Relationship of vegetation indices and SPAD meter readings with sugarcane leaf nitrogen under Pampanga Mill District, Philippines condition

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Abstract. Nitrogen (N) is an essential macronutrient in sugarcane that promotes vegetative growth and yield development. A study was conducted to evaluate the relationship of vegetation indices (NDVI and GNDVI) and SPAD meter readings with sugarcane leaf N and to introduce the best sampling date for the evaluation of plant N. SPAD meter readings (SMR), soil moisture, NDVI and GNDVI were gathered from 15 sampling sites in Pampanga Mill District, Philippines under different N fertilization practices and these were correlated with actual plant N. Six to thirteen, 21-28, 36-43, 100-107 and 147-154 days after fertilization (DAF) were sampling dates maintained each location. Results showed that SMR has a high positive correlation with plant N (0.86, 6-13 DAF), GNDVI (0.80, 147-154 DAF), soil moisture (0.79, 147-154 DAF) and NDVI (0.73, 147-154 DAF). Among sampling dates, it was recommended that 21 to 28 DAF using GNDVI and SPAD meter is best sampling date for evaluation of plant N status; since it coincides with stalk elongation stage and grand growth phase when rapid leaf production and vigorous vegetative development occur. Measurement of vegetation index and SPAD meter readings have potential in evaluating plant N through rapid assessment and ground validation, respectively.

Keywords: sugarcane, plant nitrogen, SPAD, NDVI, GNDVI

1. Introduction
Fertilizer is an essential input needed in sugarcane production for its growth, development, and attainment of the highest potential yield. Nitrogen is an essential macronutrient supplied by organic or inorganic fertilizers. This macronutrient is needed in large quantities to promote vegetative growth through an increase in meristematic activity of shoots [11] as well as tiller and millable stalk production in plant and ratoon cane [21]. Moreover, it has a large effect on leaf development which influences photosynthesis [3]. The pale green color on older leaves and slender stalk are symptoms when nitrogen is deficient in sugarcane [4].

Traditionally, standard Kjeldahl process is used to measure total plant N. However, it is laborious and expensive since it requires destructive sampling and laboratory analysis by technical experts; hence analyzed samples are limited. The identification of practical and reliable methods with a larger area scope is important in monitoring sugarcane plant N status.

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The chlorophyll content is approximately proportional to plant N content. It is a green-reflective substance and indicator of photosynthetic capacity, productivity, and stress levels. For this study, vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Green Normalized Difference Vegetation Index (GNDVI) from image processing and leaf transmittance properties using Soil-Plant Analyses Development (SPAD) 502 meter were processed and measured.

The Normalized Difference Vegetation Index (NDVI) is an index assesses live vegetation. It is used in crop phenology, biomass, and productivity in spatial distribution [5]. NDVI has been extracted in digital images of sugarcane fields to determine its area condition [6] and yield forecast [7]. It measures the difference between near-infrared and red light, which are reflected and absorbed by the plant accordingly, ranges from -1 to 1 [8].

Green Normalized Difference Vegetation Index (GNDVI) is a modified NDVI index used to avoid saturation at a higher leaf area index (LAI) that usually occurs in sugarcane [9]. It has been also used in predicting sugarcane yield [9-10].

SPAD-502 meter is a hand-held device used for rapid, accurate, and non-destructive measurement of leaf chlorophyll concentrations [11]. Effectivity of SPAD-502 meter is tested with various crops such as corn [12], rice [13], coffee [14], potato [15] and sugarcane [16-17]. It works by emitting two frequencies of light, 660nm (red) and 970nm (infrared). Red light is absorbed by chlorophyll while infrared is reflected; hence absorption difference is measured and termed as Optical Density Difference or ODD. SPAD-502 meter does not report the number of chlorophyll but as a ratio of reflection versus absorption [18]. The current study was conducted to evaluate the relationship of NDVI, GNDVI, and SPAD meter readings with sugarcane leaf N and to introduce the best sampling date for plant N evaluation.

2. Methodology

2.1 Study Site
The current study was carried out at Pampanga Mill District, Philippines. It has approximately a sugarcane area planted of 4,011 hectares. It is mainly composed of sandy soils with low N, low to medium P, low to medium K, and low to moderate inherent fertility [19].

