

# DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR NATURAL DAMAGE ASSESSMENT BASED ON REMOTE SENSING AND BIO-PHYSICAL MODELS

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## ABSTRACT:

Recent developments in aerospace survey technology, modelling of crop production processes, and geographic information systems have created promising opportunities for agricultural resource management. One of the potential fields of application is in the agricultural risk management, in particular in assessing the impacts of natural hazards on agricultural productions. This seems to be the bottleneck and one of the critical issues in agricultural risk management everywhere in the world, especially in Iran. This paper presents the findings of a joint research program between a number of local and international organizations to consider the state of the art development in remote sensing technology, biophysical science, the local infrastructure and to develop an appropriate model for natural hazard impact assessment on the agricultural production.

## 1. INTRODUCTION

Agricultural crop insurance has been used as one of the major supporting policies for agricultural development in many countries, as it tends to reduce farmer's risk and protect them against production failure due to natural hazards. Risk is defined as the possibility of meeting danger or suffering loss as results of an undesired event in the future, and insurance is the business of transferring risk that is based on uncertainty and the effect of an adverse or harmful event (SSYS Consulting, 2000). Organizations and individuals learn to mitigate risk and provide for risk in different ways. One way to mitigate the financial implications of a future event is to transfer the liability of potential losses arising from the event to another party, through insurance.

Agricultural insurance therefore, is often characterized by moral hazard and high administrative costs, due, in part, to the risk classification and monitoring systems those insurers must put in place to forestall asymmetric information problems. Other costs include acquiring the data needed to establish accurate premium rates and conducting claims adjustments. As a percentage of the premium, the smaller the policy, typically, the larger the administrative costs (World Bank 2005).

In this context the Iranian Ministry of Agriculture has launched an insurance policy to cover farmers against natural disasters and promote agricultural development. The policy is covering the production losses of the major agricultural productions due to flood, frost, hails, intensive rainfall and droughts. The Iranian Insurance Agency who is responsible for the implementation of the policy is facing serious challenges regarding the overall costs, low financial performance (under 20), establishment of proper rates, assessments of damages and handling the related claims. To improve the situation a joint research program between a number of international and local organizations was formulated to develop an appropriate model for natural hazard impact assessment on the agricultural production. This research

considers the state of the art development in remote sensing technology, biophysical science, with the existing local infrastructure. The main international organizations have been ITC, Wageningen University, WaterWatch consulting firm in the Netherlands, the International Rice Research Institute in Philippines and from Iran the main contributing organizations were the Agricultural Insurance Funding Agency, Iranian Rice Research Institutes and the Iranian meteorological organization. In this context, a prototype model for natural hazard impact assessment on rice production in Sumea-sara Township in Gilan province (north of Iran) has been designed, developed, and evaluated for the growing period of 2006. The study area has typically local (strong flavour; low yield; good price) and high yielding rice varieties (no flavour; high yield; moderate price). A wide range of crop yields can thus be expected. This paper briefly presents the finding of the research.

## 2. METHODOLOGY

To assess the impacts of natural hazards on rice yield production, a yield model which simulates the biomass production of the rice in the course of growing period was developed and applied. The model is making use of high and low resolution temporal satellite imagery which is collected in the course of the growing period, the SEBAL model (Bastiaanssen and Ali 2003; Zwart and Bastiaanssen, 2007) and daily meteorological data. An important input in the SEBAL models are standard meteorological data obtained from several stations in the area. During the growing season these data were collected, analyzed and interpreted. Thirteen cloud free MODIS/Aqua images were selected (May 8 to September 1, 2006) and together with the instantaneous, average daily and 10-daily averages meteorological data from Rasht weather station were processed using SEBAL model. This process resulted in maps of potential, actual and deficit evapotranspiration, biomass production (total dry matter related to stem, leaves, roots and grains), soil moisture and yield reduction caused by

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extreme temperature, drought, vapour pressure deficit maps for each decade.

