1st. Brazil-US Short Course in Biofuels - 2009

IAC
INSTITUTO AGRONÔMICO

Feedstock Production
Sugarcane

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BIOEN
FAPESP

Contents

- **Overview of sugarcane cultivation**
- **Cultivation practices**
- **Pests and Diseases**
- **Breeding**
- **Best practices/Environment**

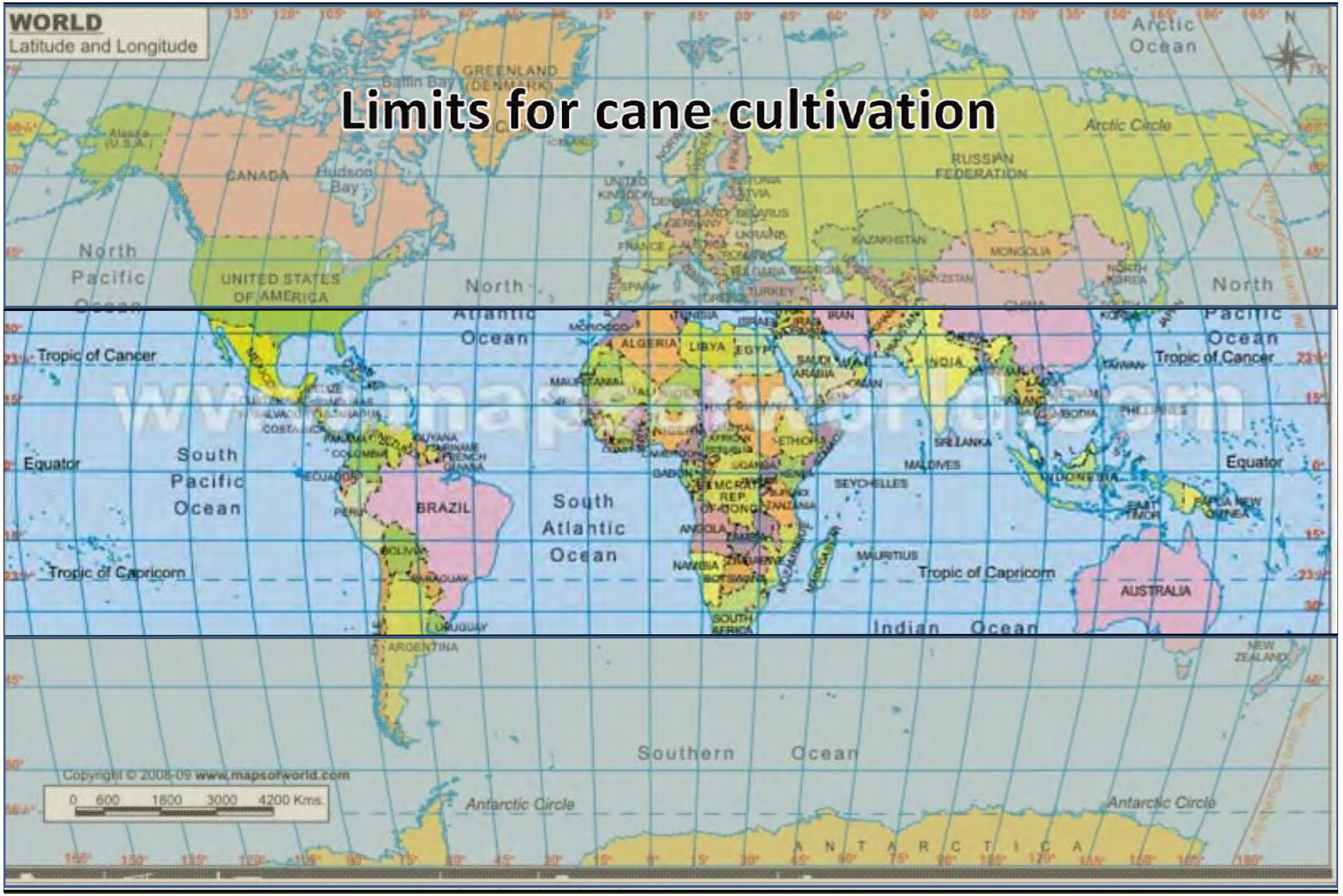
Sugarcane

- **Tropical grass of Poacea family**
- ***Saccharum* genus:**
- ***S. officinarum* known in India since 6000 BC**
- **Modern cultivars: hybrids of several species**
  - ***S. officinarum***
  - ***S. spontaneum***
  - ***S. robustum***
  - ***S. sinnensis***
  - ***S. barbery***

Sugarcane

- **Grown > 100 countries**
- **Parallels 35N e 35S**
- **22 million ha**
  - **0.45% World land**
  - **1.6% of arable land**

- **Temperatures:**
  - **Optimum T: 30 – 34°C**
  - **Growth reduced < 21°C**
  - **Leaf death < 2.5°C**
  - **Buds death -1 to -6°C**


WORLD
Latitude and Longitude
Limits for cane cultivation
Arctic Ocean
Arctic Circle
GREENLAND (DENMARK)
Baffin Bay
Alaska (U.S.A.)
CANADA
Hudson Bay
RUSSIAN FEDERATION
North Pacific Ocean
UNITED STATES OF AMERICA
North Atlantic Ocean
KAZAKHSTAN
MONGOLIA
North Pacific Ocean
Tropic of Cancer
Equator
South Pacific Ocean
BRAZIL
South Atlantic Ocean
Tropic of Capricorn
INDIA
SRI LANKA
MALDIVES
SEYCHELLES
MAURITIUS
AUSTRALIA
Indian Ocean
ARGENTINA
Southern Ocean
Antarctic Circle
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0 600 1800 3000 4200 Kms.

