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Mapping Soil Properties of Andosols and Assessment of Clubroot Disease Incidence in Cabbage Using Sojuzkarta KFA 1000 Photographic Imagery*

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Abstract : The objectives of our study were : (1) To investigate the feasibility of using the digital KFA 1000 imagery analysis as a means of accurately describing and quantifying soil properties of Andosols, and (2) to reveal the relationship between the soil properties and the extent of clubroot disease incidence in cabbage. The film (Sojuzkarta #25253, scale 1 : 250,000), acquired on June 7, 1988, was used to examine the approach in the entire area of Tsumakoi-mura of Gunma Prefecture. The film is sensitive in the red (570-680 nm) and near infrared (680-810 nm) regions. The scanner data were converted from analog to digital from by a drum scanner with a 25-μm sampling pitch. This method provided data with a pixel size of approximately 6 m×6 m. The near infrared reflectance was a better indicator for delineating five soil series than the red reflectance, indicating the differences of soil color, organic matter content, and water regime among the five soil series. The large variations in the red reflectance within a single soil series may be influenced by different soil moisture conditions ; five soil series and three drainage classes were identified. The effect of soil series on the retardation of the disease incidence was much greater in Light-colored Andosols than in other types. The disease was more severe in the poorly drained class. A season of abundant rainfall was shown to increase the incidence of the disease. Sojuzkarta KFA 1000 imagery provides good information on soil properties of Andosols for the assessment of the incidence of clubroot disease.

Key words : Andosols, Cabbage, Clubroot, *Plasmodiophora brassicae* Worn., Soil drainage, Soil properties, Soil series, Sojuzkarta KFA 1000.

コスモス衛星写真による黒ボク土の特性把握とキャベツ根こぶ病の発生評価：鳥越洋一・井上隆弘**・天野哲郎***・小川　奎・福原道一****（農林水産省農業研究センター・**農林水産技術会議事務局・***東北農業試験場・****農業環境技術研究所）

要　旨：本研究はコスモス衛星写真（Sojuzkarta KFA 1000）を用いて黒ボク土の特性分類を行い，それを基にキャベツ根こぶ病発生の特徴を明らかにすることを目的とした．対象地域は群馬県嬬恋村全域とした．使用したフィルム（番号：25253）は1988年6月7日に撮影されたものであり，赤（570-680 nm）と近赤外（680-810 nm）に感光する特徴をもつ．ドラムスキャナーを用いて，デジタル画像（地上分解能約6 m）を作成して解析に供試した．対象地域に分布する5土壌統群は近赤外の反射強度によって明瞭に区分できた．このことは土色，土壌有機物含有率，ならびに水分保持力等の違いによるものと考えられた．単一の土壌統群において赤の反射強度に大きな変異が認められた．これは土壌水分状態の違いによるものと推察された．このようにして，土壌統群と排水性の違いを把握することができた．次に過去6年の発病記録を基に作成した発生地図と土壌特性との関係を検討したところ，本病の発生は土壌統群間で異なり，特に淡色黒ボク土ではほとんど発生を認めることができなかった．また本病の発生は排水性の悪いところで著しいことが明らかになった．また，多雨年と平年との発生を比較したところ，本病は多雨年に発生が多くなることを認めた．これらの発生特徴は既往の成果によく一致することから，コスモス衛星写真は黒ボク土の特性把握に有効であり，根こぶ病の発生危険箇所の把握に有用であることが明らかにされた．

キーワード：キャベツ，黒ボク土，Sojuzkarta KFA 1000，土壌統群，土壌特性，根こぶ病，排水性，*Plasmodiophora brassicae* Worn.

The clubroot disease that occurs in species of the Cruciferae is caused by the fungus *Plasmodiophora brassicae* Worn. The life history of the pathogen consists of two phases, the

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primary phase, which is confined to the root hairs of the infected plants, and the secondary phase that occurs in the cortex and stele of the hypocotyl and roots leading to abnormal development[18]. Lateral roots as well as the main root become swollen. The capacity of infected plants to take up water and nutrients is seriously impaired. The fungus survives in the soil as resistant and highly durable resting spores that are released from infected decaying root tissue. They can persist in the soil for 7 years or more. Therefore, the disease is difficult to control once the pathogen becomes established in the soil.

