Extraction of Soil Characteristics and Monitoring of Agricultural Land Use in the Semi-Arid Tropics of India Using Remote Sensing

Satoshi UCHIDA

Environmental Resources Division
Japan International Research Center for Agricultural Sciences
(1-2 Ohwashi, Tsukuba, Ibaraki, 305-8686 Japan)

Received February 9, 1998

Abstract

In the semi-arid tropics of India, agricultural land use has been extended to meet the demand for food to match the increase of the population. A considerable portion of land used for agriculture in this area is based on rainfed cultivation and its extension has been influenced by the changes in physical conditions. It is important to analyze the conditions of the land used and to monitor annual changes of cropping in terms of sustainability of land use. This study aims at the development of methods to estimate the land conditions suitable for agricultural purposes and to monitor the temporal changes of land use using remote sensing techniques. The study includes the processing of remote sensing and geographic data by a computerized system and field verification by measuring the spectral reflectance of various types of surface conditions. As a result, two indices, the redness index (RI) and brightness index (BI) calculated from Indian Remote Sensing Satellite (IRS) multi-spectral data, were found to be applicable to estimate the land suitability especially on black soils (Vertisols) as well as to discriminate black soils from red soils (Alfisols). In order to discriminate the cropped area from other land uses and to monitor the annual changes of cropped area, the normalized vegetation index (NDVI) was employed as discriminator. NDVI value calculated from IRS data obtained during the year can be corrected by employing the representative profile of seasonal NDVI for each land use category. It was observed that the ratio of agricultural land use in the post-rainy (Rabi) season in the objective area had almost doubled during the period between 1989 and 1996 and showed a positive correlation with the amount of rainfall around the sowing season. It was also found that the area more suitable for agriculture showed a higher rate of increase of cropped area during this period.

Additional key words: land suitability, normalized vegetation index, temporal profile, IRS data

Introduction

In the semi-arid tropics, agricultural land use as well as productivity varies with the changes of environmental conditions. Food production in this area has supported a large population for a long period of time. It is important to investigate the actual state and history of development of land use to obtain basic information on land resources.

The statistical data of land use are not always accurate in the countries located in the semi-arid tropics. Even if quantitative data per unit area are available, it is difficult to describe the actual distribution of land use. In order to describe the spatial pattern of land use in detail, remote sensing techniques, which have made remarkable progress as have been disseminated for the past 25 years, are most suitable in the semi-arid areas for the following reasons. First a soil classification map can be produced due to the high percentage of surface exposed or vegetation-free portion in the driest season. Second there is a high probability of acquiring cloud-free data in the dry season.

Remote sensing data provide multi-spectral information in the visible to infrared spectral range. These characteristics of remote sensing data can be applied to analyze the properties of soils such as moisture or organic matter content[2),5)]. Soil classification maps have been also produced from remote sensing data by manual interpretation or digital image processing techniques in India[8)]. The information on soil obtained by satellite remote sensing is limited by the spectral resolution and underground structure of vertical profile. Therefore the soil characteristics estimated by remote sensing data are qualitative characteristics based on the spectral reflectance on the soil surface.

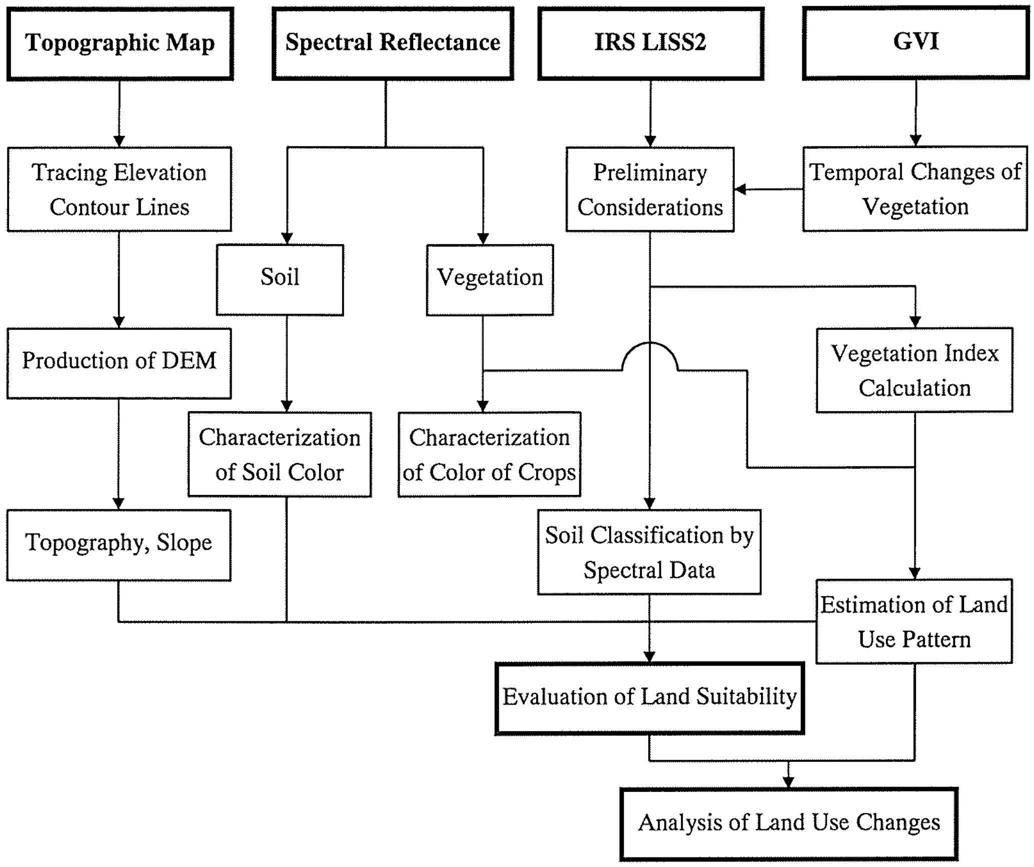
Another important application of remote sensing is to investigate the state of agricultural land including crop discrimination or yield estimation[1)]. To monitor temporal changes of vegetation activity there are two types of sensors, one with a low spatial resolution such as NOAA AVHRR[6),9),10)] and the other with a high spatial resolution such as LANDSAT TM[11)]. The former allows more frequent observations for example two times a day. If the objective area is widely homogeneous in terms of land use this sensor would be highly suitable to monitor the vegetation activity. In the semi-arid tropics of India the distribution of the size of agricultural land plots is irregular and also cropping patterns show complex features. These facts may lead to a low accuracy of estimation of agricultural land use if low spatial resolution data are analyzed. The latter sensors can depict detailed features of land cover spatially at the time of observation but the duration of the period of acquisition of cloud-free data is in the order of tens days and cannot be predicted.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India and Japan International Research Center for Agricultural Sciences (JIRCAS) started a collaborative research program on the evaluation of environmental changes using remote sensing techniques in 1994. This program includes the examination of the applicability of Indian Remote Sensing Satellite (IRS) data for the study of agricultural land use at ICRISAT campus and its surrounding area based on soil and agricultural land use surveys by remote sensing as mentioned above. This article is a summary of the results of the studies carried out by the author during his stay at ICRISAT from 1995 to 1997.

