



**1st Brazil-U.S. Biofuels Short Course:  
Proving Interdisciplinary Education in  
Biofuels Technology**

**SWEETPOTATO AS A FEEDSTOCK  
FOR ETHANOL PRODUCTION:  
how energy and food production can live in  
perfect harmony**

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**FAPEMIG**



# ENERGY TODAY

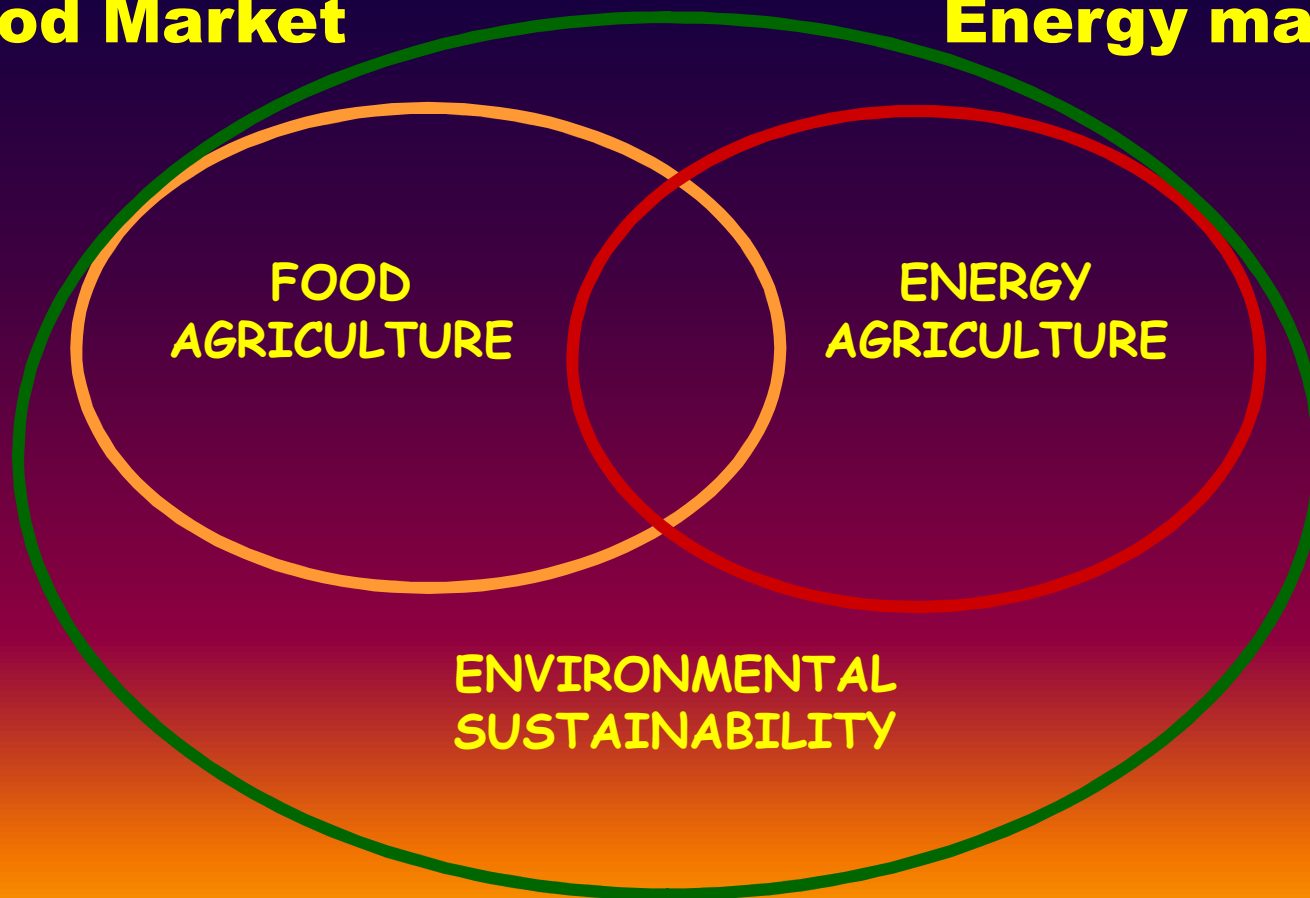
- Rising demand for energy**
  - Rising energy prices
  - Highly dependent on fossil fuel sources
    - Global climatic changes
- Oil: geopolitical instability and armed conflicts in important oil-producing countries

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# A WORDWIDE CHALLENGE

**Food Market**

**Energy market**



(Adapted from: José Nilton de Souza Vieira /MAPA)