World Top Sugarcane Producers
(among more than 100 countries)

Country	Cane Production		Harvested area	Average Yield
	1987	2007		
	------- Mt----------		1,000 ha	t/ha
Brazil	268.5	514.1	6,712	76.6
India	186.1	355.5	4,900	72.6
China	52.8	106.3	1,236	86.1
World	**990.3**	**1,557.7**	**21,977**	**70.9**

BR, India and China: 63% of world production
Production increased 57% in last 20 years
BR: 33% of world production in 2% of Brazilian arable land

Source: Faostat, 2009

Research in sugarcane in Brazil in the beginning of the XX Century

Fertilizer study of Aguirre, de 1938. Foto: IAC

Sugarcane products

- **Sucrose**
  - **4th source of calories in human diet**
    - **After rice, wheat, and maize**
  - **Main product of sugarcane industry in most countries**
- **Ethanol [Fuel and Chemical]**
  - **BR: 57% of cane in BR in 2009/2010 for ethanol**
    - **27 billion L**
    - **Almost 35,000 gas stations carry E-100**
- **Animal feed**
- **Energy [vapor power, electricity]**
- **Chemicals, plastics, polymers etc**
- **Cachaça**

Sugarcane plant

- **Semi-perennial grass**
- **Long stems germinate from rhyzomes or stools**
- **Cylindrical stalks 2 – 5 m accumulate sugar in the internodes**
  - **1st. Cycle: 12 – 18 month**
  - **Regrowth (ratoon): 3 to 8 (average 4) cut after ~12 months**

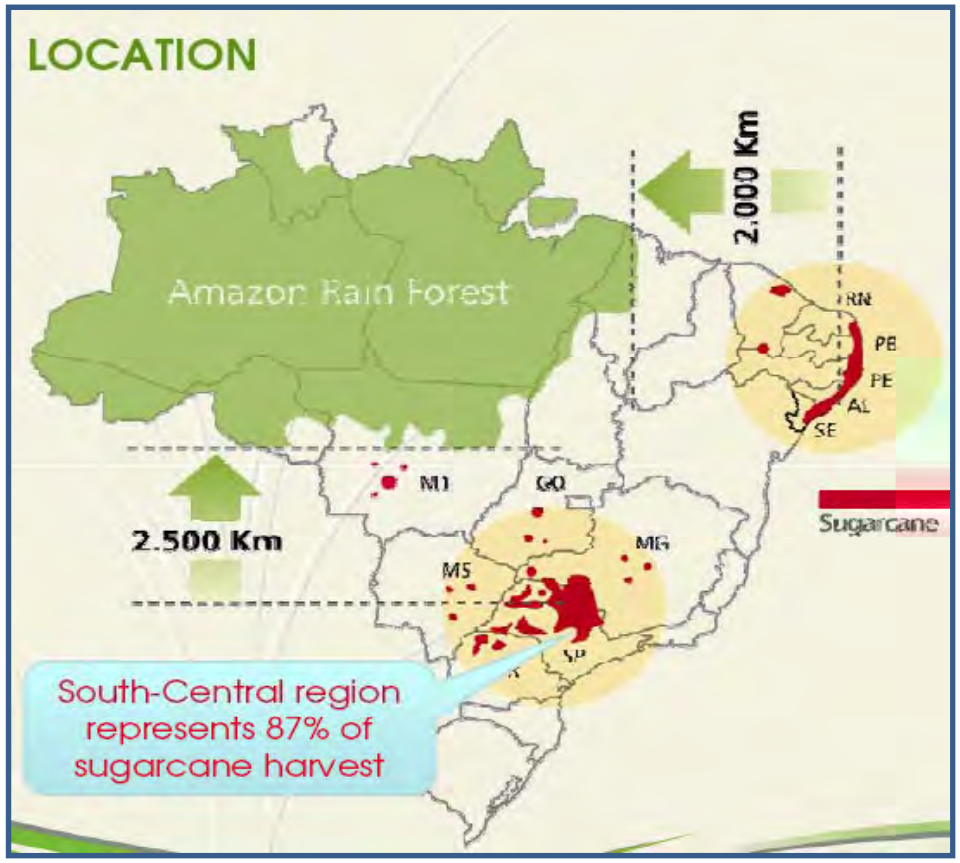
Sugarcane plant

- **C-4 type of photosynthesis**
  - **Very efficient at high T**
- **Probably the most efficient plant for biomass production**
  - **World average: 70.9 t/ha**
    - **BR: 70-75 t/ha Northeast**
    - **80-85 t/ha Southeast**
      - **First cycle (cane-crop): 120 – 200 t/ha rainfed**
  - **Theoretical yield: 285 – 470 t ha^{-1} yr^{-1}**