Materials and Methods

There were two major objectives in this study, the first was to develop a method to extract soil characteristics in the semi-arid tropics of India using IRS data and the other was to develop a method to monitor agricultural land use associated with the soil conditions.

Fig.1 shows the flow of data processing in this study. The first row surrounded by a thick line represents basic data to be analyzed including remote sensing data. Topographic map is a 1:50,000 scale map published by the Survey of India. From this map, digital elevation model



(DEM) data with the same spatial resolution as satellite data is produced by tracing contour lines, rasterization and interpolation. Spectral reflectance data are obtained by measuring the reflectance radiate level of the target compared with that of the standard reflection board. Portable photometer which measures the spectral range between 400 and 1050 nano meter was used for this purpose. IRS LISS-II (Linear Imaging Self-scanning Sensor) is the main instrument used for data analysis in this study. Both soil classification and land use map can be produced from the data analyzed with this instrument. Global Vegetation Index (GVI) is a kind of reproduction data derived from NOAA AVHRR data. Although spatial resolution is reduced to about 16 km, it can be adapted to recognize the seasonal changes of vegetation of the study area.

IRS LISS-II has 4 spectral bands and their specification is similar to that of LANDSAT TM bands 1 to 4. Table 1 shows the specification of both sensors. Comparison of the two sensors shows that the recurrent period of IRS is longer than that of LANDSAT which may hamper the monitoring of temporal features of land use.

IRS satellite which is equipped with a LISS-II sensor was first launched in 1988. The author retrieved all the available data which covered the site of ICRISAT and collected as many data as possible. Table 2 is a list of acquired IRS LISS-II data divided into 3 groups depending on the seasons. In the objective area there is a dominant rainy season, which accounts for 87 percent of annual rainfall (827mm) on an average, from June to October. This period is called Kharif after the cropping season. The second cropping season in the post-rainy period called Rabi occurs from November to February. During the rest of the year the temperature is very high with a small amount of rainfall. Table 2 shows that it is possible to

Table 1. Specification of IRS LISS-II and LANDSAT TM data

Sensor	Recurrent (days)	Swath (km)	Band	Spectral range (μ m)	Spatial Resolution (m)
IRS LISS- II (Linear Imaging Self-scanning Sensor)	22	74	1	0.45-0.52	36.25
			2	0.52-0.59	36.25
			3	0.62-0.68	36.25
			4	0.77-0.86	36.25
LANDSAT TM (Thematic Mapper)	16	185	1	0.45-0.52	30
			2	0.52-0.60	30
			3	0.63-0.69	30
			4	0.75-0.90	30
			5	1.55-1.75	30
			6	10.40-12.50	120
			7	2.08-2.35	30

Table 2. List of acquired IRS LISS-II data

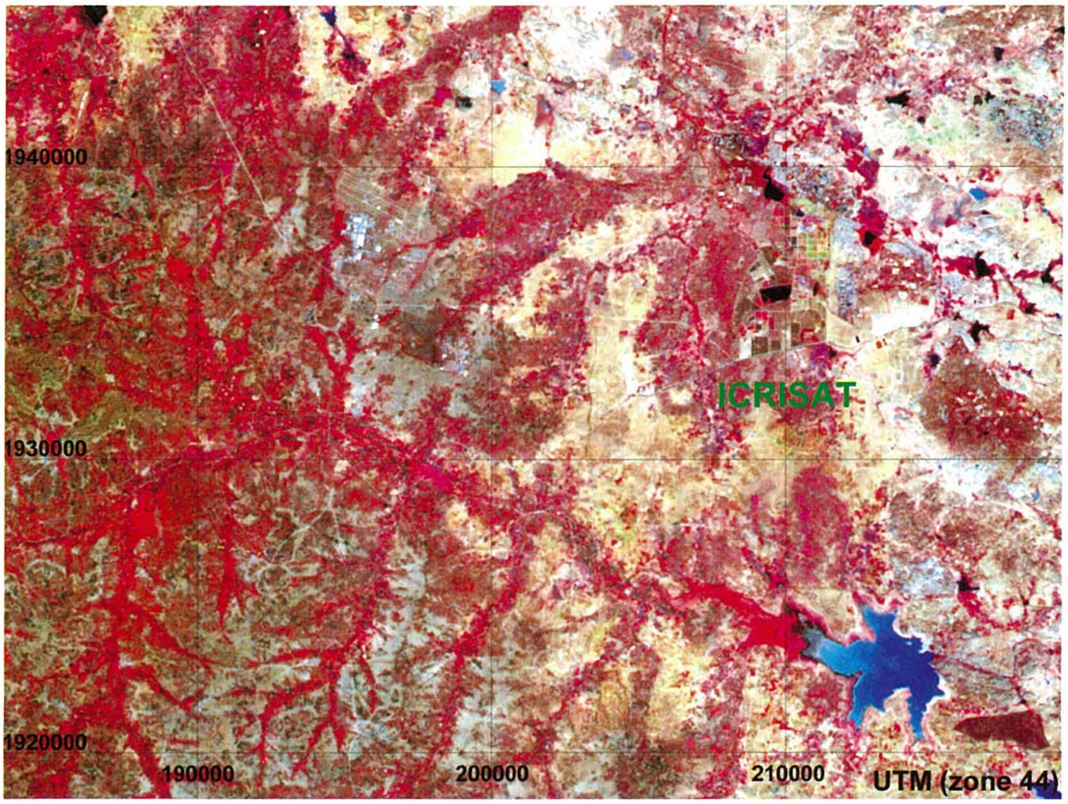
Year (June-May)	**Kharif**	**Rabi**	**Hot & Dry**
1988-1989	none	6 Feb.	none
1989-1990	none	24 Jan.	none
1990-1991	none	2 Feb.	none
1991-1992	none	none	none
1992-1993	21 Oct.	26 Dec., 17 Jan.	24 Mar., 29 May
1993-1994	none	13 Dec., 4 Jan.	24 Apr.
1994-1995	none	30 Nov., 4 Feb.	11 Apr.
1995-1996	mone	22 Jan.	none

monitor the agricultural land use year by year only in the Rabi season if an appropriate technique is adopted to correct the difference in the observation date.