# **ETHANOL AS A BIOFUEL**

## **- the Brazilian experience -**

**1975: Programa Nacional do Álcool-PROALCOOL= incentives to ethanol feedstock sources: sugarcane, cassava and others**

### **1975-1979: THE BEGINNING**

**Ethanol: 600 million L/year (1975-76 to 3,4 billion L/ano (1979-80).**

**first ethanol-powered cars: 1978**

### **1980-1986: SETTING ROOTS**

**2nd world oil shock (1979-80)**

**Ethanol: 12,3 billion L/yr in 1986-87**

**Ethanol-powered cars: 0,46% (1979) to 76,1% (1986)**

# **ETHANOL AS A BIOFUEL**

## **the Brazilian experience**

### **1986 to 1995 – STAGNATION PHASE:**

**Ethanol-powered cars: 95,8%**

**Oil prices: from US\$30-40/barrel to US\$12-20/barrel**

**1989-1990: ethanol supply crisis → loss of credibility**

### **1995 to 2000: REDEFINITION PHASE**

**deregulation of ethanol prices (supply & demand)**

**sugar production expanded at ethanol's expense**

# **ETHANOL AS A BIOFUEL**

**the Brazilian experience**

**ETHANOL TODAY:**

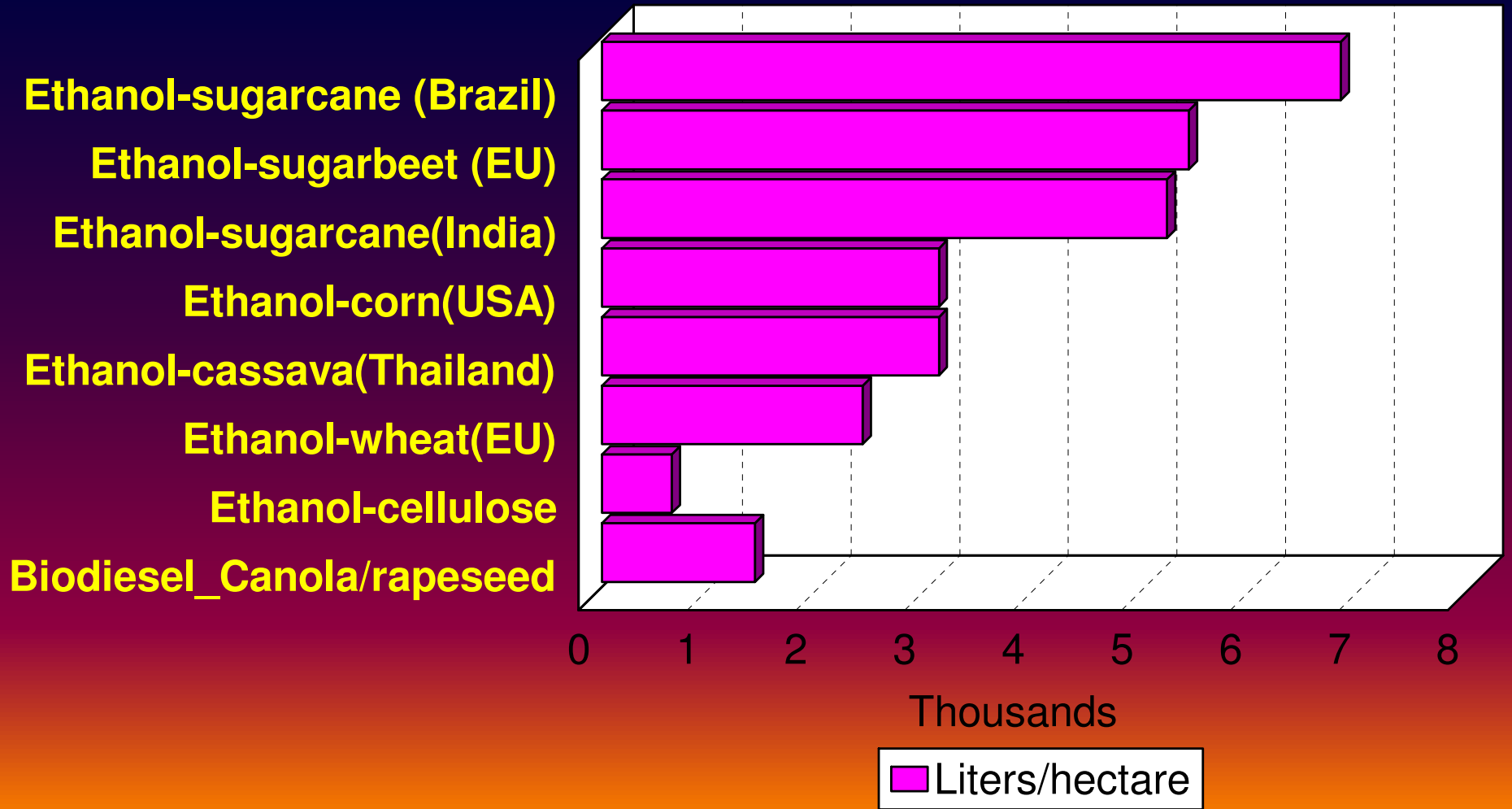
**Sugarcane expansion towards the “cerrado” region of  
Central Brazil**

