Application of Landsat TM images to map long term cropping patterns

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Abstract:

The present work proposes a method that allows mapping long term cropping patterns using time-series of crop maps derived from supervised classification of remote sensing data. These maps allow implicit spatial and temporal relationships among the crops growth in an agricultural area. Cropping pattern is understood as the spatial distribution of associations between crops or crops and uncultivated land in the same fields (although not in a definite succession) along the years of the analysed time-series. The method was applied to map the long term cropping patterns in the Flumen irrigation district (33000 ha), located in the Ebro Valley (north-eastern Spain). A 7-year time-series (1993, 1994, 1996, 1997, 1998, 1999 and 2000) of crop maps derived from Landsat 5 TM and Landsat 7 ETM+ images were used to obtain the yearly crop maps from which to derive the long term cropping patterns. For that, the proposed method looks for the spatial and temporal relationships among the main crops present in the study area in their typical locations (areas where the crops are most frequently located) and the alternate crops that have been in those locations in any of the years of the analysed time-series. GIS overlay analysis operations, mainly cross-classification operations, are applied to derive the spatial and temporal relationships among crops.

Introduction

Even though considerable progress has been made over the past 20 years in research applications, some authors still consider that remotely sensed data remain underutilized (Bastiaanssen *et al.* 2000). One particular example of the underutilization of remote sensing data in agriculture is the application to map long term cropping patterns and/or crop rotations. Although it is well known that one of the main advantages of remote sensing from satellites is the synoptic and repeated collection of data, which allow time-series of accurate information on the spatial distribution of crops over large areas (Panigrahy and Chakraborty 1998, Bastiaanssen *et al.* 2000), few examples of those applications can be found in the literature (Herrmann and Kuhn 1995, Panigrahy and Sharma 1997, Raupenstrauch and Selige 1998, Paoli *et al.* 2003). Those examples reveal different conceptions of the terms (cropping pattern and crop rotation) and the difficulty or limitations of those methods to map cropping patterns or crop rotations in more than two successive years.

The definition given by FAO (FAO, 1996), considers cropping pattern as the spatial representation of crops rotations, since it basically adds the reference to the spatial distribution of crop rotations in an area to the definition of crop rotation itself: “yearly sequence and spatial arrangement of crops or of crops and fallow of a given area”. Other authors, however, conceive cropping pattern as a list of crops that are being produced in an area and their sequence within a year (Sarker *et al.* 1997). In this respect, the same authors introduce the term multi-period cropping pattern to indicate the patterns that take more than one crop year. Finally, the simplest conception of the term cropping pattern refers to the list of the typical crops that are growth in an agricultural area, with out considering their spatial distribution or sequence (Singh *et al.* 2001, Bigman and Srinivasan 2002).

Regarding particular applications of remote sensing data to map cropping patterns or crop rotations that have been found in the literature, all the authors agree in the necessity of examine time-series of remote sensing data of successive vegetation periods. Manavalan *et al.* (1995) detected change in cropping patterns in two successive campaigns by developing an image differencing algorithm involving the near infrared and red bands (IRS-LISS 2 data). Panigrahy and Sharma (1997) based their method on the definition of the spectral signatures of crop rotations from four multi-spectral images corresponding to four crop seasons within an agricultural year. On the other hand, Raupenstrauch and Selige (1998) and Paoli *et al.* (2003) derived crop rotations from multi-temporal crop maps produced by supervised classification of remote sensing data. In the first case, they used single data sets to characterize the spatial distribution of crops for the two years considered in the study, and in the second case, they used two crop maps derived from two image data sets (winter and summer) of one campaign to assess the spatial dynamics of crops. The maps were analysed by GIS overlay analysis.

A common aspect of all these works is the short time period to which the methods are applied to identify and map cropping patterns and/or crop rotations (one or two crop years). This limits the mapping of crop rotations of more than two crops, which can be usual in intensive irrigated areas. In the present paper we propose a method that allows mapping long term cropping patterns, using time-series of crop maps derived from supervised classification of remote sensing data. These maps allow implicit spatial and temporal relationships among the crops growth in a given agricultural area. Cropping pattern is understood in this paper as the spatial distribution of associations between crops or crops and uncultivated land (mainly fallow) in the same fields (although not in a definite succession) along the years of the analysed time-series. As case study, the method was applied to map the long term cropping patterns in the Flumen irrigation district (33000 ha), which is located in the Ebro Valley (north-eastern Spain).

