MAPPING PLANT NITROGEN STATUS BY USING ADS40 TO AID PRECISION FARMING

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ABSTRACT

Agricultural practices are considered as one of the major contributor for global pollution. Besides other, agriculture related pollution comes from agricultural inputs applied to the filed, such as fertilizer and pesticide. In majority of the agriculture field, flat rate application in wider area, sometimes even in whole region, is being used. However, it is well known fact that soil is not uniformly distributed for its fertility status. Applying fertilizer according to the level of locational soil fertility will not only reduce the pollution, but also increase profitability by reducing input cost. First step for such practice is to assess real time locational plant nutrient deficiency. With the conventional method of field soil and/or plant sampling is not practical for such purpose, specifically while considering the time and crop schedule, spatial preciseness, cost and others. Airborne survey, for example with ADS40 multispectral high resolution sensor, can solve most of the problem. Considering the problem and possibility, a joint collaborative research between PASCO Corporation and Tokyo University of Agriculture and Technology (TUAT) has been initiated since spring (wheat crop) 2001 for Wheat-Soybean-Maize rotation field that is located at TUAT, FUCHU campus, Tokyo, Japan. In this study possibility of modelling for plant nitrogen, which is one of the major plant nutrient, status mapping had been fetched out by using ADS40 imagery along with conventional infrared aerial photo and field observation data, for example SPAD (plant greenness index) reading. A new index, named as Plant Vigour SPAD (PVSPAD) was formulated and its relationship with Normalized Difference Vegetation Index (NDVI) was modelled with sufficient statistical confidence. As the imagery has less than 20 cm resolution, the model can be used to map the nutrient with enough accuracy for varied rate fertilizer application.

1. INTRODUCTION

Modern agriculture practice is not free from the adverse effect on the surrounding micro environment, which finally sum-up to the global environmental problem. Agricultural inputs, specifically fertilizer and pesticides, are well recognized contributor to the ground water and nearby stream pollution (Johnston and Bruulsema, 2002). The level of such pollution depends upon the amount of fertilizer and pesticide applied.

Multispectral and/or Hyperspectral high resolution imagery (airborne and/or satellite) has, recently, been used for the various purposes in agricultural industries. One such application is assessment of overall crop health and identify the crop stress caused by particular agent, for example nutrients and its specific type, weed and pest etc. (NASA 2002; Blumhoff and Johannsen, 2001; Chong et al, 2001). Digital aerial photography, for example ADS40, revolutionized the possibility of such application. Digital data is easy to handle and open the window for short or real time interpretation with the aid of differential GPS. Time is crucial here because decision for the application of agricultural input should be made within week, days or even an hour. Depending upon the crop schedule, air-survey can be scheduled accordingly and data can be directly inputted to the system for seeking desirable solution.

Nitrogen is one of the major crop nutrient that is widely applied chemically throughout the world. Nitrogenous chemical fertilizer is short live type and easily leached out to the ground water system. The amount of leaching depends upon the applied dose, time, method, etc. It is obvious that overdose application contaminate the water system while under dose resulted into reduced yield. Soil is not distributed uniformly for its nutrient status and this fact is widely used for the site specific application of fertilizer input for crop production (Shibusawa, 2001).

Nitrogen sufficiency in the crop is shown by healthy dark green leaf while deficiency resulted into pale light green leaf. Besides, overall plant health and vigour are also affected by the nitrogen availability along with other nutrients. NDVI , calculated from remotely sensed data, reflects both plant health as well as density. Thus, to manage the nitrogen fertilizer application, which is based upon the locational requirements during the crop growth, remotely sensed data, such as from ADS40 and Infrared Aerial Photo, can be used. With this possibility, a joint collaborative project by PASCO Corporation and TUAT had been started since spring 2001 for Wheat-Soybean-Maize rotation field. Main objective of the research was to model and map the plant nitrogen status using airborne imagery with the aid of field observation data.

