Crop Growth Diagnosis from Low Altitude Platform-Sensor Systems

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Commission Number VII

Abstract

Crop growth information was obtained by using optical sensors from low altitude platforms. In the crop discrimination test using MSS mounted on an airplane, more than 80% of the crops in the fields were correctly classified with 4 bands. Bands with a reflectance of 550 nm (V550) as visible band and 860 nm (N860) as near infrared band, as well as the mid-infrared bands (M1625 or M2255) were often effective for the discrimination of the crops. The reflectance values at different altitudes of helicopter, did not exhibited significant changes between 50 m to 1,000 m elevation, especially for the visible and mid-infrared bands, but slightly decreased for the near infrared band along with the increase in altitude. High correlation coefficients of more than r=0.8 were observed between M2018 and agronomic variables in single correlations. By the application of multiple regression analysis, higher correlations exceeding R=0.9 were obtained using 2 or 3 bands.

INTRODUCTION

Due to the rapid progress recorded recently in sensor improvement and the development of information analysis, wide-areal agricultural management from high altitude sensor-platform systems has become possible worldwide. However, in Japan, the area of arable land is limited and much of it is located on complex mountainous landform. Therefore, several kinds of crops are cultivated simultaneously in a small field during one season. It is thus difficult to monitor agricultural conditions through the use of spacecraft sensors. Attempts to apply directly satellite data to agricultural monitoring are facing difficulties at present due to the following constraints; 1) spatial resolution, 2) spectral resolution, and 3) observation frequency.

Since the size of field in Japan is not larger than 0.1 ha, the 30-meter ground resolution of Landsat thematic mappers (TM) is not sufficient for crop discrimination. In addition, the wavelength divisions of current satellite sensors are not always suitable for monitoring crop information. It is thus suggested that several narrow bands with special purposes be used to detect differences in crop biomass, stress and nutrition conditions (Shibayama and Munakata, 1986a and b, Shibayama and Akiyama, 1986a and b). Moreover, as Japan is located in a monsoon area, data acquisition by satellite is often hampered by the cloud cover, and cloudless satellite images can seldom be obtained during the crop growing season.

However, progress in sensor development has been so rapid that it may become possible to use satellite data for crop monitoring as a routine in the near future. At the same time, the necessity is enhancing to accumulate basic plant reflectance information at the ground level, spectral reflectance measurements of several crop canopies under various conditions have been performed using spectroradiometers designed for field use (Shibayama et al., 1986).

In the next step, these sensors were mounted on low altitude aircrafts to detect the differences in the crop canopy reflectance associated with the altitude. By this method, the effect of air masses can be evaluated and effective wavelengths for crop diagnosis can be determined. This kind of information is not only useful for crop monitoring using aircraft on complex agricultural landform areas, but also it may give a clue for the analysis of satellite-borne data.

MATERIALS AND METHODS

1. Sensor and platform

The experiments were carried out during three summer seasons from 1985 to 1987. In 1985 and 1986, the reflectance measurement experiment was conducted from a low altitude airplane (Cessna plane 402-B) with a 12-band multispectral scanner (MSS). Eight and six effective bands were selected for data analysis in 1985 and 1986, respectively, as shown in Table 1. In this paper the reflectance factors (%) at x nm will be referred to as Vx, Nx or Mx, V standing for visible, N for near infrared, and M for mid-infrared wavelengths, respectively. As sensors of MSS, photomultipliers are used for the visible band, silicon diode for the near infrared band, germanium diode and indium arsenide for the mid-infrared band, and mercury cadmium tellurium for the thermal infrared band, respectively. Flight altitude was 450 m on August 23 in 1985, and 1,400 m on July 25 in 1986. The spatial resolutions at ground level were 0.8 m and 2.5 m, respectively.

Table 1. Spectral characteristics of airborne-MSS bands used in the experiments in 1985 and 1986.