Material and Methods

Study Area

The study area is the Flumen irrigation district, located in the middle Ebro basin (Huesca, north-eastern Spain) (Fig. 1 1). The climate is semi-arid, with a mean annual temperature of 14.5ºC and the mean annual precipitation of 423 mm. It has an extension of about 33000 ha. The main crops in the area are alfalfa, maize, rice, sunflower and winter cereals (barley and wheat). Rice is usually associated to saline-sodic soils (Herrero and Snyder 1997), although in some years, when the price of the rice raises, the crop is extended to more fertile soils, different than those typically devoted to rice. In the last decade, farmers' annual sowing decisions have been heavily influenced by European Union subsidies. The district also includes some small non-irrigated enclaves as well as about 3300 ha that have been irrigated for more than six centuries by taking water from the abutting rivers using small division dams. The most extended irrigation method is flooding, although some fields are watered by sprinklers. Small agricultural fields, less than 1 ha are frequent.

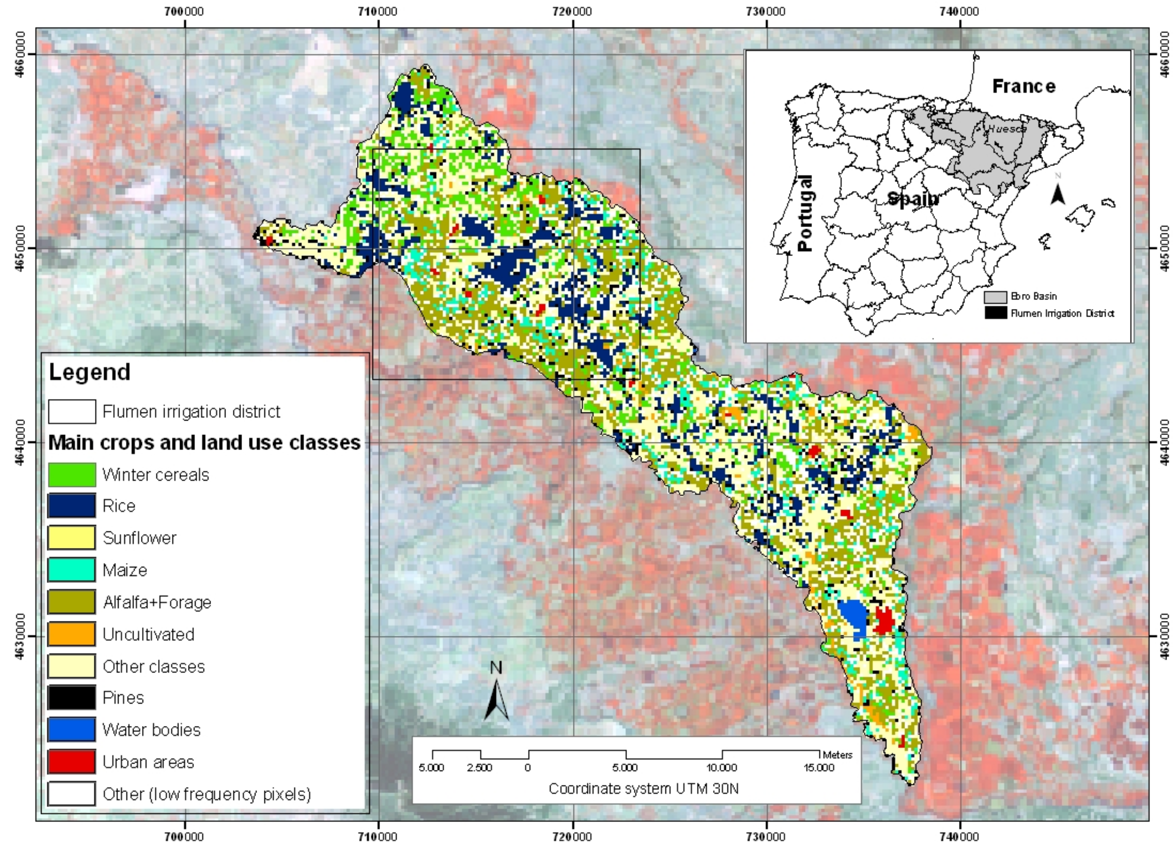

Figure 1. Typical distribution zones of the main crops in the Flumen irrigation district, period 1993 – 2000. (The frame indicates the area covered by Fig. 2).