2. STUDY SITE

Study site is locate at Fuchu campus, TUAT, Japan. Total field size is around 155 X 100 meter for fertilizer and ploughing (ploughing and limited ploughing) treatment. However, for this experiment observations were taken from only one ploughed plot (upper part; size 148.42 X 20.0 meter). Layout of the experiment is shown in figure 1.

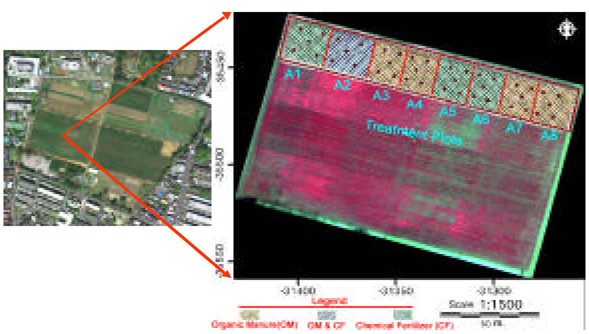

Figure 1: Study Site and Experiment Lay-Out (ADS40 2002)

The soil belongs to Andisol order and, obviously, dominated with volcanic materials with well humified organic matter (Leamy and Kinloch, 1987; Shoji and Otowa, 1987; cited in Hache, et al, 2002). It is well drained with clayey loam texture (46:34:20 percent of Sand:Silt:Clay) and belongs to Kanto Loam Series (Shibusawa, 1999).

3. EXPERIMENTAL DESIGN

3.1 Treatment and Experiment Layout

Experimental field is, basically, meant for long term fertilizer management experiment with wheat-corn-soybean crop rotation. Fertilizer treatments were applied for all three crops, but with different rate. Experiment is designed to check the long term effect, probably, from the use of Organic Manure (OM) and Inorganic (Chemical) Fertilizer (CF) in ploughed and limited ploughed areas. The dose was formulated in such a way that they should supply, somewhat, equal amount of nitrogen throughout the experimental field for particular crop and making variation in their source. There were three treatments, viz. CF, CF+OM and OM, with varied number of replications. However, some amount of nutrients were substituted through CF to OM plots during 2002 wheat. Total number of treatments plot, without bund, was eight (Figure 1). Division of the plots among treatments and their size is given in table 1.

Table 1: Treatments, Plot Size and Their Distribution

Treatment Number	Type of Fertilizer	Plot Number	Size of Plot (m.)
T1	CF	A1	20.00 X 20.00
		A5	20.00 X 17.50
		A6	20.00 X17.50
T2	CF+OM	A2	20.00 X 22.50
T3	OM	A3	20.00 X 17.70
		A4	20.00 X 17.20
		A7	20.00 X 16.70
		A8	20.00 X 18.45

Buffer area separating two treatments was about 1.5 meter
CF: Chemical Fertilizer with Three Replications
OM: Organic Manure Treatment with Four Replication (CF was also applied during 2002)
T2 is the Combination of CF and OM Treatment with One Replication.
It was supplied with Half of the dose of CF Plus Half of the dose of OM
Source: Tokyo University of Agriculture and Technology (TUAT), Japan, 2002

Present study has been taken for the spring wheat crop of year 2001 and 2002. Seed was shown continuously in row (30 - 35 cm apart) at the rate of 70 kg per hectare. The amount and timing of fertilizer application is presented in table 2. Experiment was completely rainfed and other agronomical practices (weeding, MUGIFUMI, etc.) were applied according to TUAT standard.

3.2 Instrument and Data Used

3.2.1 ADS40 Sensor and Conventional Aerial Camera (RC30)

ADS40 is the airborne digital sensor with cutting age technology. It is developed and introduced by LH Systems and is the world's first such camera. It captures 3 panchromatic channels (forward, nadir and backward) and 4 multispectral bands simultaneously. ADS40 was used for 2002 spring wheat data acquisition, while for 2001 RC30 with infrared film was used. KODAK AEROCHROME III Infrared Film 1443, with the help of filter, record the Nearinfrared (NIR), Red (R) and Green (G) bands of spectrum and creates false colour film, where NIR appears as R, R reproduces as G and G reproduces as blue (B). Use of both RC30 and ADS40 aerial photo give the opportunity for comparative study as well as validation. The specification of ADS40 and Infrared film is shown in table 3 and figure 2 respectively.

