AP7

Potentialities of Very High Resolution Remote Sensing for the Estimation of Oil Palm Leaf Area Index (LAI)

Camille C.D. Lelong[(1)], Fanny M. Roussel[(1)], Nurul Amin Sitorus[(2)], Doni Artanto Raharja[(3)], Novita Anang Prabowo[(3)] and Jean-Pierre Caliman[(4)]

ABSTRACT

A fast, reliable, and objective estimation of oil-palm leaf area index, or LAI, which is directly related with canopy response to global environmental change, could help the management of large industrial estates towards precision farming in several ways. Besides field LAI measurements, that can reveal very long and complicated, remote sensing can provide a means to extract this information exhaustively at a large scale in a limited time, as long as a robust model had been calibrated. The present work analyses two scales: a single oil-palm tree on one hand, and a block of palm trees on the other hand. It tests a protocol adapted to palm plantation structure to seek correlations between the radiometric information derived from a satellite image acquired at very high spatial resolution (0.7m per pixel) by Quickbird sensor, and field measurements performed in the fields with a LICOR LAI-2000 Plant Canopy Analyser. Finally, we derived linear models to predict LAI at the two scales: for the whole block and for an individual tree, obtained respectively with 76% and 58% of correlation, and a respective precision of LAI restitution of 0.5 and 0.9. These results are then discussed in terms of operability and usefulness, and some possible improvements are proposed, as well as future perspective given by remote sensing opportunities.

INTRODUCTION

The Leaf Area Index (LAI), defined as the total surface of green leaves included per square meter (Watson, 1947), is a key biophysical parameter in process-based models of vegetation canopy response to global environmental change, and plant physiological scenario prediction (Vargas et al., 2002; Coyea & Margolis, 1994; Granier et al., 2000). It is also a quite accurate index for direct evaluation of crop foliar development, related to crop agronomic status (Righi & Bernardes, 2008; Naert et al., 1990). In particular for oil palm trees, a fast, reliable, and objective

(1) CIRAD / UMR TETIS, Maison de la Télédétection, Montpellier, France
(2) P.T. SMART / SMARTRI, Padang Halaban, North Sumatra, Indonesia
(3) P.T. SMART / SMARTRI, Pekanbaru, Riau, Sumatra, Indonesia
(4) CIRAD / UR34 & P.T. SMART / SMARTRI, Pekanbaru, Riau, Sumatra, Indonesia

estimation of LAI could help managing planting density, pruning, and even nutritional management of large industrial estates towards precision farming. Besides field LAI measurements, that can reveal very long and complicated (Jonckheere et al., 2004), remote sensing can provide a means to extract this information exhaustively at a large scale in a limited time, as long as a robust model had been calibrated (Baret & Guyot, 1991; Jonhson et al. 2002).

The objective of the present study is to work at two scales, in order to derive from a satellite multispectral image acquired at very high spatial resolution, on one hand, the mean LAI of a block of palm trees and, on the other hand, the accurate LAI of a single tree. Such images like those acquired by Quickbird sensor provide details as small as 70cm, giving precise information of individual palm trees in four spectral bands: blue, green, red, and near-infrared spectral domains of light. Vegetation indices can thus be calculated either for a single tree, or as the mean of a block of trees. Scientists then commonly assume that radiometric indices, such as NDVI (Normalized Difference Vegetation Index), are positively correlated to LAI. It has been confirmed for oil-palm groves (McMorrow & Seng-Heng, 2000) but it is often reminded that the quality and reliability of such relationship is clearly dependant of the complexity of the canopy (Colombo et al. 2002), and suffer from noise coming from the structure of palm trees and/or plantations (McMorrow, 1995).

We thus propose in this study to calibrate a model of estimation of LAI from multispectral remote sensing data that take into account the largest variability of situations that can be encountered in an oil-palm estate, carefully adapting protocols and measurements to this specific object and its mode of plantation.

MATERIALS AND METHOD

The principle of this work is to seek for relationships that may exist between actual LAI, as it can be measured in the fields, and radiometric indices that can be extracted from multispectral remote sensing data. Therefore, these two kinds of data first have to be acquired separately, but synchronously, and then to be confronted. Experiments took place in 2008, from May to July, in Padang Halaban Estate, located in North Sumatra near the city of Rantauprapat (Indonesia). This estate covers about 7210 hectares of planted and exploited palm trees, grouping four different vegetal materials and ranging from ages of plantation from four to twenty-one years. It thus offers a very large panel of situations to work towards the most generic model than possible.

