Development Of An Index-Based Insurance Product: Validation Of A Forage Production Index Derived From Medium Spatial Resolution Fcover Time Series

A. Roumiguié, and A. Jacquin

Télédétection et Gestion des territoires
INP de Toulouse - Ecole d'Ingénieurs de Purpan – UMR 1201 DYNAFOR
Toulouse, France

G. Sigel, and H. Poilve

Airbus Defence and Space
Toulouse, France

B. Lepoivre

Marchés de l'Agriculture et des Professionnels
Pacifica Crédit Agricole Assurances
Paris, France

O. Hagolle

CESBIO UMR 5126 CNES-UPS-CNRS-IRD
Toulouse, France

ABSTRACT

An index-based insurance solution is being developed by Pacifica Crédit Agricole Assurances and Airbus Defence & Space to estimate and monitor forage production in France in near real-time. It is based on an indicator called Forage Production Index (FPI). FPI is derived from the Fraction of green Vegetation Cover (fCover) integral and used as a surrogate of forage production. fCover is a biophysical parameter obtained from Medium spatial Resolution (MR) MODIS/MERIS time series. Because one MR pixel may contain different types of land cover, a spectral unmixing model based on a statistical approach is applied to determine fCover time series for grassland. Consequently, FPI is calculated at an elementary unit (EU) scale of 3600 ha. In the insurance product, payouts are indexed on the ratio between the annual FPI and the Olympic average of FPI of the last 5 years. In the framework of FPI development, a scientific validation is implemented and this paper presents the first step of it. Local ground measurements of biomass production are compared with FPI values obtained from High Resolution (HR) space-based images provided by different sensors, in particular, SPOT4 (Take5). This paper describes the grassland parcels, the field protocol established to collect biomass production data, the method used to get the fCover biophysical variable. The analysis consists in studying the relationship between biomass ground measurements and grassland production estimated by fCover. Discrepancies between the two variables are quantified by the coefficient of determination, the mean square error (systematic bias) and the root mean square error. First, fCover values derived from the four sensors are coherent. It demonstrates the ability of the algorithm used in this study to provide a consistent way of calculating the biophysical variable. Then, for the whole dataset, the scatter plot between FPI and biomass shows an acceptable correlation (R =0.72; α < 0,0001) with a correct systematic bias. However, there remains dispersion as highlighted by the RMSE value. If we only take into account data recorded up until the production maximum, the results are improved (R^2= 0.81; $\alpha < 0.0001$ and RMSE decreases of 25%). Finally, the analysis carried out on the scale of the parcels, grass species, period of mowing or climatic conditions reveals variability on the regression coefficients. It indicates that, in addition to the fCover, other explanatory variables should be integrated to better compute the FPI. In the framework of the research activities developed to create the index-based insurance product, all these different results are discussed to make recommendations for improving the FPI index.

Keywords: Validation; fCover; grassland production; time series; index-based insurance.

INTRODUCTION

General background

In France, grasslands cover 44% of arable land, that is to say 12.8 million ha (Agreste, 2014). They are crucial for livestock farmland. But they are very sensitive to climatic events. The competitiveness of the livestock activity depends on the forage system. Today, when a drought event occurs, farmers are indemnified according to estimates made by the SCEES (Ministry of Agriculture's Statistics Department) and the information provided by the growers' associations and the collecting agencies. Losses of hay production represent 60% of annual compensation given by the French Ministry of Agriculture, that is to say €126 million/year on average. In 2003, it was as high as €750 million (Boyer, 2008).

Since 2010, the French State has decided to gradually transfer the coverage of these risks to the private sector to make savings (Ministère de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2013). For private insurers, this represents a capital to be guaranteed amounting to around €10 billion.

For forage, the traditional insurance systems used for cereals, oil and protein crops, vegetables, vineyards, fruit and silage maize are not applicable for three major reasons. (i) First, grassland production is not easily measurable. The grassland management system may vary highly from one farm to another and according to the annual climatic conditions. (ii) In addition, the grasslands are harvested several times a year and/or are grazed. (iii) Then, it is difficult to estimate the forage production losses. The forage produced is usually largely auto consumed by the animals (around 90% of total production). So it does not appear in the farm accounts and a historical reference of the production does not exist. Finally, for the above-mentioned reasons traditional human expertise would mean very high operating costs owing to the frequency of the inspections that would have to be made by the experts and to the difficulty in estimating production.

