Title: Methodology to generate yield maps of maize crops
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Abstract

During the last decade an increase in maize production has been observed in Mexico. Maize is the main staple crop in this country. The production increased from 26.2 millions ton in 2007 to 28.7 millions ton in 2008. So, the maize production does not meet the internal demand and annual imports are required, around 5 million tons are imported from the USA.

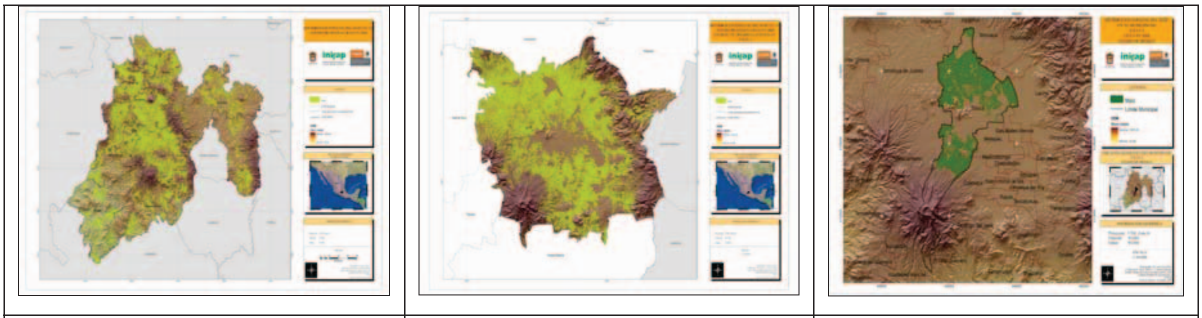
In central Mexico, specifically in the State of Mexico maize is cultivated under different technological regimes ranging from traditional rain water dependency and native seeds producing yields of under 1.0 ton/ha, up to irrigation and improved seeds regimes with yields above 12.0 ton/ha. The average state yield harvested area for this crop in the past 10 years has been 549, 000 ha with an average yield of 3.22 tons/ha and an overall average of 1.8 million tons of grain (Soria-Ruiz *et al.,* 2007). On the other hand there is a notorious decline tendency in cultivated area.

Precision farming (PF) is a system of advanced technologies and procedures which merge spatial mapping variables of the terrain and surrounding conditions with specific management actions for crops. PF requires the integration of several basic component systems such as global positioning system (GPS), data collection and processing devices based on remote sensing and geographical information management systems. Measurements provided by these systems are oriented towards assessing the terrain characteristics and spatial variability and orienting the management actions to the best practice in manner, time and place.

Crop monitoring involves estimating crop yield within a geographic area and over a certain time and producing final maps depicting with varied colors and tones the expected yield ranges of different areas for the crop. These results can then be subjected to post-harvest accuracy assessment to produce the maps that are distributed to government agencies, producer associations and research institutions. Crop monitoring and evaluation towards PF objectives include acquisition, analysis and synthesis of crop yield data and their precise location within the areas of interest using satellite images and specialized software.

In developing countries the official agricultural statistics such as cultivated areas, yield and production volumes lack credibility due to the shortcomings of traditional on the field sampling and producer survey methods which are employed. It is important to upgrade the methods and procedures using advances in geo-science and associated technologies to monitor crops. To this end this six year study aimed at generating a methodology to obtain yield maps of maize crops (*Zea mays*) from SPOT satellite images and geo-referencing of pilot plots with PDA-GPS and other equipments for crop monitoring and yield assessment on the field. The study was carried out over the period 2004-2009.

