SATFARMING: A decision support system coupling remote sensing and crop modeling

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Abstract
Satfarming is a decision support system coupling remote sensing and crop modeling to evaluate in real time and forecast crop growth and development to optimize farmer's decisions. Remote sensing component embed satellite imagery from Sentinel (ESA) and crop modeling is based on a software which simulate plant growth and development from weather data and soil information. Satfarming is the first system using both technologies together.From remote sensing technology, crop biophysical variables can be estimated as Leaf Area Index (LAI), Leaf Chlorophyll Content (Cab), Crop Nitrogen content,biomass. Intra and inter field variability is highlighted allowing specific analysis on various geographic scales. Crop identification is performed through field and crop spectral profile comparison.Field scouting and statistical analysis are used as a diagnosis tool for the areas of interest. The crop model parameters are tuned with remote sensing data (LAI, Cab), it is a good complement to RS data because, using daily weather data, it can calculate elements non detectable by the satellite (ears and grain developpement). The combination of the two complementary systems produce a good estimation of crop health status and forecast interaction between climate, plant and soil. The the system has two objectives: optimize farmers inputs efficiency and preserve environment by generating inputs modulation maps. Satfarming imbed services like ground measurements to check computing procedure accuracy in the fields and digital images processing to estimate fraction of cover vegatation and plant counting.

Keywords
Remote sensing — Crop modeling —Field management— Precision Agriculture

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INTRODUCTION

Remote sensing uses satellite imagery to yield after processing, information about agriculture on earth, three satellites generations are used MODIS with 250 m pixels,Landsat (30m pixels) and Sentinel 2 (10m pixels), S2A and S2B are very high skill satellites with some wavelength bands in the red edge region increasing accuracy in chlorophyll content estimations.These two satellites will be preferentially used. Images from thes satellites are free of charge but need to be processed to take into account of atmospheric aerosol,clouds,cirrus to obtain canopy reflectance from top of atmosphere reflectance. On a second step artificial neural networks are used to convert these reflectances to biophysical variables (LAI,Cab,Crop

Wavelength	Width	Resolution
Red	620-670	250
NIR	841-876	250

Table 1. Modis wavelengths

Wavelength	Centre	Width	Resolution
B1	435	451	30
B1	452	512	30
B3	533	590	30
B4	636	673	30
B5	851	879	30
B6	1566	1651	30
B7	2107	2294	30
B8	503	676	15

Table 2. Landsat 8 wavelengths

water content:Cw) Unmaned Aerial Vehicles (UAV) are very much used nowadays in the fields, they are easy to use but on large scale work, the cost is very expansive, a UAV is able to scan 500 ha per day, while a satellite like S2 is able to scan 29000 square km (swath of 290 kms). On the other hand satellites are subject to clouds, which is not the case in UAV technology.

1. Materials: Satellite images

1.1 Modis NASA

MODIS Terra is a satellite from NASA and products are 10 daily composite avoiding clouds.The only vegetation indices availables are NDVI and EVI, it is well suited for large area work but not adapted to small field plots.(Table 1)

1.2 Landsat (NASA)

Landsat was the first earth spatial program dedicated to agriculture, data are free of charge (USGS).A lot of vegetation indices including green,red and near infra red (Table 2) can be calculated and usefull to scout crops. Landsat 8 images earth every 16 days (8 days in combination with landsat 7).

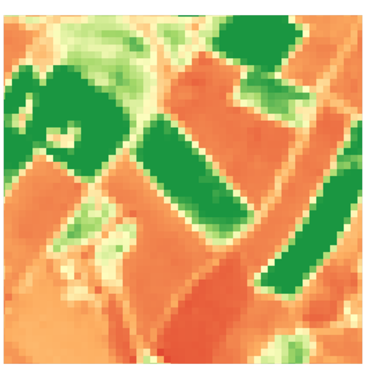

Figure 1. NDVI Landsat 30m

Wavelength	Centre	Width	Resolution
B1	443	20	60
B1	490	65	10
B3	560	35	10
B4	665	30	10
B5	705	15	20
B6	740	15	20
B7	783	20	20
B8	842	115	10
B8A	865	20	20
B9	945	20	60
B10	1380	30	60
B11	1610	90	20
B12	2190	180	20