The aerial photo of 2001 was taken using fixed wing airplane (flying height 520 m.) with 153.47 mm focal length RC30 camera. Film was scanned (R,G and B) with 10 micron pixel size and georeferenced for further processing. The ADS40 sensor was also flown with fixed wing airplane (flying height 2000 m.). Multispectral (B, G, R and NIR) imagery was georeferenced and stored.

Table 2: Fertilizer Type and Application Rate for Wheat Crop

			Treatment Rate N-P2O5-K2O kg/ha			
Crop Year	Date	Application Time	CF-Plots	Type	OM-Plots	Type
Wheat 2001	Nov. 5-10, 2000	Before tillage	90-90-90	CF	180-40-186	OM
	Nov. 15-20, 2000	Planting				
	Feb. 23rd, 2001		90-90-90	CF		
Wheat 2002	Nov. 5-10, 2001	Before tillage	90-90-90	CF	129-29-133	OM
	Nov. 15th, 2001	Planting	50-50-50	CF	50-50-50	CF

CF: Chemical Fertilizer; NPK composition 14:14:14
OM: Organic Manure (Anima l + Saw dust; moisture 60%); NPK composition 0.68:0.15:0.70
Source: Tokyo University of Agriculture and Technology (TUAT), Japan, 2002

Table 3: General Specifications of ADS40

Item	Specification
Principle	3-line CCD stereo sensor
Pixels per CCD Line; Pixel size	12000; 6.5 micrometer
Dynamic range; Radiometric	12 bit (raw data model); 8-bit
FOV (across track)	52 degree
Swath at 10,000 feet flying height	3,000 m and 25 cm ground pixel
Spectral Bands (nanometer)	Panchromatic (465-680) Blue (430-490) Green (535-585) Red (610-660) NIR (835-885)

Source http://www.lh-systems.com/

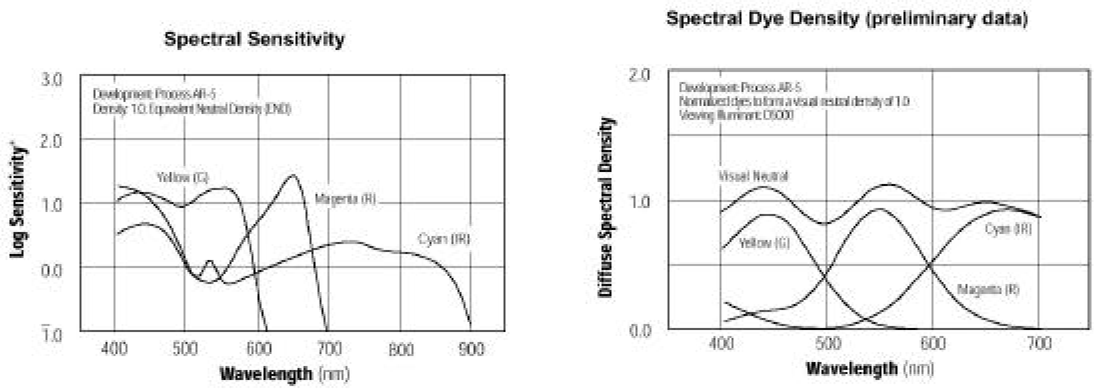

Figure 2: Specification of KODAK AEROCHROME III Infrared Film 1443 (Source: http://www.kodak.com/)

3.2.2 SPAD 502

SPAD 502, developed by Soil-Plant Analyses Development (SPAD) unit of Minolta Company, instantly measures indirectl y the amount of chlorophyll or greenness of plant. It uses optical density difference at two wavelengths: 650 mm and 940 mm and calculate SPAD Index value as given in equation 1. Silicon photodiode is used as receptor and the leaf area of 2 mm x 3 mm is used to measure the SPAD value that, usually, ranges from 0 to 50 ration index value. It is precise enough as it has repeatability within +/- 0.3 SPAD units (http://www.specmeters.com/Plant_Chlorophyll_Meters/ Minolta_SPAD_502_Meter.html).