Sugarcane plant irrigated and fertilized to show potential of variety

Sugarcane yielding 346 t/ha at IAC

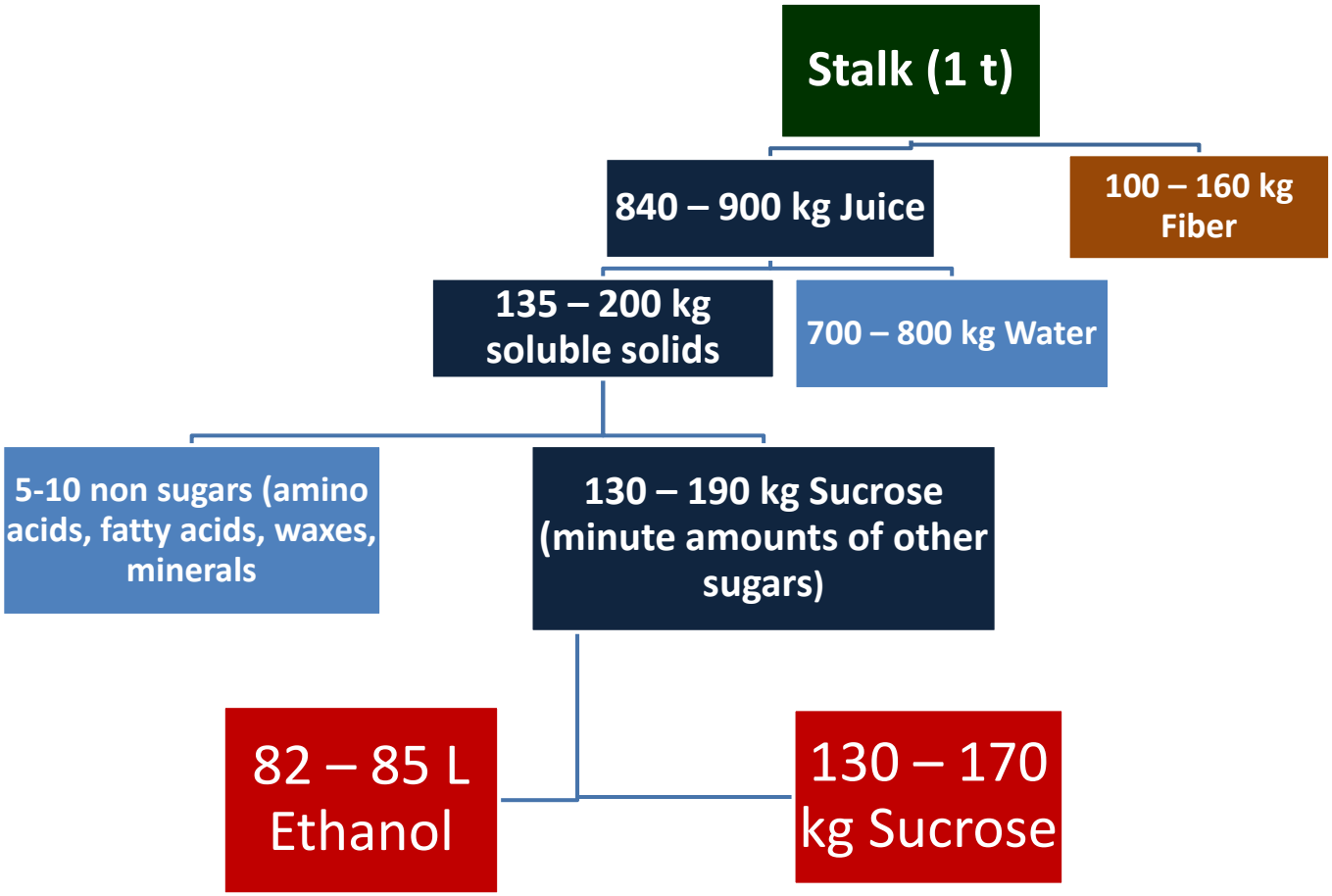
Sugarcane in Brazil



- **Sucrose accumulation: triggered by drought or low T (< 20°C)**
  - **Sucrose accumulation related to flowering (undesiderable trait in commercial varieties)**
- **Florewing optimum: T: 18 to 31°C & ∆T: 10°C**
  - **But combination of high intensity of both stresses [∆T > 14°C + drought] retard or prevent flowering**
- **Southeastern BR: favorable (but not Amazon)**

Map: Unica

Sugarcane stalk composition



Sugarcane numbers in Brazil

- **2008: 7 million ha**
- **Cane production: 601 million t**
  - **57% for ethanol and 43% for sucrose**
- **Ethanol: 27.7 billion L**
- **420 mills**
  - **248: sucrose + ethanol**
  - **157 exclusive for ethanol**

Sugarcane crop production

- **Plowing & Furrowing**
- **Fertilizer (mineral and organic) and lime**
- **Planting**
- **Cane seed (vegetative propagation)**
  - **8 – 10 t/ha stalks (12 to 18 buds/m)**

Sugarcane crop production

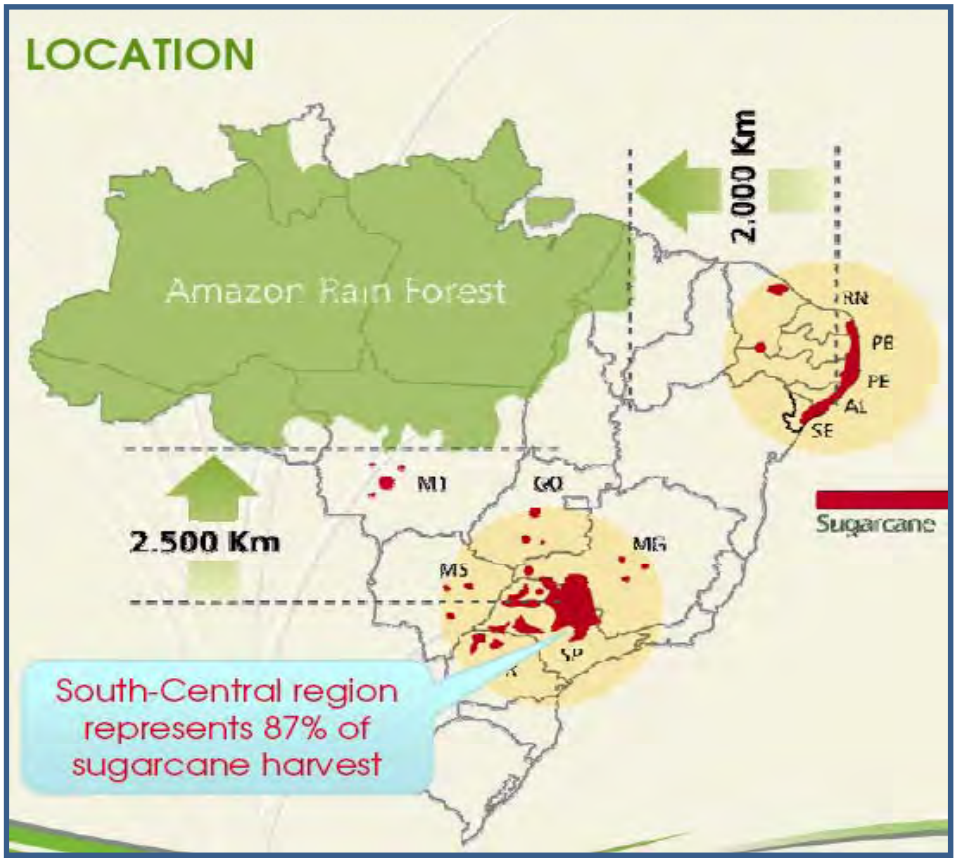
Chemical control of soil insects (including termites)

Other mechanized operations include weed control, furrow mound levelling etc.