Remote Sensing Data and Crop Maps

A 7-year time-series (1993, 1994, 1996, 1997, 1998, 1999 and 2000) of crop maps derived from Landsat 5 TM and Landsat 7 ETM+ images (the last only for the year 2000) were used. For each year, the crop maps were produced by supervised classification of spring and summer scenes (2 or 3 scenes per year). The images were processed and classified in the Centro de Investigación y Tecnología Agroalimentaria (Diputación General de Aragón, Spain). The method used was the maximum likelihood classifier. The ground-truth areas were automatically selected from field sampled segments. The land use classes mapped were: Winter cereals, Rice, Sunflower, Maize, Alfalfa+Forage (mainly alfalfa and other forage species, the last in minor quantities) (Barbosa *et al.* 1996, Herrero and Casterad 1999), Uncultivated land (includes mainly fallow and other uncultivated enclaves), Pines and Other classes. Water and Urban areas were digitized from existing maps. Confusion matrices used the same ground truth to both train and evaluate the supervised classifications. After the classification process, a 95% confidence level threshold and a 3x3 majority filter were applied (Barbosa *et al.* 1996, Martín-Ordóñez *et al.* 2000). The classification accuracy was always higher than 70%. The crop maps are in raster format, with a spatial resolution of 25 m.

Analysis of Crop Maps and Cropping Pattern Mapping

The proposed method looks for the spatial and temporal relationships among the main crops present in the study area, in their typical distribution locations (areas where the crops are most frequently located), and the alternate crops that have been in those locations in any of the years of the analysed time-series. The phases of the method could be summarized as follows. First, the typical distribution locations of the main crops need to be mapped. Next, other crops that alternate in the same locations are looked for by means of cross-tabulations with the maps of the typical distribution of the main crops. The details of the process are explained below.

Mapping of typical distribution locations of the main crops is based on a frequency analysis, applied to the time-series of crop maps: the number of times that a crop is present in a specific location (raster pixel). For that, first the reclassification of the annual crop maps to produce annual-per-crop maps (*e.g.* Rice-1993, Rice-1994… Rice-2000) is required. Next, annual-per-crop maps were added together by a sum operation. These sums resulted in different frequency maps, one per each crop, which were reclassified according to following criteria: it was used 50% as the cut threshold. Then, the typical distribution location of a crop is composed by the pixels whose frequency is >50% of the-time series analysed (4 years in the present case study).

Then it is necessary to know which other crops were present in those locations in any of the years that the main crop was not present. For that, GIS cross-classification operations in Idrisi32 (Clark University) were applied to map all existing combinations between the typical-distribution crop maps and the frequency distribution maps of each crop. Since in the frequent locations of main crops, more than one other alternate crop can be present along the considered years, the resulting cross-classification maps must be combined per each main crop to have the complete cropping pattern in each pixel of the study area. This combination has been achieved by applying a special codification to the cross-classification maps, which allows tracking the association of crops in a specific location. The codification consists of, for each main crop, reclassify the different cross-classification maps, starting per value 1, then multiply x2 this code to assign the resulting value to the second cross-classification map, the next x4, the next x8, and repeat this operation (multiplying the last code assigned x2) with the rest of the maps. For example, to know the cropping patterns in which Alfalfa+Forage is the main crop, the cross-classification of the alternate crops can be reclassified with the following codes: Rice (1), Uncultivated (2), Winter cereals (4), Sunflower (8), Maize (16), Other classes (32). Then, for each main crop, the sum of the reclassified cross-classification maps results in a map that allows the identification of long term cropping patterns. For example, in the case of Alfalfa+Forage as main crop, and according to the proposed encoding, a value of 3 in the sum map indicates that the cropping pattern for that location is Alfalfa+Forage + Rice (2) + Uncultivated (1), or a value or 26 indicates the pattern Alfalfa+Forage + Maize (16) + Sunflower (8) + Uncultivated (2).