Band name	Range(nm)	Year 1985	Year 1986
V 475	460 - 490		0
V 550	530 - 570	0	0
V 585	570 - 600	0	
V 625	600 - 650		0
V 705	690 - 720	0	
N 745	730 - 760	0	
N 860	820 - 900	0	0
N1050	1000 - 1100	0	
M1625	1520 - 1730	0	0
M2255	2060 - 2450		0
T 10	8 - 12 μ	0	

In 1987, an altitude experiment was carried out on July 23 by mounting an 8-band spectroradiometer on a helicopter (Aerospatial 350-B). Observation altitudes were 50 m, 100 m, 250 m, 500 m and 1,000 m. Because of the field of view angle was settled as 2 degree, the resolutions at ground level were, 1.8 m, 3.5 m, 9 m, 18 m and 35 m, respectively. Spectral characteristics are summarized in Table 2. Data of M2250 were not used for the analysis as they appeared to be abnormal.

2. Experimental area

Experimental fields used during the three years were located at and near the Agricultural Research Institute Complex at Kannondai, Tsukuba, central Japan. The experimental area was 6 km long and 2 km wide. Farmers of this area mainly cultivate upland crops such as burdock (*Arctium lappa* L.), upland rice (*Oryza sativa* L.), taro (*Colocasia esculenta* Schott), and peanut (*Arachis hypogaea* L.) during the summer. The area contains several experi-mental fields belonging to the National Institutes of the Ministry of Agriculture, Forestry and Fisheries.

Table 2. Spectral characteristics of the bands recorded the spectroradiometer mounted on a helicopter in the experiment in 1987.

Band name	Range(nm)
V 560	554 - 566
V 660	652 - 668
N 833	825 - 841
N1123	1097 - 1149
N1238	1215 - 1261
M1730	1698 - 1762
M2018	1979 - 2057
M2105	2066 - 2144

Table 3. Crop conditions in 14 training fields with forage crops in the helicopter experiment in 1987.

Field	Crop	FW(g/m²)	DW(g/m²)	LAI	CH(cm)
W-1	It	3,200	515.3	3.84	103
W-2	It+Rc	2,195	762.0	4.19	101
W-3	It	940	274.2	0.06	80
W-4	Co	8,851	1301.7	5.48	288
W-5	It	1,700	204.4	1.55	31
W-6	It	805	191.0	1.41	31
W-7	Co	315	33.9	0.50	56
I-1	Co	410	34.9	0.60	42
I-2	Co	6,253	636.1	4.97	248
S-1	Co	6,803	702.5	6.39	199
S-2	Co	5,770	851.2	3.40	202
S-3	It+Al	2,310	589.7	3.27	87
S-4	Co	6.360	732.8	5.89	211
S-5	It	1,770	402.7	0.98	80

FW:Fresh weight, DW:Dry weight, LAI:Leaf area index, CH:Canopy height, It:Italian ryegrass, Rc:Red clover, Al:Alfalfa, Co:Corn

Out of 14 fields used in the helicopter experiment in 1987, 7 were corn fields with plants at various stages of growth such as young seedlings with fully expanded 5th or 6th leaf, maturity stage after tasseling, etc. thus the LAI ranged from 0.50 (W-7) to 6.39 (S-1). The other 7 fields consisted of meadows with mainly Italian ryegrass. Five of them were pure stands, and 2 mixed stands with legumes. The growth stages of the plants ranged from the vegetative stage to senescence. In the fields with plants with a large weight but low LAI such as the W-3 field the plants were in the late reproductive stage. In addition, there were private farmers' fields belonging to the Nakayama community in Kukizaki town. The average size of the fields was 0.1 ha in this community.

3. Ground truth data

A cropping map of the whole experimental site was prepared about one week prior to the aerial survey experiment. Crop name, growth stage and canopy height in each plot were recorded during a field survey. Besides, in the fields within the Institute, some plants were sampled to analyze agronomic characters such as fresh and dry weights (g/m^2), leaf area index (LAI). These ground truth data were analyzed in combination with spectral data. Agronomic data for the helicopter experiment are shown in Table 3.