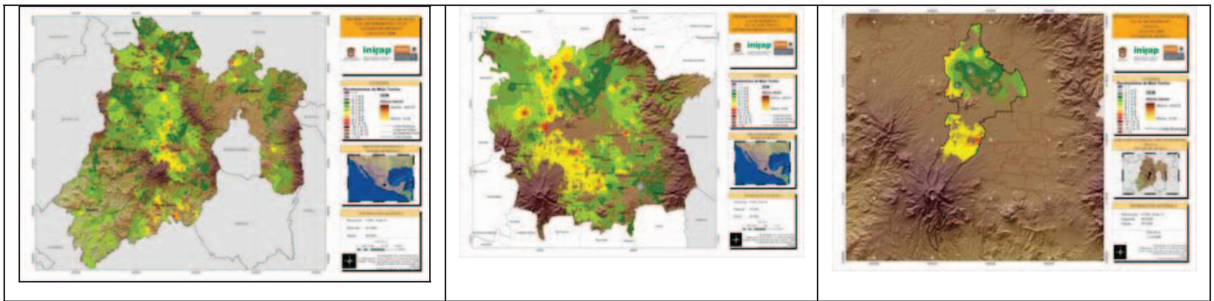
To obtain the cultivated area, SPOT panchromatic and multispectral satellite images were processed over the growth and development stages of the plants (Figure 1). In the cultivated areas sample yield data were collected, geo-referencing the collection sites with geographic information management products (ESRI, 2004). These data were spatially represented via interpolation using the inverse weighted distance method (Mitas & Mitasova, 1999); the final products were yield maps at different cartographic scales (Figure 2) (Soria-Ruiz *et al.*, 2009). A yield map graphically represents the collected data resulting from the direct field monitoring for which we used in first instance information layers of the spatial distribution of the crop derived from the remote sensing data analysis, the DEM and terrain slope information, as well as 2400 geo-referenced sampling points providing yield data from 2004 through 2009.



(a) (b) (c)

Figure 1. Cultivated surface of maize at: (a) state level, (b) regional level and (c) municipal level from SPOT satellite images in Central Mexico.

125 yield maps were obtained at the municipal level, eight regional maps at rural development district (DDR) level and a state yield map. The 14 yield ranges are separated into three levels: less than 3.0 ton/ha, which are considered low yield; from 4.0 to 6.0 ton/ha, which are considered as medium yield; and over 7.0 ton/ha, which are labeled as high yield.



(a) (b) (c)

Figure 2. Yield maps of maize at: (a) state level, (b) regional level and (c) municipal level in the State of Mexico.

A summary of the methodology is graphically shown in Figure 3 (Soria-Ruiz, 2008). Yield maps are useful as quick references with a 91% degree of accuracy since the information source is backed by a data base of historic yields collected over six full agricultural cycles. This information source supports decision making for three levels of government in Mexico (federal, state and municipal) mainly for the aid programs to the rural sector and more specifically for maize producers.

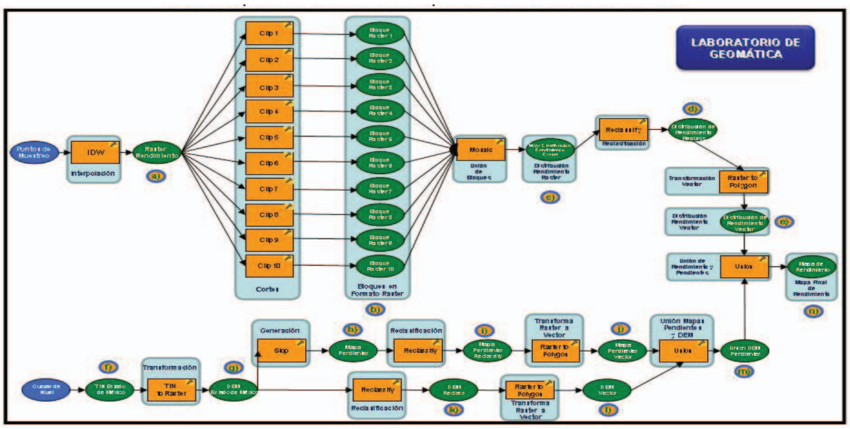


Figure 3. Methodology to generate yield maps of maize from field data.

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