on losses by volatilization and quantification of potassium in the profile of soil grown with sugarcane can be found in Ref. [1].

The application of the fertilizer in regrowth using a walk-behind spreader has been traditional in small properties. It is of low cost and precise, which greatly increases the workers' efficiency. A worker using a spreader covers more than 2.0 ha per day. The use of dairy cattle manure to fertilize sugarcane is a way to reduce production costs, recycle nutrients, and improve soil physical, chemical and biological properties. The efficiency of dairy cattle manure in the mineral nutrition of sugarcane depends on the chemical composition of the waste, the dose and environmental factors, especially temperature and soil moisture. The chemical analysis of cattle manure allows us to calculate the amounts that should be applied to the soil to restore the nutrients removed by harvesting. **Table 7** shows the results of the chemical analysis of manure of dairy cattle fed with different roughage and amounts of concentrated feed. In harvesting 150 tons of forage (culms + side branches + leaves), 150, 45, and 225 kg of N, P, and K, respectively, were removed. The K/N ratio of forage is 1.5, which is much higher than that of cattle manure. Thus, if the sugarcane plantation is fertilized with cattle manure, it is necessary to supplement fertilization with potassium to replace nutrients removed with the harvest.

Poultry litter is another alternative for the organic fertilization of sugarcane. In recent years, this waste has had its demand and price reduced because of a ban on its use in cattle feed. The concentration of nutrients in poultry litter is influenced by the bedding material. Most poultry farmers of the Zona da Mata region use rice husk, coffee husk, napier grass, shavings, and corn cobs. **Table 8** shows the nutrient contents of five poultry litters composed of different bedding materials collected after being used in a batch of broilers (48 days on average), at a density of 15 birds/m².

The authors evaluated the maturation and broth quality of the sugarcane variety RB867515, which were influenced by the fertilization with poultry litter. The study

Feed	Concentrad feed (kg/cow/day)	% de DM in manure	N	P	K	Ca	M	S	K/N ratio
.----- g/kg of manure dry matter-----.									
Pasture	9.0	14.1	19.4	14.4	12.0	13.9	7.1	3.5	0,62
Corn silage	8.0	13.9	23.6	10.0	10.4	10.5	5.1	3.1	0,44
Corn silage	10.0	11.7	21.1	10.9	11.2	11.6	4.5	3.4	0,53
Corn silage	12.0	12.9	24.1	11.2	11.7	12.3	4.6	3.6	0,48
Average		13.1	22.0	11.6	11.3	12.0	5.3	13.6	0.52

Table 7. Percentage of dry matter in dairy cattle manure (% DM in manure) and nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) contents in manure of dairy cows fed with different roughage and quantities of concentrated feed.

Poultry litter	N	P	K	Ca	Mg	S
.----- g/kg of DM-----.						
Rice husk	34.7 a	15.9 b	26.8 b	25.7 a	6.2 a	16 ab
Coffee husk	32.8 a	14.4 b	28.9 ab	25.0 a	5.5 b	15 b
Napier grass	34.8 a	15.1 b	23.3 c	25.5 a	6.0 a	15 b
Wood shavings	30.9 a	13.7 b	24.4 c	25.8 a	5.7 b	14 b
Corn cob	34.2 a	18.6 a	29.7 a	28.3 a	6.7 a	18 a
Average	33.5	15.5	26.6	26.1	6.0	15.0
CV (%)	10.6	12.2	10.0	6.6	8.2	10.1

Means followed by the same letter in the column do not differ statistically from one another by the Tukey test at 5%. Source: Ref. [16].

Table 8. Nutrients in dry matter (g/kg of DM) of poultry litter in which five different materials were used for bedding.

was conducted in three agricultural years: first, second, and third regrowth. The experiment was a randomized complete block design with four replicates. The treatments consisted of fertilization with three doses of poultry litter 7; 10 and 13 t of poultry litter dry matter/ha/yr), in addition to a control treatment (no chemical or organic fertilization), and chemical fertilization (180 kg N + 225 kg K/ha/yr). Sugarcane was harvested in early August in all 3 years. Fertilization of sugarcane with poultry litter did not interfere with maturation, nor did it affect broth quality, even at high doses. The difference in broth quality from 1 year to another was small. The average of the 3 years for soluble solid content, sucrose in the broth and broth purity were 22, 19, and 86%, respectively. Thus, the use of poultry litter as an organic fertilizer is an alternative to chemical fertilization. Also, just as cattle manure, it should be supplemented with potassium, because the average K/N ration in poultry litter is 0.80.

10. Final considerations

The technologies recommended to the small farmers for the implantation and management of sugarcane plantations have resulted in high yields in the plant-cane

cycle with small decreases in the subsequent cycles. Furthermore, the techniques proposed by the authors maximized the use of inputs, land, and human resources, thus reducing the operating costs.

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Author details

Mauro Wagner de Oliveira¹, Luís Cláudio Inácio da Silveira²,
Alexandre Bosco de Oliveira^{3*}, Márcio Henrique Pereira Barbosa²,
Manoel Gomes Pereira⁴ and Terezinha Bezerra Albino Oliveira¹

1 Federal University of Alagoas, Rio Largo, Brazil

2 Federal University of Viçosa, Viçosa, Brazil

3 Federal University of Ceará, Fortaleza, Brazil

4 Research and Development Sector, Triunfo Mill, Boca da Mata, Brazil

*Address all correspondence to: aleufc@gmail.com

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