GROUND-TRUTH DATA

We performed a field survey covering the whole area of the plantation, using Licor LAI-2000 Plant Canopy Analysers. Two independent devices were simultaneously operating (cf. *Figure 1*): (A) was fixed on a tripod in an open area to acquire the amount of radiation of the incident light each 15 seconds, while (B) was mobile under the oil-palm trees to acquire the amount of radiation of light transmitted by the canopy, following different protocols. A “45°” cap was used to mask the operator’s sector of lens field of view, for each device. After co-calibration of the two devices, both measurements A and B are processed in the C2000 (©Licor) software to derive the interception factor and thus the LAI of the canopy.

(1) To measure the LAI of an individual tree, we performed 12 acquisitions regularly distributed around the stipe circumference to take into account the tree

architecture, and with the PCA's cane stuck to the stipe and the lens looking to the edge of the canopy. These measurements were then averaged before processing.

(2) To evaluate the mean LAI for an entire block of trees (about 3000 individuals planted at angles of an equilateral triangle), we crossed several times the block from East to West and forward, stopping each 30m and acquiring four measurements with different orientation of the lens. The whole set of measurements is averaged before processing, and a factor of clumping is used in C2000 to take into account the grove structure.

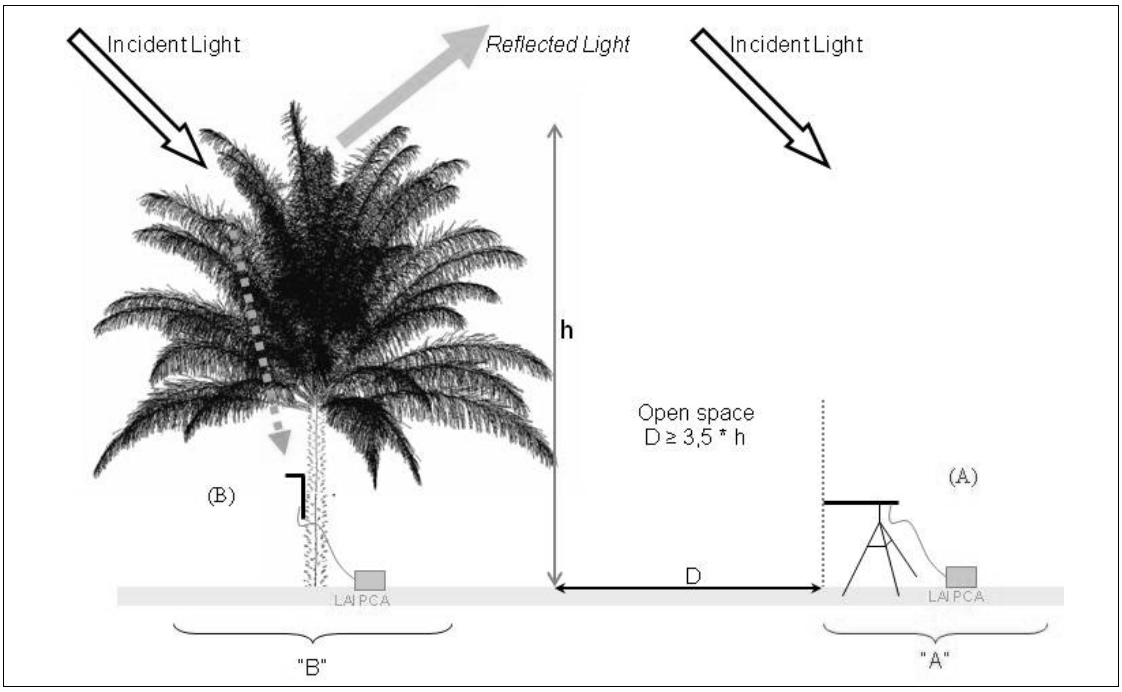

Figure 1 : Principle of LAI2000-PCA acquisitions using two devices respectively located (A) in an open area distant from any obstacle at least more than 3.5 times the height of this obstacle, and (B) below the vegetation cover to be analyzed. (A) acquires the incident radiation coming from the sun while (B) acquires the transmitted radiation through the canopy.