Fig.2 depicts a IRS LISS-II false color composite image for two different seasons in the study area in which the campus of ICRISAT was located. This imagery is geometrically corrected to the right direction so as to set the north on the upper side and consists of 1024 columns by 768 lines with 36 meter pixel size. On the imagery the red part represents the vegetation and the blue part represents the water surface. The allocation of the vegetation area would be restricted mainly along the narrow strips of river course if the imagery was taken during the hot and dry season (b). This imagery is more suitable to interpret the characteristics of soils and it indicates generally the distribution of the two representative soils in the semi-arid tropics of India, i.e. Vertisols (black soils) and Alfisols (red soils)[7]. Black soils was found to be mostly located in the southwestern part of the study area and red soils in the rest of the area.

In this study, multi-temporal remote sensing data with different atmospheric conditions were employed. The radiate signal strength of the band sensor can be affected by these conditions. This effect should be corrected if it is necessary to compare indices calculated from remote sensing data quantitatively. In the following process the digital number of each band represents the minimum value of the histogram subtracted from the original value.

(a) Rabi season : 17 January 1993



(b) Hot & Dry season : 29 May 1993

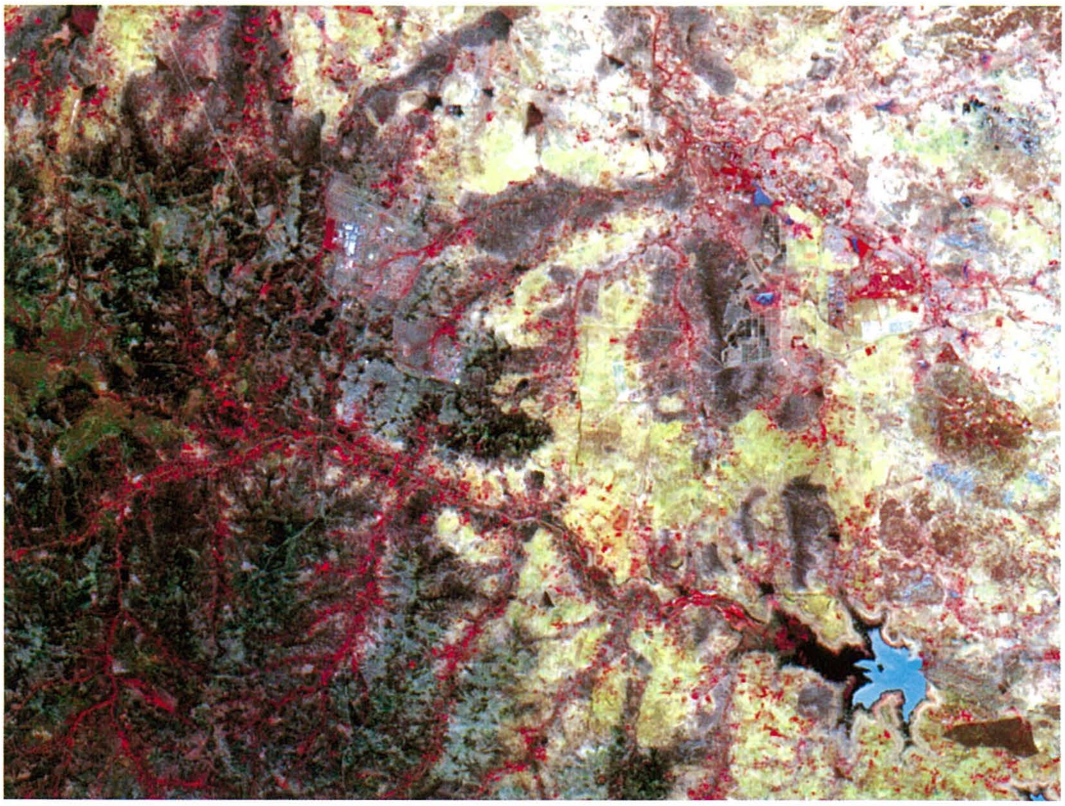


Fig.2. IRS LISS-II false color composite image of the study area

Results

1) Extraction of soil characteristics

Measurements of spectral reflectance were conducted for various types of ground surface conditions at ICRISAT campus. Fig.3 is a scattergram of spectral reflectance data at 650 nm (red range (R)) and 850 nm (near infrared range (NIR)), where black dots represent bare soils including black soils and red soils. The figure indicates that the samples of bare soils tended to be located on a single soil line. This finding suggests that if a soil line can be set to pass the origin of the scattergram, the normalized vegetation index (NDVI), which is expressed as NDVI=(NIR-R)/(NIR+R), would be an appropriate indicator to discriminate bare soil from other land cover categories.

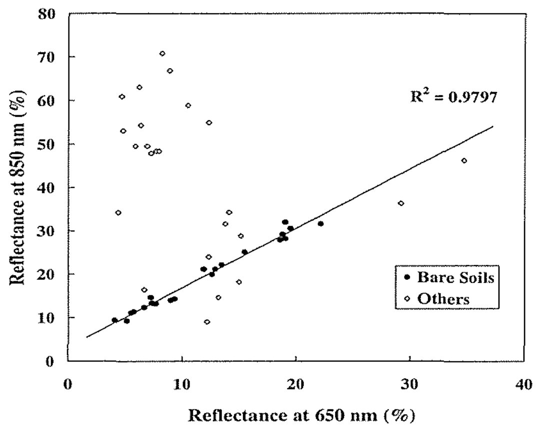


Fig.3. Scattergram of ground spectral reflectance measured at 650 nm and 850 nm

In order to discriminate black soils from red soils by spectral reflectance, NDVI is not a suitable indicator. Soil color is often characterized by Munsell representation based on hue, saturation and intensity components. Fig. 4 shows the distribution of hue and intensity of the soils sampled at ICRISAT, where 0, 60 and 120 degree of hue indicate red, yellow and green colors, respectively. It is evident that the clusters of red soils in Fig.4 are located in the more reddish and higher intensity zone compared with those of black soils.

Redness of color can be directly expressed by using the redness index (RI), which is calculated from IRS spectral band data. Red soils also have a higher reflectivity than black soils which can be expressed by the brightness index (BI).

$$RI=(B3-B1)/(B3+B1)$$

$$BI=\sqrt{\sum(Bi)^2}$$

where Bi is the digital number of band i of IRS data.

