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## A Gis Approach Using Remote Sensing Derived Products for Quantification of Sugar Cane Productivity in Brazil

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### RESUMO

Este estudo teve como objetivo de desenvolver uma metodologia baseada na aplicação de produtos GEONETCast-EUMETCast para estimativa da produtividade da cana-de-açúcar utilizando-se de um modelo agrometeorológico-espectral. O estudo foi desenvolvido no município de Coruripe, localizado no estado de Alagoas, Brasil. O teste foi realizado num período de cinco meses, abril a agosto, do ano de 2010. Conclui-se que a metodologia utilizada indica ser útil para o apoio operacional de estimativa da produtividade da cana-de-açúcar, fornecendo valores médios de 37 a 40 t/ha.

Palavras-chave: Spot Vegetation, Meteosat-9, Produtividade Safra, Ilwis

### ABSTRACT

This study aimed to develop a GEONETCast-EUMETCast product-based method of estimating the productivity of cane sugar using an agrometeorological-spectral model. The study was carried out in the Municipality of Coruripe, located in the state of Alagoas, Brazil. The test was performed over the period of five months, from April to August of 2010. It was concluded that the methodology is useful for developing estimates of operational support for the cane sugar productivity, providing mean values of 37 to 40 t/ha.

Keywords: Spot Vegetation, Meteosat-9, Crop Yield, Ilwis

### 1. Introduction

#### 1.1 The gap between science and practical agricultural management

Current management practices in Brazil in the field of agricultural management are very often still based on outdated knowledge and technology. Similarly to what

happens in many other regions of the world, frequently scientists plan and develop their methods in isolation, not grasping what is really required by relevant stakeholders. On the other hand, stakeholders are often unaware of what science or knowledge-based alternatives are available. Scientific research is further isolated by lack of proven utility

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and inadequate representation of results, whilst agricultural policy and management is isolated by legal and professional precedence.

1.2 Making crop modeling useful for decision-making: what output is needed, and what input data are required to achieve the modelling goals

In the scientific community frequently model performance is evaluated using procedures and statistical indicators which do not necessarily reflect the usefulness for practical decision-making in the region of interest. Improved awareness of stakeholders' real needs can help scientists to better orient their work. On the other hand, typical current performance rates of crop modelling applications in the region may not be sufficient for practical decisionmaking.

Low model performance is often a consequence of limited input data sets on which the model application is based. However, over the past decades an increasing amount of potentially useful products derived from remote sensing have become available, but their potential for improving model performance in the region has not been well assessed yet.

1.3 Agro-meteorological parameters from satellite remote sensing products and GIS approach

Remote sensing images play an important role in agricultural crop production over large area, quantitatively and nondestructively, because agricultural crops

are often difficult to access, and the cost of ground based estimation of productivity can be high. The recent development of GEONETCast–EUMETCast data has provided the capability to obtain frequent and accurate measurements of a number of basic agro-meteorological parameters (e.g. evapotranspiration, surface albedo, surface temperature, solar radiation, rainfall etc.). The GEONETCast real-time data dissemination system represents a global network of communication satellite based data dissemination system to distribute space-based, air-borne and in situ data, metadata and products to diverse user communities. The satellite estimated agro-meteorological parameters provide a complete and spatially dense observations capability for assessing regional vegetation potential productivity (Barbosa et al., 2006; Barbosa et al., 2009). With a Geographic Information System (GIS) approach, it provides a framework to ingest in the analysis the information of agrometeorological parameters that influence crop yield.

1.4 Sugar cane crops in Brazil

Agricultural production in the semi-arid region of Brazil is characterized by extensive, low investment subsistence farming focused on limiting the impacts of hydrological and policy risks. As a consequence, agricultural, labor and natural resource productivity has remained low, however at high environmental costs,

especially with respect to land degradation and loss of natural resources and biodiversity. Agriculture is the primary social and productive economic sector in the semi-arid Latin American countries and forms the basis for rural welfare and food security, and the platform for structural change and economic take off towards sustainable socio-economic development and growth. Sugar cane is one of the most important cash crops in Brazil. It is an annual crop with solid jointed stems and its mode of photosynthesis is very efficient and growth is quick. Brazil is the biggest grower of sugarcane, which is used to produce sugar and ethanol gasoline-ethanol blends gasohol for transportation fuel. Its bio fuel industry is a leader, a policy model for other countries, and sugarcane ethanol is considered the most successful alternative fuel to date.