Table 3. Sentinel 2 wavelengths

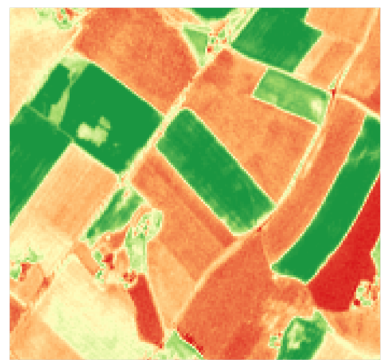

Figure 2. NDVI S2A 10m

1.3 Sentinel 2 (ESA)

Sentinel 2A was launched in 2015 from European Spatial Agency and a second satellite (S2B) was launched in 2016, allowing a revisit time of 5 days. In comparison with Modis or Spot, S2 offer a lot of free images but need to be processed to take into account the clouds, Spot produce cloud free images from composite images. Sentinel proposes reflectances in the red edge region which improve spectral information for chlorophyll estimation.(Table 3) Figure 2 and figure 1 show Sentinel and Landsat pixel resolution, a pixel from Landsat area is 900 m2 and S2A and B 100 m2.

2. Methods:How it works

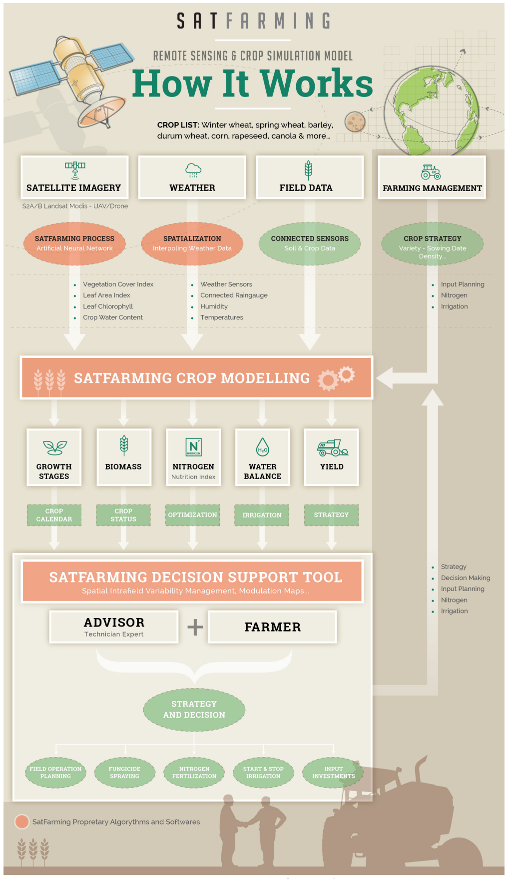

Figure 3. satfarming

Satfarming is a decision support system which is devoted to analyzing and forecasting crop growth and development to help the manager to optimize his decisions efficiency in the fields.(Figure 3) The system is built on two software compartments: One about remote sensing data from satellite imagery and one about crop modeling. The remote sensing brick is based on Sentinel 2 satellite using free images from European Spatial Agency, the satellite images need to be processed before being usable, the main purpose is to convert reflectance data into biophysical variables (Leaf Area Index, canopy chlorophyll content and crop water content), this step uses techniques from artificial intelligence like Neural Network which yield better results than vegetation index during inversion of reflectance spectra simulations models. That part of the system deals with mathematics, physics and large matrix calculations on Geographic Systems Information procedures. This part generates fields matrix information about crop cover vegetation and crop spatial variability. All these information will be useful in the second part of the system. The second brick is composed of a crop model software which is the brain of the system. The crop model is a set of mathematic equations which mimics all the plant life processes, these are the interactions between the plant, the climate and the soil. It will need information from the local weather data station and possibly some from field connected sensors (like temperature, rainfall, solar radiations, air and soil humidity), the soil from the field (like soil texture, soil depth, stone proportion) and the farming management (Crop variety, sowing date, sowing density). The algorithms calculate at a daily step the crop growth stages occurrence and development including soil water balance, photosynthesis, leaf area index, nitrogen assimilation, chlorophyll content, biomass and forecasted yield. Some parameters like available nitrogen and roots system dynamic are essential in crop cover expansion, so, remote sensing data are used to tune these parameters during the growing season to improve the crop analysis and forecasted results. The manager, in collaboration with an agronomist or a technician expert has a decision support tool to optimize his agricultural options. The system is a dynamic process which is daily fed by weather data and around weekly by satellite imagery depending on the clouds cover from the sowing date till the harvest. Spatial crop cover variability will be partially corrected by fertilization modulation map generated by the system, irrigation schedule will be optimized by the water balance module, spraying and field managing operations will be precise thanks to the predicted growth stages and yield information will be useful to anticipate farmer strategic decisions. The advantages of the system are that is offers a crop scouting and watching via satellite imagery, weather data and crop modeling, it watches the fields crops and warns the farmer when necessary throughout the growing season.