Instead of hue and saturation, the scattergram can be described by BI and RI as shown in Fig.5. The discrimination between black soils and red soils is expressed in Fig.4 and Fig.5 by the distance between the centers of each cluster. In Fig.4 the distance weighed by standard deviation is 2.107 while in Fig.5 it is 3.427. These results suggest that the method used in Fig.5 would enable a better discrimination of black soils from red soils.

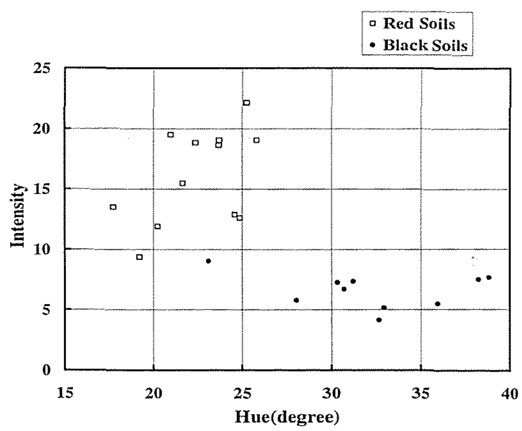


Fig.4. Distribution of hue and intensity of soil color observed at ICRISAT

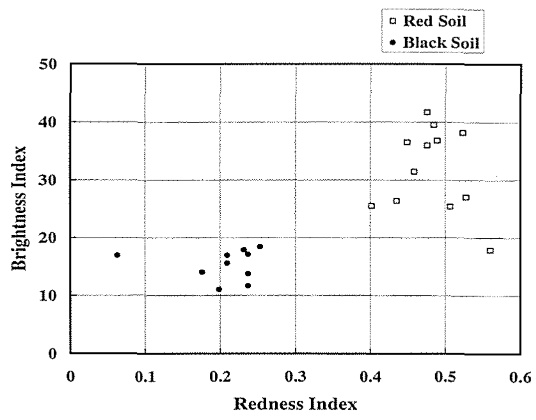


Fig.5. Distribution of redness index and brightness index of soils observed at ICRISAT

Table 3. Locational conditions of classified soil types

Soil Type	Pixel Number (unit:36x36m)	Soil Classification (%)		Elevation (m)		Slope(%)	
		Red Soil	Black Soil	Average	S.D.	Average	S.D.
1	89492	81.3	18.7	557.73	20.64	1.98	2.55
2	92182	22.4	77.6	571.31	27.51	2.33	3.42
3	71602	94.8	5.2	557.67	20.25	1.84	2.14
4	37569	97.6	2.4	556.75	21.70	1.72	1.92
5	115826	3.1	96.9	592.54	29.78	2.27	2.47
6	10074	99.1	0.9	554.43	22.37	1.69	1.85
7	23091	77.3	22.7	554.18	21.85	1.88	2.91
8	106859	0.2	99.8	606.51	21.44	2.19	1.96
9	46756	38.4	61.6	568.00	23.19	2.43	3.75
Total	593451	41.7	58.3	572.19	30.31	1.93	2.49

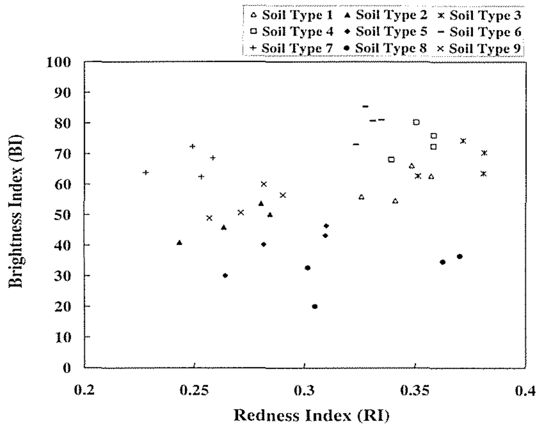


Fig.6. Distribution of redness index and brightness index for soils classified by IRS data

Due to the limitation of the penetration of the IRS sensor, only the area where soils are exposed on the surface becomes the target of soil analysis. The most exposed soil among the IRS data obtained was observed in a scene taken on 29 May 1993. After removal of the vegetation cover and water surface part by thresholding of the NDVI value, 4 bands of IRS multi-spectral data were classified by unsupervised method into 9 classes.

Table 3 shows the locational conditions of the classified soils. The boundary of red soil and black soil used in the soil category was independently obtained by manual interpretation of color composite imagery. This table indicates that soils numbered 2, 5, 8 and 9 predominated in the black soil area where the topography is rather hilly and

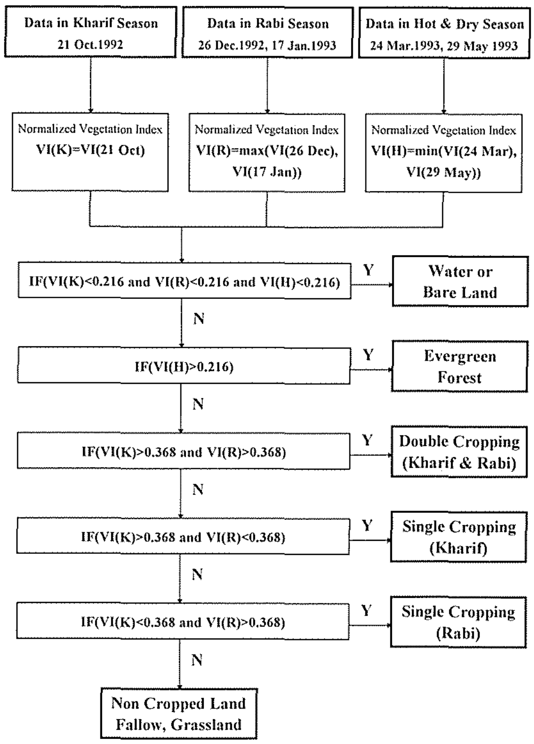


Fig.7. Flow of estimation of land use pattern

undulating.