Small stalk cuttings used as seeds
(Technology under development)

Sugarcane crop production

- **Southeastern BR: > 1100 mm rain**
  - **Rainfed**
  - **“Salvation” irrigation to ensure germintion in dry periods**
  - **Irrigation is option for higher yields**
- **Northeastern BR: irregular ou insufficient rain**
  - **Part of the area is irrigated**



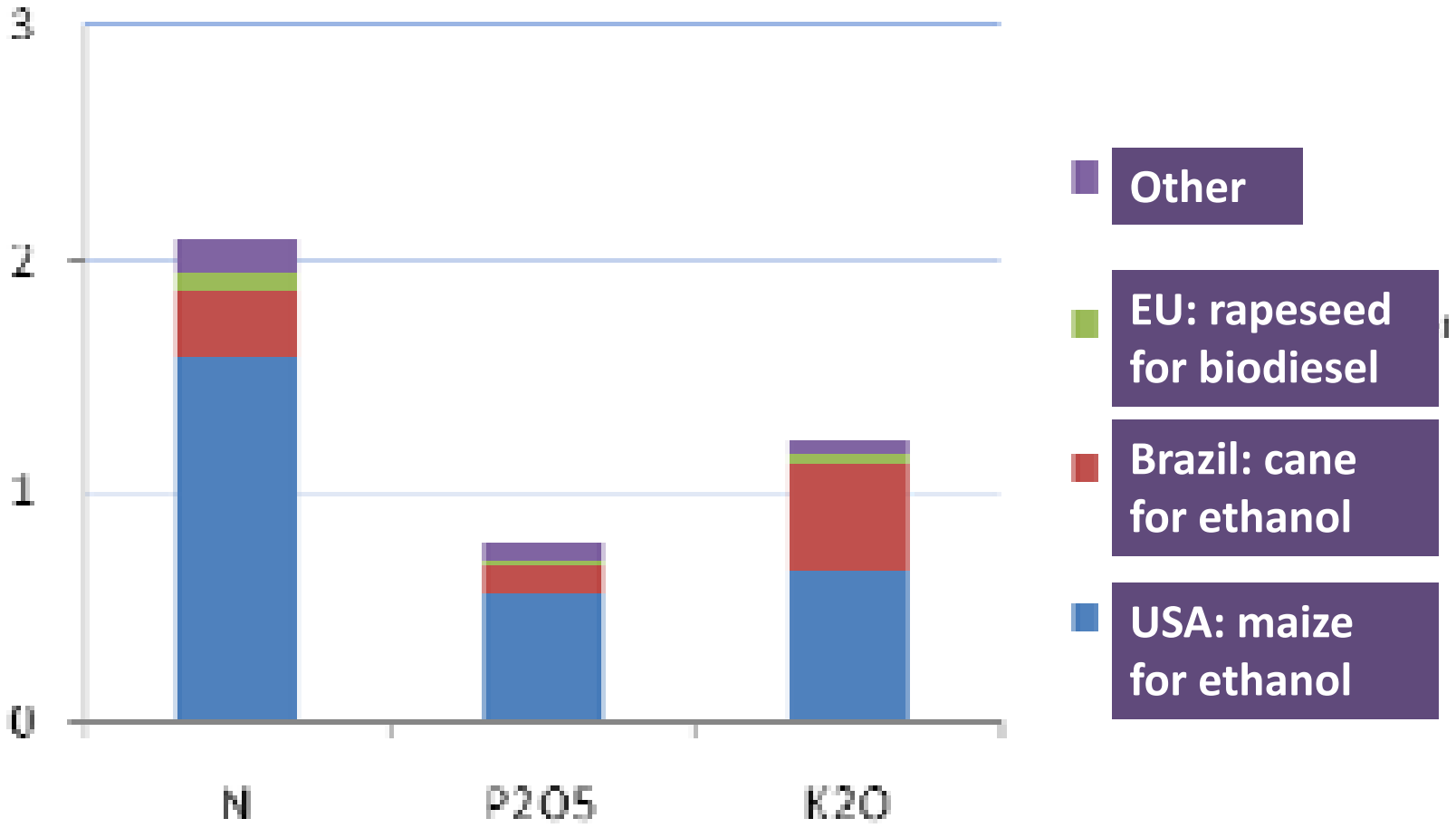
Fertilizer used for sugarcane production in Brazil (2006/07)

	Fertilizer mass (mil t)	Percent of fertilizer used in Brazil
N	535	23,3
P_2O_5	274	8,7
K_2O	713	20,6
Total	1.522	17,1

Figures refer to sugarcane for sucrose and ethanol

Source: Heffer & Prud'homme. IFA 2008

Estimates of global fertilizer use on biofuel crops in 2007/08 (Mt nutrients)



Total: 4.1 Mt nutrients (2.4% of world consumption)

Source: Heffer & Prud'homme, 2008

Estimate fertilizers used for biofuel crops 2007/2008 (Million t N, P_2O_5, K_2O).

Data from BR and USA are for ethanol

Fertilizer consumption	World	Brazil (Cane)	EUA (Corn)
N	2,1	0,32	1,57
P_2O_5	0,8	0,16	0,58
K_2O	1,2	0,43	0,65
Total	4,1	0,91	2,80
Ethanol Production (billion L)		22,5	24,7

Source: Heffer & Prud'homme. IFA 2008

Liming and Fertilization

- **Sugarcane is relatively tolerant to soil acidity and efficient to use soil nutrients:**
  - **Liming soil pH < 5.5**

Nutrient export	kg/100 t cane
N	100 – 150
P_2O_5	15 – 25
K_2O	100 – 250
S	15 - 49

Fertilizer used	Plant cane	Ratoon
	kg/ ha	
N	30 – 60	60 – 140
P_2O_5	30 – 150	0 – 40
K_2O	30 - 150	30 - 150

Liming and Fertilization

- **Fertilizer use in sugarcane in Brazil:**
  - **Average 408 kg/ha NPK**
  - **Similar to most grain crops but DM yield is much higher with sugarcane**

Cane yield	~ 80 t/ha	35 t/ha DM
Grain	3 – 10 t/ha	< 10 t/ha DM

Sugarcane uses 17% of the mineral fertilizer in Brazil

Sugarcane plant cycle

Cycle varies from 4 to 10 years

	Cuttings	Harvest (months)	Yield (t/ha)
Plant (1st)	1	12 – 18	90 - > 150
Ratoons	3 to 8 (4)	10 – 12	60 - 130