The Index-Based Insurance product developped by Pacifica – Crédit Agricole Assurances and Airbus Defence & Space

Given the French context, the Research Initiative put in place by Pacifica – Crédit Agricole Assurances, Airbus Defence & Space and Grameen Micro-Assurance, has been developing an Index-Based Insurance (IBI) product since 2010, using an index derived from satellite images to monitor grassland production variations. The purpose of the processing chain put in place (Roumiguié, et al., 2014) is to demonstrate how remote sensing images can be efficiently integrated into an insurance product.

In order to monitor the grassland's biomass, medium spatial resolution images (300m) are acquired every day over France. A time series of images provided by MODIS/MERIS sensors has been built up since February 2000 (start date for the MODIS image archives). Once orthorectified using the AMORGOS or MRTSwath software, these images are processed using the Overland™ software application developed by Airbus Defence & Space. This tool allows extracting the biophysical parameters from the vegetation by inverting a radiative transfer model while simultaneously considering the scene and atmosphere models (Poilvé, et al., 2012). This processing results in the production of biophysical parameter images of the vegetation while taking into account characteristics of the sensors and the directional conditions (Sun and viewing angles). The output parameter used here is the fCover, which corresponds to the proportion of ground covered by active vegetation when the scene is observed vertically (Poilvé, 2012). In order to keep only high-quality information, in particular by eliminating images with a high degree of cloud cover, a ten-day synthesis is drawn up using an optimised algorithm based on the MVC method. Given that each pixel records the spectral signature of all the land uses, an unmixing model based on a statistical approach is used to obtain the fCover information for the grasslands (Di Bella, et al., 2004; Faivre and Fischer, 1997). It involves a change of scale. The fCover for the grasslands is then obtained on the scale of a 6x6 km grid (that is to say four hundred 300m-pixels). When applied to all the images in the time series, it enables to get an fCover profile of the grasslands over France, uninterrupted since 2000. The insurance product developed is based on the hypothesis that the annual integral fCover constitutes an indirect measurement of the grasslands' biomass production (Pettorelli, et al., 2005). A Forage Production Index (FPI) is constructed using Equation 1:

$$FPI_n = \sum_{i=01/02}^{i=31/10} (fCover_i - NPf) \text{ Equation 1}$$

The FPI is calculated for year n. This is the sum of daily fCover between February 1 and October 31 (*fCover$_i$*) from which a part characterising the proportion of non-productive vegetation (*NPf*) is subtracted. This last parameter is calculated by forage region (stratification of France into homogeneous regions from the viewpoint of the types of farming and the levels of production carried out by Hentgen (1982)) and from the regional production estimates provided by the Ministry of Agriculture's Statistics Department. In the case of a drought event, farmers are indemnified based on the variation observed within a 6*6 km grid between the annual FPI and the Olympic average of annual FPI of the last five years and given by Equation 2.

$$\Delta FPI_n = \frac{FPI_n}{Olympic\ average(FPI_{n-1};\ldots;FPI_{n-5})} \text{ Equation 2}$$

This measurement scale represents a good trade-off making it possible to monitor the local variations in grass production without taking into account the stock-breeders' individual cultural practices.

fCover was preferred to the conventional vegetation indexes such as NDVI (Rouse, et al., 1974) because of its robustness properties. The measurement stability for fCover according to the sensors and acquisition conditions allows to analyse a history that is comparable with biomass production measurements (Camacho and Cernicharo, 2011; Meroni, et al., 2013). However, a validation step is required because in the framework of the development of the IBI for the grasslands the fCover application scale is more local and the end-use highly specific. So, an ad hoc two-step validation protocol has been defined. (i) The first step consists of checking whether the FPI can be used to estimate the production of grassland biomass by comparing measurements in the field with index measurements on HR images. (ii) The second validation step consists of assessing whether the FPI measured from MR images can be used to estimate variations in grassland production. The purpose of this article is to present the results of the first step in FPI validation.

METHODOLOGY

Experimental sites

The study site is centred on the city of Toulouse, France (43° 37'N, 1° 27'E) (Figure 1). The region's climate is subject to Mediterranean, oceanic and continental influences. This characteristic gives summers that tend to be hot and dry whereas the winters are mild and relatively damp. The average temperature is 6°C in winter and 22°C in summer. The average rainfall over the 1981/2010 period is 638 mm/year.

Six grassland parcels were selected according to the following criteria: length of grassland establishment, diversity of grassland species and types of farming. The characteristics for each of the parcels are detailed in Table 2.