The values of RI and BI for the classified soils are shown in Fig.6, where each type is represented by 4 temporal data taken during the hot and dry season. It was found that black soils were present on the lower left side and red soils on the upper right side as expected from Fig.5. Another characteristic of allocation is that each type tended to be aligned along a radial direction from the

Table 4. Constitutional ratio (%) of land use in 1992/93 by classified soil type

Soil Type	Major Soil	Kharif&Rabi	Kharif	Rabi	Non Cropped Land	Water or Bare Land
1	Red Soil	5.1	44.3	3.8	41.7	5.1
2	Black Soil	13.1	46.4	10.5	27.6	2.4
3	Red Soil	1.1	27.8	1.1	59.8	10.2
4	Red Soil	0.2	17.1	0.7	63.4	18.6
5	Black Soil	25.3	44.6	10.2	18.5	1.3
6	Rock, Stony	0.0	10.5	0.3	57.7	31.5
7	Settlement	1.4	28.3	1.8	45.0	23.5
8	Black Soil	51.7	32.0	4.0	11.5	0.8
9	Black Soil	4.7	42.4	5.4	39.1	8.3

Suitability Estimation : 8 > 5 > 2 > 9 (Black Soil)
1 > 3 > 4 (Red Soil)

origin of the figure. This phenomenon is probably associated with the difference in reflectance due to soil moisture conditions because drier soils gave a higher reflectance in general. For all the types the nearest point to the origin was represented by the value obtained on 29 May 1993 when 19 mm of rainfall was recorded one day before.

The soil conditions may be related to agricultural land use. To produce an annual land use classification map from remote sensing data, representative information for each specific season in terms of agricultural activity should be acquired. In this study the period from 1992 to 1993 was selected to produce a land use map due to the availability of data for the Kharif season in 1992. Fig.7 describes the flow of discrimination of land use categories, where threshold values were determined based on the ground truth of IRS data implemented in 1996.

The distribution of land use by soil type is shown in Table 4. If the land suitability can be estimated from the intensity of land use for agricultural purposes, the order of suitability would correspond to the indication below the table. This assumption could be confirmed because the study area had been developed for a long period of time and the present state would reflect the sustainability of soil conditions for agricultural activities which may be related to land suitability.

Fig.8 schematically illustrates the relation between soil characteristics and indices derived from IRS multi-spectral data. This figure may be used to evaluate the land suitability as well as to discriminate black soils from red soils occurring over a considerable area in the semi-arid tropics of India. Fig.9 shows the distribution of the soil types obtained from IRS data along the boundary lines of black and red soils manually interpreted from the printed imagery. The color representation of each soil type expressed the order of suitability, where the darker part would indicate a higher suitability in the case of black soils.

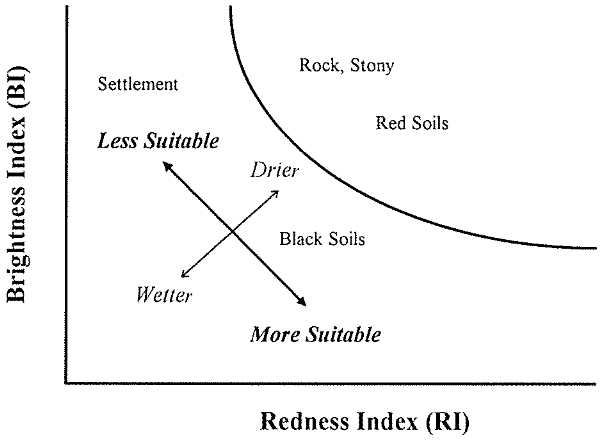


Fig.8. Relation between land suitability and indices derived from IRS data

2) Monitoring agricultural land use

Annual changes of vegetation activity in the study area can be generally represented by GVI

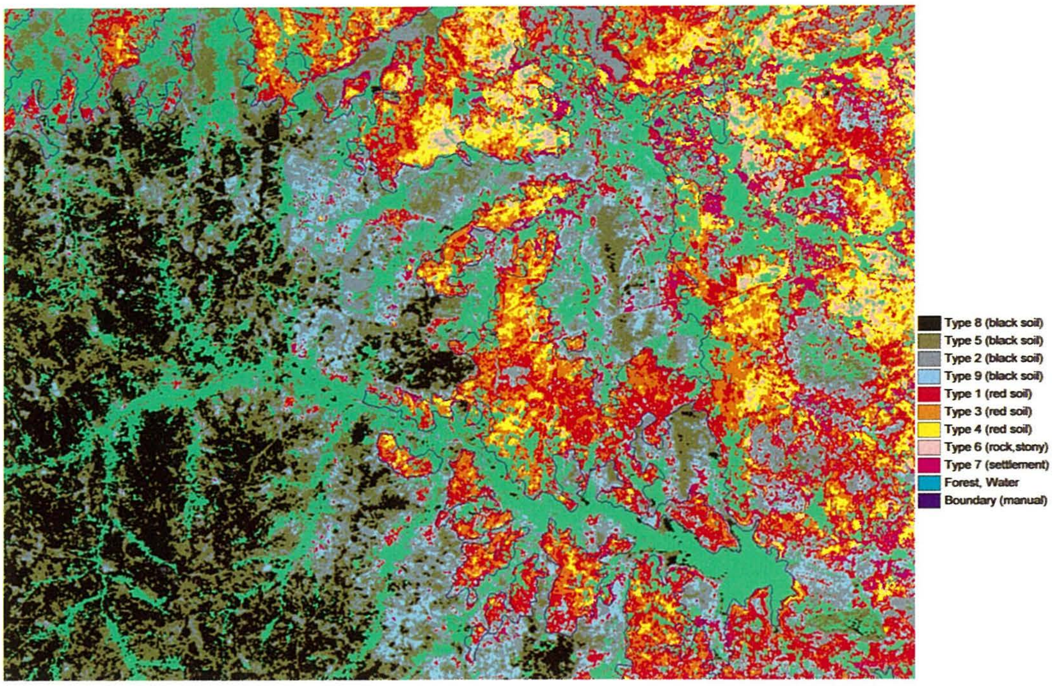


Fig.9. Distribution of soil types obtained from IRS data

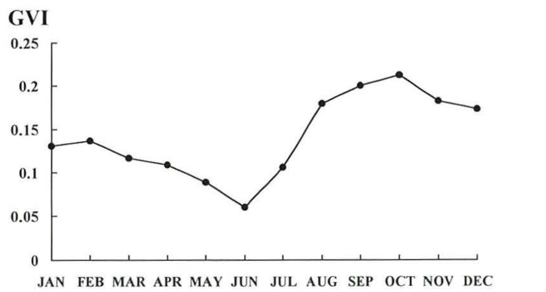


Fig.10. Monthly GVI values at the pixel level including ICRISAT area (1986-1989 average)

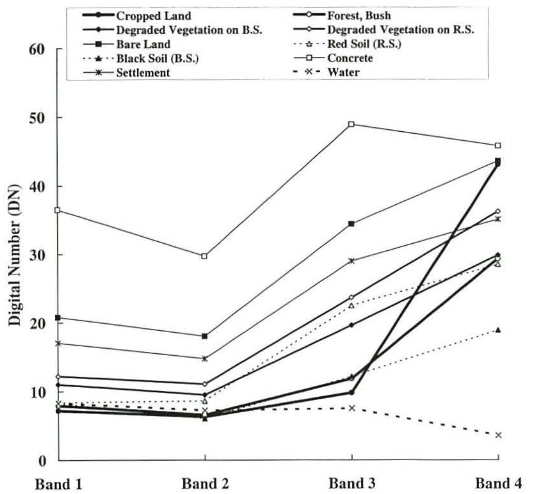


Fig.11. Spectral band profile of land cover category sampled from data collected on 22 January 1996

data. Fig.10 shows the monthly GVI values of 4-year average from 1986 to 1989 at the ICRISAT campus. This figure shows that the minimum GVI value appeared in June and the maximum in October. The fact that the decrease of the curve after the maximum was not smooth and a small maximum value was detected in February, may be attributed to the double cropping season[4].