4. Analysis

Airborne-MSS data in 1985 and 1986 were recorded and stored in magnetic tapes. They were used for the crop inventory test. The analysis was performed using the Agricultural Remote Sensing Analyzing System available in the National Institute of Agro-Environmental Sciences. Maximum likelihood method was applied for the classification based on crop discrimination. Three to five statistics data for each crop were collected as a training data file. Also the same amount of data was stored as test data file for further analysis of the classification performance.

In the helicopter experiment conducted in 1987, reflectance data were obtained on a 12-pen recorder chart due to the restriction of the reaction time of the sensor and the values were read on recording sheet. The statistical analysis was performed on a personal computer.

RESULTS AND DISCUSSION

1. Crop identification

Crop classification trial was performed in using with the cropping maps available for the Institute experiment fields in 1985, and farmers' fields in the Nakayama area in 1986, respectively.
In 1985, 10 cluster classes were defined as follows; 6 classes of upland crops including soybean (*Glycine max* (L.), corn (*Zea mays* L.), sweet potato (*Ipomaea batatas* LAM.), sorghum (*Sorghum nervosum* BESS.), upland rice (*Oryza sativa* L.) and peanut (*Arachis hypogaea* L.). In addition there were 4 cluster classes such as grassland, forest land, bush, and bare ground.

In the case of the 1986 MSS experiment, 11 cluster classes including 7 crop and 4 vegetation classes were used as training classes in the farmers' fields in the Nakayama area. Crops included paddy rice, upland rice, burdock, sweet potato, taro, peanuts and corn.

Table 4. Increment of classification performance(%) along with the increase in the number of bands used.

Item	Band numbers 1	2	3	4	5	6	7	8
6 crops	41.9	58.4	74.6	83.6	87.4	89.0	90.1	90.5
6 crops+4 veg.	35.1	57.6	69.2	78.1	81.6	83.1	84.4	82.7

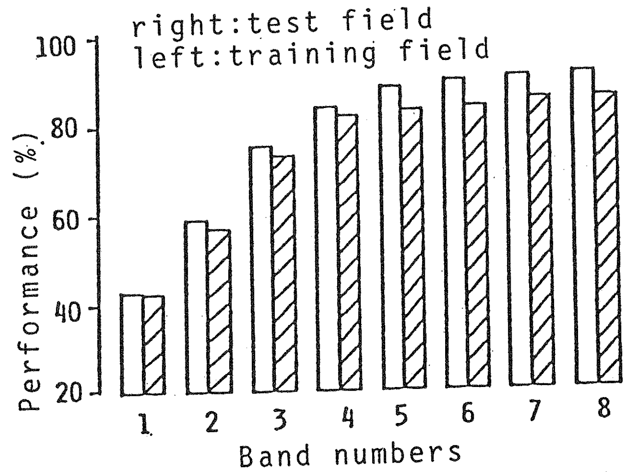

Fig. 1 Increment of classification of performance in relation to increase of number of bands used.

Table 4 shows the relationship between the number of spectral bands selected for crop classification, and correct answers (%) obtained in the 1985 MSS experiment. In the case of crop classification, an 83.6% performance was attained using 4 bands, and 89.0% for 6 bands. The values decreased for other types of vegetation. Fig. 1 shows the increment of the classification performance in relation to the increase in the number of bands used. A plateau was reached when 4 or 5 bands were selected. The performance was 4 or 5% lower in the test area than in the training area.

Table 5. Selected bands for crop discrimination in 1985 and 1986.

Band	1985 2	1985 3	1985 4	1985 5	1985 6	1986 2	1986 3	1986 4	1986 5	1986 6
V 475	-	-	-	-	-					0
V 550	0	0	0	0	0		0	0	0	0
V 585						-	-	-	-	-
V 625	-	-	-	-	-				0	0
V 705						-	-	-	-	-
N 745				0	0	-	-	-	-	-
N 860	0	0	0	0	0	0	0	0	0	0
N1050					0	-	-	-	-	-
M1625			0	0	0			0	0	0
M2255	-	-	-	-	-	0	0	0	0	0
T 10		0	0	0	0	-	-	-	-	-
Performance(%)	58	75	84	87	89					

Table 6. Ratio of contribution, eigen vector of Principal Component Analysis.