$$SPAD = K \log_{10}\left[\left(NIR_t / NIR_p\right)/\left(R_t / R_p\right)\right] \quad (1)$$

Where, SPAD: Chlorophyll level by SPAD Index value, K: Calibration constant, NIR_t and R_t: Transmittance of NIR (940 nm) and R (650 nm) respectively, NIR_p and R_p: Supplied light power of NIR and R respectively

For 2001 wheat altogether 72 SPAD observations (9 from each plot) were taken , while for 2002 wheat total of 40 observations (5 from each plot) were recorded. For each observation, 6 plants were selected from those that fall inside prescribed observation polygon (size 80 X 60 cm), which was drawn with reference to the given observation point. After discarding maximum and minium value, the average of remaining 4 was recorded as SPAD reading. SPAD observation of 9-10 May 2001 and 9 April 2002 and aerial imagery of 12 May 2001 and 5 April 2002 were used in this research. Wheat 2001 and wheat 2002 were harvested on 15th May 2001 and 4th June 2002 respectively and dry biomass was recorded after drying the plants for 1 month in vinyl house. For wheat 2001biomass, in each measurement point only 6 representative plants were taken, while for 2002 plants inside 0.25 m^2 were used.

4. METHODOLOGY

Empirical modelling has been employed in this research using first hand field experiment/observation data and aerial imagery. Field experiment for two basic plant nutrient sources (OM and CF) was designed to see their effect on plant vigor. Plant vigor includes both over all plant health and its density. Besides other, inherent spatial variability of the soil properties affect such vigour. The variation of plant vigor across the field from other sources (except those two mentioned above), for example weather, cultural practices etc., has none or negligible effect as those were constant throughout the filed. Thus, mapping of the plant vigour directly aid to the manure management strategies for the precision farming. Such mapping is desirable in critical time of growing stage of the crop. Here, effort has been paid to map the plant vigour by using the empirical model. The model must be able to take care the issue those mentioned above.

4.1 Evaluation of SPAD and NDVI Relationship

From the ADS40 and RC30 imagery, Normalized Difference Vegetation Index (NDVI) was calculated using equation 2 (Rouse et al, 1973). The average NDVI values for each observation point of plots were extracted using the same polygon that was used to sample the SPAD value. Widely used, simple linear regression (equation 3) was employed using the vegetation index and SPAD. The relationship was evaluated for further modelling.

$$NDVI = (NIR - R)/(NIR + R) \tag{2}$$

Where, NIR and R is the Near Infrared and Red band of the aerial imagery.

$$y = ax + b \tag{3}$$

Where, y and x represent SPAD and NDVI respectively and a and b are constants.

4.2 Model Formulation

Several researchers have argued that NDVI corresponds, in general, directly to the biomass (amount of vegetation in the field) and, at the same time, other plant properties (Rouse et al, 1973, Varvel et al, 1997, Johannsen et al, 2002). The SPAD reflects the overall plant health by assessing the amount of greenness (chlorophyll) and indirectly correspond to the nitrogen status in the plant. However, it does not explain the plant density (number of plant per unit area and other plant attributes) or biomass in the filed. Normalized biomass (equation 4) can be treated as the relative plant density throughout the crop growing period that include the time of SPAD observation as well.

$$PDF = w/\hat{w} \tag{4}$$

Where, PDF : Plant Density Factor; w : Sampled biomass of individual observation point; : Average of w.

Using PDF and SPAD, a new SPAD index, named as Plant Vigor SPAD (*PVSPAD)*, has been formulated (equation 5). The name of this new index that is plant vigor SPAD has been selected as it represents overall plant health (by SPAD) and the plant density (by PDF). The plant vigor is usually referred for both overall plant health and its density in the field.

$$PVSPAD = SPAD \times PDF \tag{5}$$

Finally, using *PVSPAD* and NDVI, simple linear regression (equation 3) was calculated.

