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# Assessment of spectral-temporal dynamics for mapping the main summer crops in the Rio Grande do Sul State

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Abstract

This study aimed to develop a low-cost method for mapping summer crops in the Rio Grande do Sul State, from the spectral-temporal behavior of vegetation indices and the HAND Model. The study was conducted in the Rio Grande do Sul State in the 2011/2012 harvest. It was used EVI images from the MODIS sensor and SRTM data. To evaluate the results, we used field data and IBGE data and a reference map elaborated with RapidEye images. The results of the MODIS classification and the IBGE data generated a correlation coefficient (r) of 0.98 for rice and 0.89 for soybeans. Validation with data collected in the field, irrigated rice obtained a Kappa coefficient of 0.66 and soybean, 0.61. In the Fuzzy similarity analysis, the irrigated rice achieved a similarity of 87% and soybean, 81%. Therefore, multi-temporal MODIS data, combined with the delineation of flood areas, using the HAND model, allow to estimate the area planted with the main summer crops in the Rio Grande do Sul State.

Key words: MODIS, EVI, HAND model, agriculture.

## 1. INTRODUCTION

Summer crops are responsible for most of the grain production in the Rio Grande do Sul State. According to the Brazilian Institute of Geography and Statistics (IBGE, 2013), soybean and irrigated rice are the main crops accounting for 79.51% of the area and 67.62% of the production in the state. Rapid, systematic and reliable surveys on agricultural production provide the government with ways to improve supply policies, control the stocks, the supply, the demand and hence costs. The major challenge for official bodies, including the IBGE and the National Supply Company (Conab), is the monitoring, estimates and prediction of harvests in a systematic way, in almost the whole continent, with a huge variety of crops, climate, soil and management techniques.

The use of objective and accurate methods that combine surface data and orbital data can improve the production of agricultural information. In this sense, data from remote sensing can be used for this purpose. The use of images with moderate spatial resolution and high temporal resolution for mapping and monitoring the agricultural activity, based on the analysis of the time spectrum behavior of vegetation indices can produce more accurate results more rapidly and with lower operating cost than conventional techniques currently used.

Among the operating sensors, the one that best meet these demands is MODIS (*MODerate resolution Imaging Spectroradiometer*), which has been widely used in agricultural studies. Several studies point to the feasibility of using MODIS images for the development of maps, based on the time spectrum attributes of agricultural crops (Brown et al., 2013; Chang et al., 2007; Epiphanio et al., 2010; Johann et al., 2012; Victoria et al., 2012). In these, spectral variations over the cycle are used as a criterion for differentiating cultivation areas, being successful when there is compatibility between the spatial resolution of the sensor and the size of the crops, as well as when the recommended range for seeding is narrow.

In the Rio Grande do Sul State, crops of irrigated rice and soybeans have similar phenological cycles, which becomes complex the application of remote sensing techniques that use only time spectrum attributes to distinguish such crops. As the lowland areas are the most suitable for rice cultivation, the correct delineation of these areas can be considered as essential for the refinement of the mapping between the summer crops, allowing the distinction of areas planted with irrigated rice from the areas occupied by other crops with similar cycle, such as soybeans. In this context, the use of HAND terrain descriptor (*Height Above the Nearest Drainage*) (Nobre et al., 2011; Rennó et al., 2008) to discriminate the lowland areas, or areas suitable for growing irrigated rice, is very important and has very positive characteristics, low cost and easy implementation.

This study aimed to develop and test a low-cost method for mapping summer crops (soybean and rice) in the Rio Grande do Sul State, at the municipal and state levels, based on the time spectrum behavior of vegetation indices from high temporal resolution satellite imagery and the HAND Model.

## 2. MATERIAL AND METHODS

The study area is located in the Rio Grande do Sul State, Southern Brazil, between latitudes 27°05'S and 33°45'S and longitudes 49°43'W and 56°20'W, covering 497 municipalities, with 281748 km² total area. The study was conducted from August 2011 to May 2012, comprising the period of development of irrigated rice and soybeans in the State.

There were used TERRA MODIS satellite images, MOD13Q1 product, collection 5, which contains compositions of images of 16 days as EVI vegetation indices (Huete et al., 1994), with a spatial resolution of 250 meters. This product is available at www.embrapa.br (EMBRAPA, 2014). With MODIS images, the first step was to perform the temporal layer stacking of EVI images, required to build the time spectrum profiles. We also obtained the 18 pixel reliability images for the same period.

In order to reduce the interference of noises from the presence of clouds, detector failure, imaging geometry, among others, and smooth the time spectrum curve, it was applied the flat bottom smoother filter (Wardlow et al., 2006). Thus, it was used the Interactive Data Language programming (IDL), version 7.1.2, adapted by Embrapa Information Technology.