Finally, the different cropping patterns maps (one for each main crop) were added by a sum operation in Idrisi32, which resulted in a map with more than 400 classes. Two types of criteria were used to generalize this map: a) cropping pattern classes with <560 ha (threshold established according to classes with very low frequency in the study area) were aggregated to larger related classes, which included the same crops in the pattern (*e.g.* the pattern Alfalfa+Forage – Rice, with <560 ha, was aggregated to the pattern Alfalfa+Forage – Maize – Winter cereals – Uncultivated – Rice); b) cropping patterns classes with the same crops, but with different one as a main crop, were aggregated together (*e.g.* Alfalfa+Forage – Maize and Maize – Alfalfa+Forage were joined). These generalization processes reduced the number of legend classes to 129 and 22, respectively, producing the final map of the long term cropping patterns.

Results

Main Crops and Typical Distribution Areas

Table 1 summarizes the area covered by each crop in the different years of the analyzed maps, which were derived from supervised classification of remote sensing data. The most frequent distribution areas of the main crops is presented in Fig.1. A summary description of those areas is presented in Table 2.

From Table 1, a great variability of crop surfaces in the different years can be observed. This is consequence of several factors, of which the most relevant are the subsidies of the European Agricultural Policy, the evolution of the market prices and the limitations of irrigation water in some years. The presence of saline-sodic soils has also a big influence in the cropping pattern of the study area (Herrero and Snyder 1997), and makes rice one of the typical crops of the pattern, ranging about 3000 – 4500 ha in the study period (in typical years without important irrigation water constrains). Moreover, rice typical-distribution zones, about 3765 ha in the study area (Table 2), can be useful to identify saline-sodic soils (Martínez-Casasnovas and Martín-Montero 2003). Nevertheless, it is observed that there are areas where soil degradation problems are not as intense as in the typical-distribution zones or areas without soil problems where rice is cultivated in years in which the market is favourable and there are not irrigation water constrains. This is a frequent practice in the study area, in which rice is an alternative to high income crops in some years.

Other important class is Alfalfa+Forage, which ranges from 4806 to 8124 ha in the study period (Table 1). Together with maize, Alfalfa+Forage is typical in areas without important soil problems. The typical-distribution locations of Alfalfa+Forage represent 22.7% of the study area (7524 ha) (Figure 1 and Table 2), indicating that it constitutes the base of the most beneficial crop rotations in the irrigation district. Regarding maize, the results confirm that it does not constitute a mono-crop: only 1855 ha having maize for more than 4 years. This figure contrasts with the annual mean surface covered by maize (about 3140 ha), which indicates both the large spatial variability of this crop and its importance as participant in the most beneficial rotations.

Table 1. Surface (hectares) of the main crops in the Flumen irrigation district, period 1993 – 2000.

Crop/Year	Winter cereals	Rice	Sunflower	Maize	Alfalfa+Forage	Uncultivated	Other classes
1993	7017	2998	3697	297	7124	9303	1690
1994	3126	2955	1317	1861	7044	10027	2588
1996	3065	4360	894	4824	4806	9918	4363
1997	2937	4508	1128	5795	5318	9239	3284
1998	5399	3607	858	3791	6707	7473	4149
1999	5543	1183	2051	1791	7577	10885	3060
2000	5568	3076	354	3628	8124	7368	4040
Annual mean	4665	3241	1472	3141	6671	9173	3311
Standard deviation	1611	1110	1110	1919	1196	131	962

Table 2. Surface of the main crops in their typical distribution zones in the Flumen irrigation district, period 1993 – 2000.

Crops	Typical-distribution zones (ha)	% with respect total area
Winter cereals	3432	10.3
Rice	3765	11.3
Sunflower	109	0.3
Maize	1855	5.6
Alfalfa+Forage	7524	22.7
Uncultivated	8993	27.1

Other classes	1451	4.4
Pines	493	1.5
Water	200	0.6
Urban areas	277	0.8
Other (low frequency pixels)	5106	15.4
TOTAL	33205	100

Sunflower is an irregular crop in the study area, very much influenced by European Union subsidies. Its surface has ranged from 354 to 3698 ha. Winter cereal (mainly barley) is another important class in the Flumen irrigation district (ranging from 2937 to 7017 ha).The typical-distribution zone of winter cereals is relative low (10.3% of the study area), and it is mainly concentrated in the non-irrigated enclaves (north-western part of the study area). The mean annual occupation reaches, however, 14.1% of the study area, which indicates its importance as alternative crop in the irrigated land, particularly in years with water shortages. Finally, uncultivated land, which includes mainly fallow and other unproductive areas (marls and/or sandstone outcrops, steep terrain, etc.) is another main category in the Flumen irrigation district, ranging 7368 to 10885 ha in the study period, and having a typical zone of about 8993 ha.