The MODIS results have a resolution of 250 meter which is too coarse to distinguish individual fields. Therefore the MODIS products were upscaled to field level with SEBAL results of high resolution Landsat images (30 meter), which is suitable for detecting rice at field scale. The upscaled model results were

### 3. SYSTEM COMPONENTS AND IMPLEMENTATION

The rice damage assessment system as designed and developed is composed of several modules as follows (Figure 1):

- **Rice land cover map**, based on temporal Landsat data
- **Biomass assessment**, based on 10-daily MODIS biomass production maps, and monthly Landsat biomass production

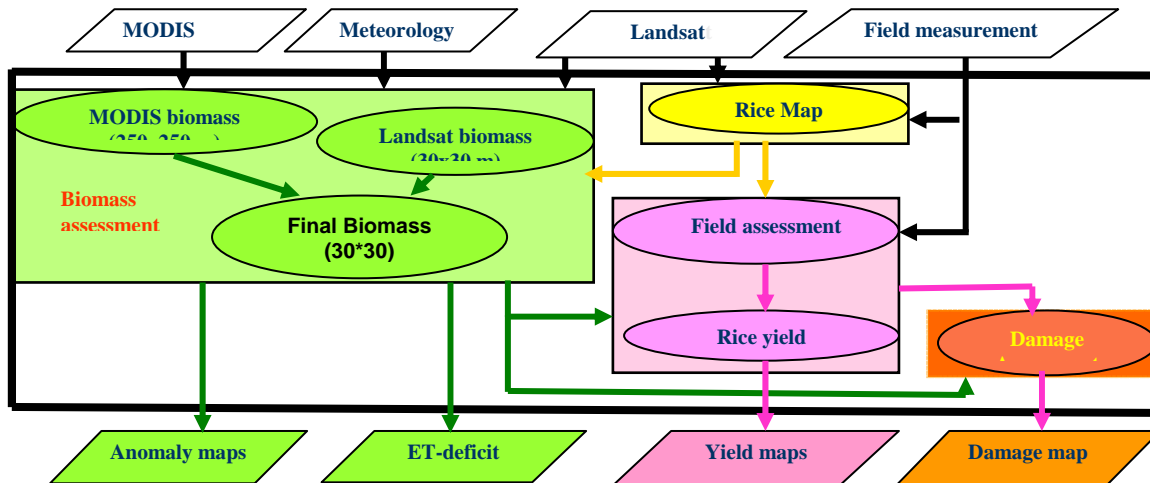


Figure 1. modules (each module in one colour) of the Damage Assessment System.

calibrated using field measurements of dry matter production and yield in the pilot area in more than 200 locations.

To assess the impacts of natural hazard on yield two different methods, one based on biophysical and the other based on empirical relations were designed and applied. The biophysical approach tries to detect the impact of natural hazards on rice yields, by estimating yield losses due to meteorological conditions that temper photosynthesis. Yield losses or yield gap is defined as the difference between a hypothetical potential yield and the actual yield calculated by SEBAL model. The impact of low and high temperature extremes, vapour pressure deficit and water shortage was quantified during growing period. The remaining part of the yield loss that could not be explained was caused by factors that cannot be directly measured with remote sensing and crop growth modelling. These include farm management, hail and rain storms, soil organic matter, amongst others. The impact of these events was detected using a time series of NDVI maps that were derived from MODIS satellite images acquired throughout the growing season. A fitting model was established on a pixel by pixel basis to establish the rice growing period. Anomalies from this model were mapped and related to the events that could have had impact on the yield production (rain events, hail, frost, flooding, etc.).

The empirical approach compares the derived yield or biomass at each point in time with its corresponding yield or biomass average of the same period (point in time) at village, sub-district and township level. In this approach, it is assumed that a natural hazard will not only affect one field but will affect a larger area; therefore the yield per point is compared with the averages of its neighbourhood to assess the impacts of the natural hazards. In practice the combination of the two is more fruitful. Finally a Damage Assessment System (DAS) was developed to organize input maps and images, visualization, and facilitating the analysis (Sharifi 2007).

maps, measuring growing period per pixel based on time series of MODIS NDVI time series, and assessing biomass on 30 meter resolution, The SEBAL model was applied to obtain biomass production maps..

- **Rice yield assessment**, converting the biomass map into the actual rice yield. The conversion is carried out through harvest index which is derived from field measurements
- **Natural damage assessment**, combing the derived layers and provide potential damage extent and intensities.