The time spectrum profile was built by evaluating the pattern of EVI of pixels classified as irrigated rice and soybean in the reference map constructed with images from 10/1/12 and 14/2/12 of the RapidEye sensor with spatial resolution 5 meters (images furnished by the project Methodology for Mapping the Brazilian Agriculture (MAPAGRI) of Embrapa). For preparing the reference map, a digital classification was made using the unsupervised classification algorithm Isodata, setting a minimum of five classes and a maximum of ten classes with five iterations. From the unsupervised classification, spectral classes were grouped and a revision step was performed, where all the fields of rice and soybean were visually analyzed to detect and edit possible misclassification.

Given the possible variability of sowing dates between crops of irrigated rice and soybean in different regions of the State, we used images composed of minimum value (related to implementation of the crop) and maximum value (related to the maximum vigor of crops) of EVI.

For irrigated rice crop, the preparation of the EVI minimum image used the images from 9/14/2011 to 11/17/2011 (5 images), covering the stages of pre-planting and early crop development. The period from 11/17/2011 to 22/4/2012 (11 images) was used for generating the EVI maximum image. For soybean, we used images for the period from 10/16/2011 to 3/12/2011 (4 images) for generating the EVI minimum image and the period from 12/3/2011 to 4/6/2012 (9 images), for EVI maximum image (Figure 1).

For the generation of the crop masks for irrigated rice and soybean, we used the supervised parallelepiped classification method. Samples for classifier training were collected in a RGB color image, which were used to highlight the areas planted with spring-summer crops. In preparing the colored composition, the image of maximum was placed in the R channel (red) and the image of minimum was placed in the channels G (green) and B (blue). The red areas represent the summer crops and other colors, other targets (Figure 2).

The last step consisted of crossing the flood areas, generated with the HAND model, with the classifications of

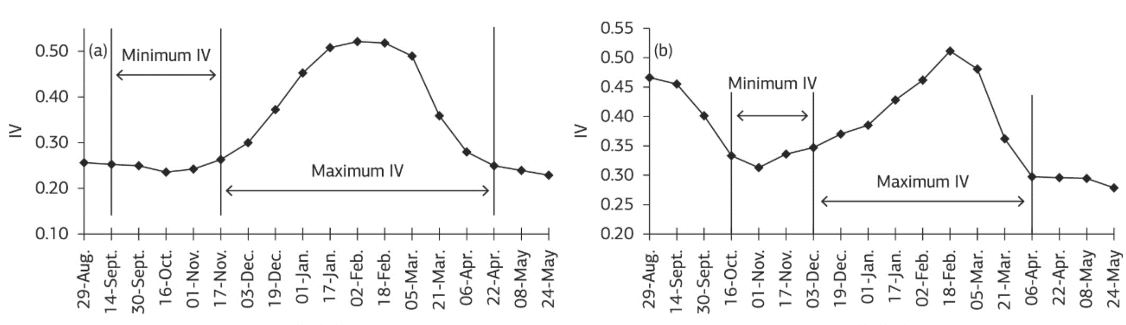


**Figure 1.** Spectral-temporal profile of irrigated rice (a) and soybean (b) crops and the periods of EVI minimum and maximum.

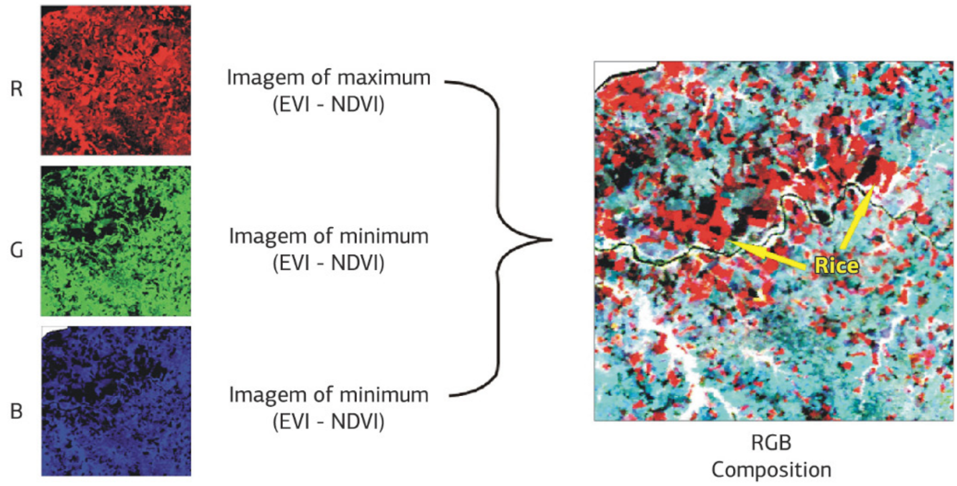


**Figure 2.** Example illustrating the application of the multitemporal composition technique of images for irrigated rice, in RGB.

irrigated rice and soybean, following the rule: areas classified as irrigated rice inside the flood areas were computed; areas classified as rice, but outside the flood areas were disregarded. Areas classified as soybean inside the flood areas were disregarded; areas classified as soybean, but outside the flood area were computed.