Component	Contribution	Eigen vector					
		V475	V550	V625	N860	M1625	M2255
1	0.70	0.46	0.41	0.47	-0.06	0.43	0.44
2	0.22	-0.05	0.39	-0.10	0.85	0.19	-0.27
3	0.05	-0.38	-0.36	-0.29	0.08	0.69	0.39

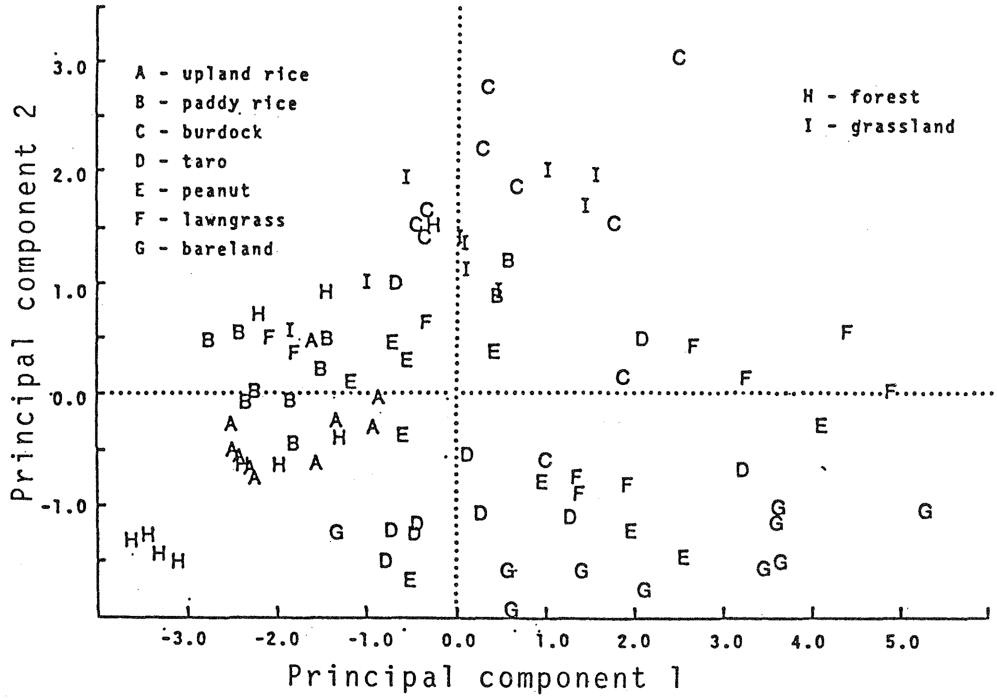

Fig. 2 Scattergram of Principal Component Analysis for training fields.

The optimum band combinations selected for crop discrimination were compared in Table 5 for the 1985 and 1986 experiments. It is interesting to note that N860 of the near infrared wavelength band and V550 of the visible band were selected in both years. It also seems that M1625 or M2255 of the mid-infrared wavelength bands may contribute significantly to crop discrimination.

Table 6 and Fig. 2 show the results of principal component analysis of 11 cluster classes in the training area. Table 6 shows that 92% of the phenomena observed could be explained on the basis of the 1st and 2nd principal components. In this analysis, it is considered that the 1st component is related to brightness, the 2nd to biomass, and the 3rd to dryness.

Fig. 2 presents the scattergram between the 1st and the 2nd components. Burdock (C) could be discriminated in this scattergram. However most of the crop species were still intermingled.

One of the reasons for the difficulty in classifying crop species spectrally is the difference in the crop conditions associated with the growth stages, nutrition conditions and agronomic practices. The spectral variances within and among fields were

Table 7. Comparison of variance of crop reflectance between among and within fields.