3. Products

3.1 Crops visual interpretation

Using different vegetation indices allow to observe specific traits of a field.Satfarming process many different vegetation indices involving all the Sentinel wavelengths.

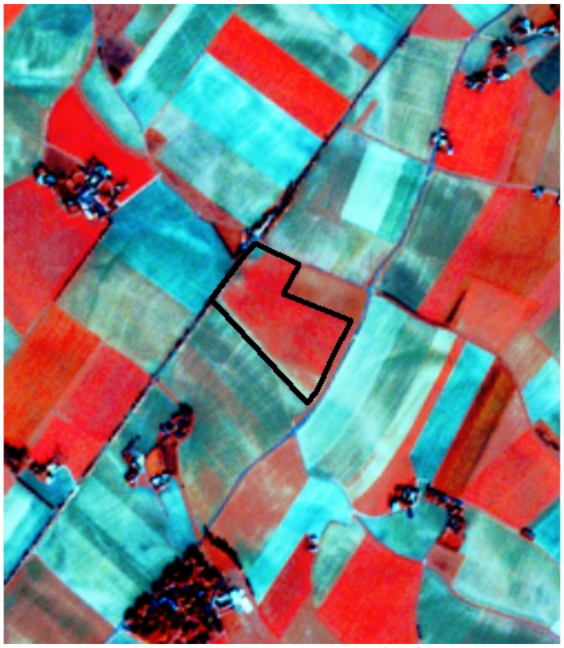

Figure 4. NIR/G/B Composite image

Figure 5. NIR/G/B composite

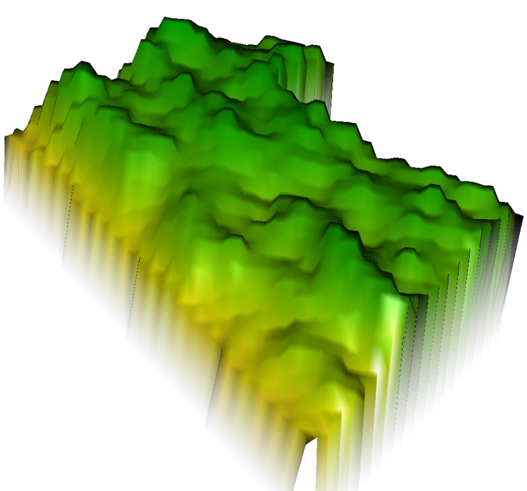

Figure 6. 3D image

Enlarging vue allow to see neighboured fields and compare with other crops and soil types (Figure **??**), using a map as background is usefull to geolocalize the fied (Figure **??**) and a three dimension plot can highlight specific zones (Figure 6)

3.2 Crops Intra field variability:Mean and standard deviation

A SIG use rasters which can be considered as two dimensions matrix and a classical statistical analysis can be processed. Mean and standard deviation will be interesting indicators about the field status.