Long Term Cropping Patterns

The result of the method to map long term cropping patterns in the period 1993 – 2000 gave a map with 22 classes, (Figure 2 and Table 3). Cropping patterns with more than six crops represent 41.2% of the study area, being the pattern that includes the main crops growth in the Flumen irrigation district the most frequent one: Alfalfa+Forage–Maize–Winter cereals–Sunflower–Rice–Uncultivated (20.8% of the area). Another relevant pattern is a variation of the previous one that does not include Maize but other minority crops: Alfalfa+Forage–Winter cereals–Sunflower–Rice–Uncultivated–Other classes, representing 11.6% of the area. The rest of the agricultural land follows typical patterns of two to four crops. Of those, one of the most important is Uncultivated–Winter cereals, which is the pattern in the non-irrigated enclaves that exist within the study area. This class, together with the patterns Uncultivated–Other classes and Uncultivated–Winter cereals–Other classes represent 13.8% of the area.

In the irrigated zone, Alfalfa+Forage is one of the main components of the cropping patterns, being present in the patterns of two to four crops that cover 16.2% of the area. Of those, the most frequent are Alfalfa+Forage with Uncultivated or Winter cereals (10.3% of the area), and with maize and other crops (winter cereals or sunflower) (5.9%). These results reveal the relative less importance of maize in the typical cropping patterns with respect other less beneficial crops (*e.g.* winter cereals). This is consequence of the analyzed period, in which maize was not as subsidized in first years of the period as in the last years, when the area dedicated to maize increased (*e.g.* in 1993 the area with maize was 296 ha while in 2000 was 3628 ha). On the other hand, water constrains in some years that are usually known by farmers before the sowing of summer crops, have also a negative influence on this crop. Regarding sunflower, it appears as secondary component in cropping patterns of more than 4 crops, which indicates that it is an occasional crop, in this case very much influenced by European Union subsidies.

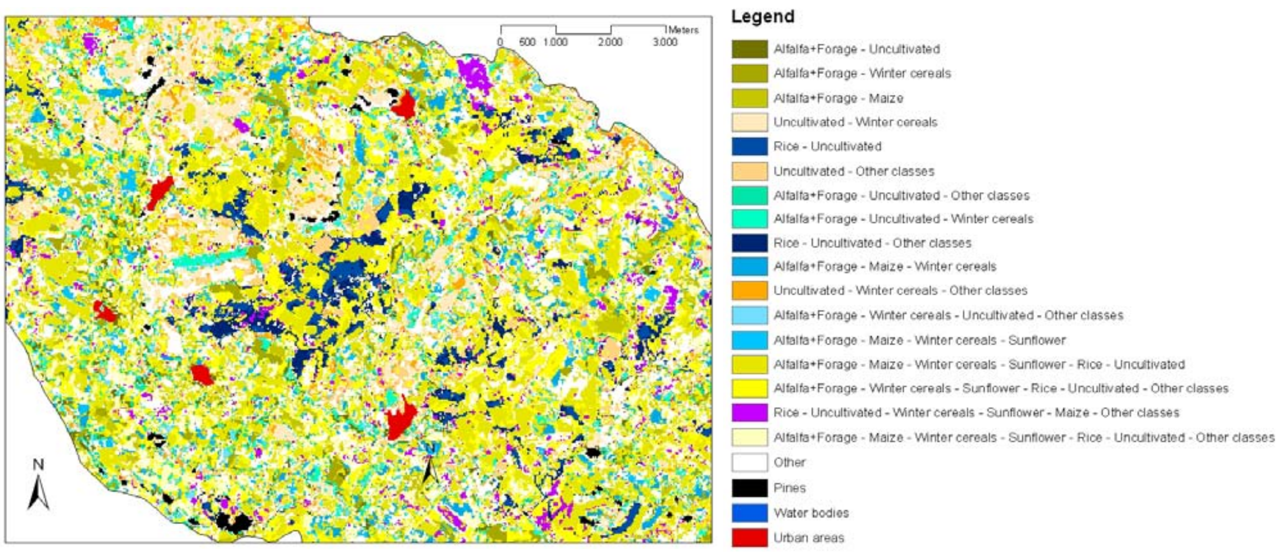

Figure 2. Main long term cropping patterns in the Flumen irrigation district, period 1993 – 2000.