5. RESULT AND DISCUSSION

The long term effect of different types of fertilizer application has been shown clearly with the colour and texture pattern of the plots (Figure 3a and 3b). Accordingly some of the important soil properties, for example EC, pH and OM, were also showing variation across the field (Hache et al., 2002). Furthermore, yield and other crop agronomical attributes were also showing variations between as well as within the plots. Most of the soil and crop properties were, somewhat, more stable for the combined fertilizer (Chemical and Organic fertilizer treatment) treatment (Hache et al., 2002).

The NDVI of year 2001 and 2002 crops are shown in figure 3d and 3c respectively. The pattern of NDVI looks different . It might be due to the difference in the sensor type, the stage of crop growth and others. For example, the wheat 2001 was at doughing sage, while wheat 2002 was at vegetative growth stage at the time of data observation. Furthermore, it has been observed that the abundance of weed was varying significantly between the plots and in different year as well. It should be noted that the rate of nitrogen application was almost constant (the time of mineralization of OM to release the nutrients was also considered) with only variation in its source. However, the amount of phosphorous varied significantly among the treatments, which might had caused the crop establishment and the number of tiller. In spite of these anomalies, NDVI still able to reflect the useful pattern according to the treatments in different plots.

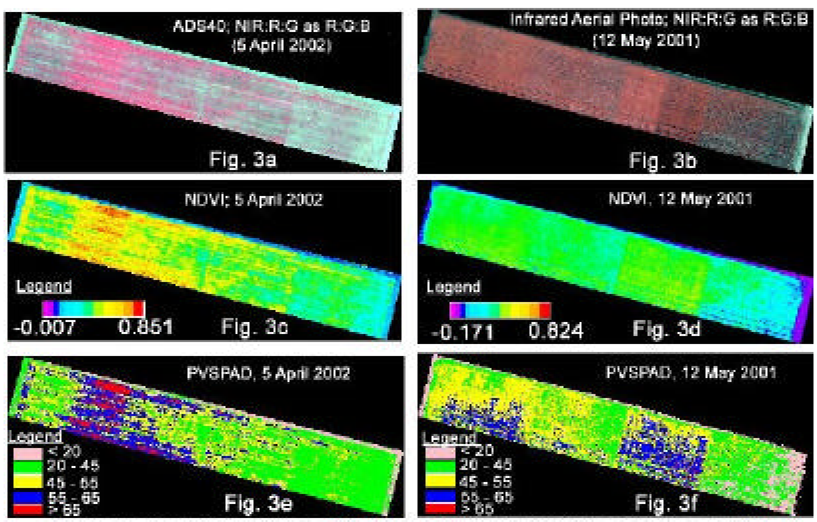

Figure 3: FCC; NDVI and Calculated PVSPAD of Year 2001 and 2002

5.1 Regression Analysis

5.1.1 NDVI and SPAD Relationship

Simple linear regression analysis between SPAD and NDVI, for both wheat 2001 (Figure 4) and 2002 year crops (Figure 5), had been performed to fetch out the possible relationship. The year 2001 wheat crop SPAD gave acceptable regression result with NDVI estimated from infrared aerial photo of year 2001. However, the relationship between NDVI calculated from ADS40 of year 2002 with 2002 wheat crop SPAD is not so encouraging. The most important factor for this anomaly is the addition of CF in the OM treatment plots for wheat 2002. Besides, the other probable factors for this un-uniform relationship between the two year crop might have been induced from the sensor type used for imagery acquisition and different crop growth stage while observing SPAD data. The infrared band of ADS40 is with shorter range as comp ared to RC30 imagery. Also, as mentioned before, there was flat rate nitrogen application to the whole experimental field, which might had been resulted with almost equal amount of nitrogen content in the plant leaf while acquiring the SPAD during the month of April 2002.