Figure 7. NDVI

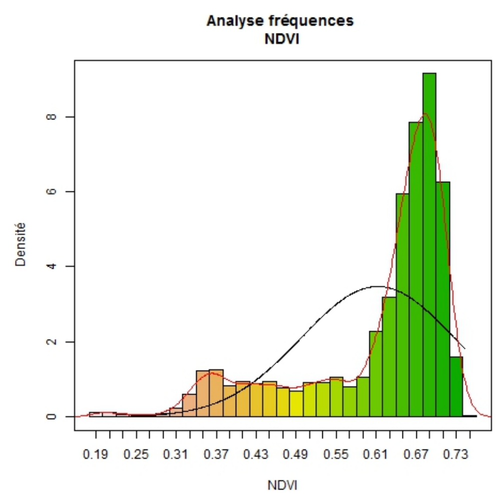

Figure 8. NDVI frequential analysis

Field vegetation variability is mainly driven by soil caracteristics (texture,depth,stones) with consequences on water and nutrients availability with irregular root exploration potential. Using field maps, farmers can adjust field inputs to improve his profits and preserve environment.

3.3 Crop biophysical variables from remote sensing analysis

- Leaf Area Index:LAI (unitless)

Ratio between leaf area versus soil.It vary function of the crop growth stages and is a good plant health indicator by comparing actual values to conventional values.

- Leaf chlorophyll content (Cab g/m2)
  Leaf nitrogen assimilation indicator, giving leaf health status.It's estimation is not easy and reflectance in the red edge domain improve results.

- Leaf water content (g/m2)
  Reflect leaf transpiration potential and indirectly available soil water, low level indicates drought occurence and scaled on the canopy level, it can be used to manage irrigation.

- Canopy chlorophyll content (g/m2)
  Product between leaf area index and leaf chlorophyll content, it is a very good indicator about crop nitrogen uptake.

- Canopy Nitrogen content (kgs/ha)
  This information is very important in nitrogen balance sheet, especially for rapeseed, its variability in the field will be compensated by modulation map generated by geographic information systems.

- Aerial fresh and dry crop biomass (T/ha)
  Crop biomass is directly linked to leaf area index and vrop growth stages, using harvest index, it will be used as a yield indicator.

3.4 Crop identification

- Crop NDVI pattern Crop NDVI patterns from the satellite are compared to spectral signatures from different crops which are calculated by the crop model, thus wheather is taken into account to avoid mismatch.Then each pixel of the area of interest is classified function of an euclidean distance to each crop.

- Crop spectral signature Winter cereals are well discriminated from rapeseed crops, but separating barley from winter wheat seem very difficult.

3.5 Field scouting and statistical analysis

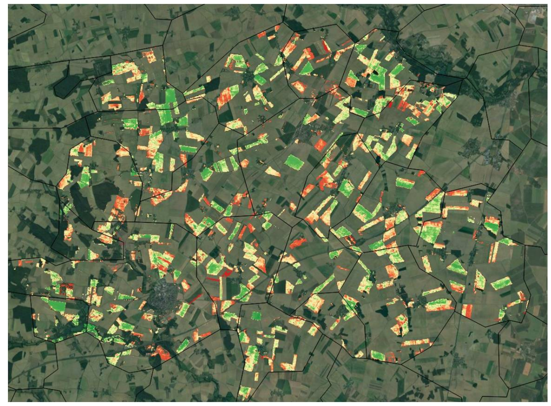

Figure 9. Rapeseed biomass

Using crop identification or shape files grouping same crop fields allows statistical analysis to identifate fields with problems and estimate mean biophysical value for a large area (Figure 9)

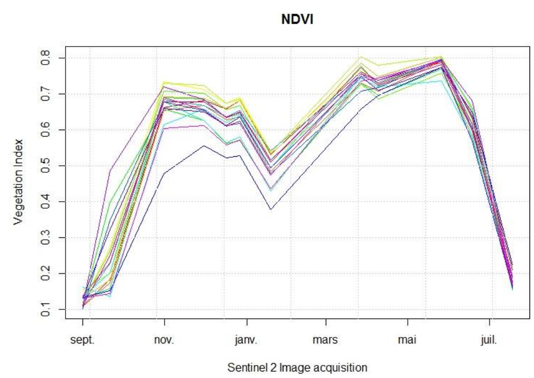

Figure 10. NDVI rapeseed

Analysis of several fields temporal spectral profiles helps in highlighting the fields where problems may occur, in this exemple (Figure 10) large areas where destroyed by wild animals on the lowest curve.