The clubroot on cabbage is one of the most serious diseases in the study area, Tsumakoi-mura, Gunma Prefecture. The disease is widespread and tends to be worst in the area where cabbage is intensively cultivated. The area is characterized by complex rolling hills formed from volcanic ash deposits. The soils distributed are classified into Andosols, conventionally called *Kurobokudo* in Japan. Andosols have a thick black A horizon with a high content of organic matter and a brown to yellowish brown clay-enriched B horizon. Further classification of Andosols was based upon thickness of the A horizon, mixing of the B horizon material in the A horizon, and color of the A horizon[28]. The disease is usually most severe in organic matter rich topsoils and rare in the position with exposure of clay-enriched subsoils[22]. It is usually most severe in the lower areas or depressions in a field. Differences in the prevalence and severity of clubroot have frequently been attributed to variations in climatic conditions. The disease was more severe after wet season.

Control measures commonly recommended include the addition of lime to create an alkaline soil, long rotations with noncruciferous crops, and the addition of fungicides to the soil. The effectiveness of lime under field conditions is known to be extremely variable. Pentachloronitrobenzen (PCNB) was shown to be effective in controlling the disease in transplanted cabbages under varied field conditions in the area. However, the effectiveness of lime and PCNB applications depends upon soil conditions. Therefore, the areal assessment of soil properties is necessary to more accurately forecast and monitor the incidence and severity of the disease for purposes of quarantine, control, and eradication.

Aerial photographs have been used as a soil survey tool since the 1930's. Since July 1972, imageries from the Earth Resources Technology Satellite (now called Landsat) have been available. Satellite remote sensing applications rely on the existence of characteristic spectral differences among components of the soil scene. A variety of soil components individually and in association with one another contribute to the spectral reflectance of soils. These are known to include the physicochemical properties of organic matter, moisture, texture, and iron oxide content as well as other variables less well defined as contributors to reflectance[33,34]. Remotely sensed satellite data have great potential for providing areal estimations of soil classification[23,37,38], soil color[4,9], soil moisture content[7,16,19,21], and organic matter content[10,13,39]. These investigations have demonstrated the utility of Landsat and SPOT imageries for assessing soil properties. However, little research has been directed toward the use of Sojuzkarta KFA 1000 photographic imagery to quantify the spatial heterogeneity of soils.

The objectives of our study were (1) to investigate the feasibility of using the digital analysis of KFA 1000 imagery as a means of accurately describing and quantifying soil properties of Andosols, and (2) to reveal the relationship between the soil properties and the extent of the disease incidence in cabbage.

Materials and Methods

1. Study area

Tsumakoi-mura is located in the northwest part of Gunma Prefecture and covers 33,600 ha, of which 11 percent is arable land and 27 percent forests and natural vegetation. At present, approximately 2,500 ha of cabbage are grown in the area of the Andosols. The elevation of cabbage fields ranges from 1,000 to 1,500 m. Cabbage is planted from May to July and harvested from July to October. The main cropping season is from June to September. The test site at Kitayama (400 ha) is located in the region consisting of rolling hills with exposed subsoil or shallow topsoil on ridges, and thicker topsoil with high organic matter content on lower slopes and bottom lands.