### 1.5 General objective

The general objective of this application is to increase the role of crop modelling applications for estimating sugar cane productivity in Brazil by incorporating satellite remote sensing products to evaluate estimation of productivity of sugar cane crops. A number of tailored and GIS-compatible products are generated and integrated to quantify sugar cane productivity.

### 1.6 Specific objective

For this application products that are disseminated through GEONETCast (NDVI S-10, SPOT Vegetation DMP and ETp) are

used to develop a remote sensing based approach to improve sugar cane productivity estimation for the municipality of Coruripe, located in Alagoas, Brazil. The study is conducted for the period of April to August, 2010. The sugar cane productivity is derived in 9 computational steps.

## 2. Methodology

### 2.1 Data Used

#### 2.1.1 Local/Regional (in-situ) data

The application focuses on the sugar cane plantation for the entire Coruripe municipality, located in Alagoas State, Brazil.

The sugarcane parameters used are:

BF = Respiration Factor (0.5 for temperatures  $\geq 20^{\circ}\text{C}$  and 0.6 for temperatures  $<20^{\circ}\text{C}$ ), after Gouvêa (2008);

APF = Agricultural Productivity Factor (2.9), after Ruddorf (1985);

Ky= yield response factor, after Doorenbos et al (1979);

Kc= Crop coefficient.

The crop coefficient is defined as the ratio of crop evapotranspiration (Etc) with respect to reference evapotranspiration (ET0). Kc is crop specific and is depending on the crop growth stage. Crop evapotranspiration at any time during the growing season is the product of reference evapotranspiration and the crop coefficient, expressed as:  $ET_c = ET_0 * K_c$ . Crop coefficients have been developed for nearly all crops by measuring crop water use with lysimeters and dividing the crop

water use by reference evapotranspiration for each day during the growing season.

## 2.2 Products used from GEONETCast

The following data delivered through GEONETCast has been used for the period April to August, 2010:

Remote sensing images: SPOT Vegetation-2 and SPOT-5, SEVIRI instrument on METEOSAT-9;

Remote sensing based products:

- NDVI S10 (NDVI) and Dry Matter Productivity (DMP) having a spatial resolution of 1Km.;
- LSA-SAF Etp product for South America.

Source of the data is the GEONETCast ground receiving station installed at the Laboratory of Analysis and Processing of Satellite Images (LAPIS), Federal University of Alagoas (UFAL) (see: <http://www.lapismet.com>) and the SPOT Vegetation products are obtained from the archive, maintained by VITO (see: <http://free.vgt.vito.be/>).

This application proposes to test a remote sensing approach to quantify estimates of sugar cane productivity over the Coruripe municipality and sugar cane crop estimates are computed for each map pixel using NDVI, DMP and Etp images by applying radiative, aerodynamic and energy balance physics using 9 computational steps. The flow diagram of the methodology to quantify sugar