3.6 Satellite images interpolation

Satellites images are subject to cloud cover and during winter or early spring some periods with no available images may occur.To overcome this problem, interpolation between two dates is calculated with the objective to keep information fluidity.End of period information can come from the crop model which uses weather datas to simulate biophysical variables and canopy reflectance data along the growing season.Thus it is possible to produce one image per day.

3.7 Field Modulation map

The user can choose a vegetation index according to his preference and use intra field variability to tune the modulation map, defining the decision thresolds.

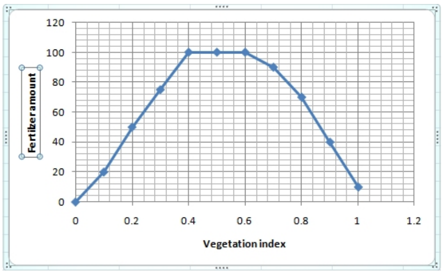

Figure 11. Vegetation index

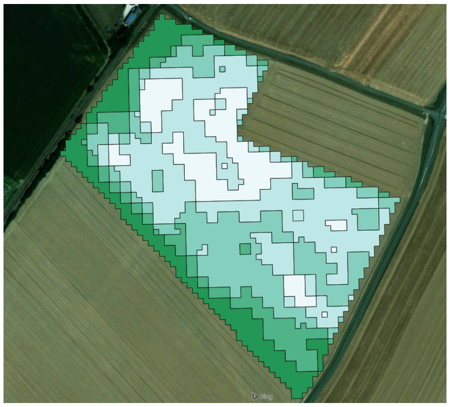

Figure 12. Nitrogen modulation map: Rapeseed 147-250 kgs/ha

The system calculate a raster from the user defined decision rule (Figure 11) and convert it to a shape file which is used as a modulation map for any sprayer. The data source to calculate the modulation map be from the user formulas or from Satfarming,(Figure 12)

3.8 Crop model

The crop model use weather datas at a daily time step to produce results, it calculates crop growth stages occurences and simulate plant biophysical processes as photosynthesis, biomass accumulation,nitrogen and water nutrition and yield formation. Using weather forecast data, the results can be anticipated and allow the agricultural manager to take good decision before problem occurence in the field.(Figure 13) This may be important when some operations need to be executed at precise growth stages or non visible stages or to manage irrigation with drought which has to be anticipated befor crop stress damages.

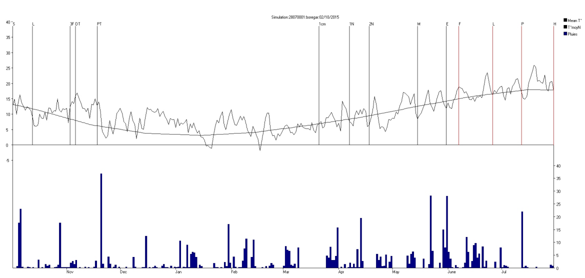

Figure 13. Model simulation

The model can be used on a large scale by using many weather station data and spatializing the results.(Figure 14)

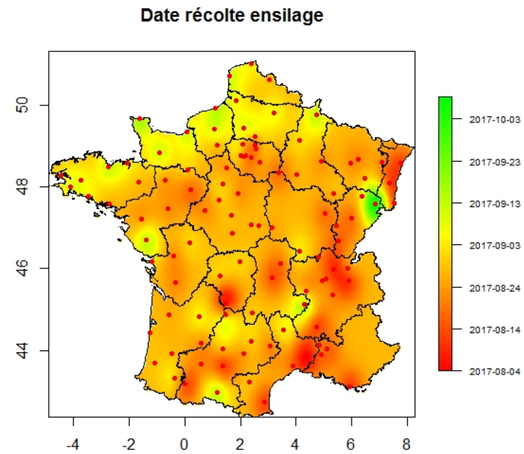

Figure 14. Maize silage harvest date

3.9 Remote sensing and crop model coupling

The crop model calculates biophysical variables which are observed by the satellites, according to the fact that the soil variability in the field lead to nutriments and water supply variability the field data matrix is used to tune the model parameters on the satellite pixel resolution scale.The model produce georeferenced results to perform its utility and is hence able to generate nitrogen modulation maps to optimize nitrogen assimilation in the plant.