2. Satellite photography by KFA 1000 and data processing

The film (Sojuzkarta #25253, scale 1 : 250, 000), acquired on June 7, 1988, was purchased through the Japan Society of Photogrammetry and Remote Sensing. This scene was selected because the data were (i) of high quality, (ii) acquired when most arable land was in a bare soil state, and (iii) free of interfering atmospheric and surface conditions (i. e., clouds, haze, and standing water). The spectral-zonal film is sensitive in the 570-680 nm and 680-810 nm regions. The 3 channel R, G, B scanner data were converted from analog to digital form by a drum scanner with a 25 μm sampling pitch. This provided data with a pixel size of approximately 6 m×6 m. The channels 2 and 3 correspond to the near infrared and the red regions, respectively. Channel 1 corresponding to the blue region is the photography-dependent factor. Channel 2 corresponds approximately to the near infrared part of the band 6 (700-800 nm), and channel 3 to the red part of the band 5 (600-700 nm) of Landsat MSS. The various image characteristics recorded on the image were mainly due to the variation in soil color mixed with the colors of topsoil and subsoil. Soil moisture condition is affected by amount of previous rainfall, as well as time and weather since the last rainfall. Meteorological data before the image acquisition are shown in Table 1. These data show that the image should be favorable for detecting the spatial variability of drainage conditions.

Twenty-four spectral classes were defined, representing 13 soil and 9 vegetation (including early planted cabbage) classes, man-made materials, and lake water classes. Overall correct percentage among the 13 spectral soil classes yielded 98.8 percent in the training data set with the linear discriminant analysis. The results of grouping the 13 spectral soil classes representing 5 soil series are given in Table 2, with soil color and organic matter content. Surface soil samples taken from within each of the mapped spectral soil classes showed a progression in organic matter content ranging from 1.4% to 19.6%. Munsell soil colors correlated well with organic matter content among the 5 soil series. Image analyses were carried out using the NINES Agricultural Remote Sensing Analyzing System (CPU : Facom-M310, Image processor : Graphica I-5088). We adopted the maximum likelihood method with a supervised classification approach for image classification.

3. Ground truth data

1) Color aerial photography

Color aerial photography, taken on May 9, 1986, was used to interpret the surface soil color. Closer examination of the photograph revealed dark and light patterns in the soil and an intermediate tones between the dark and light soils. Color aerial photography, taken on August 12, 1987, was additionally used to interpret the land cover classes.

2) Soil survey and analysis

Computer printout maps showing the areal distribution of the spectral soil classes were compared with field conditions. Surface descriptive characteristics of the observation sites, mainly the landscape position and slope form, were recorded. Surface soil color was recorded as hue, value, and chroma, using the revised Munsell soil color chart[29]. Soil samples were gathered and profile descriptions written at the sites. Detailed profile descriptions collected from soil borings were recorded for horizon, depth, color and the appearance depth of hard pan, stagnant water and breaching layer. A total of 176 surface soil samples were gathered from 0-10 cm depth. The samples were air-dried and passed through a 2-mm sieve. Organic carbon was determined by the dry combustion procedure using a CN-corder (Yanagimoto Model MT-1600) with copper oxidation accelerator. The organic matter content was determined by multiplying the organic carbon concentration by 1.724 (Nelson and Sommers, 1982).

To reveal the relationship between landscape position and the spectral soil classes, the computer printout map was superimposed upon the topographic maps (scale 1 : 2,500) at a total of 1218 sites selected randomly. At each site sampled the landscape position was described according to Ruhe's classification scheme[25]. The landscape positions identified were knoll, shoulder, backslope, footslope and toe. The knoll position is a ridge or crest. The shoulder position is the transitional convex area between the knoll and backslope. The backslope position is in a topographic position both to receive runon from the knoll and shoulder, as well as contribute to runoff to

Table 1. Meteorological conditions before photography acquisition. Data were obtained at the Experimental Station of Gunma Agricutural Research Center located in the study area.

Date	Mean air temperature °C	Relative humidity %	wind speed ms^{-1}	Precipitation mm	Solar radiation $MJ\ m^{-2}\ day^{-1}$
June 1	12.2	85.6	1.1	2	8.7
2	11.4	91.7	1.4	37	2.9
3	14.3	91.0	0.9	69	3.7
4	17.7	68.2	3.6	2	27.7
5	13.2	53.9	3.6	0	28.8
6	13.8	67.0	1.5	0	28.4
7*	16.6	53.2	2.1	0	28.9

*: The photography was taken on June 7, 1988.