The sampling sites were from Porac and Bacolor municipalities; since these are the two largest planted areas with 960.25 and 437.46 hectares, respectively. Seven sites in barangays Manibaug Paralaya and Pio, Porac, and five locations in barangay Maliwalu, Bacolor were sampled. Moreover, an experiment was established in Sugar Regulatory Administration – Luzon Agricultural Research and Extension Center (SRA-LAREC) in Floridablanca, Pampanga to determine the effect of different N levels on sugarcane. Experimental plots under control (indigenous fertility), full dose, and half dose of recommended rate (RR and ½ RR) of N were also included as sampling sites.

2.2 Fertilization Practices
Identified sampling sites in Porac and Bacolor were visited to interview their respective planters about their fertilization practices. The amount and kind of fertilizer as well as the timing of application were asked. Sampling sites were grouped based on their crop age. It was identified that a decrease in yield, N absorption [20], and leaf N [21] were related to crop age. For SRA-LAREC, the amount and timing of N application under RR and ½ RR plots were recorded. Initial soil sampling was conducted in sampling sites to determine their N fertilizer recommended rate. These were used to compare with their fertilization practices whether deficient, sufficient, or excessive in terms of actual N application.

2.3 Sampling Dates
The sampling dates on each site was based on when the planter (for Porac and Bacolor) and researcher (for SRA-LAREC) fertilized their plots. Six to thirteen, 21-28, 36-43, 100-107, and 147-154 days after fertilization (DAF) were sampling dates maintained each location.
2.4 Data Gathering and Image Processing

For each sampling, SPAD meter readings (SMR), soil moisture (SM), plant N, and vegetation indices (NDVI and GNDVI) were measured and processed. SMR and SM were measured in situ using field instruments such as SPAD-502 meter and TDR 350 Soil Moisture meter, respectively. Alternatively, pre-measured SMR sampled leaves were subjected to plant N analysis while NDVI and GNDVI values were extracted from satellite images of sampling sites.

2.4.1 SPAD meter readings and soil moisture data. The leaf transmittance and soil moisture were measured using SPAD-502 meter and TDR 350 Soil Moisture meter, accordingly. For SMR, two sets of 30 to 45 3rd leaf from the top of stalk were randomly sampled each location. SMR was taken on the middle part of the leaf, one on each side where readings should not exceed 50.0 with less than 5.0 difference. All readings were averaged. For SM, 30 points per location were measured with percent volumetric moisture content (%VMC) as a unit of measurement and were also averaged.

2.4.2 Plant Nitrogen. The N content of leaf samples preliminary measured with SPAD-502 meter was evaluated using the Kjeldahl method with a UV Vis spectrophotometer instrument. For plant tissue preparation, the sampled leaves were cut. The middle section of leaves was retained while the top and bottom sections were discarded. The leaf strips were bundled together and labeled based on their sampling sites. Samples were placed in a well-ventilated area until these were dried and be readily delivered to the laboratory.

2.4.3 Normalized Difference Vegetation Index (NDVI). NDVI is calculated as the ratio difference between measured canopy reflectance in the red and near-infrared [22]. It ranges from -1 to 1 and calculated as:

\[
\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}
\]

(1)

2.4.4 Green Normalized Difference Vegetation Index (GNDVI). GNDVI is calculated as the ratio difference between canopy reflectance in the green and near-infrared [9].

\[
\text{GNDVI} = \frac{(\text{NIR} - \text{Green})}{(\text{NIR} + \text{Green})}
\]

(2)

The high-resolution images of sampling sites were captured through Kompsat-3, GeoEye-1, WorldView-1, WorldView-2, and Planet satellites from February to December 2019 with 0.50 to 3.0 meters spatial resolution and multispectral bands (red, green, blue and near-infrared). These satellite images were processed to extract NDVI and GNDVI values.

2.5 Statistical Analysis

The descriptive statistics of SMR, SM, plant N, NDVI, and GNDVI values were defined by mean, minimum, and maximum. The results of these variables were submitted to correlation analysis per sampling date to determine their relationship. Sampling date with the highest correlation of plant N with NDVI, GNDVI, or SPAD was recommended as the best sampling date for the evaluation of N.

3. Results and Discussion

3.1 Fertilization Practices

After interviews with planters at Porac and Bacolor, Pampanga, fertilization practices were recorded. It was identified that planters commonly used urea (46-0-0), a nitrogen fertilizer, during June or July. Due to the absence of irrigation, planters applied a full dose of fertilizer when soil moisture is enough after heavy rain onsets.
It was observed that sampling sites in Porac, Pampanga (sites P1 to P7) applied excessive actual N fertilizer rate (12 to 15 bags 46-0-0 ha$^{-1}$) as compared to their recommended N fertilizer rate (7.5 to 8 bags 46-0-0 ha$^{-1}$). The crop age in these sampling sites was as follows: P1 was plant cane, P2 was 1st ratoon cane and P3 to P7 were 2nd ratoon cane.