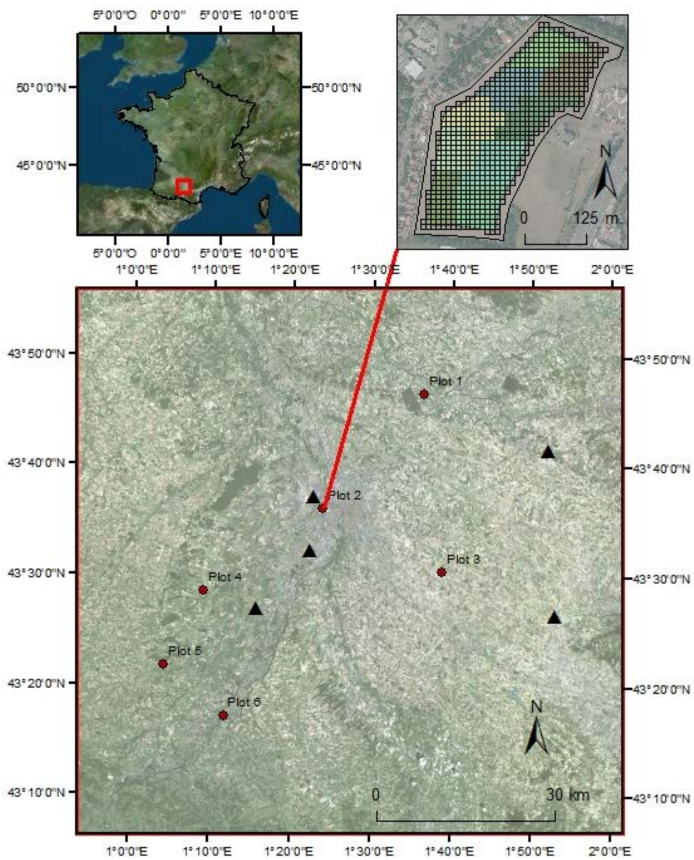


Figure 1 : Location of the studied plots (●) with meteorological tower (▲). Top right: example of the sampling methodology with the grid pixel and the coloured plots on parcel 2.

Table 1 : Overview of the characteristics of the 6 studied parcels

Parcel number	Year	Grassland type and main species	Area (ha)	Pasture management	Sampling repetition	Plots sampled
1	2013	Temporary with Alfalfa	7.3	Exclusively cut for hay production	7 plots / 15 days	35
2	2012	Permanent with mixed Poaceae species	9.4	1 cut in June	12 plots / 7 days	168
	2013				10 plots / 15 days	75
3	2013	Temporary with Ray-Grass	8.6	Silage in May and cut in June	7 plots / 15 days	43
4	2013	Permanent with mixed Poaceae species	6.0	1 cut in June	6 plots / 15 days	44
5	2013	Temporary with Fescue / Dactyl /White clover	9.5	1 cut in June then pasture	10 plots / 15 days	66
6	2013	Temporary with Fescue / Dactyl	6.8	Exclusively cut for hay production	7 plots / 15 days	57

Remote sensing data and processing

In 2012, 9 Formosat-2 images acquired between 01/03 and 01/06 were analysed. In 2013, 24 images from 4 different sensors acquired between 16/02 and 26/06 were processed. The SPOT4 images (14 in all) were supplied by CNES and produced by THEIA in the framework of the SPOT4 (Take5) programme (http://www.cesbio.ups-tlse.fr/multitemp/). The Formosat-2 (9 images in 2012 and 5 in 2013) and SPOT-6 (3 images) images were supplied by Airbus Defence & Space and the Landsat-8 (2 images) images by USGS. All the images – supplied orthorectified – were re-projected in Extended Lambert-2 and for those from 2013, re-sampled to a resolution of 10m. For all the images, fCover was calculated with the Overland^{TM} software. Traditionally, raw images (without atmospheric corrections) are used as input to be converted into biophysical parameters. However as the SPOT4 images are distributed pre-processed in "top of atmosphere" reflectance (Level 1C) in the framework of the SPOT4 (Take5) program, a modification to the Overland^{TM} processing algorithm was required. Then a linear interpolation function was applied between each processed-image date to obtain a daily fCover. There are two main reasons explaining the choice of this method: the sufficiently dense data acquisition frequency and a limited time autocorrelation effect in the series processed compare to canopy structural dynamic model (Koetz, et al., 2005; Bsaibes, et al., 2009; Duveiller, et al., 2013). The calculation of the FPI is carried out using equation 1 with a null value for NPf given that the 6 parcels are located in the same forage region.