Table 2. Munsell soil color and organic matter content in five soil series. Significant differences on value, chroma, and organic matter content were not observed among the subunits of each soil series.

Soil series* (subunits)	Munsell soil color**			Organic matter content (%)			
	Hue	Value	Chroma	Mean	S. D.	Max.	Min.
A: Light-colored Andosols (A1, A2)	7.5YR	4~5	4~6	2.7	0.80	3.7	1.4
B: Humic Andosols (B1, B2, B3)	7.5YR	3~4	3~4	6.4	1.38	9.1	4.3
C: Thick Humic Andosols (C1, C2, C3)	7.5YR	3	1~3	11.2	2.00	15.2	7.1
D: Thick High-humic Andosols (D1, D2)	7.5YR	2~3	1~2	13.2	1.51	15.8	10.5
E: Thick High-humic Wet Andorsols (E1, E2, E3)	7.5YR	2	1~2	15.6	2.01	19.6	12.1

* Soil series classification was based on profile observation.

** Soil color was observed under field conditions.

lower areas. The footslope position is at the base and receives runon from higher areas. The toe position is a bottom of hill slopes. Slope gradient was not considered in this analysis.

3) Assessment of clubroot disease incidence

We have been monitoring the extent of clubroot disease in the test site from 1985 to 1990, under the combined aerial surveillance and ground inspection program. Using the 6-year disease records, we composed the map showing the land area afflicted with clubroot. The past disease incidence map was superimposed onto the resulting computer printout map of the spectral soil classes to assess the relationship between the soil properties and the clubroot incidence. The number of pixels overlying healthy areas and the number of pixels overlying areas diseased with clubroot were counted in each of the spectral soil classes. The disease incidence percentage was obtained for each spectral soil class by dividing the number of diseased pixels by the total number of pixels.

It is known that differences in the prevalence and severity of the disease have frequently attributed to variations in climatic conditions. We have chosen the disease records of 1988 and 1989, to compare the relationship between rainfall conditions and clubroot incidence under the same spectral soil classes. The season of abundant rainfall (1988) and a season of normal rainfall (1989) were based on the total amount of precipitation in June, the main periods of transplanting, because the amount of precipitation in the first 2-3 weeks was one of the variables most highly correlated with disease development[36]. The disease incidence percentage was obtained by the same procedure mentioned above.

Results and Discussion

1. Soil properties delineation

The channel 3 (red) versus channel 2 (near infrared) scatter plot of the 13 spectral soil classes is shown in Figure 1. The soil data are presented as a wide line that we will refer to as the "soil line". Lake water is well defined, and the spectral soil classes contrast sharply with the vegetation classes. Nine vegetation classes were identified above the soil and vegetation borderline. These 13 spectral soil classes could be separated into 5 distinct soil series on the basis of surface color and profile descriptive characteristics. Accordingly, 5 soil series were delineated by the near infrared reflectance, and denoted soil series A, B, C, D, and E. Each soil series was subdivided again into subunits with the red reflectance, and these were denoted A1, A2, B1, B2, B3, C1, C2, C3, D1,D2, E1, E2 and E3, respectively. In this way, 13 spectral soil classes were recognized in the whole study area. Soil series A (Al and A2) at the high end of the soil line represented Light-colored Andosols and soil series E (E1, E2 and E3) at the low end, Thick High-humic Wet Andosols. Soil series B, Humic Andosols, had lower reflectance than soil series A. Soil series D, Thick High-humic Andosols, had higher reflectance than soil series E. Soil series D, Thick Humic Andosols, was located on the intermediate position.