REMOTE SENSING IMAGE

We programmed a Quickbird image over Padang Halaban Estate, acquired in June, the 8th 2008 (cf. *Figure 2*). It consists in multispectral images at 2.4m and a panchromatic image at 0.70m. Those images were calibrated and orthorectified using the ENVI (©ITT) software. NDVI was then calculated as the ratio of the difference of infrared and red radiance and their sum, extracted from the multispectral image. Individual tree radiance was derived as the mean radiance of pixels belonging to a circle of 9m in diameter, centred on the palm tree digitalized by photo interpretation in the panchromatic image. Block radiance was derived as the mean radiance of pixels belonging to the rectangle defined by blocks borders in the original multispectral image.

Due to the amount of clouds and cloud-shadows that cover part of the satellite image, only 21 visited blocks were visible in this image, and 60 of the measured individual trees.

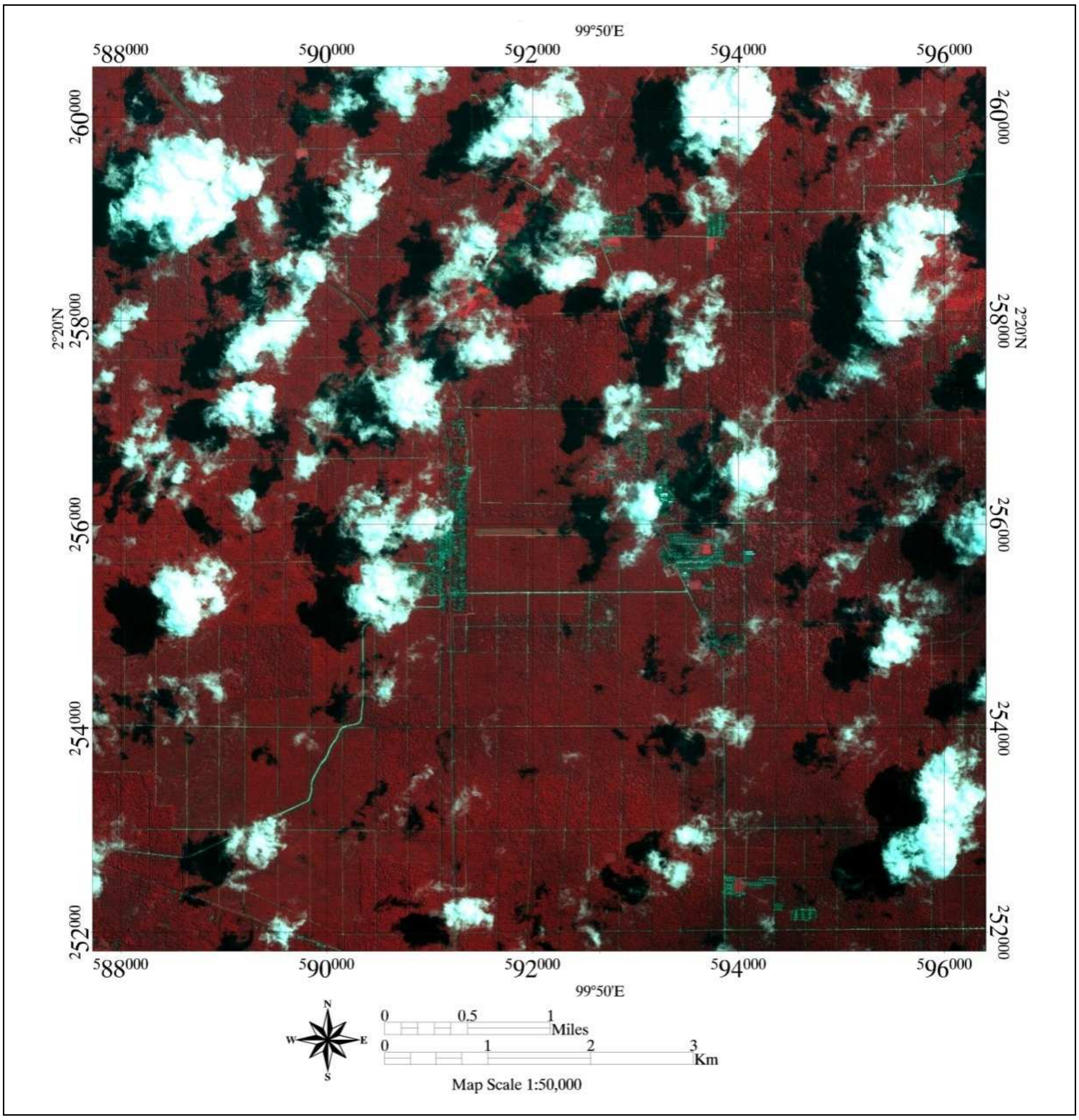

Figure 2: Satellite image acquired by Quickbird sensor at 2.4m/pixel in June 2008, displayed in false-color composition shifted to the infrared (vegetation appears red).