The main objective of the DAS was to measure the extent, and intensity of natural hazards and their impact on the obtained rice yields. In fact the system should help verifying the existence of any natural hazard, and measuring its extent and impact on the rice yield per farm, so that it could be used by insurance company to process the damage claims that is coming from farmers. This means that the result has immediate legal, social and economical impacts and therefore the result has to be reliable and accurate. To derive this product, the DAS will basically monitor the rice production process at each point (pixel) from cultivation to harvesting date. In this process large amounts of information (over 700 map layers) is generated that have their own specific applications. The generated information includes:

- Accumulated values of biomass production per decade.
- Accumulated values of actual and potential evapotranspiration and evapotranspiration deficit (defined as potential minus actual evapotranspiration as an indicator of drought) per decade.

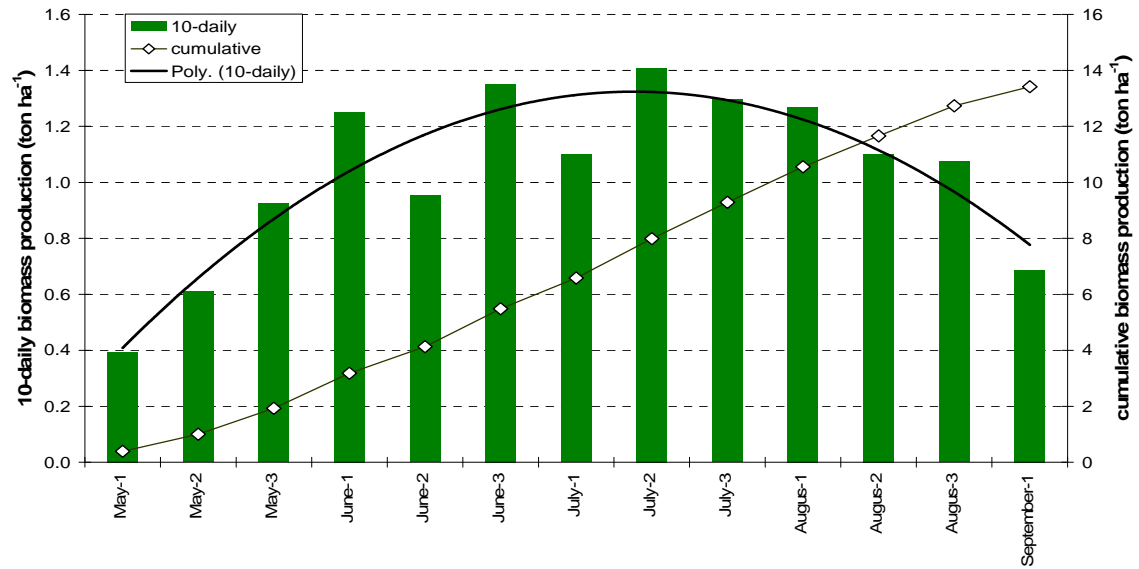


Figure 2. Average ten-daily and cumulative (May 1, September 10<sup>th</sup>) biomass production for rice in the pilot area.