**2003: flex-fuel car technology  
(gasoline+ethanol in any proportion)**

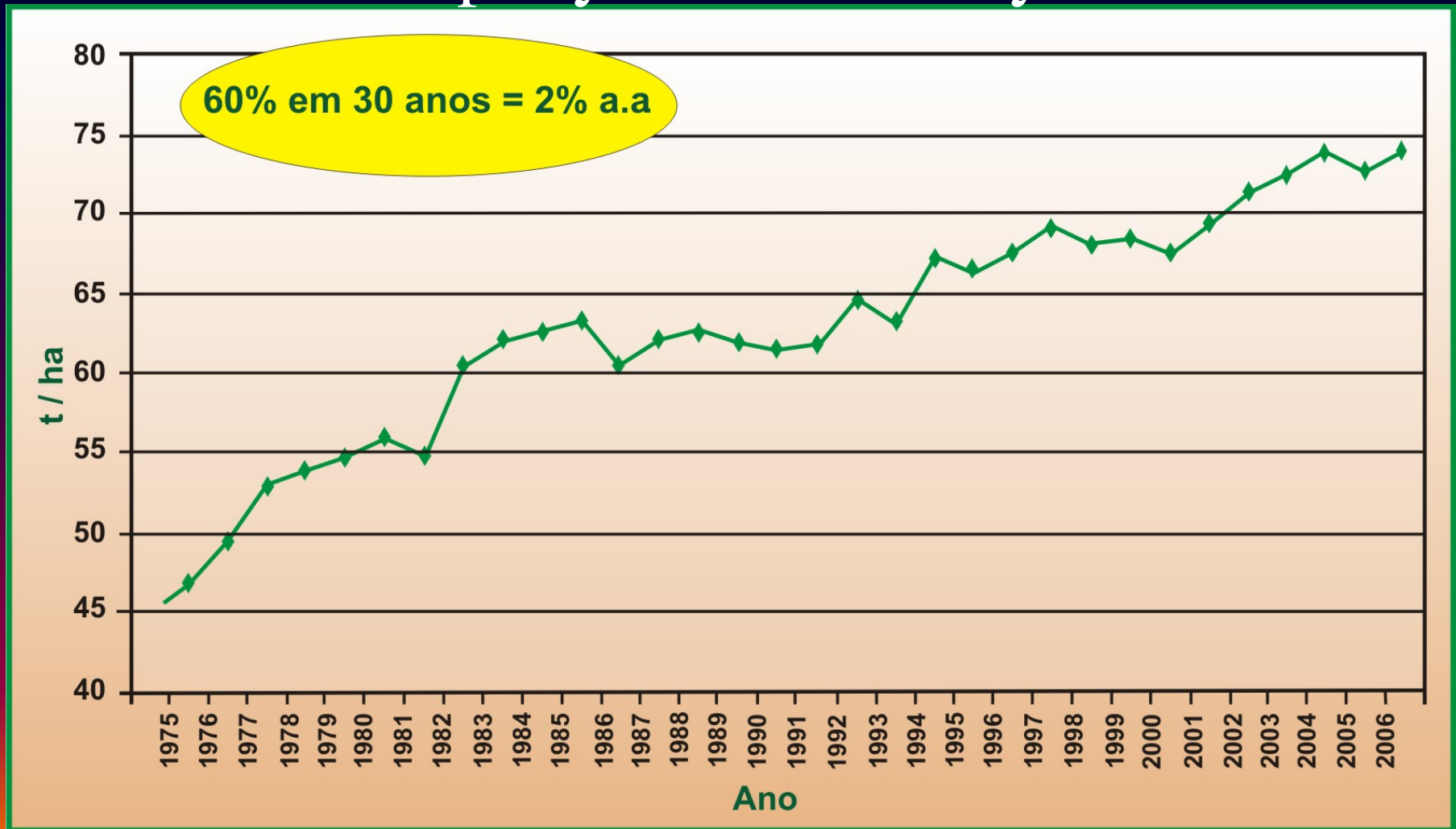
**the oil rising oil prices (peak in 2008?)**

**THE QUEST FOR NEW ENERGY ALTERNATIVES  
(FOR ETHANOL & BIODIESEL)**

# Brazil: largest ethanol yield with sugarcane - corn and wheat are low yielding -



# Brazil: Sugarcane yields + 2% per year over >30 years





# Sugarcane yield gains (t/ha)

<b>No. cuts(yrs)/crop</b>	<b>1975</b>	<b>2005</b>	<b>2015</b>
1	100	120	135
2	65	100	114
3	45	88	95
4	-	76	84
5	-	65	76
Yield/year (3 cuts)	70	102,7	114,7
Yield/year (5 cuts)	70	90	100,8

<b>Yield/yr</b>	<b>Gains 2005/1975</b>	<b>Gains 2015/1975</b>	<b>Gains 2015/2005</b>
<b>3 cuts</b>	<b>46,7%</b>	<b>63,8%</b>	<b>11,7%</b>
<b>5 cuts</b>	<b>28,6%</b>	<b>44,0%</b>	<b>12,0%</b>

