Quantifying spatial and temporal patterns of the water related yield gap, using synoptic data and a dynamic Crop Growth Model (PSn) - A Case Study of Sunflower in Andalucia, Spain

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ABSTRACT

Various approaches and methods have been developed to quantify yield gap constraints to crop production. Among land factors, water plays an important role in determining yield gap, especially in regions where land management factors are homogeneous. The aim of this study is to quantify the spatial and temporal patterns of the water related yield gap by using synoptic data and a dynamic Crop Growth Model.

A combination of data from weather station and remote sensing data (from MODIS imageries) were applied to calculate the potential and water limited yields of sunflower in Andalucia for 5 years (2001 – 2005) by Production Situation Model (PSn) level 1 and 2. Point results were extrapolated to the region using regression models with Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) from MODIS imageries. PSn model successfully identified the variability of potential and water limited yields of sunflower in space and time. Using remote sensing data, it is possible to extrapolate this variability to broader scale.

The output maps of water limited yield gap prove that water is a main limiting factor causing yield gap for sunflower in Andalucia. For every year, this factor contributed more than 60% to overall yield gap of sunflower in most areas. Thus, less than 40% of overall yield gap was caused by other limiting factors of land and management. Map produced by this study could be a reference for farmers and decision makers in improving the production of sunflower in Andalucia.

Keywords: PSn model, Water limited yield, yield gap, sunflower, Andalucia

1. INTRODUCTION

Various approaches and methods have been developed to research on yield gap constraints to improve crop production and assist to gain food security. One of attractive methods is called "Comparative Performance Analysis" (CPA)(De Bie, 2000). The principle of this method is to identify and quantify all factors of land and management that cause a gap between actual and potential yield of a certain crop in an area. In this method, factors as shown in table 1 can be identified and their impact also can be quantified.

Recently, some researchers have used the data from remote sensing (temperature, rainfall, NDVI) for estimating the crop production for food security purposes (Metternicht, 2003; Rugege, Bouma, Skidmore, & Driessen, 2002; Venus, 2000). These researches have been found to be very useful for crop production estimation and contributed to improve the crop growth simulation techniques as well as crop modelling methods. Although it has been very practical of using those RS data for estimating the crop production, these spatial factors (derived from satellite images or from weather station based data) have not been used as based attributes for mapping the yield gap and improving the methodology of yield gap analysis.

Beside the CPA, the "Production Situation Model" (PS-n) can be used with weather based data (temperature, precipitation, relative air humidity and ETo etc) to estimate crop potential and water limited yields in study areas (points). The principle of this model presents a simplified Land Use System in which crop production and yield are solely determined by availability of light, the temperature, the photosynthetic mechanism and other factors.

The main idea of this research is to combine the use of Production Situation Model (with data from weather stations), remote sensing data and techniques to quantify the water related yield gaps of Sunflower in space and time following CPA logic.

2. METHOD

2.1 Study area

Andalucia is an autonomy region located in the south of Spain. It is composed of 8 provinces including: Sevilla, Malaga, Almeria, Cadiz, Cordoba, Granada, Huelva and Jaen, stretching from Southeast to Southwest of the country. The total natural area is of 87,300 sq km (17.3% of Spanish territory) with total population estimates of 7 million people (20% of Spanish total population).

Andalucia is the home of olive and sunflower cultivation in Spain. Besides that, the main agricultural crops of this region include wheat, barley, fruit, grape and vegetable. Due to the influence of specific climate condition (hot in summer and cold in winter), Andalucia has produced very good products and olive (fruit and oil) and grape wine meanwhile it provides most of sunflower oil in EU. Figure 8 presents the agricultural area in Andalucia which is home of grape, olive, wheat and sunflower.

2.2 Field data collection

2.2.1 Sampling scheme

In order to make a random sampling scheme, a crop map of sunflower for the study area was developed (figure 1). This map was made through image classification of SPOT-VGT NDVI images in combination with crop statistic data and Corine (land cover map) with GIS analysis.