Table 3. Surface of the main long term cropping classes in the Flumen irrigation district, period 1993 – 2000.

Cropping pattern	Area (ha)	% with respect total area
Alfalfa+Forage – Uncultivated	637	1.9
Alfalfa+Forage – Winter cereals	628	1.9
Alfalfa+Forage – Maize	591	1.8
Rice – Uncultivated	620	1.9
Uncultivated – Winter cereals	2298	6.9
Uncultivated – Other classes	1284	3.9
Alfalfa+Forage – Uncultivated – Other classes	563	1.7
Alfalfa+Forage – Uncultivated – Winter cereals	942	2.8
Alfalfa+Forage – Maize – Winter cereals	807	2.4
Rice – Uncultivated – Other classes	908	2.7
Uncultivated – Winter cereals – Other classes	996	3.0
Alfalfa+Forage – Winter cereals – Uncultivated – Other classes	635	1.9
Alfalfa+Forage – Maize – Winter cereals – Sunflower	568	1.7
Alfalfa+Forage – Maize – Winter cereals – Sunflower – Rice – Uncultivated	6901	20.8
Alfalfa+Forage – Winter cereals – Sunflower – Rice – Uncultivated – Other classes	3861	11.6
Rice – Uncultivated – Winter cereals – Sunflower– Maize - Other classes	894	2.7
Alfalfa+Forage – Maize – Winter cereals – Sunflower – Rice – Uncultivated – Other classes	2038	6.1
Pines	469	1.4
Water bodies	200	0.6
Urban areas	277	0.8
Other (include mono-cropping areas: Alfalfa+Forage 241 ha, Maize 1 ha, Rice 97 ha, Winter cereals 71 ha, Uncultivated 1486 ha, Other classes 72 ha and low frequency pixels 5106 ha)	7088	21.3

Another relevant cropping pattern is Rice-Uncultivated and or with Other classes (4.6% of the area). This is the pattern in the typical-distribution zone of rice, where moderate to important sanility-sodicity problems exist and other crops fail. However, as stated in Table 3, there are other cropping patterns, with six or more crops, in which rice forms part of and that represent 41.2% of the area. Its inclusion in those highly variable patterns is due to rice market prices that, in some years in which high prices are paid, influence next year the rice sowing of fields with low saline and/or exchangeable sodium content.

Discussion and conclusions

In contrast with other existing methods, based on two date image differencing (Manavalan *et al.* 1995), or based on spectral signatures of crop rotations of more than two years of multispectral data (Panigrahy and Sharma 1997), or the tracking of crop successions by cross tabulation of maps of no more than two years (Raupenstrauch and Selige 1998, Paoli *et al.* 2001), the method that we propose uses longer time series of remote sensing data (7 years in the present case study). To avoid the huge number of possible factorial crop combinations along the years, that is an important limitation of cross-classification methods when more than two years data are involved in the analysis, the method identifies first the typical-distribution zones of the main crops growth in the study area. This method, although does not allow tracking the exact definite succession of crops along the years, or in other words it does not map crop rotations as such, allows mapping spatial relationships among crops that exist in a specific location during the considered period. It is of particular application in small irrigation districts, as the study area, where the land is highly divided (fields less than 2 ha are frequent).

Another advantage of the long term cropping pattern method is that, since it allows going beyond the characterization of crop spatial distribution within a specific campaign or in two consecutive years, some spatial relationships among crops that could reveal certain soil problems could be apparent. Some of this type of problems (*e.g.* relationship between rice and saline-sodic soils) could not be surely detected in the study area with crop rotations derived from data of only 2 years, since market prices may influence very much the location of crop out of their typical-distribution zones.

An additional possibility of the long term cropping pattern map is its use in future spatial crop distribution prediction, since it contains expert knowledge about spatial relationships among crops in the study area and implicit probabilities of changes.