Soil properties reported as being highly correlated with spectral measurements at various wavelengths were organic matter content, moisture content, color, sand, silt, clay content, and iron oxide content. The red and the near infrared regions are the most favorable for a qualitative and quantitative description of soils, as shown in the studies using Landsat TM[13], Landsat MSS[4,11,21,30], SPOT[39], and aircraft MSS[1] data and field[5] and laboratory[3,15,24,31,34,35] measurements. A strong relationship exists between a soil's visible color and its organic matter content (Table 2). As either value or chroma increased, the reflectance increased in the red and near infrared regions, as shown in Figure 1. It is a well-known fact that the red and near infrared reflectances are a good indicator of soil moisture and organic matter contents. The near infrared reflectance was a better indicator for delineating the 5 soil series than the red reflectance. This indicated the differences in soil color, organic matter content and water regime among the 5 soil series.

A plot of the near infrared and the red bands of Landsat MSS for bare soils would fall on a straight line[11,21,30]. However, as observed in Figure 1, the line has a slight curvature and width that should be accounted for in this study. This nonlinearity was also observed by Jackson et al. (1980) and Thompson et al. (1983). The large variations in the red within a single soil series may depend upon the difference in soil moisture condition, because soil organic matter content, soil color, texture, and iron oxide content were considered to be similar in each of the 5 soil series. Soil moisture conditions are strongly affected by amount of previous rainfall, and time and weather since the last rainfall. The meteorological conditions shown in Table 1 produce a favorable condition for measuring the soil moisture. The subunits near the soil and vegetation borderline were considered to be more wet and the subunits away from the line more dry. This variation may indicate soil surface and subsurface drainage characteristics. The information obtained from borings allowed the 13 spectral classes of soil to be correlated with the 3 soil drainage classes. The subunits (A1, B1, C1, and E1) with the lowest relative red reflectance corresponded to the poorly drained class. The subunits (A2, B3, C3, D2, and E3) with the highest relative red reflectance corresponded to the well-drained class. The remaining subunits (B2, C2, D1, and E2) were represented by the intermediate-drained class. In soil series D, the poorly drained class was not observed in the study area.

2. Relationship between spectral soil classes and landscape position

The specific question addressed is how are the spectral soil classes related to the land-

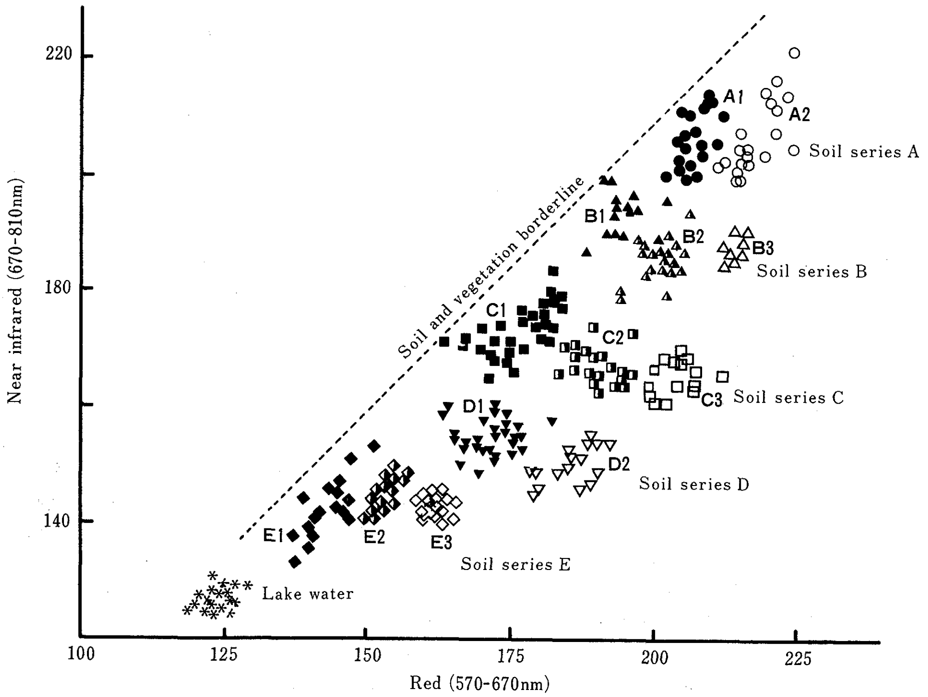

Fig. 1. Red and near infrared scatter plot of 13 spectral soil classes. Figures on X and Y axes show digitized density.

scape positions, since probably the most important effect of slop is its influence on the moisture condition of the profile. When the spectral soil classes were plotted as a function of position on the landscape, various trends became evident (Figure 2).