CORRELATION MODELS

Linear models were derived under "R" software, in the form:

$$LAI = C1 * NDVI + C2 .$$

For LAI estimation of individual trees, 30 sets of (calibration+validation) couple were randomly extracted from the whole population of 60 individuals, containing 40 individuals for the calibration and 20 for the validation. Linear regression was then performed for each couple, with the determination of C1, C2, determination coefficient, correlation coefficient, and root mean square error. The stability of the estimation of these five parameters was very strong, proving that a reliable model can be established on the base of this population.

For LAI estimation of the whole block, the total set of 21 blocks was used in a cross-validation iterating process, because the dataset is too small to follow the same method than above. C1, C2, determination coefficient, correlation coefficient, and root mean square error were also derived to evaluate the final model.

RESULTS AND DISCUSSION

Correlation between LAI and NDVI inside the ground-truth data set is of, respectively, 76% for the blocks, and 58% for the individual trees. This means that a strong correlation exists for the mean LAI of blocks but that values are more scattered for trees (see *figures 3 and 4*).

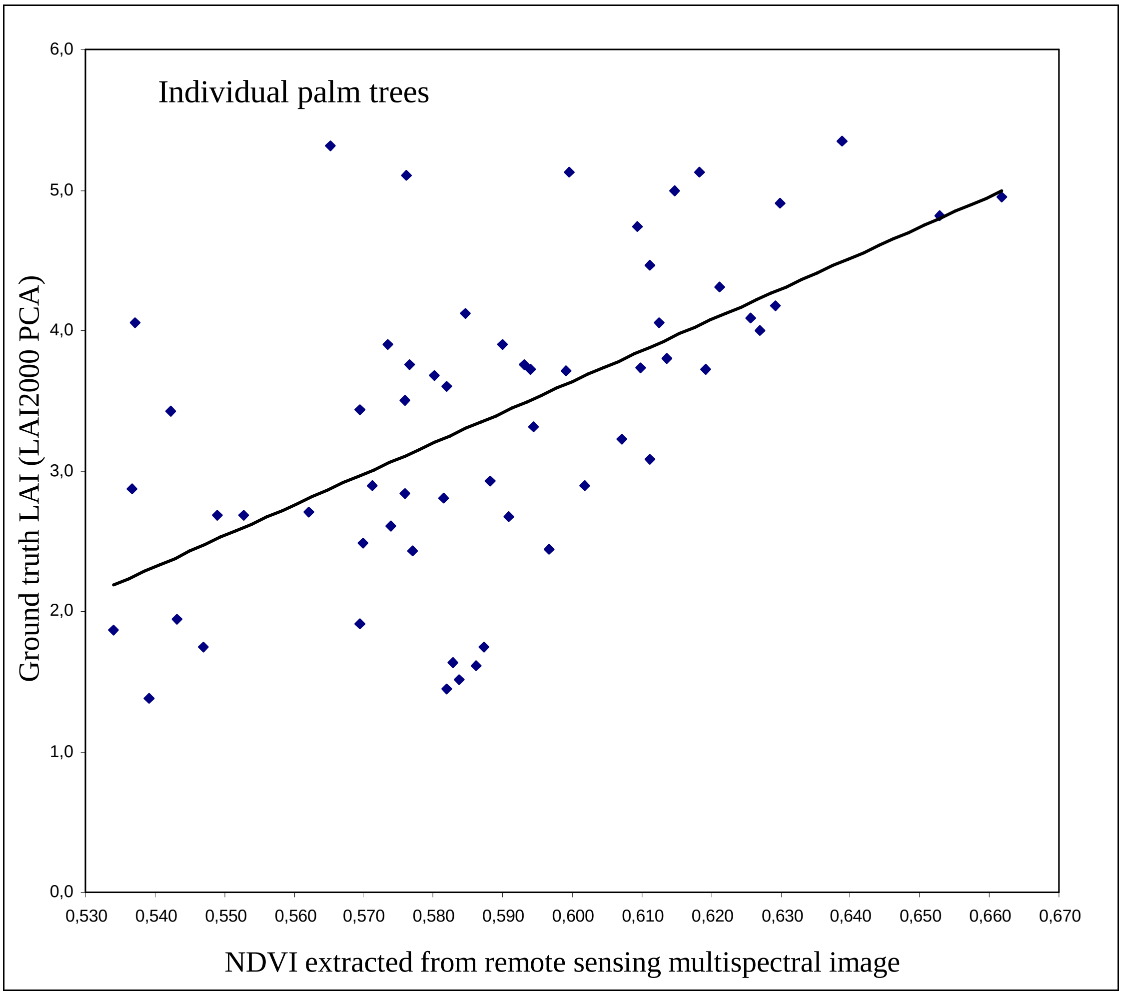

Figure 3: Correlation between LAI measured in the field with LAI2000-PCA and NDVI extracted from the remote sensing multispectral image, for individual palm trees.

This dispersion can be explained by radiometric noise due to palm-tree architecture, either in the LAI2000-PCA or the satellite measurements, or to inadequate protocol of measurements in the field. Also, other indices than NDVI (eg. SAVI or EVI, cf. Baret & Guyot, 1991) might present a higher correlation with LAI in this particular case and might be tested.

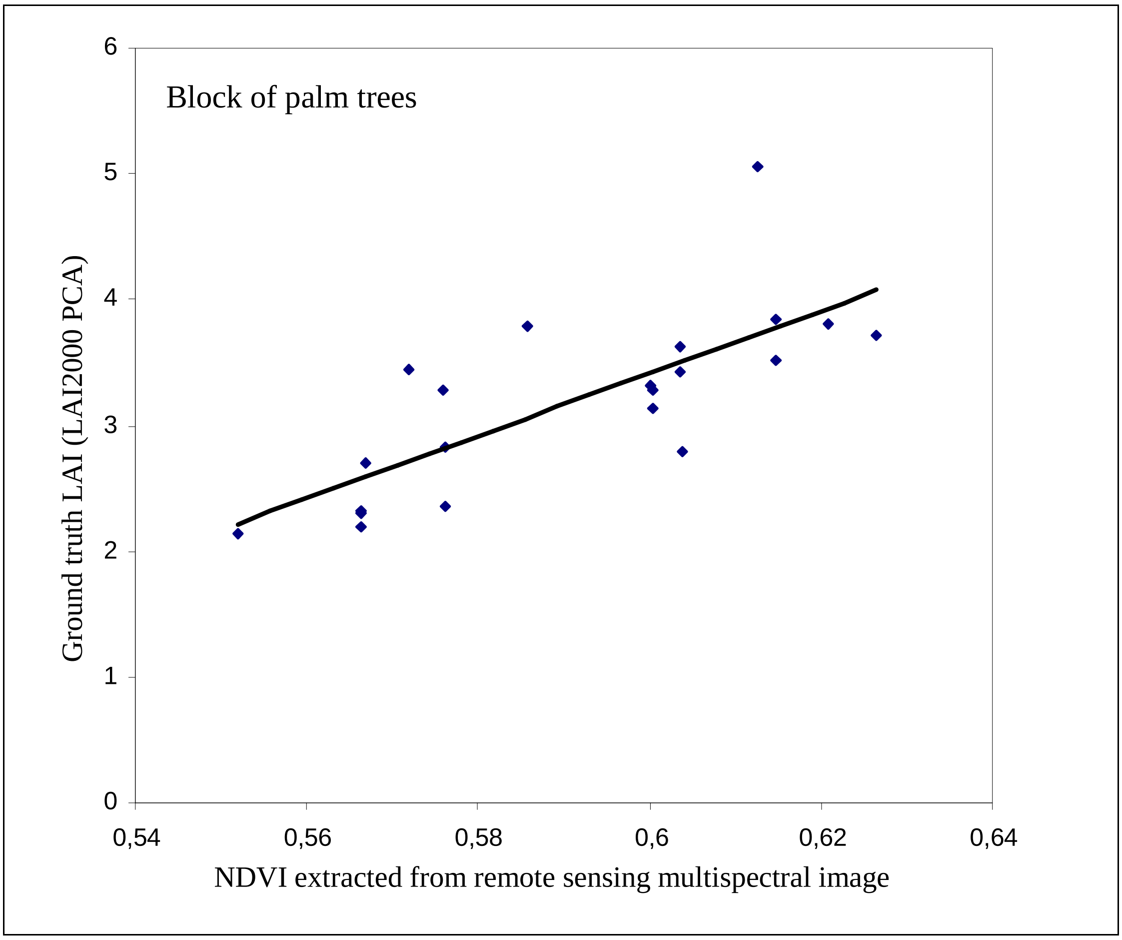

Figure 4: Correlation between LAI measured in the field with LAI2000-PCA and NDVI extracted from the remote sensing multispectral image, for blocks of about 3000 palm trees.