The major land cover categories found on the imagery in the Rabi season (22 January 1996) are listed in Fig.11, which shows the spectral profile of each land cover category. It is obvious that the more densely vegetated area corresponded to the higher ratio of band 4 to band 3. The difference in the value of the ratio between similar vegetation conditions would not be sensitive enough to enable the discrimination of a cropped area from other land cover categories. Therefore in this study the land cover categories were reclassified into 5 categories as shown in Table 5 by combining categories with similar conditions of vegetation density.

Although the land use pattern changes year by year, a portion without change through the objective period may occur. In this study an area with constant land use was identified based on the fact that all the results of land cover classification were identical for 3 temporal data observed on 24 January 1990, 17 January 1993 and 22 January 1996.

The temporal changes of NDVI averaged over each land use type are shown in Fig.12. This figure illustrates the following two significant features, 1) the value of NDVI decreased in the order of cropped, forest or bush, degraded vegetation and bare land for every sample and 2) the decrease of NDVI with time for each land use type assumed a linear pattern during the period from November to February.

The relation shown in Fig.12 may lead to the development of a temporal profile model of NDVI that would enough to discriminate land use types. Fig.13 depicts the lines of boundary of land use types. These lines were obtained by a linear regression method for the middle points weighed by standard deviation for the 9 temporal samples observed during the period between November and February from 1990 to 1996. The correlation

Table 5. Reclassification of land cover categories based on vegetation density

Categories obtained by supervised classification method	Newly assigned categories based on vegetation density	Conditions of vegetation density in Rebi season
Cropped land	Cropped land	very dense around flowering stage
Forest, Bush	Forest, Bush	dense but not concentrated
Degraded vegetation on black soils	Degraded vegetation	low density with decayed vegetation
Degraded vegetation on red soils		
Bare land	Bare land	none or very sparsely distributed vegetation
Red soils		
Black soils		
Concrete		
Settlement		
Water	Water	not considered

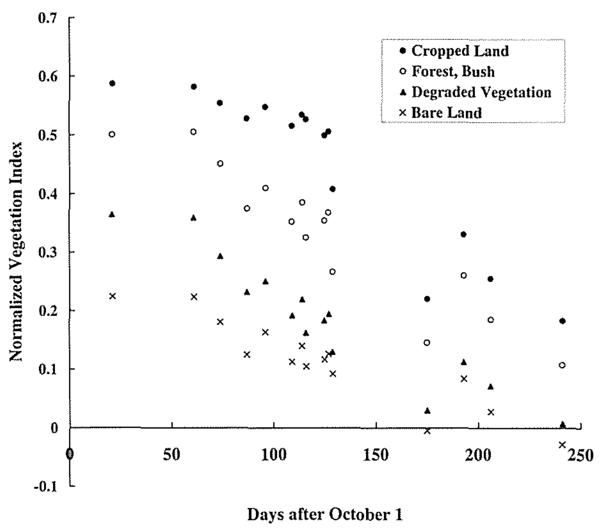


Fig.12. Temporal change of normalized vegetation index associated with land use type

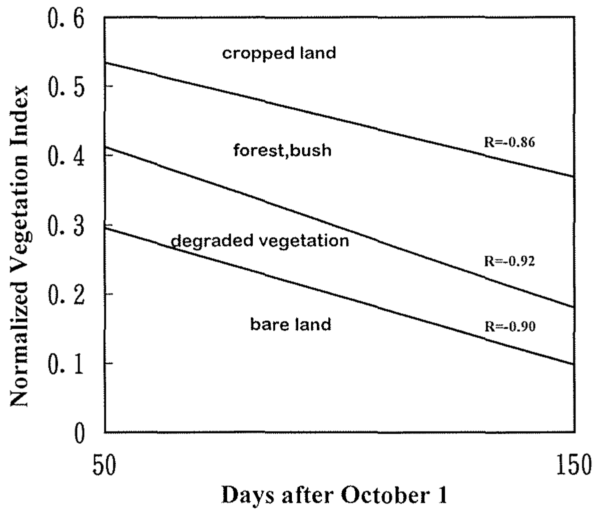


Fig.13. Scheme of land use discrimination by normalized vegetation index

coefficients of the regression lines were -0.86, -0.92 and -0.90 from top to bottom, respectively.

This concept of land use discrimination is based on the presence of a specific temporal profile of spectral information[12]. Fig.14 shows that in both Kharif and Rabi cropped areas, the value of the vegetation index was maximum around the stage of flowering while a considerably low value was recorded at the stage of sowing and harvesting. In the case of forest and grassland the vegetation index also varied with the seasons according to the climatic conditions. Since this study site is characterized by a dominant rainy season with high temperature in a year, unique maximum value of vegetation index would be recognized for forest and grassland. The model constructed to discriminate land use shown in Fig.13 could be applied during the period between the maximum value of NDVI of the Rabi crop and the time when the curve becomes flat. This period corresponds to the season between flowering and harvest in terms of crop stage or the months of December and February.

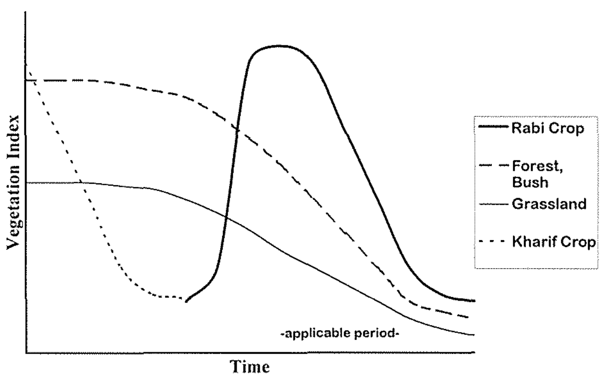


Fig.14. Schematic model of representative temporal profile of vegetation index associated with land use type

Fig.15 shows the estimated Rabi cropped area every year through the application of the model described in Fig.13. This figure also represents the amount of rainfall during the period from October to December, which may contribute to the soil moisture content around the sowing stage. There was a positive correlation between the estimated cropped area and the amount of rainfall except in 1996 when the amount of rainfall was excessive. It was also noted that the cropped area had almost doubled during the objective period irrespective of the variation of rainfall.