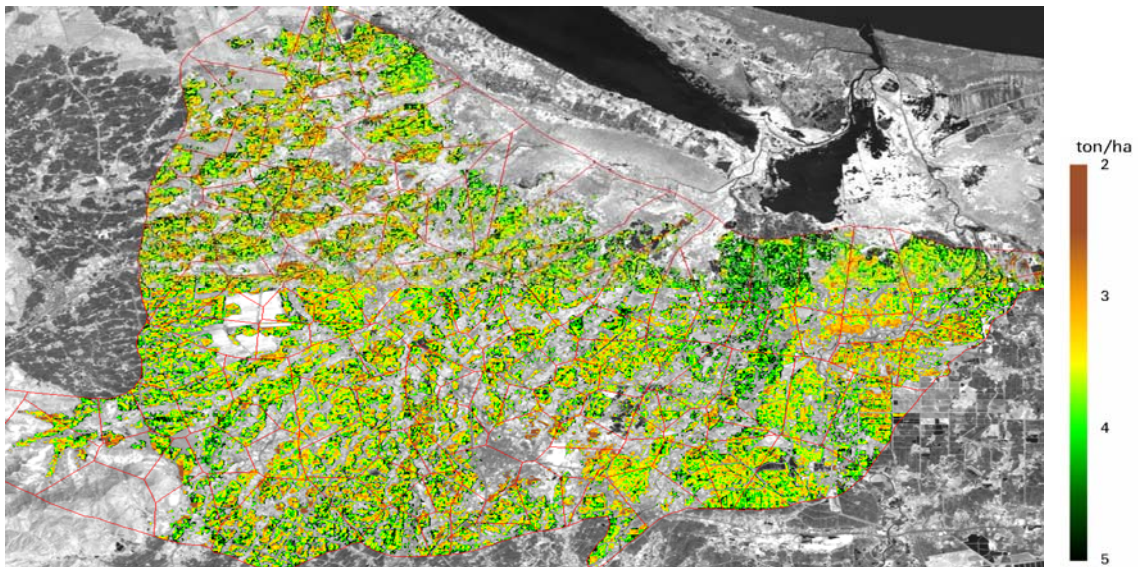


Figure 3. Rice yield map at 30 meter resolution.

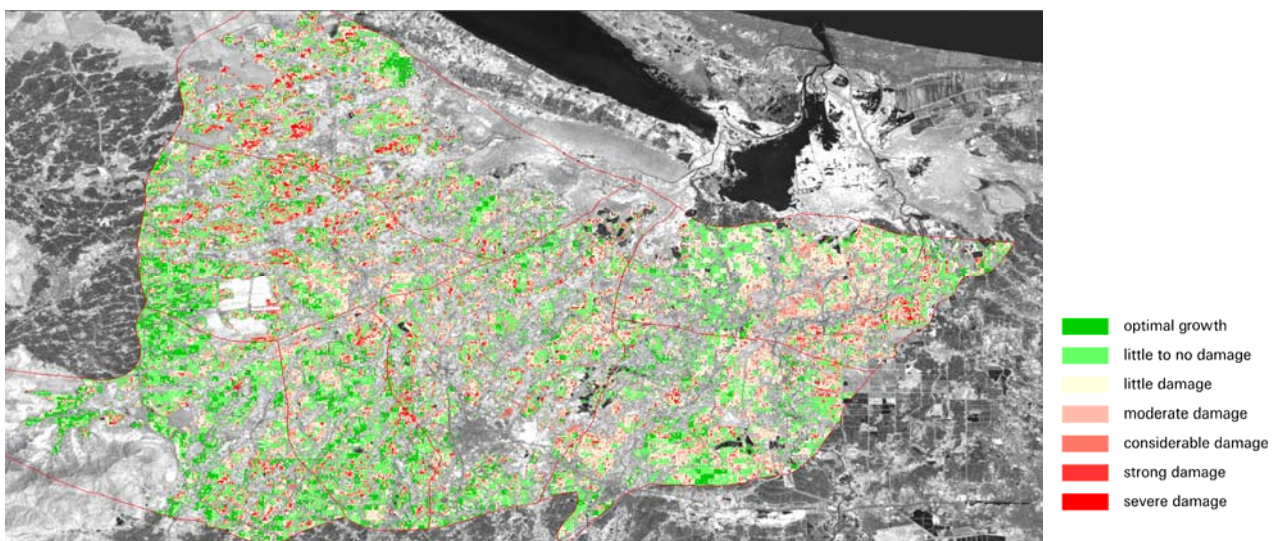


Figure 4. Potentially affected areas.

- Average soil moisture for each decade.
- Crop growing period (cultivation, harvesting dates per pixel) and accumulated biomass production.
- Seasonal accumulated ET and water productivity maps.
- Trend analysis of all the above indicators.
- Land use/cover and anomaly maps.
- Meteorological grids of 1 km resolution for standard weather parameters (air temperature, relative humidity, cloud cover and wind speed) for each day in the growing season.
- Precipitation maps with daily intensities. As an alternative for measured rainfall from meteorological stations, the daily and monthly precipitation products from the Tropical Rainfall Measurement Mission (TRMM) were analyzed and tested for accuracy.