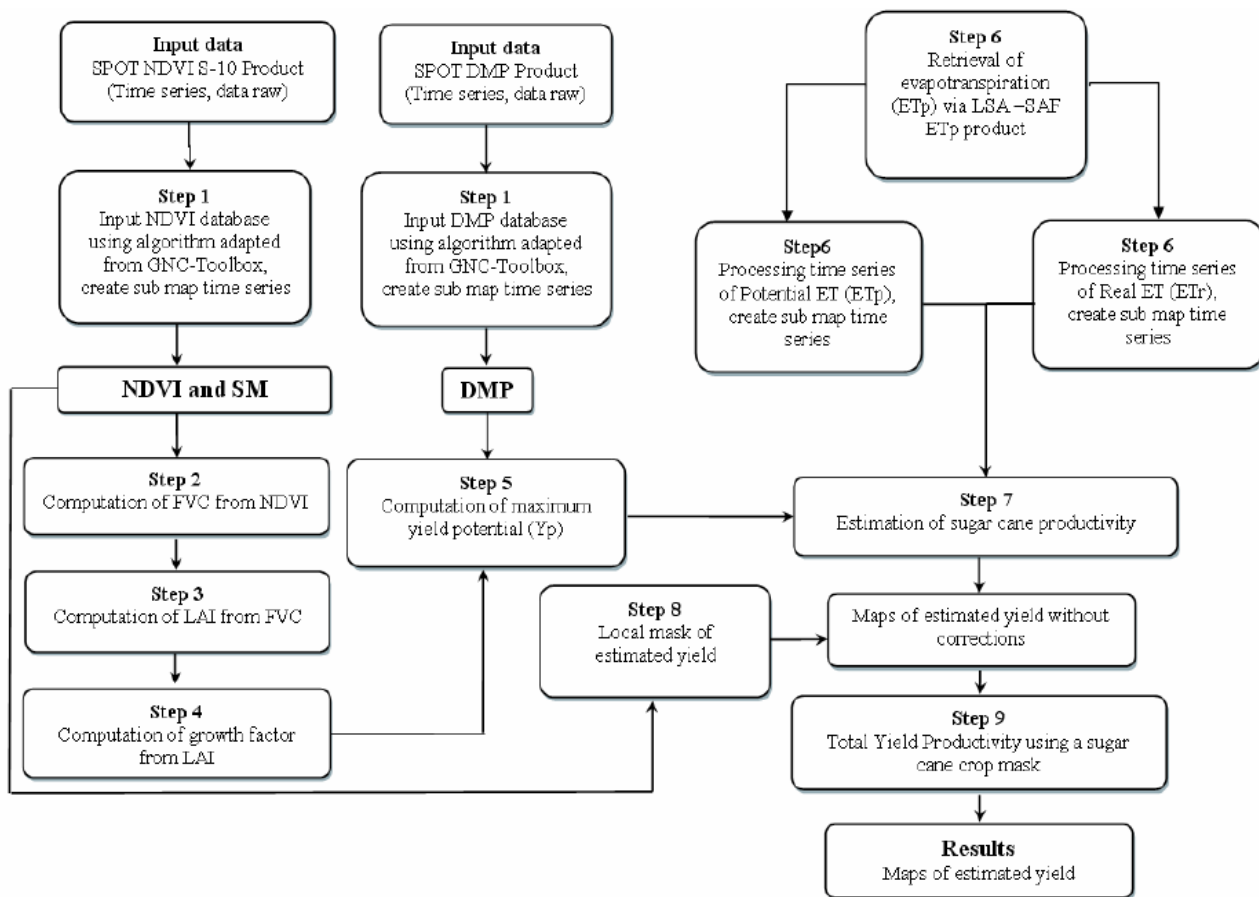
cane productivity using these satellite derived products is shown in figure 1.

## 2.3 Data pre-processing for quantification sugar cane productivity

Ensure that you have unzipped the exercise data and move using the ILWIS navigator to this active working directory. Close ILWIS and open ILWIS again and ensure that the path to your active working directory is correct. In order to minimize the data load for this exercise all time series data (NDVI, with and without status mask, DMP, Etp\_avg and Etp\_std) have been pre-processed and sub maps for the Coruripe Municipality have been created. The pre-processing steps are described in the following section.

## 2.4 Step1: Input NDVI and DMP databases using algorithm adapted from GEONETCast Toolbox

To implement a methodology to import both the NDVI and DMP time series raster data into ILWIS, specific routines available within the GEONETCast-Toobox are adapted for import. Upon import also the status mask was applied, to retain only the map values that meet the flag criteria, such as cloud free, land pixels, good radiometric quality in the Red and NIR bands. For further details see also Chapter 4.5.1.2 as well as Maathuis et al, 2011.



**Figure 1:** Flow chart of the methodology adapted

Open the MapList “NDVI\_Coruripe\_Apr\_Aug” and display the time series as an animated map sequence, using as Representation “NDVI1”. Note that there are 15 maps and each map is representing the decadal NDVI computed using a Maximum Value Composite Algorithm. Map layer 1 represents the 1st decade of April 2010 and map layer 15 is the last decade of August 2010. Move the mouse, keeping the right mouse button pressed, over the active map display window and note the values. From the menu of the active map display window, select the option “Layers => Add Layer” and select the Polygon Map “coruripe”, in the Display Options window unselect “Info” and select the option

“Boundary Only” and press “OK” to see the municipal boundary. Close the Active map window and now display the time series “NDVI\_SM” in a similar manner. Here the status flags have been applied and those pixels that did not meet the flag criteria have been re-assigned as “no-data”, represented by a “?”.