Biomass ground measurements and Spatial sampling strategy

In parallel with the HR image acquisition period, a sampling strategy was established for each parcel according to the following principle. A grid set on the processed images and corresponding to their spatial resolution (8m for 2012 and 10m for 2013) was created using the ArcGIS software. The sampling points were positioned on the grid according to the given rules: (i) A sampling point must be situated in the centre of one of the grid's. (ii) In order to limit the edge effect, a minimum distance from the edge of the parcel equivalent to the resolution of one pixel is compulsory. (iii) A sampling point must be located at a distance of at least 2 grids from any other sampling point. This makes it possible to take into account the localisation errors with the GPS in the field, and the HR image setting accuracy estimated by Airbus Defence & Space at one half-pixel on average. The sampling points by date were selected according to a stratified and systematic method (Martínez, et al., 2009) in order to cover the spatial variability of the fCover on the intra-parcel scale. The parcel was stratified into blocks each with an equivalent surface area. Within each of these blocks, a systematic draw of the points' sampling order was performed with the constraint that the distance must be maximised between the samplings made on close dates. This sampling method, put in place in 2012 on parcel 2, was applied to the 6 parcels in 2013. In total, 488 points were acquired (168 in 2012 and 320 in 2013). The detail for each parcel is shown in Table 2.

The method used to measure the biomass on the sampling points is based on the protocol put in place by ARVALIS – Institut du Végétal (Protin, 2010). The farm machinery used consists of a motor mower with a 1.10m cutting bar placed 7 cm above the ground. The operation consists of cutting the grass over a strip more or less 7 m wide according to the amount of standing biomass. The length really cut was then measured. The above-ground biomass harvested was weighed. A sample was taken, weighed and then placed in an oven at 105°C for 48 hours in order to calculate a dry weight and deduce the humidity rate. Given the green biomass harvested, a yield expressed as an amount of dry matter per unit surface area was calculated for each sampling point.

Meteorological data

During the parcel monitoring period, the temperature data were recorded thanks to the MétéoFrance weather stations located close to the parcels (Figure 1). The variables collected were the daily minimum and maximum temperatures. Using these data, a daily average temperature was calculated using equation 3:

$$T_{avg} = \frac{T_{max}+T_{\ min}}{2} \qquad \text{Equation 3}$$

T_{max} and T_{min} are respectively the maximum and minimum temperatures given by the recording stations close to the experiment parcels. Because the grassland development stages are controlled by the Degree Days (DD), the data were analysed on a time scale expressed as a sum of degree days received by the plant cover. The addition of the positive daily average temperatures is done with the method used by Duveiller, et al. (2013), Al Haj Khaled, et al. (2005) and Stöckle, et al. (2003). Only the positive temperatures from 1st February are accumulated. This threshold set at 0°C is recommended by Beurs and Henebry (2010) and Duru, et al. (2009) for monitoring the grassland biomass in temperate zones.

Statistical analysis

The agreement between the FPI calculated from the series of HR images and the production of grassland biomass was quantified using the coefficient of determination, RMSE and MSE (Systematic Bias). The resulting model is characterised by the regression coefficient (a). Scatterplot analyses are perfectly suited to describing the correlation between two datasets (Meroni, et al., 2013).