Resulting models predict LAI values with a respective precision of 0.5 (about 10% of relative precision) at the block scale, and 0.9 (about 15% of relative precision) at the individual tree scale. LAI of the oil palm blocks is thus clearly predictable with robustness and efficiency thanks to this model. Applying the relationship to each digitalized block in the satellite image allows drawing the whole map of LAI over the plantation (figure 5). Then, such digital map can be directly integrated in a Geographical Information System (GIS) for analysis and management, or in a physiological model working at the tree-population scale. It is also a convenient tool for field-agronomists and planters to plan targeted visits.

On the other side, the relationship obtained for one single tree retains too much error of prediction (close to a unit of LAI on a scale from 0 to 5) to be directly useful for the agronomist. It thus has to be analysed further before an actual operability, either for management of canopy density or for models of vegetation growth. However, it gives a valuable information on the ***relative*** distribution of vegetation density inside the parcel, for instance to detect and map any intraparcellar heterogeneity, for stress management. Linear model can be applied to each digitalized palm in the satellite image to get the exact LAI map of any parcel at the tree scale (see example given *Figure 6a*). As palm-tree digitalization might be a long and tough task at a large scale such as a whole industrial estate, it might also be used directly on the multispectral image pixels. *Figure 6b* presents for instance the result for the same block than in *Figure 6a*, showing that the same spatial and quantitative information is given by such map, as long as the exact contour of the tree is not needed. It thus provides the agronomists with a fast and efficient tool to map any irregularity in the vegetation growth, as well as holes in the canopy, at the tree level.