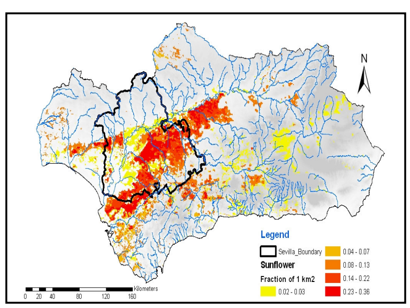

Figure 1: Crop map of rain-fed sunflower in Andalucia

Based on the crop map of Sevilla province, the method of strata sampling scheme was applied. The buffer zones were created around the main towns with a distance of 20 km from every town. These buffer zones were chosen to conduct the interview with farmers for data collection. Due to high fraction of sunflower in these areas, the interviews have been conducted randomly in any farm of the strata.

2.2.2 Field data collection

Most of field data were obtained by two traditional methods: observation and through interview. The observation was used to collect data that related to land at plot size such as soil quality and current operations on the field. Meanwhile, the interview (by semi-structured method) was applied to obtain the data related to land use operations (management) such as land preparation, soil treatment, planting time, fertilizer application, water shortage and yield etc. All the data from interview were used to discuss about the variable of land and land use operation and to develop the assumption for the research. In this fieldwork, statistical data of sunflower actual production in Andalucia (from Ministry of Agriculture, Spain) from 2001 to 2005 were also collected. In this data, the actual production of a certain crop (sunflower, wheat etc) is recorded for different random selected strata of 700 m x 700 m in Andalucia.

2.3 Research flowchart

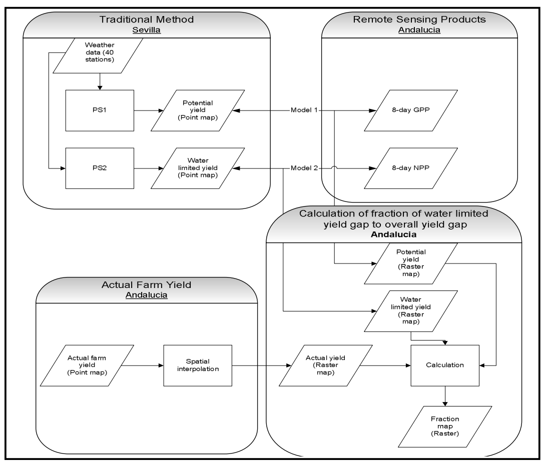

Figure 2: Overview of research method

3. RESULTS AND DISCUSSION

3.1.Potential yield of sunflower calculated by PS1 model

Production Situation Model (PS1) was used to calculate the potential yield of sunflower in 40 weather station points in Sevilla province. These yield values were defined by climate factors of solar radiation and temperature (Driessen & Konijn, 1992). Based on the variation of climate in space and time, the potential yields are also variable from plot to plot and from year to year.

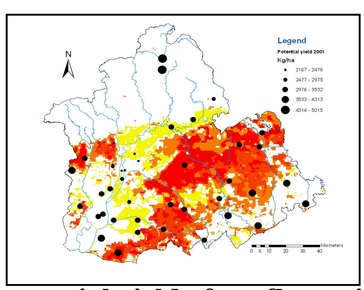

Figure 3: Point map of potential yield of sunflower in Andalucia, year 2001

To extrapolate the point map of potential yield (40 points) to raster map of whole sunflower cultivation in Andalucia, the step-wise multiple regression has been conducted to quantify the correlation of potential yield value and GPP values (figure 4). The regression analysis (linear, step-wise) results show that there is a significant correlation between potential yield of sunflower and GPP values through many 8-day periods (16 periods):

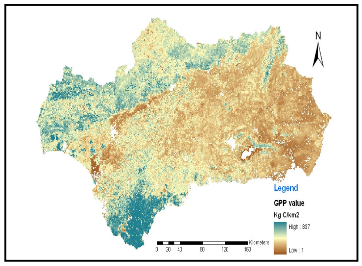

Figure 4: One of GPP images from MODIS, used for potential yield extrapolation

Based on the regression analysis, the correlation between potential yields of sunflower and GPP values in 2001 is:

$$Potential\ yield\_2001 = 7.401*GPP81 + 11.989*GPP121 + 5.531*GPP177$$

Apply this equation to GPP images, the raster map of sunflower potential yield is produced and presented in figure 5:

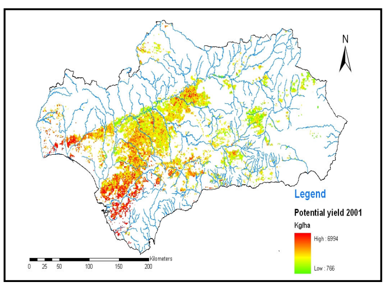

Figure 5: Raster map of potential yield of sunflower in Andalucia, year 2001

3.2.Water limited yield of sunflower

The results of PS2 calculation for water limited yield of sunflower in 40 points of Sevilla province is showing in figure 6.