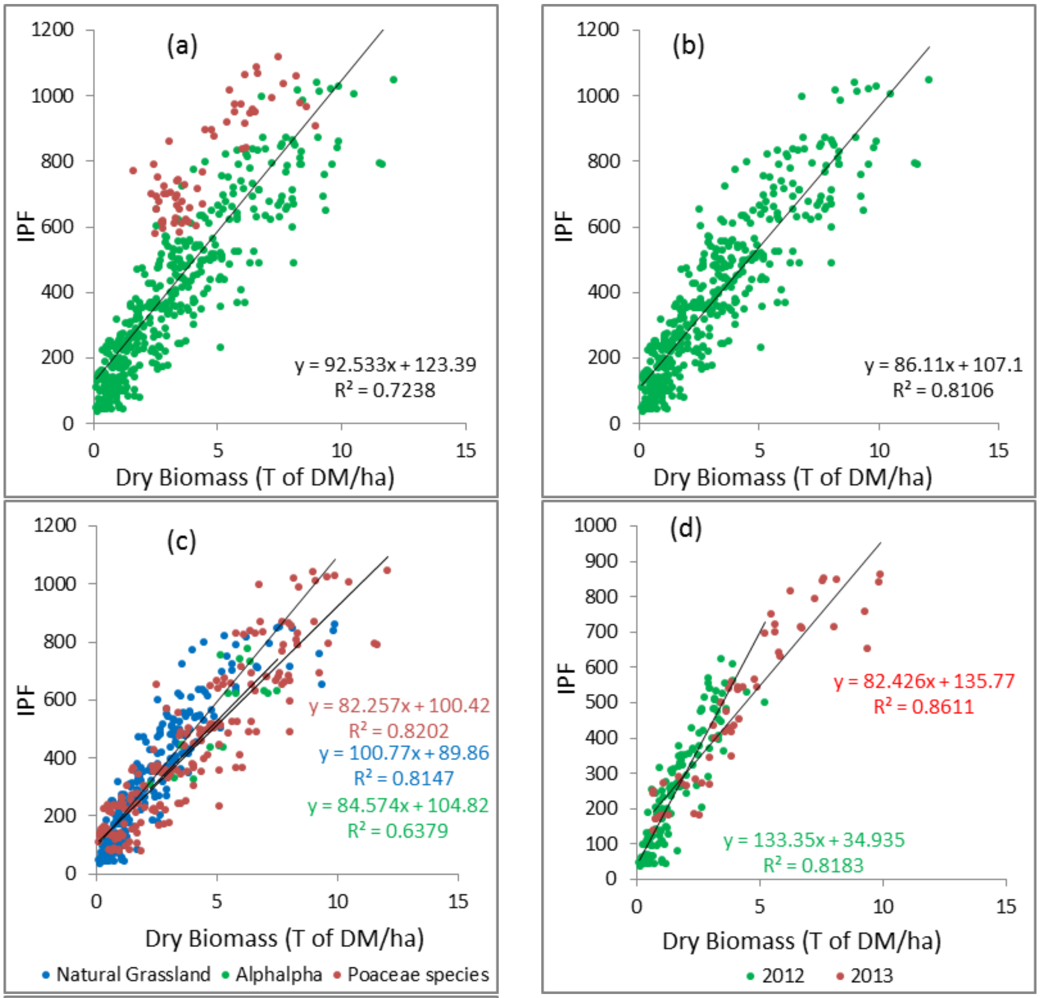
The relationship was tested at different levels: (i) Level 1, the whole dataset over the whole biomass measurement period (growth period and possibly the grass senescence period defined according to the production maximum observed). (ii) Level 2, the whole dataset without the data acquired during the senescence period: this makes it possible to study the effect of grass senescence on the FPI calculation. (iii) Level 3, the different parcels: the effects attributable to climate variations, types of cover and the length of establishment were analysed simultaneously. (iv) Level 4, the data were aggregated in order to evidence only the effects of the species and of the length of grassland establishment. There were three groups: Group 1: Permanent grassland with Poaceae species; Group 2: Temporary grassland with mono-species or mixed Poaceae species; Group 3: Temporary with Fabaceae Species (Alfalfa). (v) Level 5, parcel 2: the data acquired in 2012 and 2013 show the effect of the inter-annual weather variations. (vi) Level 6, parcel 3: the effect of the type of farming was examined with two cuts carried out on this parcel in the spring.

RESULTS

Table 3 presents the results of the statistical analyses. Figure 2 shows the scatterplots obtained for Level 1 (Figure 2a), Level 2 (Figure 2b), Level 4 (Figure 2c), Level 5 (Figure 2d) and Level 6 (Figure 2e). The indicators of the relationship between the FPI and the measurements in the field of the biomass calculated for Levels 1 and 2 are good. The quality of the relationship is all the better when the data acquired during the grass senescence phase (shown in red in Figure 2a) are not taken into account in the analysis: increase in the value of R of 0.09 and decrease in the RMSE and MSE of 26% and 46%. In this situation, the FPI values overestimate production: the FPI calculation method takes into account the fraction of plant cover that becomes senescent or that is exported. Given this result, for the following analysis levels, all the data acquired during the senescence period were excluded (this concerns data for parcels 1 and 2).