Ratoon crop

- **Replant when yields fall bellow a baseline for specific field or variety (usually 50 to 70 t/ha)**

Harvesting

- **Maturation and harvest: in Fall and Winter (Apr - Nov in Southeastern Brazil)**

HARVEST

- **Manual: Burn & Cut**
- **Mechanized: usually unburned (green cane)**
  - **Law restriction to burning in parts of BR. In SP prohibition after 2014-2017**
  - **Mechanical harvesting in already about 40% of the area**
    - **90% in some mills in SP and in new expansion areas in Central Brazil**

Questions involved: labor replacement X environmental and economic problems

Traditional Burn and Cut

Air pollution
Nutrient losses (N, S)
Biomass loss
Soil left with little crop residue

Harvest: labor intensive operation

Green cane & mechanical harvest

Plant residues preserved (9 to 15 t/ha DM)
Soil and water protection: increase soil OM
Nutrient conservation, higher soil moisture
Yield increases
Trash may be used for 2nd generation biofuel

Lay off labor
Plant germination
Increase of some pests and diseases
Difficult to incorporate fertilizer
Risk of fire

Crop rotation

- **Before replanting (after 5-8 yr cycle)**
  - **1 million ha/yr is replanted in Br**
  - **Green manure**
  - **Soybean/Peanut (for grain)**
    - **OM incorporation to soil**
    - **Pest and disease control**

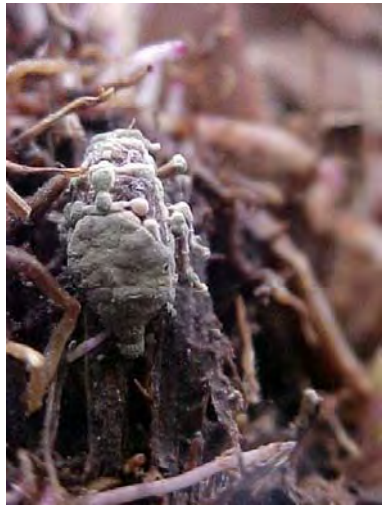
Pests and Diseases

- **Sugar borer (*Diatrae saccaralis*)**
  - **Open holes in cane: yield and quality**
    - **Biological control (*Cotesia flavipes*, *Lydella mimeuse* etc)**
- **Spitlebug (*Mahanarva fimbriolata*)**
  - **Important in green cane**
    - **Control: mechanical destruction/burning of stubbles**
    - **Biological: *Metarhizium anisoplia***

Biological control

Sugar borer controlled by Cotesia

Spitlebug attacked by *Metarhizium*

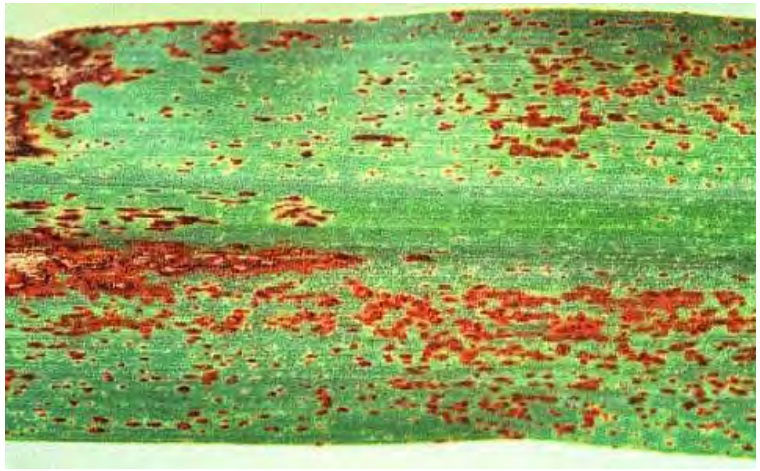


Soil pests

Migdolus, Sphenophorus levis, termites and nematodes require chemical control and or management practices (burn stools, crop rotation)

Fungus and virus diseases

Smut (*Ustilago scimatinea*)



Rust (*Puccina melanocephala*)

Mosaic virus

Sugarcane diseases are dealt with resistant varieties and management practices (nursery survey, heat treatment etc)

Bacterial diseases

Ratoon stunting (*Leifsonia xyli*)

Leaf scald (*Xanthomonas albilineans)*

Use of resistant varieties is the main form of control

Sugarcane is seldom sprayed for diseases

Variety management

- **Sugarcane growers usually cultivate more than 15 varieties:**
  - **Decrease risks of loss of resistance to pests/diseases**
  - **Benefit from maturation/harvest periods**
  - **Benefit from adaptation to soil/climate**

Plant breeding

- **Commercial varieties are hybrids of several species**
  - **Complex inter-specific hybrids with 100 – 130 chromosomes**
- **Cultivars usually are replaced at the most after 15 years**
  - **Genetic erosion, loss of quality, loss of resistance to diseases, yield and quality improvement**