The knoll, shoulder and backslope positions occupied about 98 percent in soil series A. The difference between the drainage classes, A1 and A2, was shown on the knoll position. The foot and toeslope positions in the poorly drained class in soil series B, C, and E occupied about 30 percent, 51 percent, and 48 percent, respectively of those soil series. The well-drained class in soil series B, C, D, and E were predominately located on the backslopes. The intermediate-drained class in soil series B, C, and E showed a transitional pattern between the poorly drained class and the well-drained class. In soil series D, the intermediate-drained class was similar in the poorly drained class of soil series E. The results suggested that there was no systematic relationship between the 5 soil series and the landscape positions.

The amount of water retained by a soil, therefore, is greatly determined by landscape position. The reason for this may be movement of water by runoff and internal drainage from upslope to lower positions. These differences of histograms between the drainage classes, shown in Figure 2, were probably due to differences in runoff among landscape positions and to the effects of internal drainage from the upper to the lower positions. Soil moisture conditions are affected by position of the soils on the landscape and relationship with their neighbors[12,27,32,40]. The close relationship between landscape position and drainage characteristics shown in soil series B, C, and E suggested the presence of a spatial dependency for the spectral soil classes.

3. Relationship between soil properties and clubroot disease incidence

An important element in the study of a soil-borne disease is the investigation of its distribution, both within a field or other unit of cultivation, and on a larger scale[2]. Distribution patterns may help to determine the natural sources of a disease, which may also indicate methods of avoiding and controlling it by revealing correlations with environmental fac-

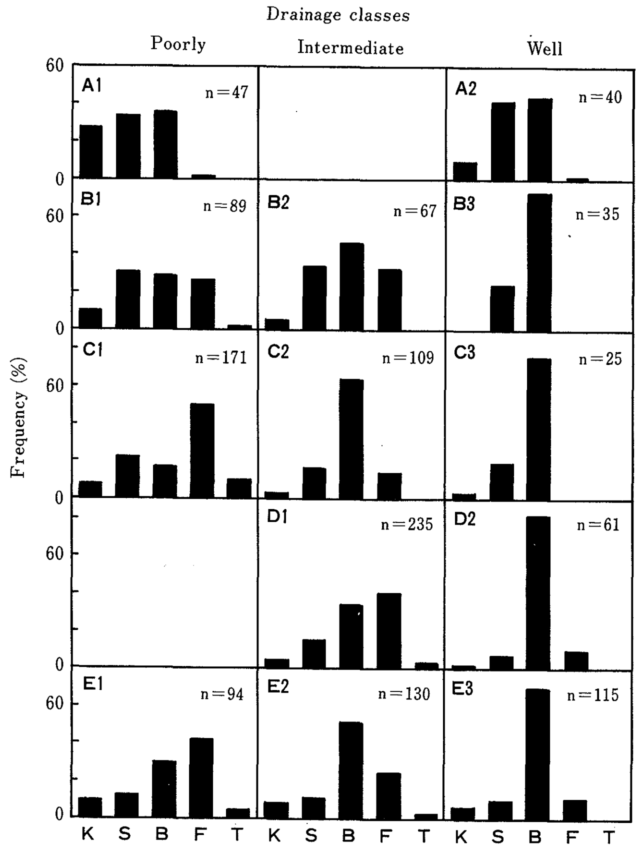

Fig. 2. Distribution patterns of 13 spectral soil classes on landscape position.
The subunit's notation is common in Fig. 1.
K, Knoll ; S, Shoulder ; B, Back ; F, Foot ; T, Toe.

tors. The results of the past disease incidence percentage in each of the spectral soil classes are shown in Table 3. The figures show the percentage of diseased pixels.