# How to tell a lie just by telling the truth...

	<b>Yield</b> t/ha	<b>Ethanol</b> L/t	<b>Ethanol</b> L/ha	<b>%</b> sugarcane
<b>Arrowroot</b>	<b>12.0</b>	<b>208</b>	<b>2496</b>	<b>37.5</b>
<b>Potato</b>	<b>20.0</b>	<b>80</b>	<b>1600</b>	<b>24.0</b>
<b>Sweetpotato</b>	<b>11.7</b>	<b>170</b>	<b>1989</b>	<b>29.9</b>
<b>Sugarbeet</b>	<b>15.0</b>	<b>107</b>	<b>1605</b>	<b>24.1</b>
<b>Sugarcane</b>	<b>74.0</b>	<b>90</b>	<b>6660</b>	<b>100.0</b>
<b>Yams</b>	<b>25.0</b>	<b>192</b>	<b>4800</b>	<b>72.1</b>
<b>Cassava</b>	<b>13.5</b>	<b>363</b>	<b>4901</b>	<b>73.6</b>
<b>Corn</b>	<b>3.3</b>	<b>420</b>	<b>1386</b>	<b>20.8</b>
<b>Grain sorghum</b>	<b>2.3</b>	<b>478</b>	<b>1099</b>	<b>16.5</b>
<b>Wheat</b>	<b>2.3</b>	<b>435</b>	<b>1001</b>	<b>15.0</b>

Adapted from Machado,CMV (2007)

# Is sweetpotato really that bad?

Sweetpotato statistics reflect:

- a biased view (food crop)
- a very low level of technology
  - crop under-utilization
  - crop under-consumption

*Not even remotely does it reflect the true crop potential for ethanol production*

# **Prejudice against sweetpotato exist in many countries besides Brazil...**

## ***Sociological view:***

**It is usually thought of as a non-staple crop that only becomes a staple in times of hardship (US after the Civil War; Asian countries after the Word War II)**

## ***Agronomical view:***

**It is viewed mostly as a dessert crop whose production aims at maximum yield of US No. 1 roots (preferred by consumers) > harvest (at 4 months after planting) is performed before maximum root yields can be achieved (7 months or more, such as can be done in Brazil ). Yield statistics are therefore usually low, even in the US or Japan.**

## **Was sweetpotato ever given a chance?**

- **Many crops besides sugarcane were considered as potential feedstocks for ethanol production in the early days of the PROALCOOL program in the 1970's and 1980's: cassava, sugar sorghum, ... even bamboo...**
- **Because of biased views of the crop, SWEETPOTATO was never given any serious consideration as an alternative crop for ethanol production**

# SWEETPOTATO

## Comparing two BRIC countries:

	Brazil	China
<b>Population (millions)</b>	<b>186</b>	<b>1330</b>
<b>Per capita agricult. area (ha)</b>	<b>1.8</b>	<b>0.1</b>
<b>Sweetpotato production (million tons/year)</b>	<b>0.5</b>	<b>118</b>
<b>Gross per capita consumption (kg/person)</b>	<b>2.7</b>	<b>88.7</b>
<b>Total area (1000 ha)</b>	<b>44</b>	<b>6000</b>
<b>Animal feeding</b>	<b>very little</b>	<b>41% (+100% vines&amp;leaves)</b>
<b>Starch and derivatives (noodles)</b>	<b>nil</b>	<b>33%</b>
<b>Fresh consumption</b>	<b>≈ 100%</b>	<b>26%</b>
<b>kg/person (fresh consumption)</b>	<b>2.7</b>	<b>23.1</b>

# **Reason for low sweetpotato yields in Brazil:**

- **a neglected non-staple crop**
- **obsolete cropping practices**
- **inappropriate cultivars (susceptible to pests and diseases)**
- **low adoption of already existing crop production technologies**
- **lack of knowledge about cultivar aptitudes**
- **a vicious circle: under-production > under-consumption > under-production**

How to tell a lie just by telling the truth... part 2

## Which is the best starch-based feedstock?

Crop	Yearly Production (1000 ton)	Total area (1000 ha)	Mean Yield (ton/ha)	Crop cycle (months)	Comparative level of technology and production costs
Potato	2915	159	18.4	3.5	high
Cassava	22302	1651	13.5	18.0	low
Sweetpotato	495	44	11.2	5.5	low



# **Mean sweetpotato yields in Brazil could easily double or triple...**

*Plain “rice and beans” (“meat and potato”) technologies available for > 25 years:*

- **choice of cultivars with resistance to soil pests and diseases**
- **higher quality cuttings or slips**
- **appropriate soil preparation**
- **proper fertilization**
- **ensuring stand**

# What sweetpotato yields can we expect?

## IN THE SHORT RUN

yields could triple with currently available technologies of easy adoption (developed by IAC, EMBRAPA over 25 years ago):

**30-40 ton/ha threshold with**

**current available cultivars with disease&pest resistance**

**quality cuttings/slips**

**appropriate stands (30000 to 40000/ha)**

**moderate use of fertilizers**

# What sweetpotato yields can we expect?

**MEDIUM RANGE (5 years?)**

**Additional gains from breeding and selection of clones suitable for ethanol**  
**40-100 ton/ha threshold with**  
**higher yielding cultivars**  
**with higher starch contents**