On the other, sampling sites in Bacolor, Pampanga (sites B1 to B5) applied the actual N fertilizer rate (7 to 9 bags 46-0-0 ha$^{-1}$) similar to their recommended N fertilizer rate (8.5 bags 46-0-0 ha$^{-1}$). The crop age was as follows: B1 was plant cane, B2 to B4 were 1st ratoon cane and B5 was 3rd ratoon cane.

The crop age of canes in SRA – LAREC sampling sites (L1 to L3) was plant cane. L1 was maintained on its indigenous N level; therefore no N fertilizer was applied. For L2 and L3, the recommended rate of N fertilizer was implemented where L2 was in full while L3 was in half dose of N fertilizer.

3.2 SPAD meter readings and soil moisture data

3.2.1 SPAD meter readings. Sampling sites were grouped based on crop age. The SPAD meter readings (SMR) of sampling sites with plant cane ranged from 35.16 to 45.75 (Fig 1.1). Across sampling dates, P1 has the highest (43.38) while L1 has the lowest average SMR (38.40).

The SMR of sampling sites with 1st ratoon cane ranged from 31.13 to 45.51 (Fig 1.2). It was observed that P2 has the highest SMR across sampling dates except at 21 to 28 DAF when B2 to B4 have maximum SMR. Nonetheless, P2 has the highest (42.61) while B4 has the lowest (36.57) average SMR.

![Fig 1.1 SPAD data of Plant Cane](image1.png)

N fertilizer applied (PC) L1 – no N, L2 – sufficient N, L3 – deficient N, P1 – excessive N, B1 – sufficient N

N fertilizer applied (1st RC): P2 – excessive N, B2 to B4 – sufficient N

![Fig 1.2 SPAD data of 1st Ratoon Cane](image2.png)

![Fig 1.3 SPAD data of 2nd Ratoon Cane](image3.png)

N fertilizer applied (2nd RC): P3 to P7 – excessive N

N fertilizer applied (3rd RC): B5 – sufficient N

![Fig 1.4 SPAD data of 3rd Ratoon Cane](image4.png)
The SMR of sampling sites with 2nd ratoon cane ranged from 26.06 to 42.25 (Fig 1.3). Most sampling sites (P5 to P7) have the lowest SMR at 100 to 154 DAF while P3, P5, and P6 have peak SMR at 21 to 43 DAF. Across sampling dates, P3 has the highest (36.93) while P4 has the lowest (31.28) average SMR. Site B5 with 3rd ratoon cane has SMR ranged from 27.19 to 44.37 (Fig 1.4) and average 36.13. The lowest SMR was recorded at 6 to 13 DAF (27.19) while the highest SMR was observed at 36 to 43 DAF (44.37).

It was reported that higher nitrogen application provides higher chlorophyll content, through SPAD-502 meter readings because of higher nitrogen concentration accumulated into the leaf [23]. Moreover, it was supported that sugarcane has been related to crop age which young plants assimilated higher N rates than older ones [24].

3.2.2 Soil moisture data. Sandy soil has permanent wilting point of 0 to 5% while field capacity of 6 to 15% VMC. The lower limit of field capacity (6%) was considered to determine the presence of insufficient soil moisture in sampling sites. It was observed that sampling sites in SRA-LAREC (L1 to L3) have ample water across sampling dates because irrigation facility is available.

On the other hand, it was recorded that permanent wilting point was experienced during early to middle days after fertilization (6 to 43 DAF) at sampling sites (P1 to P7) in Porac, Pampanga. Alternatively, permanent wilting point was observed during late days after fertilization (100 to 154 DAF) at sampling sites (B1 to B5) in Bacolor, Pampanga.

3.3 Plant Nitrogen (Plant N)

The critical value of plant N is 1.80% and the optimum range is 2.0 to 2.6% for sugarcane leaves [25]. The plant N of sampling sites with plant cane ranged from 1.078 to 2.253% (Fig 2.1). All sampling sites have the lowest plant N at late days after fertilization (100 to 154 DAF) while peaked at 21 to 28 DAF. Across sampling dates, P1 has the highest (1.864%) followed by L2 (RR, 1.811%) while B1 has the lowest (1.317%) average plant N. It was observed that P1 and L2 have adequate plant N.