#### 4. RESULTS

Thirteen cloud free MOIDS/Aqua images were selected (May 8<sup>th</sup> to September 1, 2006) and together with the instantaneous, average daily and 10-daily averages meteorological data from Rasht weather station were processed using SEBAL model. The process resulted in potential, actual and deficit ET, biomass production (total dry matters related to stem, leaves, roots and grains), soil moisture and yield reduction caused by extreme temperature, draught, vapour pressure deficit maps for each decades. The average biomass production (Figure 2), for the entire period was 13.4 tons per hectare (between 10-17). This was based on the assumptions that all fields were cultivated first May and harvested on August 31 which does not count for all fields. To correct for this an automated procedure was developed to determine the start, end and length of the rice growing period for each pixel using a time series of 18 NDVI maps between May and September (WaterWatch, 2006). The results were then used for calculation of the seasonal biomass production. In the same process maps of the sudden changes of NDVI "anomaly" in the growing season were also generated. At the next step the MODIS 250 meter biomass was up scaled into a high resolution 30 meter paddy rice yield map. This was carried out in three stages:

- Compute accumulated MODIS biomass production for three periods by incorporating the growing season start and end.
- Upscale the accumulated biomass production map of step 1 with three Landsat high resolution relative biomass production maps from May 30, July 17 and August 2.
- Calibrate the high resolution seasonal biomass production map with field measurements of paddy yield.

Biomass was converted to yield through the harvest index (HI), which was established based on measurements of biomass and yields of 224 (1 by 1 meter) field samples. An average harvest index of 0.45 was measured with 14% moisture. Since this index did not include under ground biomass, a new harvest index was calculated considering the averages field measurements at 224 points (3.7 ton) and the estimated average SEBAL biomass (11.9 ton). The new harvest index (0.31), was then applied to convert the SEBAL high resolution biomass map into fresh paddy yield at 14% moisture (Figure 3). For validation, the model results in 59 fields were compared with the actual field data which were collected by the ministry of Agriculture. The results are presented in table 1 and Figure 5.

As it can be seen from the table and figure the regional accuracy of the model defined by the mean yield difference of

the 59 fields is around 0.04 tone per ha (in the order of % 1) and the point accuracy defined by RMSE is 0.402 kg/ha with a CV of around 11%, which are satisfactory results. The regression coefficient ( $r^2$ ) between the filed measurements and the model yield equals 0.49, which in comparison to the critical value of 0.330 for the 99% confidence interval, shows a significant relation between the two values.

To support damage assessment, a potential damage map was produced. This map is resulted from combination of yield, yield gap (potential yield – the reductions caused by temperature, vapour pressure deficit and draught), and anomaly maps (Figure 4). This map together with all the other products was integrated into a DAS which can support the insurance company to verify and process the claims coming from framers. The system helps assessors to compare the yield at each point with its average at village, district and township levels. It further allows detailed study of the behaviour of various indicators affecting the yield in the course of growing season (Figure 6).

	field reported yield (ton/ha)	modelled yield (ton/ha)	difference
Mean	3.57	3.61	-0.04
Median	3.6	3.59	0.01
Mode	3.5	3.3	0.20
Stand.deviation	0.44	0.33	0.11
Minimum	2.4	2.8	-0.38
Maximum	4.3	4.7	-0.40
Count	59	59	
Mean bias error of model versus field results			-0.04
Variation of errors with respect to mean field results (CV)			0.11
Root mean square error of model results (RMSE)			0.40

Table 1. Comparison of field and model results for several villages in the pilot area.

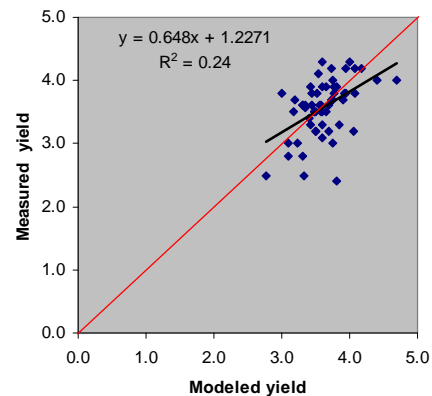


Figure 5. Modelled against measured yield in 59 sample points. The one to one line is presented for comparison.