## **The 2002 Brazilian energy crisis: turning a sour lemon into a sweet limonade...**

**In the aftermath of the 2002 electric energy crisis in Brazil, agencies like the CNPq opened competitive grants to look for alternative energy sources in the Northern part of Brasil.**

**That helped to establish the 1st sweetpotato breeding programme in the country aimed specifically at developing cultivars with aptitude for ethanol production – led by Dr. Marcio Antonio da Silveira, in the state of Tocantins (programme planned years before, during Dr.Silveira's tenure as a graduate student under my supervision)**

... and the 1st pilot ethanol plant (at the Univ Federal do Tocantins campus in Palmas)....





**Pilot sweetpotato ethanol plant  
operating at the Palmas campus of  
the Universidade Federal do  
Tocantins**

Ethanol capacity= 30 L/hour (720 L/day)







**Me... powered by sweetpotato ethanol  
(and I don't even drink liquor !)**



# Root and ethanol yields of sweetpotato clones selected at the Universidade Federal do Tocantins at Palmas (1997-2007)

Cultivars	Root Yield t/ha	Starch %	Ethanol L/ton	Ethanol L/ha	DryMatter %	Cycle (months)
1	65.5	24.4	161	10467	40.4	6 – 7
2	46.7	21.4	141	6595	32.4	4 – 5
3	45.7	23.4	154	7058	35.4	6
4	43.0	26.2	173	7436	33.2	6
5	40.6	24.6	162	6585	37.3	4 – 5
6	37.7	23.2	153	5773	33.2	6 – 7
7	37.2	18.8	124	4616	28.6	4 – 5
8	36.8	22.2	147	5392	33.7	6
9	36.4	25.1	166	6030	36.3	6
10	32.2	30.2	199	6412	40.9	6 – 7

**Sugarcane: 74 ton/ha = 6660 L ethanol/ha**

**90 ton/ha = 8100 L ethanol/ha**

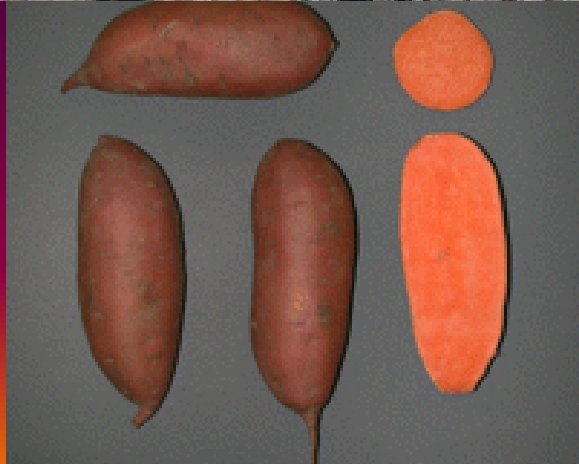
Our program at the Universidade Federal de Lavras has identified (2007) clones with yield potential of aprox. 100 ton/ha in a 7-month cycle

Clone	Name	Root Yield (ton/ha)	%dry matter	Ethanol potential (L/ton)	Ethanol potential yield (L/ha)
UFLA07-47	Brazlândia Branca	28.0	30	146	4099
UFLA07-50	Palmas	27.3	34	158	4308
UFLA07-01	CORAÇÃO MAGOADO	46.4	28	141	6529
UFLA07-04	Arruba	55.4	25	132	7322
UFLA07-05	Licuri	44.9	32	152	6829
UFLA07-12	DIA-BD-06	98.0	24	129	12673
UFLA-07-15	DIA-BD-42	30.9	33	155	4788
UFLA07-16	DIA-BD-15	45.7	27	138	6300
UFLA-07-21	DIA-BD-65	15.5	45	189	2932
UFLA-07-24	DIA-BD-67	46.2	31	149	6896
UFLA07-31	DIA-BD-38	56.8	28	141	7992
UFLA-07-42	UFT-BD-58	42.9	29	144	6159
UFLA07-43	UFT-BD-02-AI	95.0	33	155	14721
UFLA07-49	UFT-BD-04-AI	64.3	33	155	9963
UFLA-07-53	UFT-BD-08	45.5	32	152	6921

# Sweetpotato: a realistic view

<b>Scenario</b>	<b>Yield ton/ha</b>	<b>Etanol L/ton</b>	<b>Ethanol L/ha</b>	<b>cycle (months)</b>
<b>Corn (Iowa 2008)</b>	<b>10.7</b>	<b>420</b>	<b>4494</b>	<b>4</b>
<b>Corn (Brazil, 2008)</b>	<b>3.7</b>	<b>420</b>	<b>1554</b>	<b>5-6</b>
<b>Sugarcane (Brazil)</b>	<b>74</b>	<b>90</b>	<b>6660</b>	<b>12</b>
<b>Sweetpotato (actual)</b>	<b>11.7</b>	<b>160</b>	<b>1872</b>	<b>5.5</b>
<b>Sweetpotato (feasible-short term)</b>	<b>35</b>	<b>160</b>	<b>5600</b>	<b>5.5</b>
<b>Sweetpotato (feasible-medium term)</b>	<b>50</b>	<b>160</b>	<b>8000</b>	<b>6</b>
<b>Sweetpotato (feasible/optimistic-medium term)</b>	<b>70</b>	<b>160</b>	<b>11200</b>	<b>6-7</b>
<b>Sweetpotato (recorded potential)</b>	<b>100</b>	<b>160</b>	<b>16000</b>	<b>7</b>