#### Step 2: Computation of FVC from NDVI

The FVC is the one biophysical parameter that determines the contribution partitioning between bare soil and vegetation for surface evapotranspiration, photosynthesis, albedo, and other fluxes crucial to land-atmosphere interactions. The NDVI needs to be converted to FVC. Here

use is made of the formula proposed by Muñoz et al (2005), see equation 1. The flag corrected NDVI time series is going to be used.

$$FVC = 1.1101 * NDVI - 0.0857 \quad (\text{Eq 1})$$

To carry out this calculation for each NDVI map within the time series open from the main ILWIS menu the option “Operations => Raster Operations => MapList Calculation” and provide the information as given in figure 6.2.

Press “Show” to execute the operation, display the resulting time series as an animated sequence, use as Representation “fvc” and check the values obtained using the mouse, keeping the right mouse button pressed, over the active map display window.

### Step 3: Computation of LAI from FVC

The LAI, defined, as the total one-sided leaf area per unit ground area, is one of the most important parameters characterizing a canopy. Because LAI most directly quantifies the plant canopy structure, it is highly related to a variety of canopy processes, such as evapotranspiration, interception, photosynthesis and respiration. The FVC is converted to Leaf Area Index (LAI) by means of the formula proposed by Norman et al (2003), see equation 2.

$$LAI = -2Ln(1 - FVC) \quad (\text{Eq 2})$$

To carry out this calculation for each FVC map within the time series open from the main ILWIS menu the option “Operations => Raster Operations => MapList Calculation”

and provide the information as given in figure 6.3.

Press “Show” to execute the operation, display the resulting time series as an animated sequence, use as Representation “lai” and check the values obtained using the mouse, keeping the right mouse button pressed, over the active map display window. Now also check the command line history from the main ILWIS menu by pressing the “drop down” button on the right hand side of the command line. Note the command line string that has been used to create the LAI time series. It is given by the following string:

```
LAI.mpl = maplistcalculate (" -2*ln(1-@1)",0,14,FVC.mpl)
```

Check the expression, compare it with figure 6.2. Note that in the following sections the command line expressions to calculate a maplist will be given.

### Step 4: Computation of growth factor from LAI

Experimental evidence indicated that the growth rate of several agricultural crop species increases linearly with increasing amounts of LAI, when soil water nutrients are not limiting (Doorenbos and Kassam, 1979). Berka et al (2003) developed a simple approach for deriving the growth rate from the LAI, see equation 3.

$$CGF = 0,515 - e^{(-0,667 - (0,515 * LAI))} \quad (\text{Eq 3})$$

Where: *CGF* = Corrected Growth Factor and *LAI* = Leaf Area Index.

To derive the Corrected Growth Factor (CGF)

type the following equation on the ILWIS command line:

```
CGF.mpl:=maplistcalculate("0.515-exp(-
0.667-(0.515*@1))",0,14,LAI.mpl)
```

Press “Enter” to execute the operation, display the resulting CGF time series as an animated sequence, use as Representation “Pseudo” and check the values obtained using the mouse, keeping the right mouse button pressed, over the active map display window.

#### Step 5: Computation of maximum yield potential (Yp)

The final equation that can be used to derive maximum yield potential (Yp) is based on an equation which includes evaporative fraction corrected growth factor (CGF), respiration factor (BF), agricultural productivity factor (APF) and production of dry matter (DMP) product.

$$Yp = CGF * BF * APF * DMP \quad (\text{Eq 4})$$

Where Yp is the maximum yield potential (kg ha<sup>-1</sup>), BF is the respiration factor (0.5 for temp.  $\geq 20^{\circ}\text{C}$  and 0.6 for temp  $<20^{\circ}\text{C}$ ), APF is the agricultural productivity factor (2.9) as described in Rudorff (1985) and DMP is the Dry Matter Productivity derived from Spot-Vegetation data. First display using an animated sequence the time series “DMP\_04\_08\_coruripe” using as Representation “Pseudo” and check the map values using the mouse, keeping the right mouse button pressed, over the active map display window. Further information on this product can be found in Bartholomé (2006),

the unit is kg/dry matter/ha/day. After you have seen the animated sequence, close the animation.