The HAND Model uses topographic data in the form of Digital Elevation Models - DEM to map the surface, based on the vertical distance to the nearest drainage. The implementation used SRTM (Shuttle Radar Topographic Mission) data (NASA, 2000), obtained for free, available at (Brasil, 2005). The SRTM images are provided in articulation compatible with the scale 1: 250,000 (IBGE, 2012a), which required 21 images to compose the mosaic that covers the entire study area, which was held in the software Envi 4.7 (Exelis, McLean, VA, USA). To process the SRTM data and generate the HAND model, we used the Distributed Hydrology Modelling System, also called TerraHidro, which is inserted into the software TerraView, developed by the National Institute for Space Research (INPE, 2010).

The image of the HAND model was exported as GeoTIFF; in Envi 4.7, image slicing was performed to define the flood area, in other words, it was chosen the flooding level from the nearest drainage. The value of the slicing was not the same for the entire rice crop region; the minimum height was 8 meters in some regions and the maximum was 40 meters. The choice of height followed criteria of visual analysis in better spatial resolution satellite imagery, such as Landsat 5 (spatial resolution of 30 m) and Resource Sat-1 (spatial resolution of 24 m). Finally, we applied a median convolution filter 5×5 to remove minor inconsistencies (holes caused by local topography) inside the flood area.

The schematic representation of the steps for processing and generating crop masks for irrigated rice and soybean is shown in figure 3.

The results of the MODIS classification were validated by using three sets of information: field data, official data and map reference from RapidEye images.

Two field surveys were conducted in February and April 2012 aimed at assessing the quality of the results obtained in the classification and interpretation of images. After, we calculated the Kappa index (KI) and the overall accuracy (OA) of the classification.

For reference purposes, we also used the acreage data (ha) of irrigated rice and soybean, obtained from LSPA prepared by IBGE, at the municipal level for the 2011/2012 harvest. After crossing information of official data (IBGE, 2012b) with data obtained from the MODIS mapping, at the municipal level, statistical tests were run. First, the data at the municipal level were tested for normality by the Shapiro-Wilk test (Shapiro &Wilk, 1965). As the data showed no normality, a sequence of statistical tests was performed: nonparametric Spearman correlation coefficient (rs), correlation analysis (r), Willmott index of agreement (d) (Willmott et al., 1985), refined Willmott index of agreement (dr) (Willmott et al., 2012), mean error (ME) and the square root of the mean square error (RMSE).

Finally, we used thematic maps as a reference to evaluate the accuracy of the MODIS mapping. Thus, we used two RapidEye satellite scenes to construct the reference map of irrigated rice crops, and two other scenes, for the soybean crop, totaling four scenes. The RapidEye images have a spatial resolution of 5 meters and each scene, an area around 628 km$^2$. With the reference maps, we used the validation method by fuzzy similarity index, proposed by Hagen (2003). The index ranges from 0 to 1, values close to zero indicate low similarity and values close to one indicate high similarity between the maps. We used the constant decay function with window sizes ranging from 1×1 to 11×11 pixels.