Crop	Variance	
	Among-field	Within-field
Upland rice	9.9	5.5
Paddy rice	13.3	6.5
Burdock	18.4	7.4
Sweet potato	13.6	5.4
Taro	18.5	5.9
Peanut	21.6	5.5
Corn	8.2	5.0

compared for each crop as shown in Table 7. The values which were always as low as 5 or 7 for the variance within fields became nearly twice as high or more in many crops for the variance among fields. As a result the spectral dispersion within farmers' fields became large, leading to a decrease in the performance.

2. Estimation of agronomic variables at various altitudes

(1) Effect of altitude on canopy reflectance

Canopy reflectance was measured at 5 different altitudes by an 8-band spectroradiometer mounted on a helicopter in 1987. This experiment was carried out mainly in the field of the National Institute of Animal Industry.

Fig. 3 shows the changes of reflectance for each band in relation to the increment of the altitude of the platform. Reflectance values used were taken from the average of 7 corn fields as shown in Table 3. Although they were almost constant in the range of 50 m to 1,000 m for visible (V560) and mid-infrared (M1730) wavelengths, they tended to decrease for the near infrared (N833) wavelength.

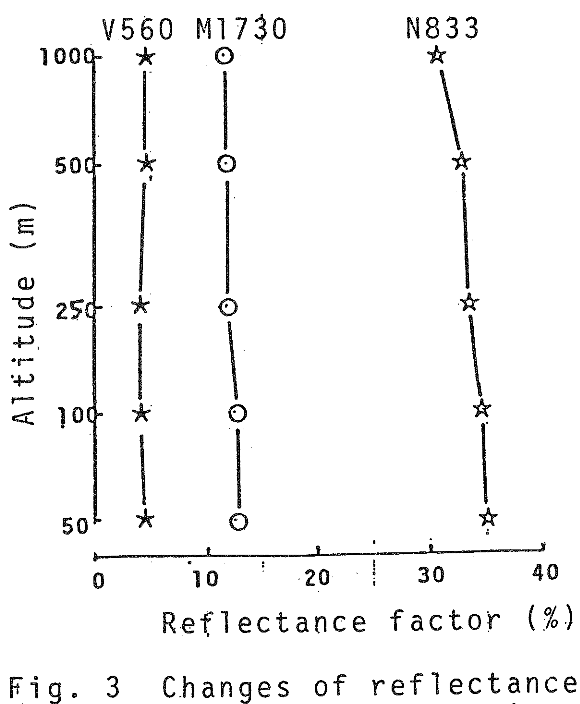

Fig. 3 Changes of reflectance in each band in relation to the altitude of platform

(2) Estimation of agronomic variables

An attempt to estimate the fresh weight (FW), dry weight (DW), leaf area index (LAI) and canopy height (CH) in forage crop fields was made using an 8-band spectroradiometer mounted on a helicopter. Spectrum and forage agronomic data are presented in Table 2 and Table 3, respectively.

Single correlations between 7 reflectance factors and 4 agronomic variables at different altitudes are shown in Table 8. High correlation coefficients of more than 0.8 were observed between the mid-infrared reflectance M2018, and each of the 4 agronomic variables. In addition, high correlation was also observed between V660 and DW, as well as between V660, N833 and LAI.

The effects of altitude were not significant, but the coefficients at 50 m and 500 m tended to be high while low at 100 m and 1,000 m. Table 9 shows the selected bands for the estimation of agronomic variables based on the multiple regression analysis at different altitudes. By applying the stepwise selection method (Fin = Fout = 2), in 19 cases out of 20 the correlation coefficient exceeded 0.8, and in 8 cases 0.9. The analysis of each agronomic variable showed that FW was discriminated with M2018, DW with V660 and M2018, LAI with N833 and M1730, and CH with V560 and M2018.