# Sweetpotatoes and their various aptitudes



**FRESH MARKET**

**ANIMAL  
FEEDING**

# Sweetpotatoes and their various aptitudes

CLONE	Name	Total root yield (ton/ha)	Ethanol (L/ha)	Marketable root yield (ton/ha)	Vines+leaves (ton/ha)	Protein in vines+leaves (kg/ha)
**UFLA07-47	BrazBranca	28.0	4099	24.6	39.6	627
**UFLA07-50	Palmas	27.3	4308	22.8	55.8	1003
UFLA07-01	CORACAO MAGOADO	46.4	6529	30.4	39.2	764
UFLA07-04	Arruba	55.4	7322	17.5	79.4	1334
UFLA07-05	Licuri	44.9	6829	26.7	76.2	1620
UFLA07-12	DIA-BD-06	98.0	12673	51.3	136.8	2280
UFLA-07-15	DIA-BD-42	30.9	4788	12.2	302.4	3922
UFLA07-16	DIA-BD-15	45.7	6300	30.6	51.9	889
UFLA-07-21	DIA-BD-65	15.5	2932	5.0	219.8	4104
UFLA-07-24	DIA-BD-67	46.2	6896	23.4	236.4	4104
UFLA07-31	DIA-BD-38	56.8	7992	27.0	117.4	2120
UFLA-07-42	UFT-BD-58	42.9	6159	35.7	53.4	1003
UFLA07-43	UFT-BD-02-AI	95.0	14721	42.7	115.4	2303
UFLA07-49	UFT-BD-04-AI	64.3	9963	44.5	84.0	1402
UFLA-07-53	UFT-BD-08	45.5	6921	26.0	102.9	1915

# Different clones, different aptitudes

Clone	Name	Ethanol (L/ha) (ETHANOL)	Marketable roots (t/ha) FRESH MARKET	Protein kg/ha ANIMAL FEED	Cultivar aptitude
**UFLA07-47	BrazBranca	4099	24.6	627	market
**UFLA07-50	Palmas	4308	22.8	1003	market
UFLA07-01	CORACAO-MAGOADO	6529	30.4	764	ethanol, market
UFLA07-04	Arruba	7322	17.5	1334	ethanol, market
UFLA07-05	Licuri	6829	26.7	1620	ethanol, market
UFLA07-12	DIA-BD-06	12673	51.3	2280	ethanol, market, animal feed
UFLA-07-15	DIA-BD-42	4788	12.2	3922	animal feed
UFLA07-16	DIA-BD-15	6300	30.6	889	ethanol, market
UFLA-07-21	DIA-BD-65	2932	5.0	4104	animal feed
UFLA-07-24	DIA-BD-67	6896	23.4	4104	ethanol, nutricao animal
UFLA07-31	DIA-BD-38	7992	27.0	2120	ethanol, market, animal feed
UFLA-07-42	UFT-BD-58	6159	35.7	1003	ethanol, market
UFLA07-43	UFT-BD-02-AI	14721	42.7	2303	ethanol, market, animal feed
UFLA07-49	UFT-BD-04-AI	9963	44.5	1402	ethanol, market, animal feed
UFLA-07-53	UFT-BD-08	6921	26.0	1915	ethanol, market, animal feed

# Sweetpotato co-products:

sundried  
chips

protein-rich  
distillation  
residue (up  
to 42%  
protein)