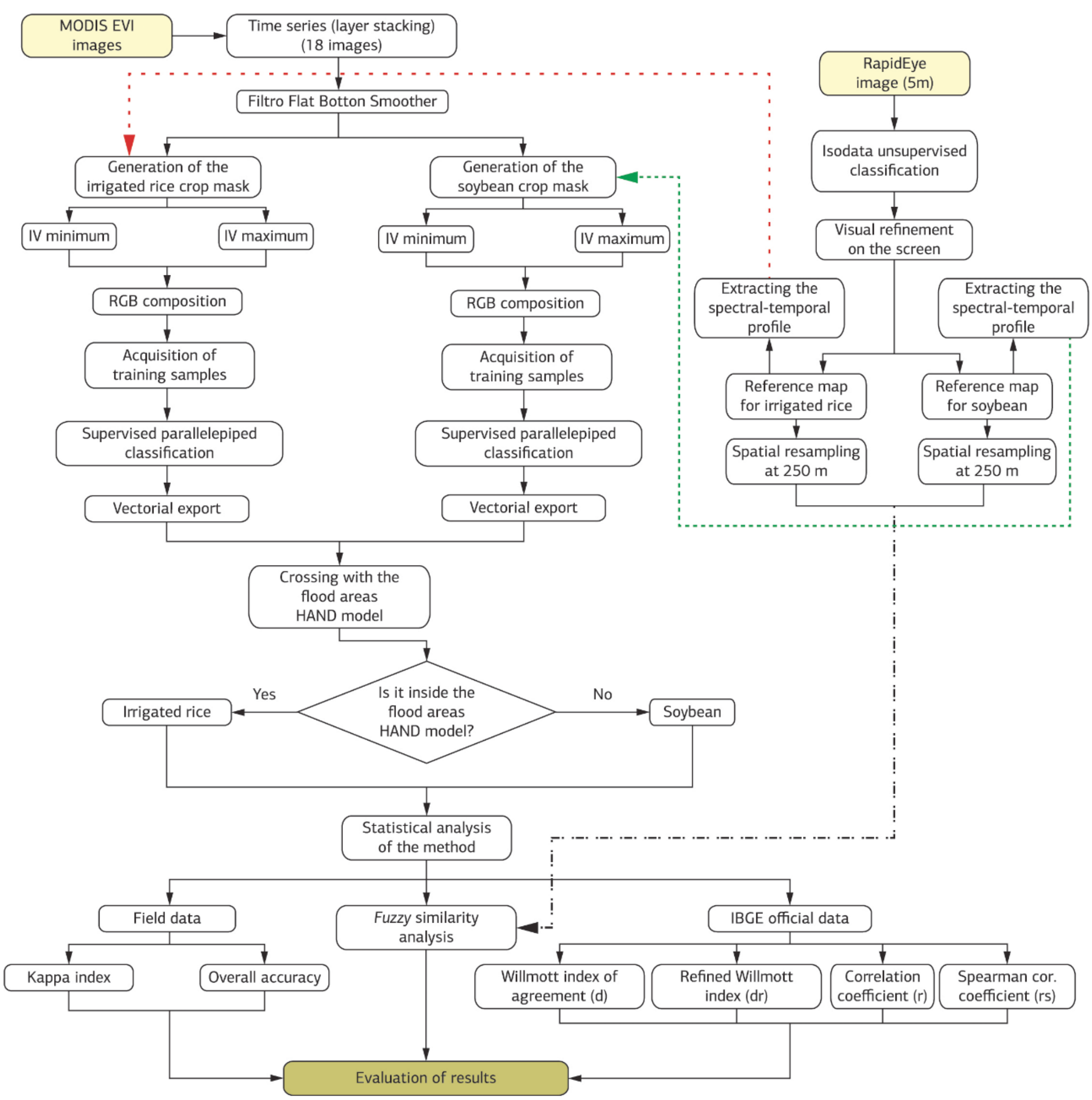


**Figure 3.** Flow chart for the steps of processing and generation of masks for the summer crops.

## 3. RESULTS AND DISCUSSION

The analysis of the temporal profiles extracted from EVI images showed the filter efficiency in correcting the variations caused by noise, which may be due to unfavorable weather conditions and the acquisition geometry (Hird & Mcdermid, 2009). The filter was able to reduce the oscillations and the time curve resulting from filtering approached the expected behavior for the summer crops, especially in the period with high values of the vegetation indices, which are associated with increased plant biomass, evidencing the attenuation of noise pixels by the filtering process (Figure 4).

The largest differences between the raw and filtered data occurred in areas destined to irrigated rice. One possible cause is that the samples selected to generate the temporal profiles are located in the internal plain to the Patos Lagoon, near the city of Camaquã, where the pixel reliability images have regions with cloud cover, especially in December and January, as seen in figure 5. In fact, this region is problematic from the perspective of obtaining satellite images, given the increased humidity due to the proximity of the sea. Custódio et al. (2009) conducted a study of daytime cloudiness in Rio Grande do Sul State and concluded that the east-northeast region shows the highest index of daytime cloudiness. This evidences an advantage of using MODIS images, whose 16-day compositions enable the mapping of this part of the State.

The crossing of the flood area generated by the HAND model with the area classified as irrigated rice crop (based on the spatiotemporal attribute in Modis images) generated a total area cultivated with irrigated rice in the Rio Grande do Sul State at 1215.529 ha, 16.72% higher than the official data (1042.443 ha).