Table 2 : Results of the linear regression between production and FPI. All regressions are significant to the Fischer test ($\alpha < 0.001$). *= without data acquired during the senescent period. Figures in brackets indicate the total number of observations in the dataset. RMSE and MSE are in FPI unit.

Level of analysis	Nature of dataset	N	R	RMSE	MSE	Slope (a)	Max. production (T. of DM/ha) average - std dev
Level 1	All parcels 2012+2013	488	0.72	142.7	20352.0	92.5	
Level 2	All parcels 2012+2013 *	426	0.81	105.3	11080.0	86.1	
Level 3	P1 *	28 (35)	0.68	95.9	9197.2	78.1	5.96 - 0.51
Level 3/5	P2 – 2013 *	56 (75)	0.86	84.8	7190.1	82.4	7.91 - 1.25
Level 3/5	P2 – 2012 *	132 (168)	0.82	69.8	4875.1	133.3	3.41 - 0.51
Level 3/6	P3 - First harvest	31	0.69	74.8	5600.3	51.2	5.22 - 2.09
Level 3/6	P3 - Second harvest	12	0.82	51.0	2598.9	63.3	3.49 - 1.49
Level 3	P4 – All plots	44	0.86	88.3	7797.3	149.0	4.66 - 0.92
Level 3	P5 – All plots	66	0.86	101.9	10385.1	86.0	7.28 - 1.04
Level 3	P6 – All plots	57	0.90	95.6	9132.8	84.8	9.17 - 1.59
Level 4	Group 1 (P2;P4)*	232	0.81	93.1	8658.3	100.8	
	Group 2 (P3;P5;P6)*	176	0.82	111.8	12509.6	82.3	
	Group 3 (P1)*	18	0.64	100.7	10131.7	84.6	



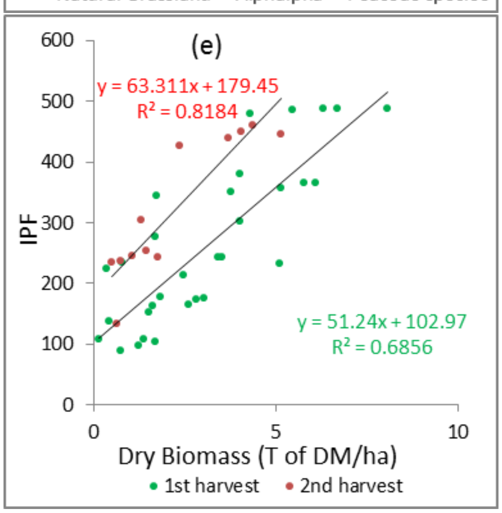


Fig. 2: Scatterplots showing the correlations between Dry Biomass (T of Dry Matter/ha) and FPI (a) for all plots (n=488). Data collected during senescence are in red; (b) for only the growing period data (n=488); (c) for the data grouped according grassland types (Permanent Grassland with Poaceae species n=232; Temporary with Fabaceae Species (Alfalfa) n=18; Temporary grassland with mono-species or mixed Poaceae species n=176); (d) for the data acquired in 2012 and 2013 on parcel 2 (respectively, n= 132 and 56); (e) for the data acquired during the two growing periods on parcel 3 (n = 31 and n=12).

The results obtained on Level 3 confirm the results observed for the whole dataset for the coefficient of determination (0.68<R <0.90). The variability observed on the other indicators (51.0 < RMSE < 101.9; 2598.9 < MSE < 10385.1; 51.2 < a < 149.0) demonstrates that the FPI, only calculated from the sum of fCovers, does not make it possible to fully explain the variability in the biomass production observed between parcels. Furthermore, amongst the parcels of grasses characterised by a single cut for the study period (P2; P4; P5; P6), those with the greatest levels of production have the least steep regression slopes and vice versa.

Concerning the analysis by group of grasslands (Level 4), the results for the grass fields (Groups 1 and 2) show the good relationship ($R > 0.80$) and a probable effect of the length of grassland establishment (variation of *a*). In the case of temporary grasslands (Groups 2 and 3), the difference in the observation number (Group 2: n = 176 vs Group 3: n = 18) does not make it possible to examine the existence of an effect linked to the nature of the grassland cover (grass vs leguminous plants).

The effect of the climatic variations is evidenced through the comparison of the data collected on parcel 2 (Level 5). A significant difference can be observed in the maximum production between 2012 and 2013, which can be attributed to the differences in the sums of rainfall accumulated since 1st February (102 mm in 2012 vs 223 mm in 2013). In Figure 2d, this variation is effectively transcribed by the FPI with slope "a" of 133.3 in 2012 and 82.4 in 2013.