Plant breeding

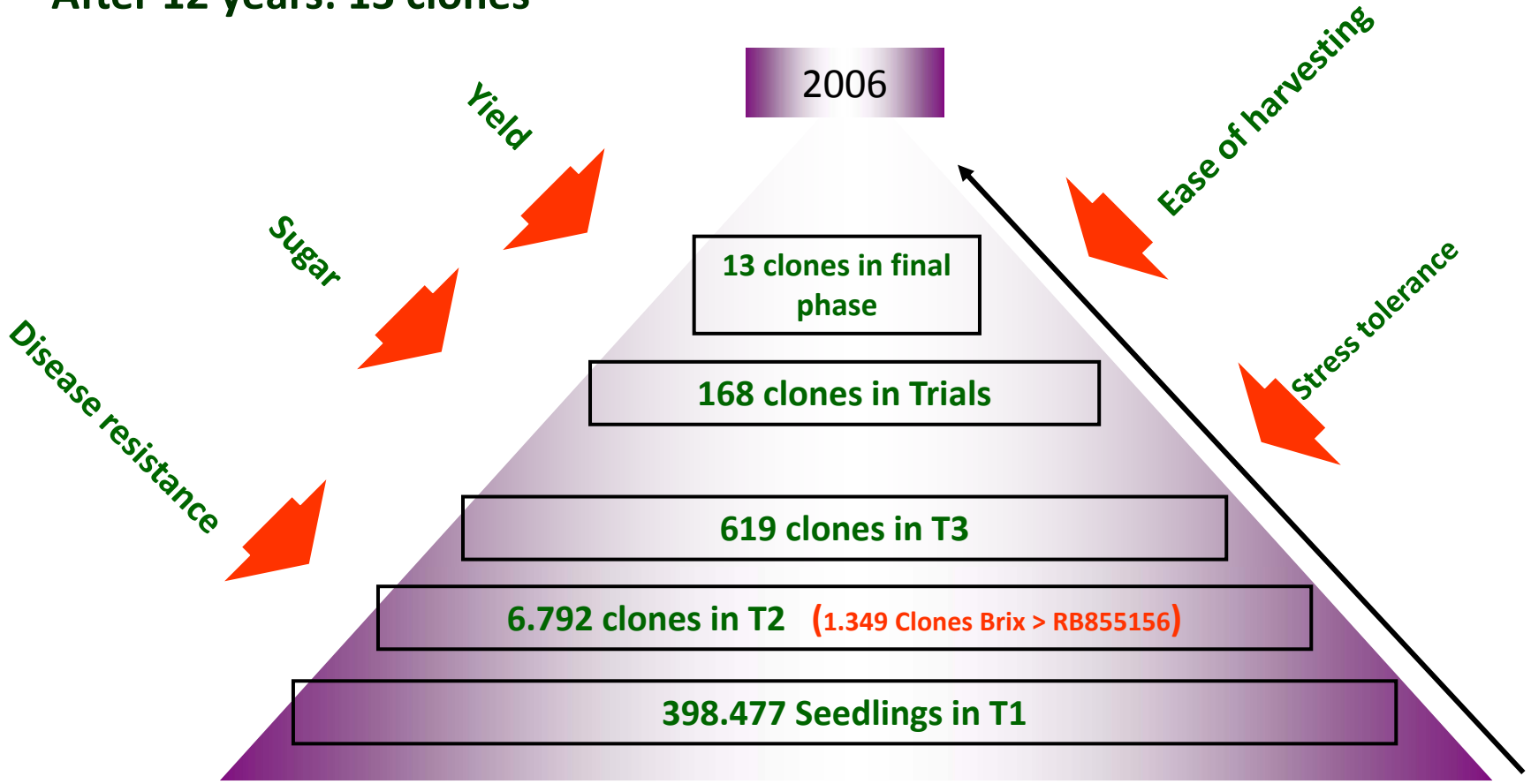
- **4 main breeding programs in Brazil**
  - **Ridesa (1971)**
  - **CTC (1968)**
  - **IAC (1932)**
  - **Canavialis (2003)**

Traditional crossing systems

Traditional method: 12 years to produce new varieties
Example of a Ridesa crossing

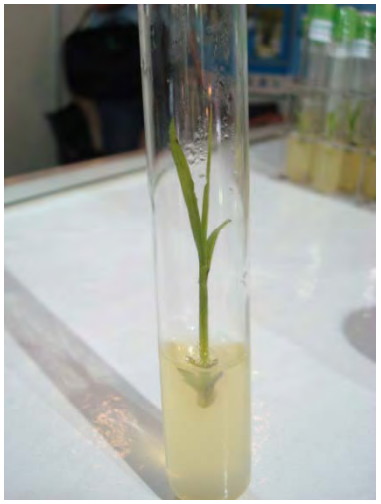
Beginning: 400,000 genotypes

After 12 years: 13 clones



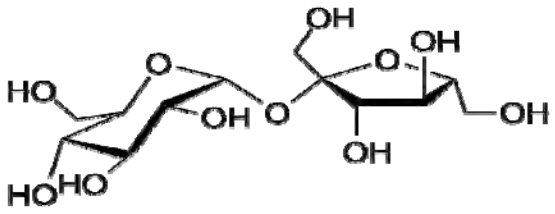
Sugarcane breeding

- **Improved tools to speed up release of new varieties**
  - **Genetic maps**
  - **Molecular markers**
  - **Transgenics**
    - **Allow to target desirable traits (disease resistance, sugar content, drought tolerance, DM yield, agronomic quality etc)**
    - **Transgene expression is unstable. No GM cultivar released for trade –**
- **Molecular biology and biotechnology have great potential**

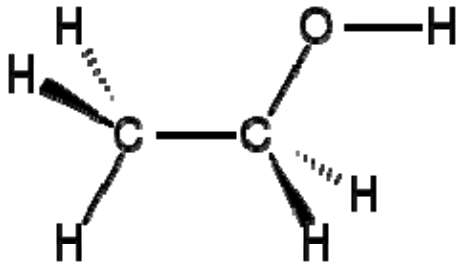


Sugarcane best practices/Environment

- **Recycling of residues**
  - **Main products of sugarcane processing carry only C, H, and O**
  - **Mineral contents of sugarcane can be reclyced back to the field**