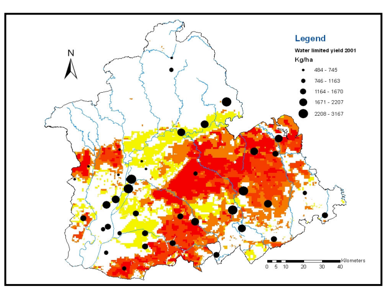

Figure 6: Point map of water limited yield, year 2001

The correlation between water limited yield of sunflower and NPP values through 16 eight day period is presented by statistical analysis (linear multiple regression).

$$Water\ limited\ yield\ (2001) = 29.361*NPP81 + 75.486*NPP153$$

Apply this equation into the NPP images, the raster map of water limited yield of sunflower year 2001 is produced and presented in figure 7.

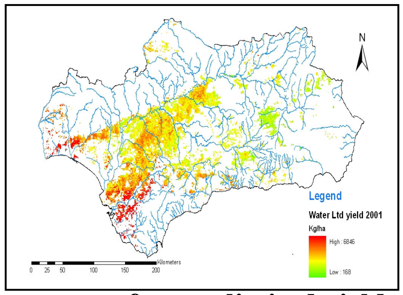

Figure 7: Raster map of water limited yield, year 2001

3.3.Yield reduction of sunflower due to water shortage

The result of raster calculation (potential yield minus water limited yield) for every year shows the patterns of water limited yield gap. A raster map of these patterns for year 2001 is presented in figure 8.

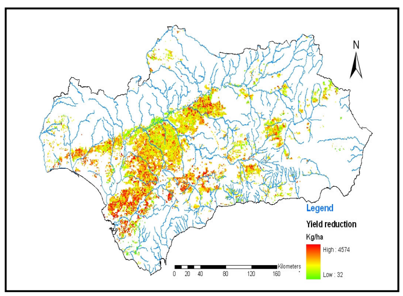

Figure 8: Yield reduction of sunflower due to water shortage, year 2001

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The Production Situation Model can be used to identify the variability of potential yield of sunflower in Andalucia during five years (2001 – 2005).

The 8 daily product of Gross Primary Productivity (GPP) which cover the space and time of sunflower growth can be used to extrapolate the potential yield of sunflower from point data to raster with the resolution of 1 km2 a pixel. The regression analysis shows that there was a strong correlation of potential yield and GPP values calculated in the time the sunflower grew. However, this correlation was different from year to year.

The Water Sufficiency Coefficient (cfH2O) aggregated for 8-day period can be used to calculate the 8-day basic water limited yield from potential yield instead of using daily data.

The final maps of water limited yield gap could quantify the patterns of water limited yield reduction in space (the variability of yield gap from plot to plot) and in time (the variability of this gap during 5 years).

The water shortage (drought) was a main limiting factor causing yield gap of sunflower in Andalucia. This factor contributed more than 60% to the overall yield gap in most area of sunflower cultivation in Andalucia for every year. It is a significant result of this research to consider the intervention for narrowing the yield gap of sunflower in Andalucia by irrigation supply.

Beside the water shortage, there are other factors causing yield gap for sunflower in Andalucia. These factors also would be variable in space and time. However, in most area, they contributed less than 40% of overall yield gap of sunflower in Andalucia.

4.2.Recommendations

The water shortage situation (drought) in Andalucia contributed more than 60% to the overall gap of sunflower (in most area). Another gap component (30 to 40%) could come from other constraints or limiting factors like soil or land management. Supplying enough water for sunflower cultivation should be taken into account in order to improve the productivity of this crop in Andalucia.

The maps of quantified patterns of water limited yield gap and overall yield gap of sunflower could be a reference for farmers or decision makers in implementing intervention or making plan to improve the agricultural production in the area.

5. REFERENCES

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