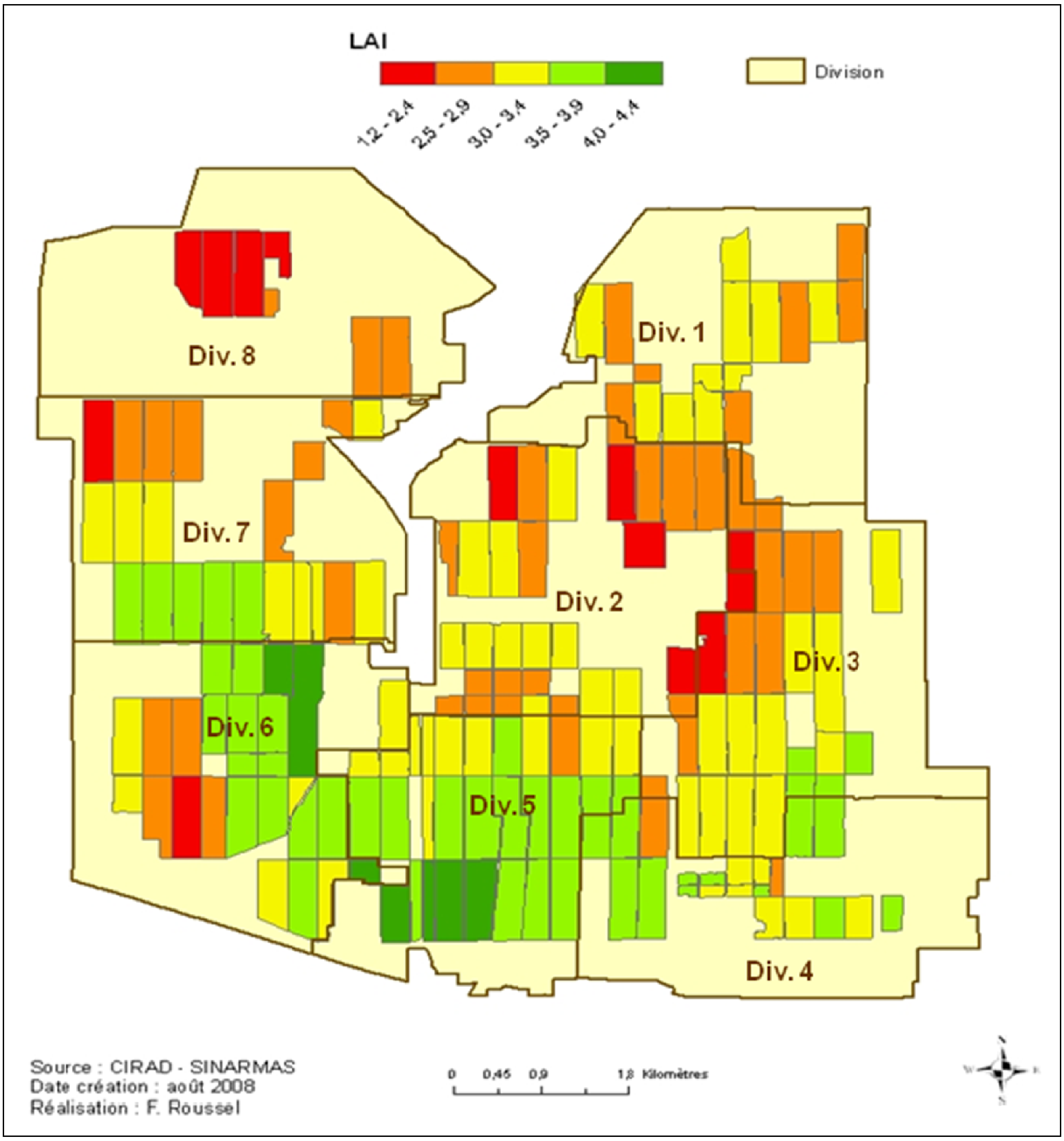

Figure 5: LAI MAP of Padang Halaban Estate in 2008: mean LAI per management blocks. ***Copyright CIRAD2008.***

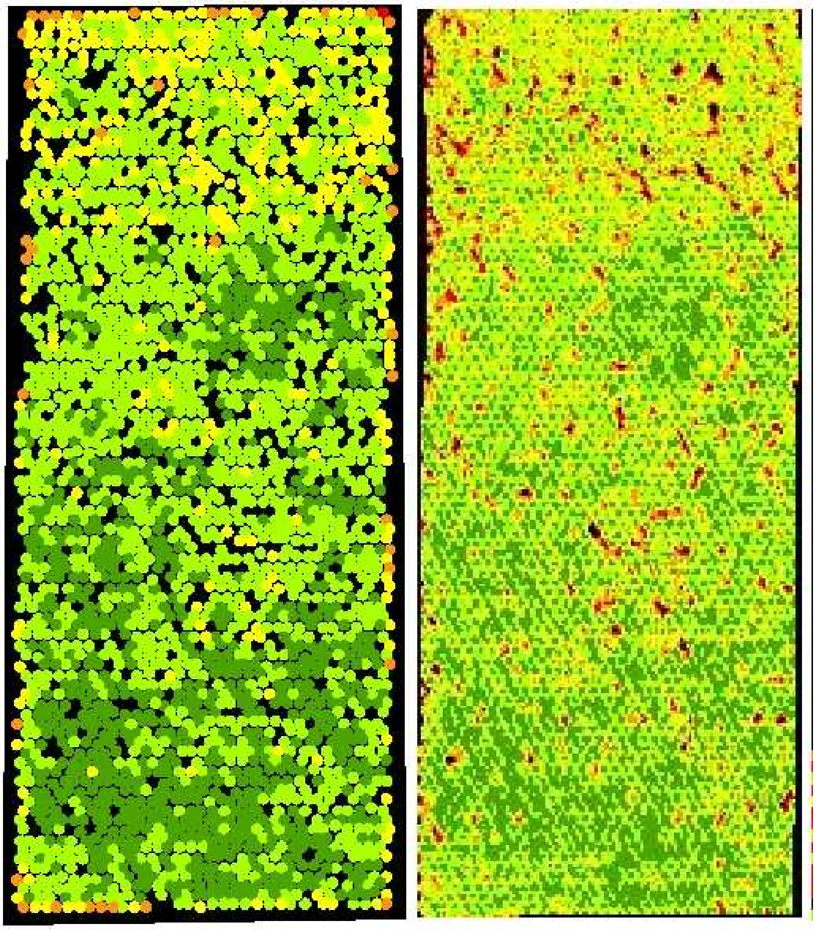

Figure 6: Examples of LAI maps obtained in an oil palm block (b) at the tree scale, and (b) at the pixel level. Both maps provide qualitatively the same amount of information: only the object contours differ.