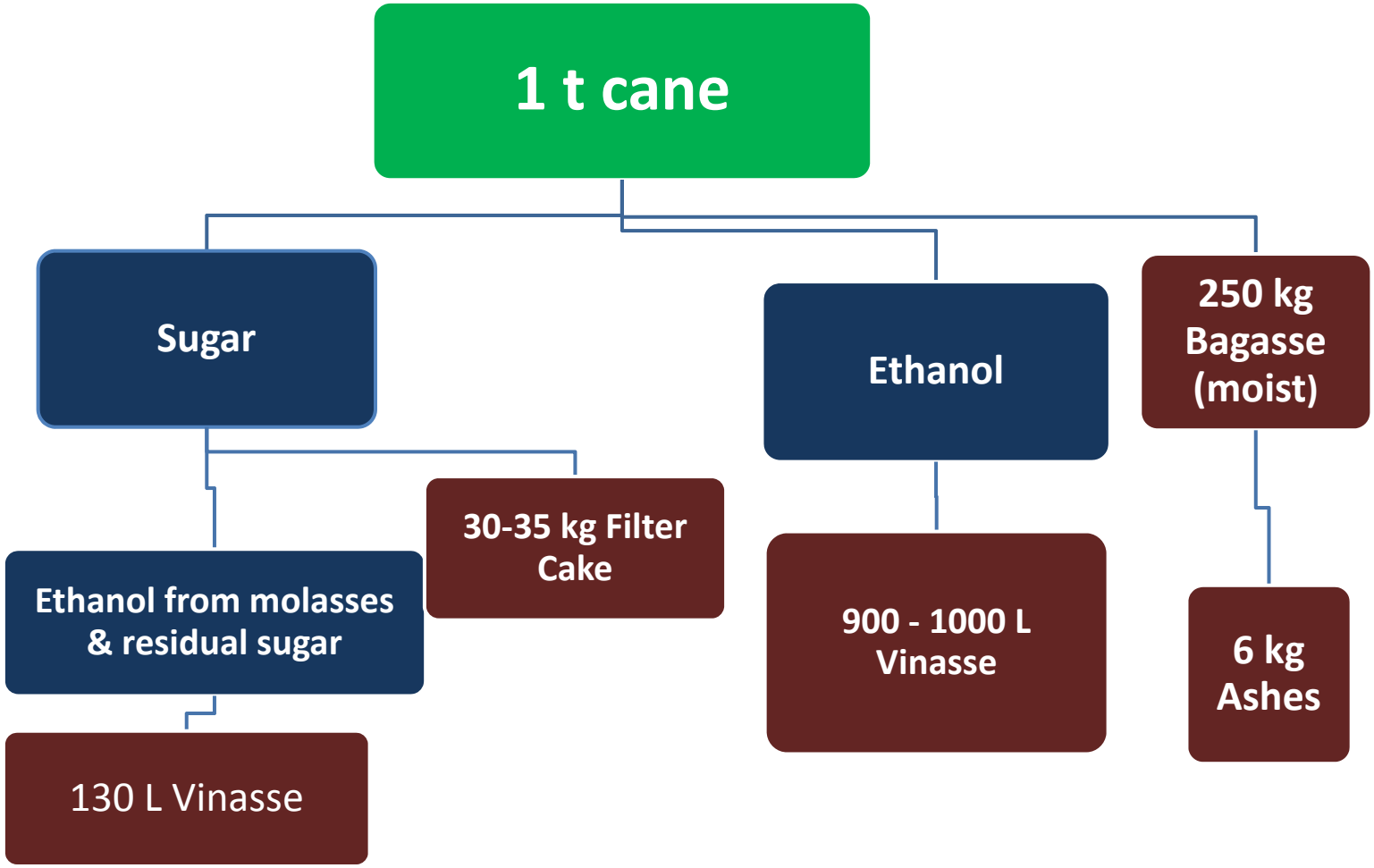


Sucrose: $C_{12}H_{22}O_{11}$



Ethanol: C_2H_5OH

Sugarcane residues



Bagasse

- **Huge amounts produced (250 kg/t cane)**
  - **Vapor power and electricity**
    - **Mills are energy self sufficient**
    - **By product: ashes**
  - **Used also for composting**

Ashes

Moisture	0.5 to 0.8 kg/kg	
N	7 g/kg	
P_2O_5	5 - 10 g/kg	Dry basis
K_2O	7 - 20 g/kg	Dry basis
S	14 g/kg	Dry basis
Si	300 - 800 g/kg	Dry basis

- **Used for direct application to the field**
- **Composted with other residues**

Filter Cake

Juice filtration: filter cake

Moisture	0.7 kg/kg
OM (dry basis)	590 g/kg
N	14 g/kg
P_2O_5	12 g/kg
K_2O	1.8 g/kg
C:N	24:1

Uses:

Direct application (fresh weight, 50% moisture)

80-100 t/ha: surface, pre-plant

40-50 t/ha: inter-row

15-30 t/ha: seed furrow

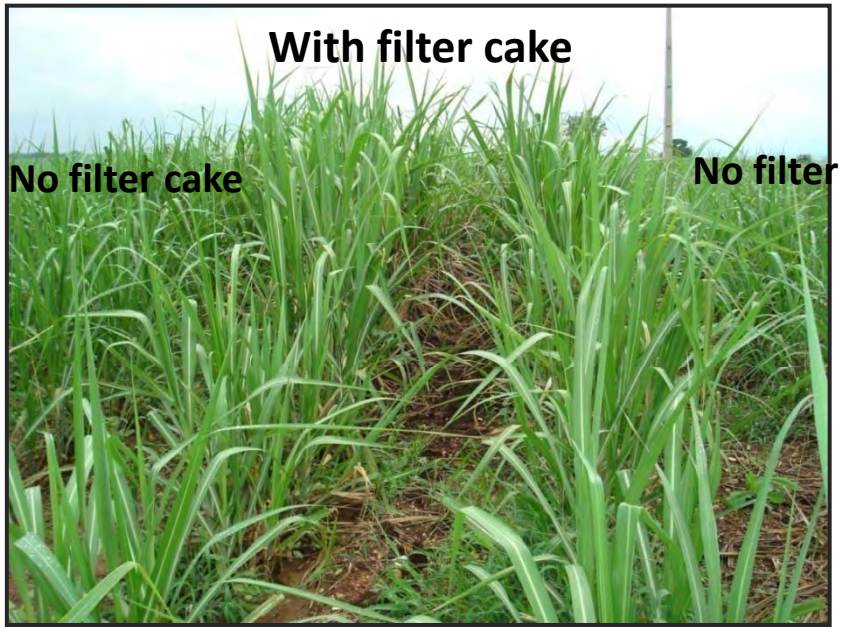
Filter cake

- **Filter cake is an excelent organic fertilizer**

Filter cake (t/ha)	Fertilizer NPK (kg/ha)	Yield (2 cycles) (t/ha)
0	0	140
15	0	184
15	0-60-120	212
0	20-120-120	191