4. Services

4.1 Digital camera picture processing

In the early growing season, picture analysis can provide usefull information like fraction of cover vegetation, leaf area index and number of plants.(Figure 15)

Figure 15. Barley RGB

On this image the software detects the green vegetation and calculated 15.37 percent of fraction cover vegetation, which represent 0.17 square on the image. Knowing, according to the leaf stage, the area of one individual, it is possible to deduct the number of plants per unit area.(Figure 16)

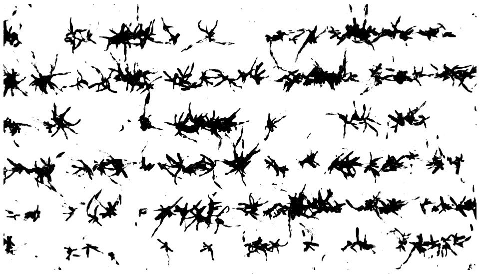

Figure 16. Barley processed

4.2 Ground data measurements

- Radiometry:MSR 16 Cropscan To check about reliability between satellite and ground, crop reflectance data are collected in the same time than the satellite images dates,a MSR 16 Cropscan is used on georeferenced points in various field crops (Table 4). This task is usefull to control atmospheric corrections due to aerosol and haze in atmosphere.After validation the radiometer can be used as a satellite emulator and it is possible to produce experimental data on small plots.(Figure 4)

Figure 17. Radiometry measurements

N	Wavelength	Width(nm)
1	520	10
2	550	10
3	580	10
4	600	10
5	630	10
6	660	10
7	690	10
8	720	10
9	750	10
10	780	10
11	800	10
12	830	10
13	860	10
14	890	10
15	930	10
16	950	10

Table 4. Cropscan MSR16 wavelengths

- Leaf area index:Decagon Accupar80

Figure 18. Decagon LAI meter

Leaf area index is controlled as well as reflectance to perform the neural network parameters and in combination with ground reflectance, it can be used to generate datasets for specific calibrations.(Figure 18)

- Leaf Chlorophyll content

Leaf chlorophyll content is estimated from Ntester measurements .(Figure 19).N tester measure the light leaf transmittance.

Figure 19. spad

4.3 Biomass

Biomass measurement are done especially for rapeseed crop during early winter to check about nitrogen uptake calculation from remote sensing.

Conclusion

- Intra field variability
  Detecting areas anomalies can help the manager to decide some specific analysis to explain the difference with the rest of the field by soil analysis.

- Biophysical variables
  The estimation of leaf area index and chlorophyll content is very important to give to the model accurate values and predict good data for nutrient management.

- Crop detection
  The system is able to differenciate winter cereals and rapeseed. Summer crops ar esay to detect from winter crops. Are for each crop type can be determined on a large scale.

- Inter field analysis
  Statistical analysis of a wide range of field in an area of interest is usefull to the technician to orgnise the fields visits. It is not usefull to check a field where there is no problem, instead of it is essential to visit a field which needs specific management.

- Field modulation maps
  Are produced from the coupled system Model/Remote sensed data or from vegetation index user formula using his own thresold for geographical nutrient amount.

- Crop model
  Using the crop model allow to give a dynamic range to the system because of weather data feeding the model at a daily time step.

- Digital pictures
  This service is devoted to small scale remote sensing and essentially focused on plant area in individual counting.

- Ground validations
  A neccessary step to insure about the results accuracy and explore new horizons and other theories

In conclusion Satfarming decision support system which observe fields crops, analyse inter and intra field variability, simulate crop growth and development to increase farmers inputs efficiency and tuning variable rate equipment to preserve environment.

The author

Xavier Bailleau: Farmer in France since 1988 (Wheat, barley, rapeseed), agronomist, crop modeler and remote sensing specialist for 20 years.