Regarding the application of the method to the Flumen irrigation district, it has revealed a great variability of cropping patterns: cropping patterns with more than six crops represent 41.2% of the study area. This is consequence of the subsidies of the European Agricultural Policy, the evolution of the market prices, the limitations of irrigation water in some years and the presence of saline-sodic soils. The rest of the agricultural land follows typical patterns of two to four crops. One relevant cropping patterns are Rice-Uncultivated and Rice-Uncultivated-Other classes. Those are the patterns in the typical-distribution zone of rice, where moderate to important sanility-sodicity problems exist.

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References

Barbosa, P.M., Casterad, M.A. and Herrero, J., 1996, Performance of several Landsat 5 Thematic Mapper image classification methods for crop extent estimates in an irrigation district. International Journal of Remote Sensing, 17, 3665 – 3674.

Bastiaanssen, W.G.M., Molden, D.J. and Makin, I.W., 2000, Remote sensing for irrigated agriculture: examples from research and possible applications. Agricultural Water Management, 46, 137 – 155.

Bigman, D. and Srinivasan, P.V., 2002, Geographical targeting of poverty alleviation programs: methodology and applications in rural India. Journal of Policy Modeling, 24, 237 – 255.

FAO, 1996, Agro-ecological zoning guidelines. FAO Soils Bulletin 73 (Rome: FAO).

Herrero, J. and Snyder, R.L., 1997, Aridity and irrigation in Aragón, Spain. Journal of Arid Environments, 35, 535 – 547.

Herrero, J. and Casterad, M.A., 1999, Using satellite and other data to estimate the annual water demand o fan irrigation district. Environmental Monitoring and Assessment, 55, 305 – 317.

Herrmann, S. and Kuhn, W., 1995, Field level survey of crop rotation by satellite imagery. Zeitschrift fur Kulturtechnik und Landentwicklung, 36, 69 – 74.

Martín-Ordónez, T., Casterad, M.A. and Herrero, J., 2000, Three years of mapping irrigation water in the Flumen irrigation district, Spain. In Remote sensing in the 21st Century: Economic and environmental applications, edited by J.L. Casanova (Rotterdam: Balkema), pp. 191 – 194.

Manavalan, P., Kesavasamy, K. and Adiga, S., 1995, Irrigated crops monitoring through seasons using digital change detection analysis of IRS-LISS 2 data. International Journal of Remote Sensing, 16, 633 – 640.

Martínez-Casasnovas, J.A. and Martín-Montero, A., 2003, Variabilidad espacial del arroz como cultivo indicador de salinidad en regadíos del valle del Ebro a partir de series temporales de imágenes Landsat TM. In Teledetección y desarrollo regional, edited by R. Pérez-Utrero and P. Martínez-Cobo (Cáceres-Spain: Universidad de Extremadura), pp. 43 – 46.

Panigrahy, S. and Sharma, S.A., 1997, Mapping of crop rotation using multidate Indian Remote Sensing Satellite digital data. ISPRS Journal of Photogrammetry and Remote Sensing, 52, 85 – 91.

Panigrahy, S. and Chakraborty, M., 1998, An integrated approach for potato crop intensification using temporal remote sensing data. ISPRS Journal of Photogrammetry and Remote Sensing, 53, 54 – 60.

Paoli, H., Volante, J., Fernández, D. and Noe, Y., 2003, Análisis de la rotación de cultivos en la región NOA por sistemas de información geográfica: campaña agrícola 2000 – 2001. Informe de la campaña agrícola 2000 – 2001, Instituto Nacional de Tecnología Agropecuaria (INTA) – Estación Experimental Agropecuaria de Salta, Salta, Argentina.

Raupenstrauchk, J.D. and Selige, T.M., 1998, Detection of crop rotation using satellite remote sensing for nutrient balance models and risk assessment. In Future trends in Remote Sensing, edited by Gudmandsen, (Rotterdam: Balkema), pp 139 – 143.

Sarker, R.A., Talukdar, S. and Haque, A.F.M.A., 1997, Determination of optimum crop mix for crop cultivation in Bangladesh. Applied Mathematical Modelling, 21, 621 – 623.

Singh, D.K., Jaiswal, C.S., Reddy, K.S., Singh, R.M. and Bhandarkar, D.M., 2001, Optimal cropping pattern in a canal command area. Agricultural Water Management, 50, 1 – 8.