Coleti et al., 1986

Filter cake application before planting



Vinasse
Liquid residue

Produced in great amounts: 8 to 12 L/L ethanol

900-1000 L/t cane (or ~140 L/t if from sucrose + ethanol production)

Total solids	10 - 40 g/L
N	90 - 800 mg/L
P_2O_5	10 - 190 mg/L
K_2O	800 - 4000 mg/L

Most common: 2 to 3 kg/m^3 K_2O

Rates used: 100 - 200 m^3/ha
[10 to 20 mm rain equivalent]
200 to 600 kg/ha K_2O

Vinasse

- **Before 1960's: source of pollution**
  - **High BOD:**
- **1967: Law prohibits dumping in rivers and water bodies**
  - **Recycle in the fields**
  - **Excess: "sacrifice" areas**
- **2005: State (SP) regulation restricts rate of application based on soil K and plant K export.**

Vinasse distribution/application

Vinasse inicially is stored in tanks for distribuition to the fields

Impermeable chanels or pipelines are used in flat areas. Pumping stations help distribute vinasse to far away fields

Vinasse application

Pumping station
Roller pipes and cannon sprinklers for vinasse application

Vinasse distribution/application

Trucks used to transport and apply vinasse in the fields

Vinasse application

Sprinkler application in the field

Vinasse distribution/application

- **Vinasse is a source of K**
  - **Where applied it totally replaces K mineral fertilizer**
    - **But it is also source of N, OM, and other nutrients**
- **Cost of transport restricts distance of application**
  - **Usually up to 30 km**
- **Concentrated vinasse can substantially increase economic distance for application**
  - **Depends on cost of energy for removing water**
  - **Production of organo-mineral fertilizer is an option**

Field application of concentrated vinasse

Concentrated vinasse is already produced in some mills

Truck application of concentrated vinasse

Recycling nutrients in sugarcane in Brazil (8.3 million ha)

Residue	Nutrient content			Nutrient recycled		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	% in dry matter			----- 1000 t/yr ----		
Filter cake	1.4	1.9	0.4	46.5	63.1	12.9
Trash	0.5	0.1	0.6	191.0	45.7	236.6
	---------- kg/m³ ----------					
Vinasse	0.4	0.06	2.0	124.5	19.9	675.6
Total				362.0	128.7	925.1

Total nutrients recycled equivalent to 2.6 x 10^6 t of fertilizer (as UR, ST and KCl).
Trash not burned

NPK fertilizers used em sugarcane in 2007/2008: 3.4 x 10^6 t

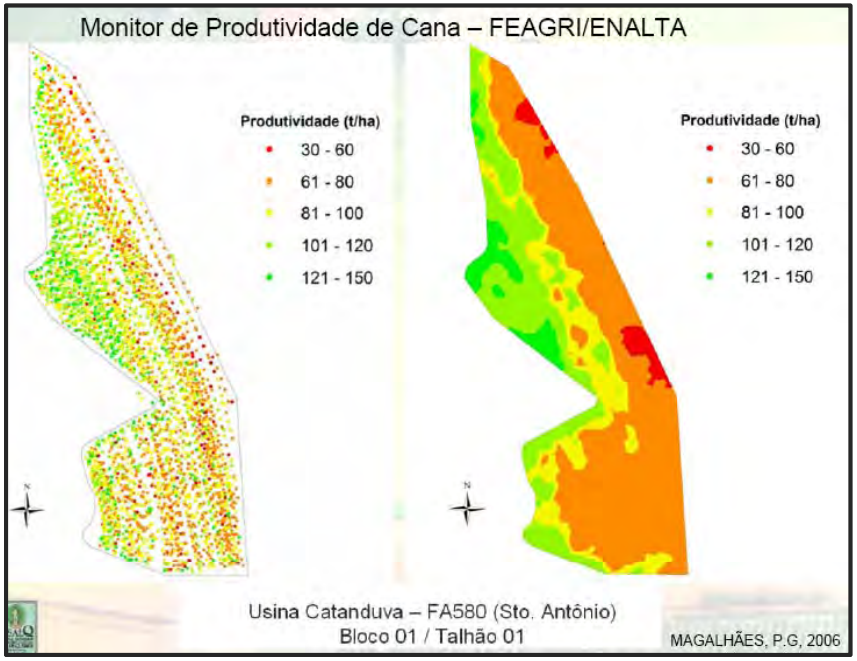
Source: Rossetto et al., 2008 e ANDA 2007

Precision agriculture

- **Already used in several mills**
- **Optiminization of fertilizer and pesticides**
  - **Fertilizer/lime application**
  - **Pest/disease/weed control**
- **Nocturnal operations**
- **Control of trafic to avoid soil compaction**

Precision agriculture

- **Yield map allows identification of high/low yielding areas to help decision making and field operations**



Precision agriculture

GPS guided variable-rate fertilizer application in green cane

GPS-controlled field operations

Tires of combine and tractor drive always in the same path in order to avoid compaction of the plant line

Other field operations (planting, cultivation, agrochemical application etc) will do the same.

Plant line is preserved (“Canteirização”)

N_2 Fixation in sugarcane

- **Several diazotrophic bacteria known to fix N_2 in sugarcane**
- **Evidences that BNF supplies part of the sugarcane N needs**
  - **Relatively little fertilizer N is used**
  - **Areas grown with sugarcane for >50 yr do not show soil degradation**
- **Presently N fertilizer cannot be replaced**
- **Potential to improve: ongoing research**
  - **Inoculant**
  - **Varieties responsive to association with BNF bacteria**

Concluding remaks

- **Sugarcane is an efficient crop to produce biomass and energy**
  - **Energy balance is highly favorable**
- **Agronomic (industrial, economic) knowledge available allow an efficient and environmentally sound production system**
  - **Demand for agrochemicals is relatively small**
  - **Biological control**
  - **Recycling of nutrient and organic matter**
  - **Soil protection**
  - **Grain and green manure produced in rotation**
- **Great potential for future improvements**
  - **Conventional research & Biotechnolgy**

Thank you

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Acknowledge the help of Raffaella Rossetto with photos and suggestions