To calculate the maximum yield potential for each time step, type the following expression on the command line in the main ILWIS menu:

```
Yp.mpl:=maplistcalculate("@1*0.5*10*2.9*
@2",0,14,CGF.mpl,DMP_04_08_Coruripe.m
pl)
```

Press “Enter” to execute the operation, display the resulting CGF time series as an animated sequence, use as Representation “Pseudo” and check the values obtained using the mouse, keeping the right mouse button pressed, over the active map display window. Note that the factor 10 in the expression above is used to convert from kg/dry matter/ha/day to kg/dry matter/ha/decade!

#### Step 6: Retrieval of evapotranspiration (ETp) via LSA –SAF ETp product

The crop coefficient is defined as the ratio of crop evapotranspiration, ETr, to reference evapotranspiration, ETp. Kc is crop specific depending on the crop growth stage and details are given in table 6.1. Crop evapotranspiration at any time during the growing season is the product of reference evapotranspiration and the crop coefficient as given by equation 5.

$$ETr = ETp * Kc \quad (\text{Eq 5})$$

By use of the newly developed LSA–SAF products, one is now able to obtain frequent and accurate measurements of a

number of basic agro-meteorological parameters (e.g. surface albedo, surface temperature, evapotranspiration). The satellite estimated agro-meteorological parameters have several advantages compared to conventional measurements of agrometeorological data using a scattered ground meteorological observation network.

Open the map list “ETp\_avg” and display the time series as an animated sequence, using as Representation “Pseudo”. This maplist has been compiled processing each 30 minutes LSA\_SAF ET-product from 1 April to 31 August 2010. All products have been added on a daily basis, corrected for the time interval, as the product unit is expressed in mm/hr, but the time step is half hourly (therefore the daily sum has been divided by 2). For each decade the respective daily products have been summed and the average was computed to obtain the average ET per decade. Also the standard deviation has been computed and was aggregated to obtain the decadal standard deviation. This map list is called “ET\_std. Display also this map list using as Representation “Pseudo”.

To obtain the crop evapotranspiration the following procedure has been adopted using the time series ETp\_avg and ET\_std data: For the months of April, May and June a crop coefficient was used of 1.68:

$$ETr = (ETp\_avg - ET\_std) * 1.68 \quad (\text{Eq. 6})$$

For the months of July and August a crop coefficient was used of 1.18:

$$ETr = (ETp\_avg - ET\_std) * 1.18 \quad (\text{Eq. 7})$$

Type the following equations in the command line of the main ILWIS menu and press enter and “OK” to execute the operations:

ed. From the main ILWIS menu, select “File => Create => MapList” and add all newly created ETr\* maps in a sequential order to the right hand listing, using the “>” icon. Specify as Map List name “ETr” and press “OK”. Display the newly created map list “ETr” as an animated sequence, using as Representation “Pseudo”, check the map values obtained.

#### Step 7: Estimation of sugar cane productivity

The sugarcane yield estimation model over the growing season, on a decadal basis, is accomplished by using an agrometeorological model (Equation 8) according to Doorenbos and Kassam (1979):

$$Ye = Yp \left[ 1 - ky \left( 1 - \frac{ETr}{ETp} \right) \right]$$

(Eq 8)

where Ye is the estimated yield (kg ha<sup>-1</sup>), Yp the maximum yield (kg ha<sup>-1</sup>), ky the yield response factor described in (Doorenbos and Kassam, 1979); ETr the actual evapotranspiration (mm) and ETp the maximum evapotranspiration (mm). Maximum yield (Yp) is established by the genetic characteristics of the crop and by the degree of crop adaptation to the environment (Doorenbos and Kassam, 1979). The ky factors used here are for April = 1.2, for May = 1.3, for June = 1.2, for July = 1.1 and for



August = 1.1. To calculate the estimated yield the following equations have to be entered from the command line on the main ILWIS menu:

$$Ye1:=Yp\_1*(1-1.2*(1-(ETr1/etp\_avg\_0401\_coruripe)))$$

In the Raster Map Definition window, set the minimum value range to “0” and the “Precision” to “0.01” and press “OK” to execute the operation. Display the map calculated and check the values obtained. Note that each pixel represents an area of 1 km<sup>2</sup> and the estimated yield is expressed in kg ha<sup>-1</sup>! Repeat the Ye calculations for the other decades using the following set of equations (note the change of the Yp) and keep on setting the minimum map value to “0” and use as Precision “0.01”:

After all calculations are performed a new map list has to be created. From the main ILWIS menu, select “File => Create => MapList” and add all newly created Ye\* maps in a sequential order to the right hand listing, using the “>” icon. Specify as Map List name “Ye” and press “OK”. Display the newly created map list “Ye” as an animated sequence, using as Representation “Pseudo”, check the map values obtained. Close all active map windows.