flour

ethanol

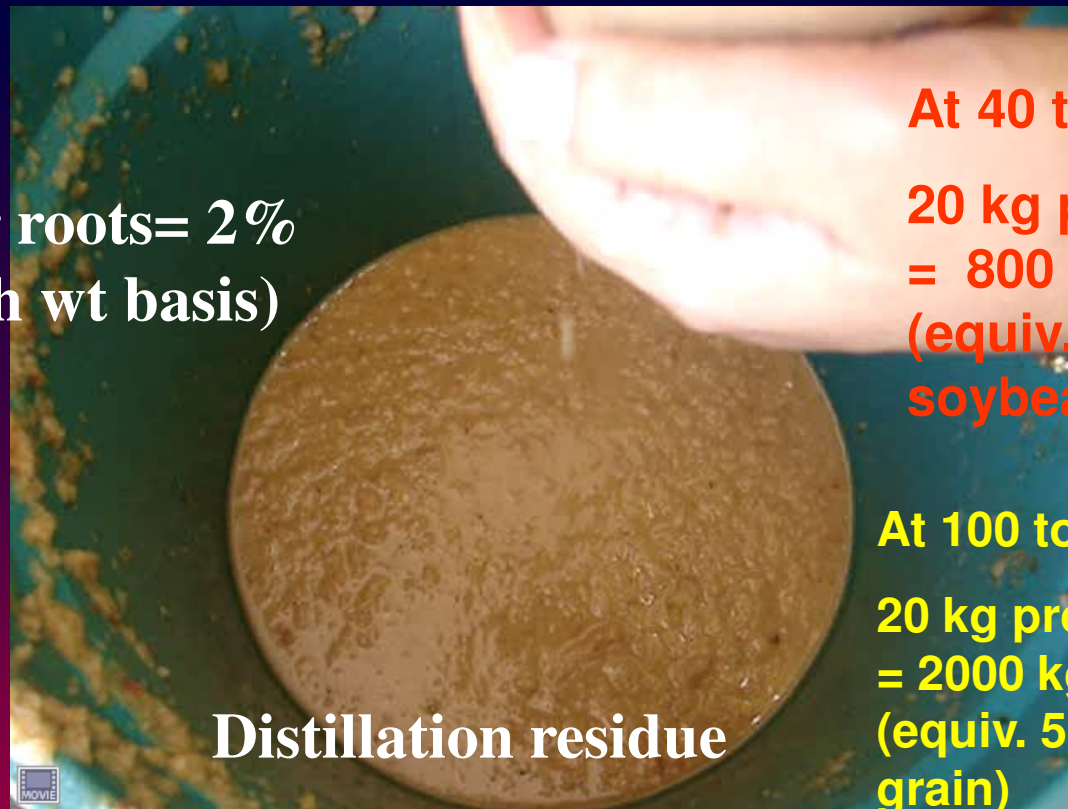




# Residue or by-product?

**Protein-poor roots= 2%  
protein (fresh wt basis)**

**1 ton roots with  
2% crude  
protein=  
approx. 150 kg  
dry matter  
residue with  
16% crude  
protein**



**Distillation residue**

**At 40 ton/ha:**

**20 kg protein x 40 t/ha  
= 800 kg protein /ha  
(equiv. 2000 kg  
soybean grain)**

**At 100 ton/ha:**

**20 kg protein x 100 t/ha =  
= 2000 kg protein /ha  
(equiv. 5000 kg soybean  
grain)**

**1 ha corn (Iowa) = 11 ton grain with avg. 9% protein =  
1000 kg protein/ha**

# Residue or by-product?



- **Up to 200 t fresh weight of vines+leaves**
- **15% dry matter (with 11.4% protein)**
- **up to 30 t dry matter/ha**