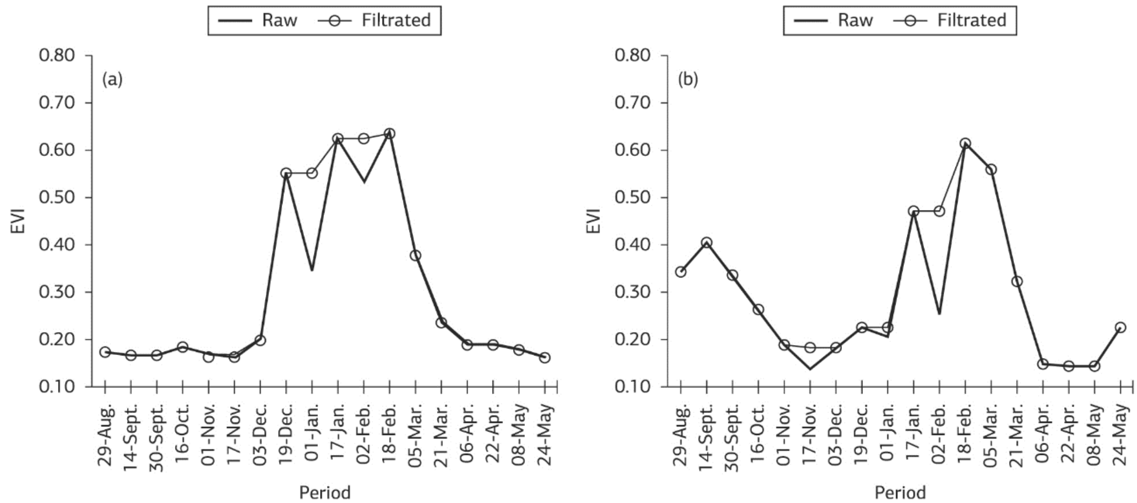


**Figure 4.** Temporal profiles EVI of a pixel located in crops of irrigated rice (a) and soybean (b) before and after the filtering process.

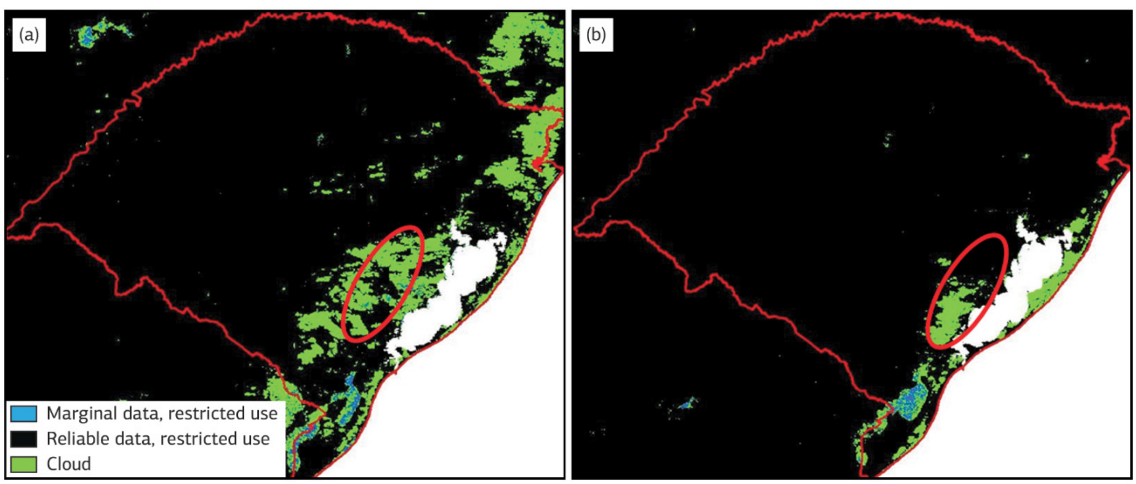


**Figure 5.** Pixel reliability image showing the locations from where the samples of irrigated rice were extracted. Date: 12/3/2011 (a) and 1/1/2012 (b).

From the soybean crop classification using MODIS data, we obtained 3794.105 ha of cultivation area after applying the flood mask generated by the HAND Model. The MODIS classification underestimated by 11.13% the IBGE official data (4269.247 ha). Considering official estimates as correct, the overestimation for rice and the underestimation for soybeans may indicate that part of the area planted with soybean in the south of the State is located in lowland areas.

When comparing the data from the MODIS classification with IBGE reference data, at the municipal level, the results show a high concordance and low dispersion in both crops. Figure 6 shows the uniform distribution of data around the 1: 1 line for irrigated rice, with a correlation coefficient (r) of 0.98, Willmott index of agreement (d) of 0.99, refined Willmott index of agreement (dr), which penalizes most the difference between the observed data from the average, of 0.89, and Spearman correlation coefficient (rs) of 0.95. For the soybean crop, the correlation coefficient (r) was 0.89, the Willmott index of agreement (d) was 0.96, refined Willmott index of agreement (dr) was 0.82 and the Spearman correlation coefficient (rs) was 0.88. The mean error (ME) for municipal masks for irrigated rice was 436.30 ha, and for soybean, the error was greater, underestimated at 963.78 ha. The RMSE, which considers the real value of the error produced by the model, was 2133.2 ha for irrigated rice and 6666.549 ha for soybean.

The results indicate a promising methodology. Ideally, these percentages errors should be as low as possible, but it should be noted that the survey is conducted at the state level and performed rapidly, systematically and with low cost, and the methodology can be implemented in another State.

The results were very similar to those obtained by Klering et al. (2013), who estimated the area planted with irrigated rice in the Rio Grande do Sul State, from a series of ten harvests using NDVI-MODIS images, and compared the results with municipal data of IBGE. The authors found values of 0.90 and 0.95 for correlation coefficient (r) and Willmott index of agreement (d), respectively.

The spatial distribution of summer crops in the State showed that the rice fields are located near water bodies (rivers, dams, lagoons) and occupy only a small part of the area suitable for cultivation (Figure 7), as expected. On the other hand, soybean crops were concentrated in traditional growing areas, such as the northern region of the State, which corresponds to the area with greater production. Moreover, it is possible to detect soybean crop areas in non-traditional areas, such as southern state formerly mainly occupied by livestock, production of rice, and the Pampa Biome (Santos et al., 2014).