The changes of the cropped area associated with the soil conditions are shown in Fig.16, where the numbers in the legend denote the soil types listed in Table 3. The figure illustrates three points, 1) the types located on red soil (dashed line) showed a small percentage of cropped area; 2) the more suitable areas tended to exhibit a higher percentage of cropped area in the case of black soils; and 3) the higher rate of increase of the cropped area was recorded in areas with the more suitable soil types during the period from 1990 to 1994.

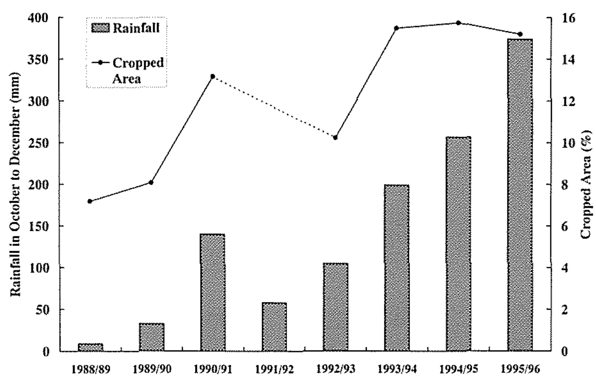


Fig.15. Estimated cropped area using normalized vegetation index and rainfall around sowing period (October to December)

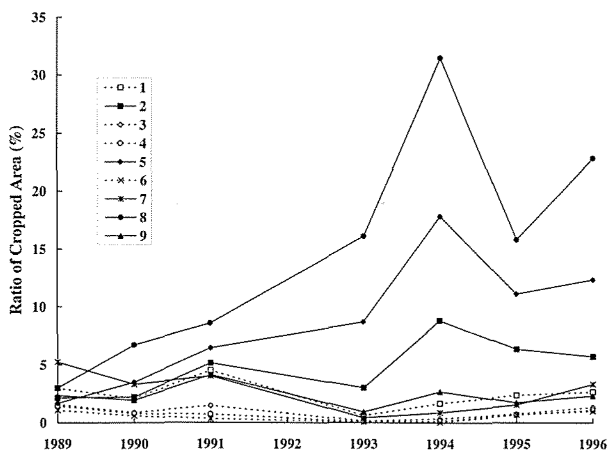


Fig.16. Temporal change of estimated cropped area associated with soil type

Fig.17 depicts the frequency of land use for cultivation in the Rabi season during the period between 1988/89 and 1995/96 excluding the year 1991/92 when no IRS data were available for estimation. It was observed that the high frequency parts were located near the river courses, where land suitability is generally high as shown in Fig.9, and that the frequency decreased toward the upper part of hills on black soils. Fig.17 also shows that some areas near lakes exhibited a high frequency of cultivation although the estimated land suitability was not the highest, presumably due to better access to water or irrigation systems of the land.

Discussion

The method applied to evaluate land suitability shown in Fig.8 does not directly deal with the physical factors involved in the existing framework of land evaluation[3]. Therefore it is necessary to examine the relationship between the data shown in Fig.8 and physical factors such as nutrient or soil moisture conditions. However even if some relation could be revealed by analyzing the data sampled at specific points this method still remains empirical and represents a form of extrapolation. However, this method could be adopted for the production of a land evaluation map at reconnaissance level for an area like India where reliable geographic information is scarce. Also an evaluation map of the objective area produced by this method could become a source of geographic data and could lead to meaningful information by overlaying other geographic data.

One of the problems in the discrimination of cropped area from other land uses in this study is that some dense forest areas with a high NDVI value would be discriminated as cropped area and part of the cropped area along the river course shown in Fig.17 presumably corresponds to an evergreen forest area. For production of a soil classification map part of evergreen forest and water were excluded by thresholding of NDVI during the hot and dry season. As a result the temporal changes of cropped area shown in Fig.15

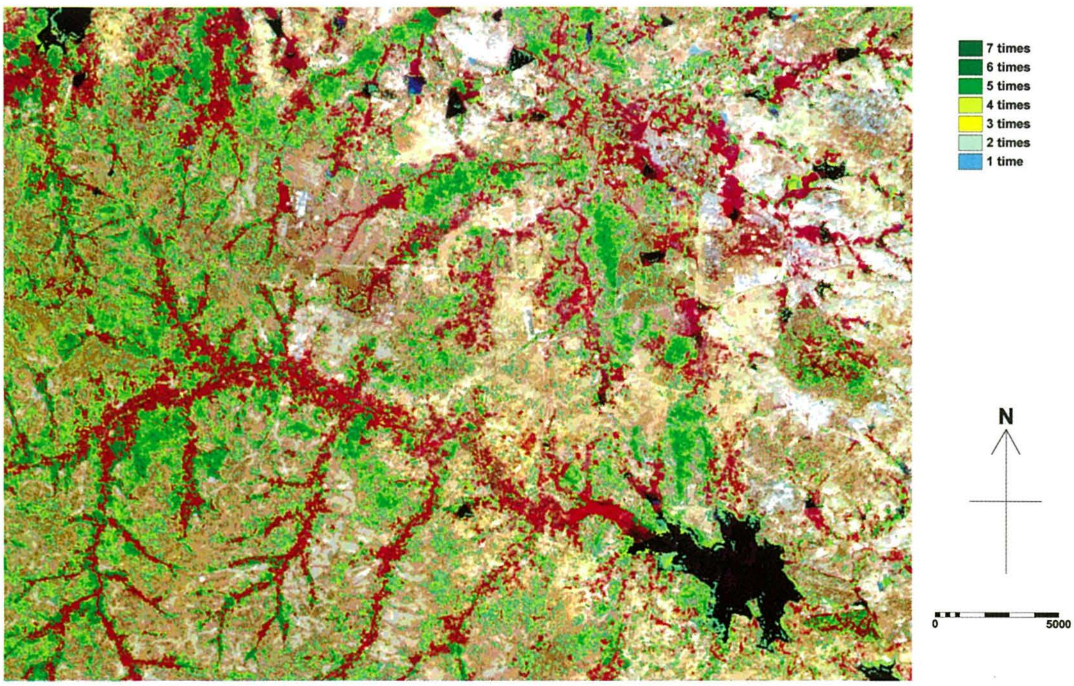


Fig.17. Frequency of cultivation in Rabi season during the period between 1988/89 and 1995/96 (excluding the year 1991/92)

and Fig.16 were not consistent. However this shortcoming can be alleviated if the data obtained are sufficient to identify the location of the evergreen forest.