Table 8. Single correlations between reflectance and agronomic variables at different altitude

Agronomic var.	Altitude(m)					
	50	100	250	500	1000	Mean
Fresh weight						
V 560	-0.662	-0.642	-0.700	-0.790	-0.638	-0.686
V 660	-0.728	-0.738	-0.757	-0.778	-0.747	-0.750
N 833	0.756	0.745	0.715	0.679	0.755	0.730
N1123	0.549	0.577	0.280	0.683	0.395	0.497
N1238	0.147	0.125	0.104	0.013	0.151	0.108
N1730	-0.760	-0.707	-0.616	-0.492	-0.534	-0.622
M2018	-0.856	-0.831	-0.873	-0.797	-0.805	-0.832
Dry weight						
V 560	-0.664	-0.643	-0.615	-0.714	-0.581	-0.643
V 660	-0.825	-0.841	-0.851	-0.826	-0.761	-0.821
N 833	0.764	0.776	0.759	0.709	0.756	0.753
N1123	0.707	0.609	0.403	0.607	0.268	0.519
N1238	0.368	0.357	0.350	0.243	0.340	0.332
M1730	-0.624	-0.569	-0.424	-0.447	-0.374	-0.488
M2018	-0.826	-0.806	-0.832	-0.807	-0.797	-0.814
LAI						
V 560	-0.485	-0.507	-0.536	-0.659	-0.588	-0.555
V 660	-0.785	-0.814	-0.838	-0.833	-0.794	-0.813
N 833	0.890	0.878	0.855	0.842	0.788	0.851
N1123	0.747	0.763	0.299	0.773	0.472	0.611
N1238	0.366	0.313	0.311	0.252	0.224	0.295
M1730	-0.670	-0.643	-0.662	-0.480	-0.627	-0.616
M2018	-0.888	-0.873	-0.913	-0.844	-0.823	-0.868
Canopy height						
V 560	-0.710	-0.698	-0.754	-0.789	-0.629	-0.716
V 660	-0.657	-0.696	-0.701	-0.706	-0.686	-0.685
N 833	0.683	0.671	0.648	0.610	0.709	0.664
N1123	0.462	0.500	0.214	0.588	0.210	0.395
N1238	0.050	0.025	0.014	-0.077	0.072	0.017
M1730	-0.790	-0.748	-0.642	-0.565	-0.550	-0.659
M2018	-0.806	-0.797	-0.836	-0.816	-0.762	-0.803

Fig. 4 shows results of the multiple regression analysis used canopy reflectance data at 500 m of altitude. It contains 7 corn plots and 7 Italian ryegrass plots. High correlations were observed with reflectance and each agronomic variable. However, some discrepancies appeared at higher values especially in LAI. It may be relieved by the application of other vegetation indices.

This work was supported by a grant from Green Energy Program of the Ministry of Agriculture, Forestry and Fisheries, Japan (GEP 87-II-4-6).