CONCLUSION

Radiometric information extracted from multispectral remote sensing images acquired at very high spatial resolution (2.5m/pixel and less) was compared to LAI value directly measured in the fields, in an oil-palm plantation providing a large variability of ages and materials. It displayed a very strong linear correlation at the oil-palm tree level, which is found also at the tree scale but with higher dispersion. Two linear models were then calibrated between the ground-truth LAI in one hand and the remotely sensed Normalized Difference Vegetation Index (NDVI) on the other hand. These models respectively predict the LAI with a precision of 0.5 at the block level and 0.9 at the tree scale. They can be applied directly to the satellite multispectral image pixels or to the relevant digitalized objects, to quickly and easily provide LAI maps of the whole plantation, either at the block scale or at the tree level. Such maps are a relevant tool for agronomists as well as plantation managers, either integrated in a SIG, in a crop model, or directly used as a fieldwork tool: it allows monitoring vegetation growth and crop stresses, even at the intraparcellar scale.

Remote sensing at very high resolution thus reveals abilities for the development of new tools towards precision farming in large oil-palm industrial plantation, helping a management aiming at lowering fertilizers spreading, and resulting pollutions, without productivity loss.

ACKNOWLEDGEMENTS

This project was funded by SMART-TBK Company in Indonesia, and the French Center of International Cooperation in Agronomical Research for the Development (CIRAD). The authors would also like to thank Dr. Prasetya, Head of SMART-RI antenna in Padang Halaban Estate, for his help organizing field surveys, and Dr. M. Weiss, French National Institute of Research in Agronomy (INRA), for useful discussions on LAI.

REFERENCES

BARET; F; and GUYOT; G (1991). Potentials and limits of vegetation indices for LAI and APAR assessment. *Remote Sensing of Environment*, 35, p161-173.

COLOMBO, R; BELLINGERI, D; FASOLINI, D and MARINO, C (2003). Retrieval of leaf area index in different vegetation types using high resolution satellite data. *Remote Sensing of Environment*, 86, p120-131.

COYE, MR and MARGOLIS, HA (1994). The historical reconstruction of growth efficiency and its relationship to tree mortality in balsam fir ecosystems affected by spruce budworm. *Canadian Journal Of Forest Research*, 24 (11), p2208-2221.

GRANIER, A; BIRON, P and LEMOINE, D (2000) .Water balance, transpiration and canopy conductance in two beech stands**.** *Agricultural and Forest Meteorology*, 100 **(**4), p291-308.

JONCKHEERE, I; FLECK, S; NACKAERTS, K; MUYS, B; COPPIN, P; WEISS, M end BARET, F (2004). Review of methods for in situ leaf area index determination-Part1: Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology*, 121, p19-35.

JONHSON, LF; ROCZEN, DE; YOUKHANA, SK; NEMANI, RR and BOSCH, DF (2002). Mapping vineyard leaf area with multispectral satellite imagery. *Computers and Electronics in Agriculture*, 38, p33-44.

MCMORROW, J (1995). Relation of oil palm spectral response to stand age. *International Journal of Remote Sensing*, 16 (16), p203-3209.

MCMORROW, J and TEY, SH (2000). The potential of Landsat TM Remote Sensing Images for Oil Palm Estate Management. *Proceedings of the International Planters Conference, Pushparajah Ed.,* 17-20 May 2000, Kuala Lumpur (Malaysia), p769-791.

NAERT, B; GAL, R; LUBIS, AU; SUWANDI; OLIVIN, J (1990). Première évaluation des possibilités d'exploitation de la télédétection spatiale pour l'étude du fonctionnement d'une plantation de palmiers à huile à Nord-Sumatra. *Oléagineux*, 45 (5).

RIGHI, CA and BERNARDES, MS (2008). The potential for increasing rubber production by matching tapping intensity to leaf area index. *Agroforestry Systems*, 72 (1), p1-13.

VARGAS, LA; ANDERSEN, MN; JENSEN, CR *et al.* (2002). Estimation of leaf area index, light interception and biomass accumulation of Miscanthus sinensis 'Goliath' from radiation measurements. *Biomass & Bioenergy*, 22 **(**1) p1-14.

WATSON, DJ (1947). Comparative physiological studies on the growth of field crops: Variations in net assimilation rate and leaf area between species and varieties, and within and between years. *Annales of Botany*, 11, p41-76.