Areas detected and classified as soybean by MODIS occupy the highest areas, while areas detected and classified as irrigated rice occupy lowland areas. Although there may be cultivation of soybean in lowland areas, it is less intense and

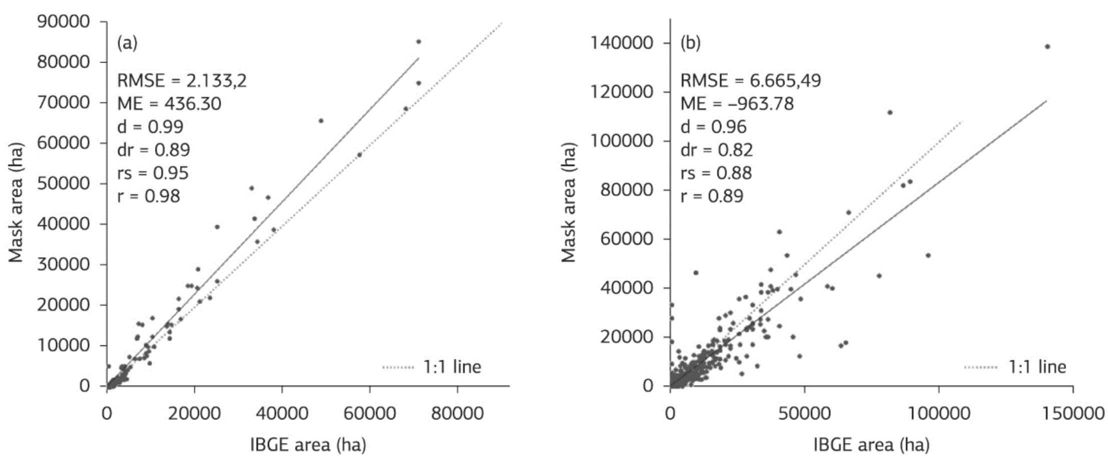


**Figure 6.** Scatter plot between data of area cultivated with rice (a) and soybean (b) MODIS - EVI and official data (IBGE, 2012b).

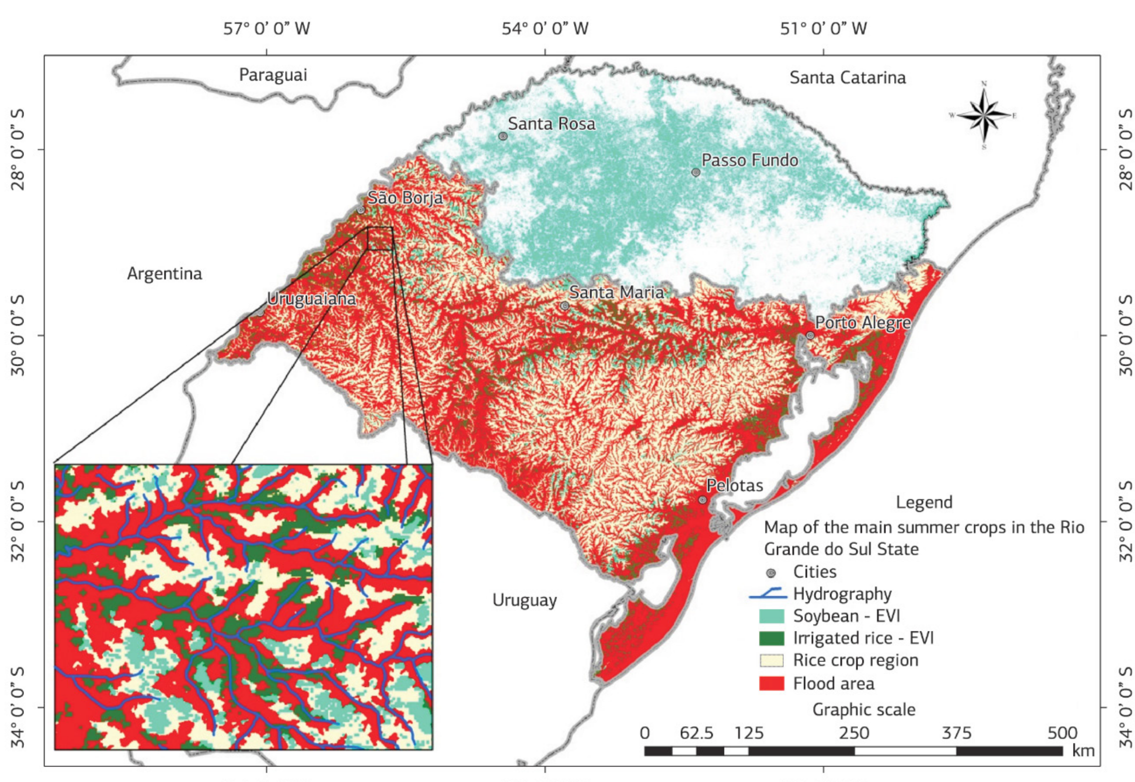


**Figure 7.** Map of the area planted with irrigated rice and soybean obtained by MODIS- EVI index in the 2011/2012 harvest.

therefore the flood area generated by the HAND model can be considered crucial to separate the areas of disagreement between the crops of rice and soybean.