#### Step 8: Local mask of estimated yield

The resulting map list of the estimated yield (Ye) should be clipped to the mask of the Coruripe municipality boundaries in the State of Alagoas, Brazil. Right click with the

mouse button on the polygon map “coruripe” and from the context sensitive menu, select the option “Polygon to Raster”, as GeoReference select “CFG\_Coruripe\_Apr\_Aug\_1”, leave the Output Raster Map name as indicated by default and press “Show”.

Display the map and note the content. Close the map, right click with the mouse on the RasterMap “coruripe” and from the context sensitive menu, select the option “Properties”. Note that the domain here is specified as Identifier “coruripe” and although when looking at the map content the “1” which was indicated is representing an identifier number but not a value. In order to use this map in a calculation we have to change it to a value. Type the following expression in the command line of the main ILWIS menu:

$$mask:=iff(coruripe="1",1,0)$$

Note that from the Raster Map Definition window the domain given is now a “value” domain. Press “OK” to execute the operation. Display the map “Mask” and note the content. Now we can use the mask to extract the “Ye” for the Coruripe Municipality. Type the following expression on the command line in the main ILWIS menu:

$$Ye\_Coruripe.mpl:=maplistcalculate("iff(mask=1,@1,?)",0,14,Ye.mpl)$$

Press “Enter” to execute the operation, display the resulting “Ye\_Coruripe” time series as an animated sequence, use as

Representation “Pseudo” and check the values obtained using the mouse, keeping the right mouse button pressed, over the active map display window.

Step 9: Total Yield Productivity using a sugar cane crop mask

The time series “Ye\_Coruripe” corresponds to the estimated sugar cane yield on a decadal basis. To estimate Total Yield Productivity for whole time series, each decadal period from the Map List Ye\_Coruripe should be accumulated. Enter the following expression on the command line to obtain the sum of the time series and press enter to execute the operation:

$Ye\_sum:=MapMaplistStatistics(Ye\_Coruripe.mpl, Sum, 0, 14)$

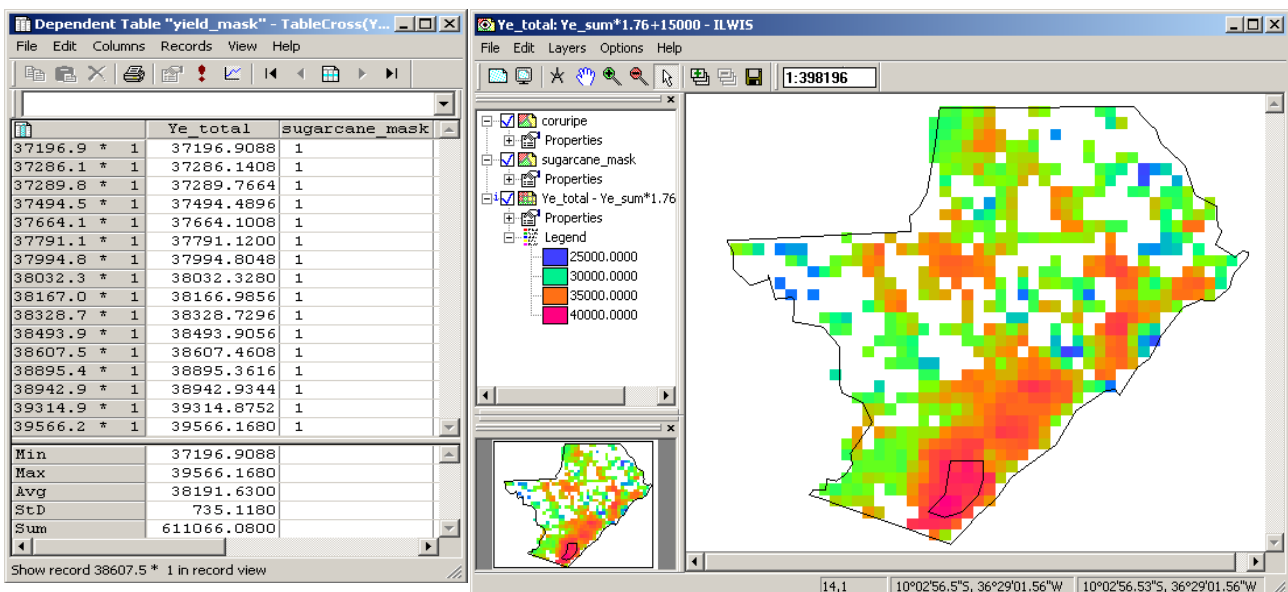
Finally to estimate total yield productivity the average amount of water (76 %) without stress is added to the sugar cane and the initial