It is important to recognize cropping systems and the temporal pattern of NDVI for each land use type when the method used in this study is applied to another objective area. Such an information should be accumulated and compiled in a database to perform a temporal analysis of agricultural land use using high resolution remote sensing data. The author hopes that the method described in this paper will be reexamined and improved to become a useful tool for remote sensing data analysis.

Acknowledgments

The author thanks Dr.James G. Ryan, Director General of ICRISAT, for his encouragement in pursuing the collaborative research programs. He is also grateful to Dr.F.T.Bantilan Jr., Head of GIS unit of ICRISAT, and Mr.M.Srinivas, Research Associate, for their assistance.

References

1) Akiyama, T. (1992). Crop discrimination and yield estimation. *In* Present state and perspective of agricultural remote sensing. Symposium on Agro-Environment, No.12, Nat'l Inst. Agro-Environ. Sciences, 19-26 [In Japanese].
2) Baumgardner, N. F. *et al.* (1985). Reflectance properties of soils. *Advances in Agronomy* **38**: 1-44.
3) FAO(1976). A framework for land evaluation. Soils Bulletin, No.32, FAO, 1-72.
4) Fischer, A. (1994). A model for the seasonal variations of vegetation indices in coarse resolution data and its inversion to extract crop parameters. *Remote Sens. Environ.* **48**: 220-230.
5) Fukuhara, M. (1992). Extraction of soil properties and production of soil map. *In* Present state and perspective of agricultural remote sensing. Symposium on Agro-Environment, No.12, Nat'l Inst. Agro-Environ. Sciences, 43-50 [In Japanese].
6) Gupta, R. K. (1993). Comparative study of AVHRR ratio vegetation index and normalized difference vegetation index in district level agricultural monitoring. *Int. J. Remote Sensing* **14**: 53-73.
7) Kanwar, J. S. (1982). Problems and potentials of Vertisols and Alfisols -The two important soils of SAT- ICRISAT experience. *Tropical Agriculture Research Series* **15**: 119-138.
8) Karale, R. L. (1992). Remote sensing with IRS-1A in soil studies: developments, status and prospects. *In* National resources management -a new perspective. ed. Karale, R. L., National Natural Resources Management System, Bangalore, 128-143.
9) Maselli, F. *et al.*(1993). Environmental monitoring and crop forecasting in the Sahel through the use of NOAA NDVI data. A case study: Niger 1986-89. *Int. J. Remote Sensing* **14**: 3471-3487.
10) Millington, A. C. *et al.*(1994). Explaining and monitoring land cover dynamics in drylands using multi-temporal analysis of NOAA AVHRR imagery. *In* Environmental remote sensing from regional to global scales. ed. Foody,G. and Curran,P., John Wiley & Sons, 16-43.
11) Mino, N. & Saito, G. (1996). Monitoring annual changes in grasslands using multi-temporal satellite data. *J. Jap. Soc. Photogram. Remote Sensing* **35(3)**: 26-33 [In Japanese with English summary].
12) Odenweller, J. B. & Johnson, K. I. (1984). Crop identification using Landsat temporal-spectral profiles. *Remote Sens. Environ.* **14**: 39-54.

リモートセンシングを用いたインド半乾燥熱帯地域における土壌特性の抽出と農地のモニタリング

内田　諭

国際農林水産業研究センター環境資源部
（〒305-8686　茨城県つくば市大わし１－２）

摘　要

インド・デカン高原中央部の半乾燥地域に位置するICRISAT（国際半乾燥熱帯作物研究所）及びその周辺地域を対象として，インドが開発したセンサーを搭載する衛星リモートセンシング（IRS）データを用いた農地の立地条件の解析を行った。解析目的は，土壌特性の抽出及び農地の空間的分布の経年変化を調べることであり，比較のための地上での分光反射特性の測定を併せて実施した。

対象地域においては，熱帯半乾燥地域の代表的土壌の内の２種類（Vertisols（黒色土），Alfisols（赤色土））が存在しているが，両者の識別のためには，IRSデータから求められる２個の指標値（RI（赤色度指数），BI（明度指数））が有効であることが確認された。次に，1992年から1993年における通年の土地利用パターンを推定した後，土壌識別に用いた２個の指標値との関係を調べたところ，特に黒色土域において農地としての土地利用強度と指標値間の一定の関係を見出した。現地は，農地としての開拓の歴史は古く，天然林は殆ど残っておらず，また土地利用の現況は農地としての適性度を反映しているとみなされることから，本手法は農地適性度の評価に対して有効であると考えられた。

過去のIRSデータの検索結果から，雨季作（カリーフ）には観測条件が極めて悪いが，雨季後の作期（ラビー）においては条件が良い場合が多く，この時期の農地の経年変化を調べることとした。対象地域においては，作付けの形態は複雑であり，個々の作物の判別は困難である。本研究では，作物が生育している農地を１個のカテゴリーとし，他の土地利用種との識別のためにIRSデータによる正規化植生指数（NDVI）の時間的断面に着目して解析を行った。その結果，ラビー期の後半に対応する１２月から２月の期間においては，土地利用毎のNDVIが一定の低減率を示し，たとえ観測日が毎年同じでなくとも農地分布の経年的傾向を調べることが可能となった。

1989年から1996年の期間（1992年を除く）における観測日が１月から２月にあるデータを用い，各年次における農地分布の推定を行った。年々のラビー期における農地面積は，播種前後の降水量が少ない場合には小さくなる傾向があるが，全体的には1990年代の前半にかなりの増加が示されている。土壌条件と農地の経年変化の傾向との関係を調べたところ，土地適性度の高い地域での増加率がより高くなる様子が示された。

本研究で開発したIRSデータを用いた解析手法に対し，理論的な論証と定量的な評価は課題として残されている。しかしながら，土地利用の実態に関する信頼できるデータの乏しい地域においては，たとえ精度上の問題を多少含むとしても，衛星リモートセンシングを用いて土地利用の空間的・時間的断面を記述する情報を蓄積することは有意義であると考えられる。

キーワード：土地適正度，正規化植生指数，時間的断面，IRSデータ