Data generated by the HAND model are accurate and of rapid implementation; the scale of analysis will depend on the quality of HAND data. According to Nobre et al. (2011), the quality of the model will depend on the resolution of the input data, i.e. the quality of the Digital Elevation Model. The smaller the pixel size, the more accurate and reliable the data of the HAND model.

A major difficulty in this work was the separation of soybean from other crops, such as corn, across the State and the rice in the southern half. In previous studies using MODIS images to detect and map soybean in the Rio Grande do Sul State (Gusso et al., 2012; Santos et al., 2014), the study area did not cover the entire territory of the Rio Grande do Sul State, but rather focused the analysis on the area of increased production of soybean, located in the northern region, therefore the whole southern region of the State was not considered in the analysis. In the present study, we computed all the 497 municipalities of the State, which increases variability and disagreements in the detection of crops with similar phenological cycle, such as soybean (Table 1).

Analyzing the reference data collected in the field, compared with maps of the MODIS classification in the areas of irrigated rice and soybean, the processing performed herein were satisfactory. The areas classified as irrigated rice (Table 2) showed better results when compared to data of soybean classification (Table 3).

Spectrally, the irrigated rice has very different characteristics from the other crops. In theory, the irrigation system should allow an easy differentiation of the rice crop from the others by remote sensing techniques (Gumma et al., 2011). Nevertheless, due to the thickness of the content of suspended organic matter in water, areas with spring-summer crops of similar cycle, such as soybean and corn, can be included in the mapping.

The overall accuracy (OA) was 90.56% and the kappa index (IK) was 0.6613 for irrigated rice. The highest classification errors were found for soybean and corn. Similar results were reported in other studies, using field data to validate the classifications. García & Martínez (2010) identified areas of rice crops in the provinces of Cundinamarca and

**Table 1.** Official area (IBGE, 2012b) and areas obtained with MODIS-EVI classification of major summer crops of the Rio Grande do Sul State in the 2011/2012 harvest

| Variables | Irrigated rice | Soybean |
|---|---|---|
| Official area - IBGE (ha) | 1041.44 | 4269.24 |
| Mask area - MODIS (ha) | 1215.52 | 3794.10 |
| Difference (MODIS - IBGE) (ha) | 174.086 | –475.142 |
| Difference (%) | 16.72% | –11.13% |
| Average difference (ha) | 436.30 | –963.78 |
| RMSE | 2133.2 | 6665.49 |
| Mean error - ME | 436.30 | –963.78 |
| Willmott index of agreement - d | 0.99 | 0.96 |
| Refined Willmott index of agreement - dr | 0.89 | 0.82 |
| Spearman correlation coefficient - rs | 0.95 | 0.88 |
| Correlation coefficient - r | 0.98 | 0.89 |

**Table 2.** Confusion matrix for the irrigated rice crop for the MODIS-EVI classification

| | | Field reference | | | |
|---|---|---|---|---|---|
| | | rice | non-rice | Total | Inclusion error [%] |
| Thematic map classes | rice | 336 | 137 | 473 | 29.0 |
| | non-rice | 127 | 2196 | 2323 | 5.5 |
| Total field points | | 463 | 2333 | **2796** | |
| Omission error [%] | | 27.4 | 5.9 | | |

**Table 3.** Confusion matrix for the soybean crop for the MODIS-EVI classification

| | | Field reference | | | |
|---|---|---|---|---|---|
| | | soybean | non-soybean | Total | Inclusion error [%] |
| Thematic map classes | soybean | 779 | 313 | 1092 | 28.7 |
| | non-soybean | 328 | 3032 | 3360 | 9.8 |
| Total field points | | 1107 | 3345 | **4452** | |
| Omission error [%] | | 29.6 | 9.4 | | |

Tolima, Colombia, in an area of 4519.01 km², with NDVI data from Landsat 7 ETM+ and ASTER and compared the results with a map generated by data obtained in the field. These author registered IK values between 0.45 and 0.74 and EG above 72%.

Important to emphasize, in the work mentioned authors used smaller study areas and satellites with lower spatial resolution and presented lower accuracy compared to the present study.

For soybean, the major inclusion errors involved the spectral confusion with irrigated rice, Pampa biome and especially corn crop. Inclusion errors for the corn crop were around 60% of field samples, which were concentrated in the northwestern Rio Grande do Sul State, a traditional soybean producing region.