Lastly, analyses of the data for parcel 3 (Level 6) shows that for an equivalent biomass value with the first or second cut, the value of FPI varies (Figure 2e). Furthermore, the quality of the relationship is better with the second cut: the MSE decreases by 54 % between the two cuts (Table 3). Indeed, the plant cover when production starts again after the first cut, with favourable temperatures and without any water deficit, is more homogeneous than that observed coming out of the winter.

CONCLUSIONS

In the framework of the validation protocol, the fCover is calculated from a series of multi-sensor HR images (SPOT4, SPOT6, Formosat-2 and Landsat-8). The results obtained leads to two main conclusions. (i) The fCover, produced by Overland^{TM}, provides a measurement that is not sensitive to the image acquisition conditions and that is stable over time and in space unlike NDVI (Brown, et al., 2006, Chen, et al., 2011, Meroni, et al., 2013; Herbold, 2013). (ii) The FPI derived from fCover time series is highly correlated to biomass production measurements. However, the conclusions of the different levels of analysis reveal the interest of introducing additional agronomic, physiological and climatic variables in the calculation of the FPI to improve the ability to estimate the biomass produced (Polley, et al., 2011). Further works will be to evaluate the capacity of the FPI, obtained from MR images, to estimate variations in inter-annual productions (second step of the FPI validation protocol).

REFERENCES

Al Haj Khaled, R., Duru, M., Theau, J.P., Plantureux, S. and Cruz, P. 2005. Variation in leaf traits through seasons and N-availability levels and its consequences for ranking grassland species. Journal of Vegetation Science 16: 391-398. doi:10.1111/j.1654-1103.2005.tb02378.x.

Rouse, J. W., Haas, R. H., Schell, J. A. and Deering, D. W. 1974. Monitoring vegetation systems in the Great Plains with ERTS. Third Earth Resources Technology Satellite-1 Symposium, United States.

Agreste, 2014. Statistique Agricole Annuelle. V-Cultures fourragères, 1 pp. http://agreste.agriculture.gouv.fr/

Beurs, K. and Henebry, G. 2010. Spatio-Temporal Statistical Methods for Modelling Land Surface Phenology. *In*: I. L. Hudson and M. R. Keatley, editors, Phenological Research. Springer Netherlands. p. 177-208.

Boyer, P. 2008. Assurer les calamités agricoles?. Notes et études économiques du Ministère de l'Agriculture, n°30, 32 p.

Brown, M.E., Pinzon, J.E., Didan, K., Morisette, J.T. and Tucker, C.J. 2006. Evaluation of the consistency of long-term NDVI time series derived from AVHRR,SPOT-vegetation, SeaWiFS, MODIS, and Landsat ETM+ sensors. Geoscience and Remote Sensing, IEEE Transactions on 44: 1787-1793. doi:10.1109/TGRS.2005.860205.

Bsaibes, A., Courault, D., Baret, F., Weiss, M., Olioso, A., Jacob, F., et al. 2009. Albedo and LAI estimates from FORMOSAT-2 data for crop monitoring. Remote Sens. Environ. 113: 716-729. doi:10.1016/j.rse.2008.11.014.

Camacho, F. and Cernicharo, J., 2011. Validation Report Medium Resolution (MERIS) Vegetation Parameters. GEOLAND2. 62 pp.

Chen, F., K.T. Weber and B. Gokhale. 2011. Herbaceous Biomass Estimation from SPOT 5 Imagery in Semiarid Rangelands of Idaho. Giscience & Remote Sensing 48: 195-209. doi:10.2747/1548-1603.48.2.195.

Di Bella, C., Faivre, R., Ruget, F., Seguin, B., Guerif, M., Combal, B., et al. 2004. Remote sensing capabilities to estimate pasture production in France. International Journal of Remote Sensing 25: 5359-5372. doi:10.1080/01431160410001719849.

Duru, M., Adam, M., Cruz, P., Martin, G., Ansquer, P., Ducourtieux, C., et al. 2009. Modelling above-ground herbage mass for a wide range of grassland community types. Ecological Modelling 220: 209-225. doi:http://dx.doi.org/10.1016/j.ecolmodel.2008.09.015.

Duveiller, G., Baret, F. and Defourny, P. 2013. Using thermal time and pixel purity for enhancing biophysical variable time series: An interproduct comparison. IEEE Transactions on Geoscience and Remote Sensing 51: 2119-2127.