# Residue or by-product?

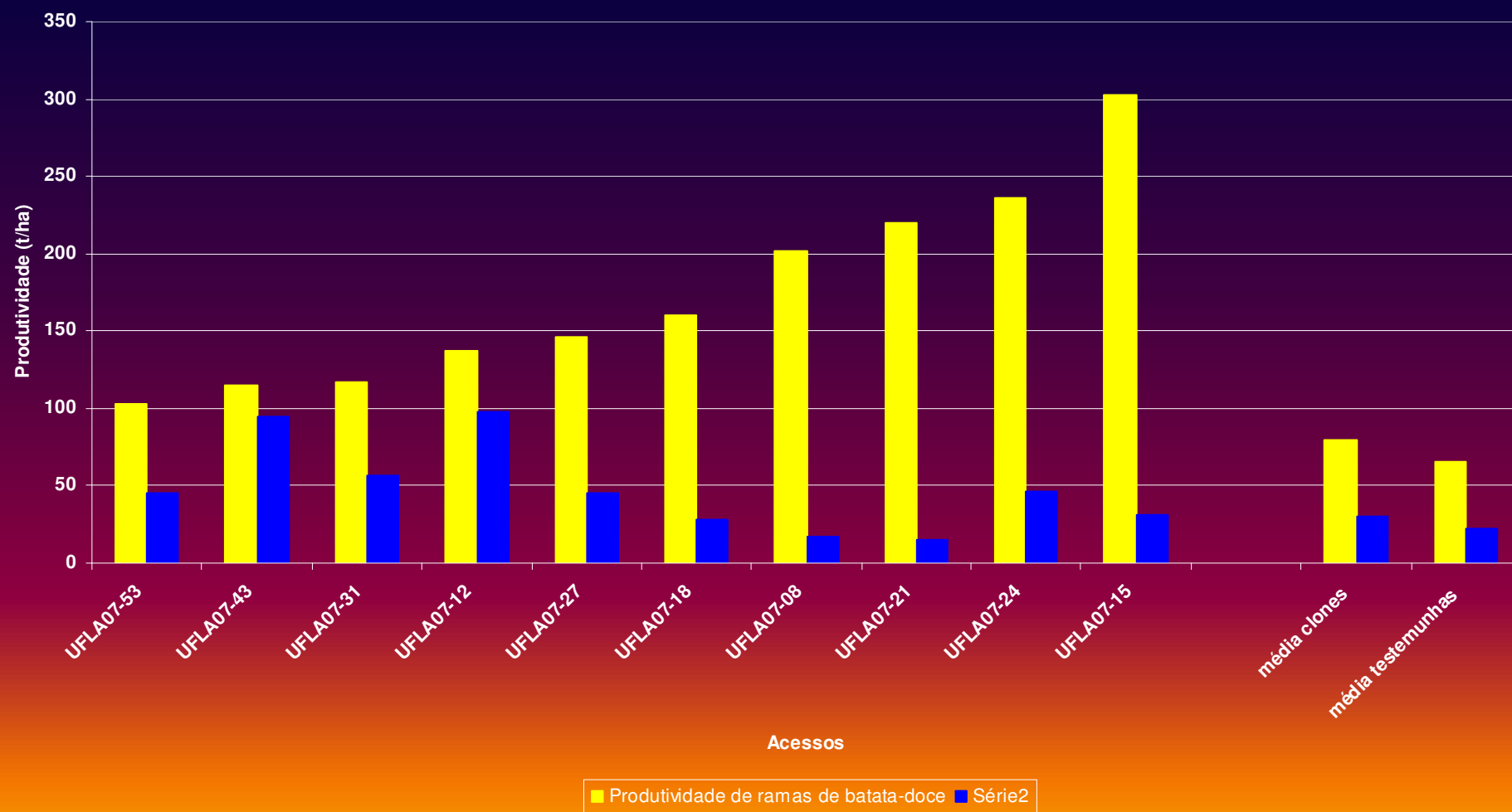


Silage	Dry Matter ton/ha	% protein	% Fiber
Corn	12	7.2	55.4
Sweetpotato (200t/ha vines+leaves)	30	11.4	44.7
Sweetpotato (80 t/ha vines+leaves)	12	11.4	44.7

**Sweetpotato silage compares favorably with corn sillage**

# Vines and leaves: a welcome nuisance

>80 ton/ha yields of vines+leaves are not uncommon



# NOT ALL SWEETPOTATOES ARE EQUAL...



**NOT ALL SWEETPOTATOES ARE EQUAL...**



UFLA07-53



UFLA07-08



**... and not all sweetpotatoes are for the fresh market**

# Further steps needed in sweetpotato agronomic research

- **Sweetpotato breeding**
  - Higher yields of roots and vines
  - Resistance to pests and diseases
  - Starch content/quality
  - Biotechnology
  - Regional trials (> genetic gains)
- **New technologies**
  - Mechanical harvest
  - Weed Control
  - No-tillage planting?
  - Longer cycles (9-15 months)



# Is sweetpotato a viable feedstock for ethanol production ?

**Ethanol yields per ton**

**Sugarcane= 80-85 L**

**Sweetpotato= 160-170 L**

**1 ton sweetpotato roots could be sold for 2 x as much as 1 ton sugarcane**

**40 ton/ha roots = 6500 L ethanol/ha**

# A multi-purpose clone:

14721 L ethanol/ha

or 43 t/ha marketable roots +

+ 52 ton/ha roots for ethanol = 8840 L/ha

2303 kg protein/ha in vines+leaves +

1880 kg protein/ha in the distillation residue

(protein equivalent= 8366 kg soybean meal)

UFLA07-43

= UFT-BD-02-AL

# Is sweetpotato a viable feedstock for ethanol production ?

*(China grows 6 million ha sweetpotato)*

*(Brazil already grows 7.8 million ha sugarcane)*

*Should Brazil grow 2 million ha sweetpotato*

*with a modest yield of 40 ton/ha roots (+50 ton/ha vines+leaves):*

It would increase current ethanol production in 12.5 billion L/year or

(1/4 of current production)

**PLUS:** It would feed (with vines+leaves alone) 3 million beef or dairy cattle  
(during 365 days/year)

**PLUS:** it would free 3 million ha of low-yielding pastures that could be set  
aside for other uses (grain production? reforestation?)

**PLUS:** It could export additional 1.6 million tons of protein-rich distillation  
residue, protein-equivalent to 4 million tons of soybean grain

# **Is sweetpotato a viable feedstock for ethanol production ?**

## **Bioex Etanol**

**2 sweetpotato ethanol plants (300,000 L/day each) being built in the counties of Ponta Grossa and Jesuitas, State of Paraná**

**2000 ha of sweetpotatoes currently being grown**

**Yields of up to 100 ton/ha are being obtained**

**Is sweetpotato a viable feedstock for ethanol production ?**

**YOU TELL ME!!!...**



**To the memory of**

**George Washington Carver**

**- botanist, teacher, scientist, inventor,  
musician, extension man ,  
humanitarian-**

**Born 1864? Diamond Grove, Missouri**

**Deceased 1943, Tuskegee, Alabama**

*“Whoever could make two ears of corn or two blades of grass grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together”*

**Jonathan Swift**  
in  
**“Gulliver’s Travels”**

**FAPEMIG**

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Científico e Tecnológico



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