The values of EG (85.60%) and IK (0.6129) obtained in the evaluation of accuracy for estimation of area planted with soybean can be regarded as satisfactory, given the high variability of soybean throughout the State. Bernardes et al. (2011) used multitemporal MODIS images to estimate the soybean area in the Mato Grosso State, compared the results with TM/Landsat-5 images, tested various types of classifiers and the best results obtained were 83% for EG and 0.63 for IK.

The quality of the results can also be evidenced from the comparison of values in studies using time spectrum data, but from another sensor. Mercante et al. (2012) found IK values above 0.63 and EG of 79.05%, when comparing spectral-temporal images of Landsat-5/TM for the 2008/2009 harvest with the results obtained by sampling control points to detect areas planted with soybeans in municipalities in the western Paraná State.

Several authors have reported the difficulties in mapping crops in southern Brazil with coarser spatial resolution sensors due to the size of the properties and topographical variations (Yi et al., 2007). According to these authors, in these regions, the use of moderate spatial resolution sensors does not provide accurate estimates of crop areas depending on local peculiarities. This condition was also recorded by Lamparelli et al. (2008), showing lower accuracy in the classification of soybean using moderate spatial resolution images and supervised classifiers.

The validation performed by fuzzy similarity analysis presented satisfactory indices, with a similarity greater than 60% (1×1) for the cultivation of rice and soybean, compared with MODIS-EVI data and reference map obtained through RapidEye images. Numerous studies (Almeida et al., 2008; Macedo et al., 2013, Santos et al., 2014; Trenti & Freitas, 2010) considered fuzzy similarity index values ranging between 0.45 and 0.50, for kernel size from 3×3 to 5×5, as acceptable concordance between the simulated map and the reference map.

Figure 8 shows the increase in values of the fuzzy index with increasing kernel size, and a stabilization in the similarity from the 5×5 window for all MODIS classifications, as expected for this type of analysis, unlike the pixel by pixel analysis as in the Kappa index. The rice crop had better similarity from the reference map. Considering the 5×5 window, the value was 87%, an excellent index, according to the literature. As for the soybean, values were slightly lower, but can also be considered as excellent. The values found for the 5×5 window were 81%.

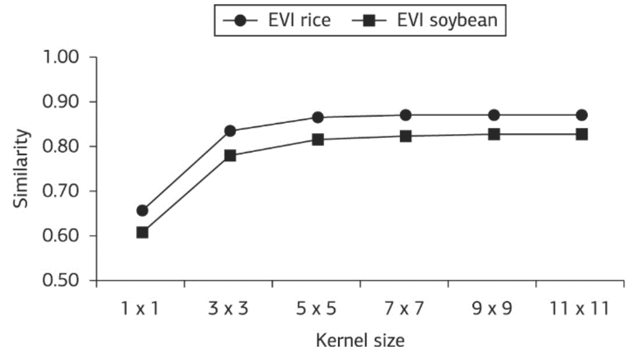


**Figure 8.** Fuzzy similarity between the reference map and the maps generated from MODIS-EVI classifications for irrigated rice and soybean.

A possible cause of the best results of similarity for irrigated rice compared to soybean is related to the characteristics of the crop, such as relief, size of properties and symmetry. In the areas destined to irrigated rice, the pattern of crops is large territory, and generally geometric shaped, these characteristics can influence a better detection of the MODIS sensor. As for soybean, these characteristics were different. Most of the soybean crop in the Rio Grande do Sul State is grown in areas where the topography is little rugged, besides having different types of planting and size. Thus, these distinguishing features between the two crops studied can influence the detection by MODIS.

This is confirmed in the study of Santos et al. (2014), who used the similarity index to validate the mapping of areas cultivated with soybean using MODIS data, reporting different patterns in some regions of the study area with predefined characteristics, i.e., soybean crops with different types of planting and size. Following this reasoning, the authors analyzed separately the municipalities with the largest and smallest percentage area (%) occupied by soybean and concluded that municipalities with larger area occupied by soybean show better similarity between MODIS data and the reference data than the municipalities with the lowest percentage area occupied with soybean. The study of Rudorff et al. (2007) evidenced that the size of soybean areas is essential for the identification and classification of these areas in the Rio Grande do Sul State, especially using MODIS images.

## 4. CONCLUSION

Using moderate spatial resolution data from the MODIS sensor, it was possible to generate and provide estimates of area planted with summer crops for the Rio Grande do Sul State. The available methodology is suitable for use on a regional scale, generates accurate estimates, with quick and easy implementation and also has a low cost.

The step of filter application was essential to reduce the noise of time series of MODIS images and enable their use for mapping agricultural areas in the RS State.

Additionally, classification with MODIS images only based on the time spectrum attribute was not enough to distinguish the rice fields from other crops with coincident cycle. In turn, the method proposed to develop a flood area through the HAND model was efficient to separate the lowland areas, suitable for rice cultivation, from higher areas that may be used for the cultivation of other crops, such as soybean.

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