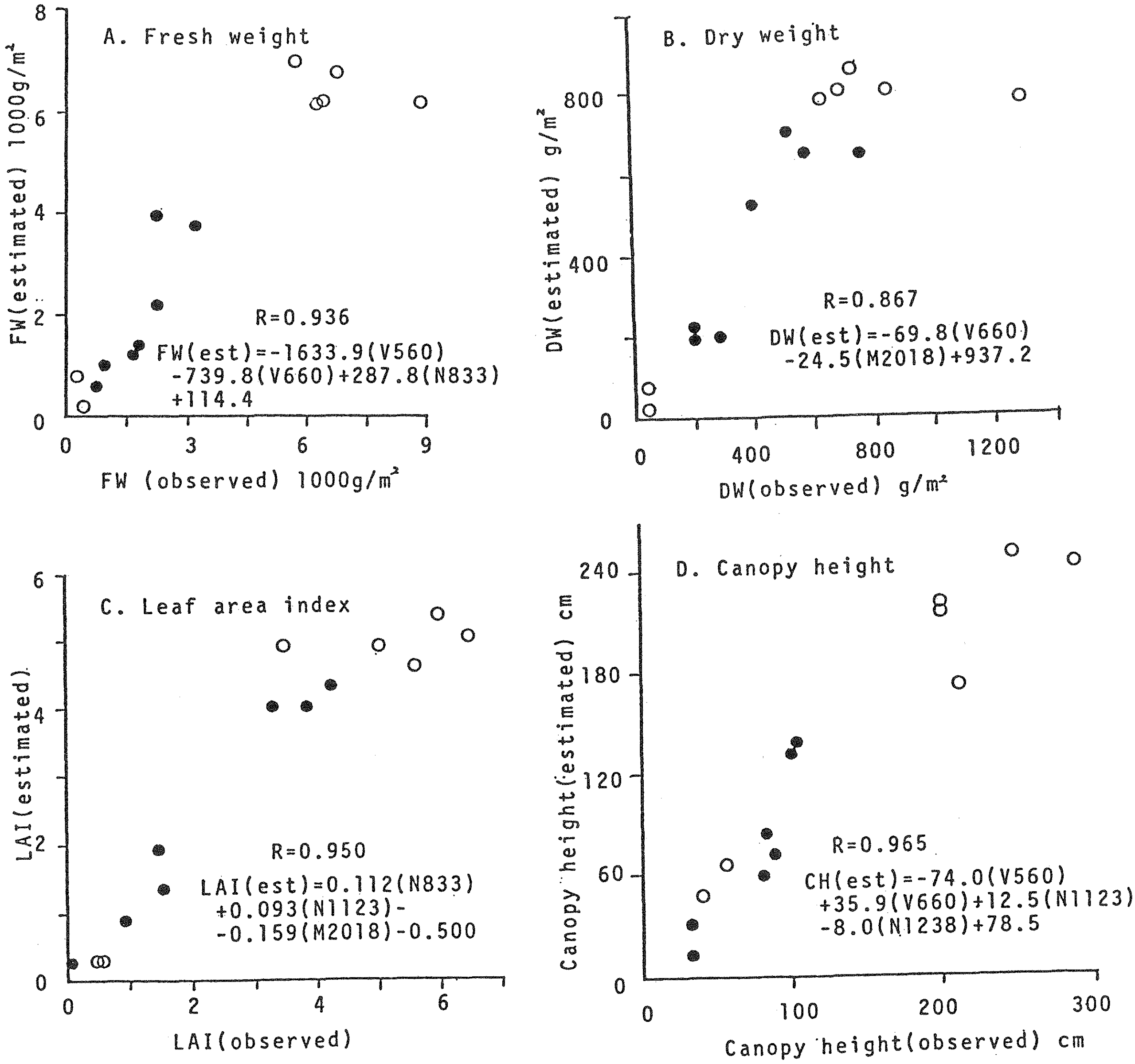

Fig. 4 Comparison of estimated and Observed agronomic variables (A:Fresh weight, B:Dry weight, C:Leaf area index, C:Canopy height). Reflectance data at a 500 m altitude were used in the multiple regression analysis. ○Corn, ●Pasture

Table 9. Selected bands in the multiple regression analysis at the different altitude levels.

Agronomic variables	Altitude (m)	Correlation (R)	Selected bands						
			V560	V660	N833	N1123	N1238	M1730	M2018
Fresh weight	50	0.856							0
	100	0.832							0
	250	0.873							0
	500	0.936	0	0	0				
	1000	0.889		0		0			
Dry weight	50	0.856		0					0
	100	0.841		0					
	250	0.878		0					0
	500	0.867		0					0
	1000	0.833			0				0
LAI	50	0.952			0			0	
	100	0.962			0	0		0	
	250	0.978	0		0			0	
	500	0.950			0	0			0
	1000	0.955			0	0		0	
Canopy height	50	0.856	0						0
	100	0.938	0	0	0				
	250	0.884	0						0
	500	0.965	0	0	0	0			
	1000	0.762							0

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