weight of the sugar cane stems during planting has to be added as well (here a value is used of 15 ton/ha). Enter the following expression on the command line to obtain the Total Yield Productivity and press enter to execute the operation:

$Ye\_total:=Ye\_sum*1.76+15000$

Right click with the mouse button on the polygon map “sugarcane\_mask” and from the context sensitive menu, select the option “Polygon to Raster”, as GeoReference select “CFG\_Coruripe\_Apr\_Aug\_1”, leave the Output Raster Map name as indicated by default and press “Show”. Display the map and note the content.

Open from the main ILWIS menu the option “Operations => Raster Operations => Cross”. Select the raster map with the total yield productivity, here called “Ye\_total” as 1st Map. Select raster map “sugarcane\_mask” as 2nd Map. Type “yield\_mask” as Output Table



**Figure 2.** Ye-total for the cururipe area and cross results using a sugar cane mask and press “Show”. Note the content of the cross table. The figure below shows the final results of the analysis, using the boundaries of the municipality and the sugar cane mask as overly on the Ye\_total map.

### 3. Summary and Conclusions

For this exercise GEONETCast–EUMETCast data (NDVI S-10, DMP SPOT and ETo) is applied to test a remote sensing approach to improve sugar cane Total Yield Productivity over the Municipality of Coruripe. The test is performed for the period April to August, 2010 and the sugar cane productivity is derived using nine computational steps.

The results show that the methodology adopted has three distinct advantages compared to the generally accepted “ $kc \times ETo$ ” method for computing ET. First advantage is that the acreage of water-using land is observed directly from the satellite products, so accurate land use is implicit to the process. Second, there is no need to incorporate a crop type map to solve the energy balance, so accurate records of cropping patterns are not required.

These features overcome the typical difficulty of assembling accurate records of irrigated areas and cropping patterns, especially for historical analyses. Thirdly, the LSA-SAF ETo (aggregated) product can be imported into a GIS for spatial analysis, either alone or in combination with land use and other spatial data, inherently accounting for the effects of salinity, deficit irrigation or water shortage, disease, poor plant stands and other ET-reducing influences on the ET flux. These influences are difficult to take into consideration using the standard “ $kc \times ETo$ ” computation. Furthermore the software tools

have demonstrated a great flexibility and ease of use.

The results presented in this research show the values of sugarcane production are in the average range of 37 to 40 ton/ha at the level of the municipality area during the test period. The sugarcane area finally selected is showing significantly higher values. This is a first indication where the sugar cane areas can be harvested. Results are very encouraging, through a high spatial variability of crop yield is found, suggesting adjustments are needed to transform the original satellite data-based scheme into satellite estimated agro-meteorological parameters. Further studies are required to analyse these results into more detail as these depend for example on the spatial resolution of the input background fields, their physical content and many other factors. Furthermore there is a need to use a longer time series and analyse into more detail the temporal response of e.g. the DMP of the study area.

These finding present a first step towards an operational use of ILWIS in Brazil using NDVI S-10, DMP SPOT and ETo for operational estimating of sugar cane productivity. This preliminary assessment demonstrates the feasibility of the proposed methodology to be useful in homogenous areas with the same characteristics and to focus on the control factors and incorporate local information to enable better model calibration and thus improve the results.

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