The grand mean of incidence percentage showed that about 60 percent of the study area has been diseased in the past 6 years. The means of incidence percentages in each soil series were quite different between soil series A and other the 4 soil series (B, C, D and E). The incidence percentage was the lowest in soil series A at 11.3 percent. In other soil series, the means varied from 55.2 percent in soil series D to 67.8 percent in soil series C. This result showed that the effect of soil series on disease incidence was much greater in soil series A than in others. Table 3 also showed that the disease has been more severe in the poorly drained class. The percentage was the highest in the poorly drained class at 81.2 percent, followed by the intermediate-drained class at 54.2 percent and the well-drained class at 34.6 percent.

The difference in disease incidence between a season of abundant rainfall in 1988 and a season of normal rainfall in 1989 are shown in Table 4. Data for soil series A were not available in this analysis. Total disease incidence in 1988 increased about 21 percent. The increase was the highest in soil series D at 46.7 percent, followed by soil series C at 21.7 percent, soil series E at 14.1 percent and soil series B at − 10.6 percent. Among the drainage classes, the increase was the highest in the well-drained class at 123 percent, followed by the intermediate class at 23.9 percent and the poorly drained class at 7.5 percent. The results suggest that a season of abundant rainfall was more favorable for the incidence of the disease. The relationship was more pronounced in the well-drained class.

In this study, the disease incidence on soil series A, Light-colored Andosols, was quite different from the other 4 soil series (B, C, D and E). This is supported by the experimental result[22]. They suggested that Light-colored

Table 3. Disease incidence percentages in 13 spectral soil classes.

Soil series	Drainage classes			Mean	The number of pixels tested
	Poorly	Intermediate	Well		
A	*A1 : 18.0	—	A2 : 6.9	11.3	793
B	B1 : 83.0	D2 : 57.6	B3 : 19.0	65.1	1732
C	C1 : 81.1	C2 : 46.0	C3 : 25.0	67.8	4607
D	—	D1 : 55.1	D2 : 57.0	55.2	4795
E	E1 : 80.0	E2 : 57.1	E3 : 33.0	59.4	4624
Mean	81.2	54.2	34.6	60.1	—
The number of pixels tested	4658	8914	1774	—	—

* Subunit's notation of 13 spectral soil classes is common in Figure 1.

Table 4. Difference of disease incidence between a season of abundant rainfall (1988) and a season of normal rainfall (1989).

Soil series Drainage classes	1988 No. of pixels (A)	1989 No. of pixels (B)	Percentage of increase (%)
Soil series			
B	278	311	−10.6
C	1219	1002	21.7
D	741	505	46.7
E	673	590	14.1
Drainage classes			
Poorly	1335	1242	7.5
Intermediate	1280	1033	23.9
Well	296	133	123.0
Total	2911	2408	20.9

Percentage of increase = (A−B)/B*100.
Data were taken in the common 80 fields.

Andosols might be a suppressive soil for the disease. The influence of soil moisture upon clubroot development has been given more attention by previous workers[6,8,17]. Both root hair and cortical infections decreased with decreasing availability of water[8]. Therefore, the drainage characteristic was found to be an important factor. There was thus a fairly close agreement between the results obtained and the previous studies. Clubroot is soil-moisture-dependent in hatching and spreading. The detailed knowledge of soil properties identified in this study will allow farmers to selectively apply pesticides that will have obvious economical and environmental benefits, as mentioned by Engman (1991).

Sojuzkarta KFA 1000 imagery holds, perhaps, the greatest medium-term potential for the remote sensing analysis of large-scale regions with it's claimed 5 m resolution[14]. There will be considerable potential for using KFA 1000 data to map within-field soil variations. This study indicates that KFA 1000 data could be used either to provide the information of soil properties for use in assessing the clubroot disease incidence and for planning detailed field sampling programs to reveal correlations with environmental factors.

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