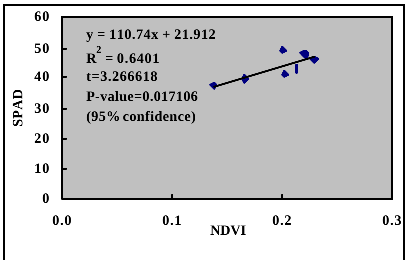

Figure 4: 2001-NDVI and 2001-SPAD Regression

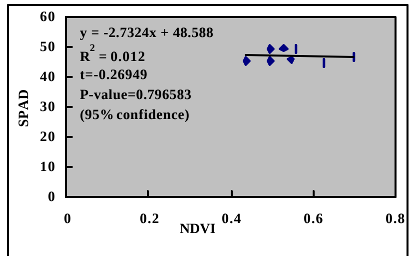

Figure 5: 2002-NDVI and 2002-SPAD Regression

This result opens the window for further inclusion of crop parameter, such as plant density in the model formulation. It also pointed for further checking of ADS40 imagery which should be acquired at different crop growth stages.

5.1.2 Modelling NDVI and PVSPAD

The regression result between NDVI and PVSPAD gave statistically acceptable relationship for both year crops as illustrated by figure 6 and 7. The R^2 value for both year crops remain well above 0.7. The result is significant while considering the t and P-value as well. It shows the NDVI is capable to map the plant vigour, which can be used for the fertilizer management, specifically nitrogen. As mentioned before, the plant health (greenness) measured by SPAD meter might had been appeared almost flat during 2002 crop, while NDVI varied significantly between the plots. After calculating the PVSPAD, which takes care both greenness and plant density of the crop, resulted into significant relationship with NDVI.

By using this model, the PVSPAD has been calculate for whole experimental plot and presented in the figure 3e and 3f for year 2002 and 2001 crop respectively. The highest plant vigour was found with CF+OM treatment plot followed by CF for 2002 crop, while during 2001 crop it is somewhat similar for CF+OM and CF plots. The plant vigour remained at the lowest level for OM plots for both year crops. Thus, it might be recommended that OM plots should had been supplied with some more amount of fertilizer.

In this research, plant density had been calculated using biomass of the crop after harvest. However, the plant density is desirable while crop is still growing and at its suitable stage for fertilizer management. The real time density can be obtained by calculating the number of plant and tiller and leaf per plant in the observation polygon that has been used for SPAD measurement. Thus, it is recommended that these attributes should be recorded per unit area basis while observing the SPAD.

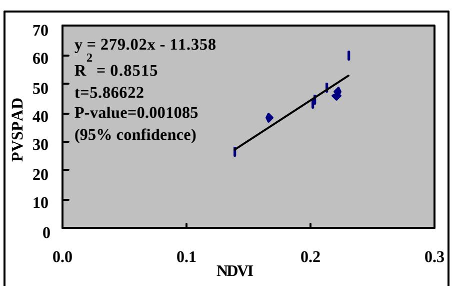

Figure 6: 2001 NDVI -PVSPAD Regression

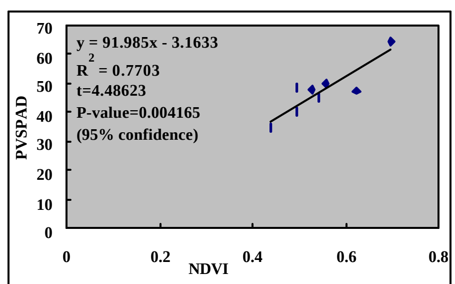

Figure 7: 2002 NDVI-PVSPAD Regression

6. CONCLUSION

NDVI from the conventional infrared aerial photo and ASD40 digital imagery have been successfully used to map the nitrogen status of the crop. New index, which is named as Plant Vigour SPAD (PVSPAD), has been formulated by using plant health or greenness (SPAD) and density (biomass) and proposed. The nitrogen status mapping model, a simple linear regression model, has been developed by using NDVI and PVSPAD from the field fertilizer type experiment for wheat crop of year 2001 and 2002. The robustness of the model has been demonstrated with the statistical tests and the consistency for both year experiment. Finally, the ADS40 airborne digital multispectral sensor can be used for crop fertilizer management with further test and verification.

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