Faivre, R. and Fischer, A. 1997. Predicting Crop Reflectances Using Satellite Data Observing Mixed Pixels. Journal of Agricultural, Biological, and Environmental Statistics 2: 87-107. doi:10.2307/1400642.

Gray, A. When rain only tells half the story: Cotton Index Insurance in Mali. Rural 21, April 2010.

Hentgen, A., 1982. Une méthode pour améliorer la connaissance de la production disponible des surfaces herbagères au niveau national. Fourrages, 92, 15-49.

Herbold, J., 2013. Remote sensing technology for crop insurance – Applications and limitations. CIMMYT Workshop: Remote Sensing – Beyond Images – December 14-15, 2013, Texcoco, Mexico.

International Fund for Agricultural Development and World Food Programme. 2010. Potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods, by P. Hazell, J. Anderson, N. Balzer, A. Hastrup Clemmensen, U. Hess and F. Rispoli. Rome.

Koetz, B., Baret, F., Poilvé, H. and Hill, J. 2005. Use of coupled canopy structure dynamic and radiative transfer models to estimate biophysical canopy characteristics. Remote Sens. Environ. 95: 115-124. doi:http://dx.doi.org/10.1016/j.rse.2004.11.017.

Martínez, B., García-Haro, F.J. and Camacho-de Coca, F. 2009. Derivation of high-resolution leaf area index maps in support of validation activities: Application to the cropland Barrax site. Agricultural and Forest Meteorology 149: 130-145. doi:http://dx.doi.org/10.1016/j.agrformet.2008.07.014.

Meroni, M., Atzberger, C., Vancutsem, C., Gobron, N., Baret, F., Lacaze, R., et al. 2013. Evaluation of Agreement Between Space Remote Sensing SPOT-VEGETATION fAPAR Time Series. Ieee Transactions on Geoscience and Remote Sensing 51: 1951-1962. doi:10.1109/tgrs.2012.2212447.

Ministère de l’Agriculture, de l’Agroalimentaire et de la Forêt, 2013. La gestion des risques climatiques en agriculture. http://agriculture.gouv.fr/risques-agriculture

Ministère de l'Agriculture et de la Pêche. Circulaire SG/DAFL/SDFA/C2006-1516. Sècheresse 2006.Dispositions à mettre en œuvre pour la reconnaissance des pertes dues à la sècheresse 2006. 12 pp.

Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J. and Stenseth, N.C. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends in Ecology & Evolution 20: 503-510. doi:http://dx.doi.org/10.1016/j.tree.2005.05.011.

Poilvé, H. 2012. BioPar Product User Manual - MERIS FR products. GEOLAND2. 50pp.

Poilvé, H., Escalbert, B., Paillet, F., Bicheron, P., Duthil, P., Mathian, C. and Cayrol, P. 2012. Operational production of biophysical parameters from MERIS/MODIS data. *In :* European Space Agency. Sentinel-3 OLCI/SLSTR and MERIS/(A)ATSR Workshop, 15/10/2012, Frascati - Italy.

Polley, H.W., Phillips, R.L., Frank, A.B., Bradford, J.A., Sims, P.L., Morgan, J.A., et al. 2011. Variability in Light-Use Efficiency for Gross Primary Productivity on Great Plains Grasslands. Ecosystems 14: 15-27. doi:10.1007/s10021-010-9389-3.

Protin, P.-V. 2010. Choix des points de prélèvement pour estimer la quantité d’herbe sur pied produite par une prairie de fauche ou offerte en pâture aux animaux. Arvalis - Institut du Végétal, 28 mai 2010, 10p.

Roumiguié, A., Jacquin, A., Sigel, G., Poilvé, H. and Lepoivre, B. 2014. A risk management solution for forage production monitoring in France: development of an index-based insurance using fcover time series from satellite images. Global Vegetation Monitoring and Modeling. Avignon.

Ruget, F., Novak, S. and Granger, S. 2006. Du modèle STICS au système ISOP pour estimer la production fourragère. Adaptation à la prairie, application spatialisée. Fourrages 186.

Stöckle, C.O., Donatelli, M. and Nelson, R. 2003. CropSyst, a cropping systems simulation model. European Journal of Agronomy 18: 289-307. doi:http://dx.doi.org/10.1016/S1161-0301(02)00109-0.