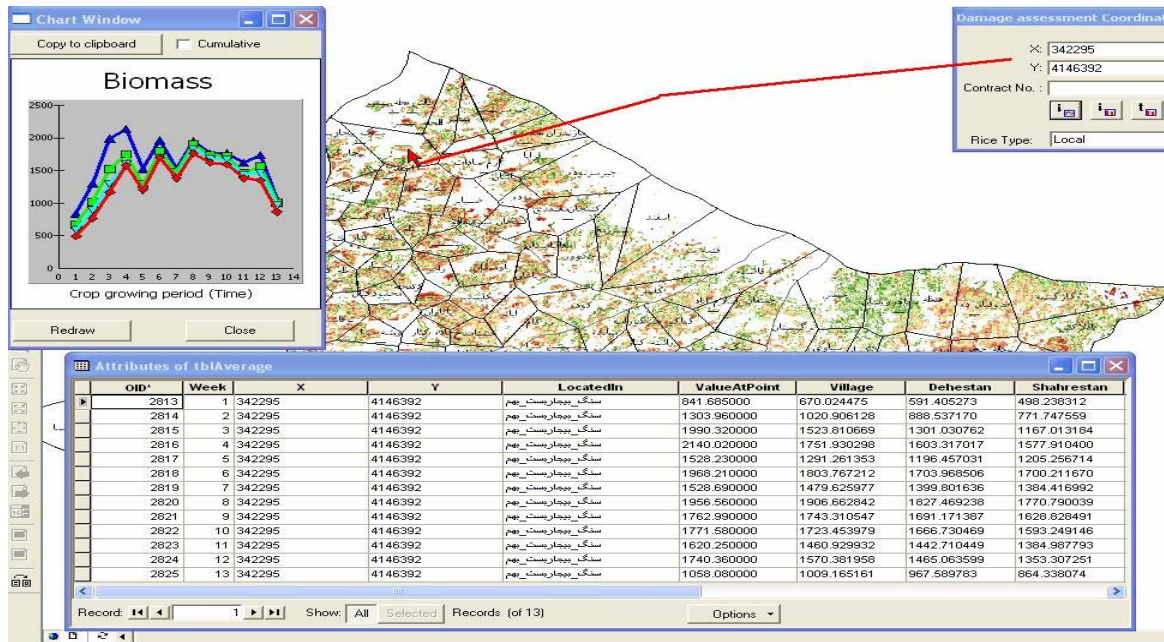


Figure 6. an output of DAS showing the trend of biomass production in the growing season as well its comparison with its average at different administration levels.

## 5. CONCLUDING REMARKS

The results of this pilot study have demonstrated that the combination of remote sensing and biophysical models can provide valuable detailed and quantified data for agricultural insurance banks. The introduction of these products into a Damage Assessment System (DAS) has resulted in a powerful tool to quickly assess damage to yields that were caused by different natural hazards. The quality of actual and potential yields maps was found to be good and the next steps will be to apply the system for larger areas and to further test and improve the DAS. This should finally result in an operational system that supports agricultural insurance bank to quickly judge claims from its clients.

## REFERENCES

Bastiaanssen, W.G.M. and S. Ali, 2003. *A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan*. Agric. Ecol. Environ. 94, pp. 321-340.

ESYS Consulting, 2000. *Earth Observation responses to Geo-Information Market Drivers*. pp 34

Sharifi, M.A. 2007. Development of a support system to assess the impacts of natural hazard on rice cultivation: the case of sume-sara, Gilan province, Iran. Project Report. pp 87

WaterWatch, 2006. *Natural Hazard Damage Assessment of rice yield in Gilan Province, Iran*. Final report, pp. 44.

World Bank, 2005. *Managing Agricultural Production Risk, Innovations in Developing Countries*. Washington DC, pp. 114.

Zwart, S.J., W.G.M. Bastiaanssen, 2004. *Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize*. Agric. Water Manage. 69, pp. 115-133.

Zwart, S.J., W.G.M. Bastiaanssen, 2007. *SEBAL for detecting spatial variation of water productivity and scope for improvement in eight irrigated wheat systems*. Agric. Water Manage. 89, pp. 287-296.