The plant N of sampling sites with 1st ratoon cane ranged from 0.915 to 2.162% (Fig 2.2). All sampling sites have the lowest plant N at 100 to 107 DAF except with the B4 site. Peak plant N values of sampling sites were observed at 21 to 28 DAF except with P2. P2 was the only sampling site with excessive while B2 to B4 have sufficient actual N application. Across sampling sites, P2 has the highest (1.808%) while B2 has the lowest (1.088%) average plant N. Only P2 has enough plant N among sites with 1st ratoon cane.

The plant N of sampling sites with 2nd ratoon cane ranged from 0.656 to 1.537% (Fig 2.3). These sampling sites have an excessive actual N application. Lowest plant N was observed at 147 to 154 DAF while the highest plant N at 21 to 43 DAF. P6 has the highest (1.182%) while P4 has the lowest (0.972%) average plant N content. Insufficient plant N was observed among sampling sites with 2nd ratoon cane.

Site B5 with 3rd ratoon cane ranged from 0.681 to 1.511% plant N (Fig 2.4). Lowest plant N was observed at 6 to 13 DAF (0.681%) while the highest plant N was recorded at 36 to 43 DAF (1.511%). There was insufficient plant N across sampling dates.

The overall observations for plant N data are: there were adequate average plant N for sampling sites with plant cane and 1st ratoon cane applied with excessive (P1 and P2) or enough (L2) N application. As ratooning continues, even excessive N application has no influence on plant N content and the latter remained deficient. Lowest plant N values were observed at late days after fertilization (100 to 154 DAF) while peak plant N values were recorded in middle days after fertilization (21 to 43 DAF). It was reported that increasing N application was significant in leaf area and biomass of sugarcane [23]. Since there is a higher N application, sugarcane plants can assimilate more N. However, because N is a dynamic nutrient that can be easily lost through leaching of nitrate, erosion, surface run-off and volatilization of ammonia [26], there is a decreasing amount of available N for plant use in late days after fertilization.
Fig 2.1 Plant N values of sampling sites with plant cane (L1, L2, L3, P1, and B1).
N fertilizer applied: L1 – no N, L2 – sufficient N, L3 – deficient N, P1 – excessive N, B1 – sufficient N

Fig 2.2 Plant N values of sampling sites with 1st ratoon cane (P2, B2, B3, and B4).
N fertilizer applied: P2 – excessive N, B2 to B4 – sufficient N

Fig 2.3 Plant N values of sampling sites with 2nd ratoon cane (P3, P4, P5, P6, and P7)
N fertilizer applied: P3 to P7 – excessive N

Fig 2.4 Plant N values of sampling site with 3rd ratoon cane (B5). N fertilizer applied: B5 – sufficient N
3.4 Normalized Difference Vegetation Index (NDVI)

The NDVI values for sugarcane range from 0.20 to 0.60. These values are further classified based on sugarcane condition. Poor growth is 0.20 to 0.24, moderate is 0.25 to 0.28, good is 0.29 to 0.38 while very good growth is 0.39 to above 0.50 [27]. The lower limit of good growth 0.29 was used to describe extracted NDVI values.

The NDVI of sampling sites in SRA-LAREC ranged from 0.18 to 0.66 across sampling dates (Fig 3.1). It was observed that during February to April 2019, NDVI values of L1 to L3 were 0.29; since sugarcane was currently at emergence to tillering stages. Developing canopy and exposed soil were possible reasons for lower NDVI values during this period. Conversely, from late April to July 2019, NDVI values of sampling sites gradually increased because sugarcanes were already at stalk elongation stage. The peak of NDVI was observed in July 2019 (7 months after planting) then decreased in September 2019 (9 MAP). It indicates that the grand growth phase of sugarcane happened between July to September 2019. L2 (RR) and L3 (1/2RR) were almost coinciding while L1 (no applied N fertilizer) remained lower in trend.

The NDVI values of sampling sites in Porac, Pampanga ranged from 0.10 to 0.48 from May 09, 2019 to December 22, 2019. These were fertilized with excessive N fertilizer (12 to 15 bags 46-0-0 ha⁻¹) as compared with their N fertilizer recommended rate (7 to 9 bags 46-0-0 ha⁻¹). It was observed that NDVI values were lower than the lower limit of NDVI for good growth (0.29) during May 2019. However, after these were fertilized last May and June 2019, NDVI values gradually increased from July to October 2019. Maximum NDVI values were observed on October 4, 2019 then were distinctly decreased on December 22, 2019. Since these sampling sites were harvested on the 2nd week of December 2019, it is expected to have lower NDVI values after harvest (Fig 3.2).

The NDVI values of sampling sites in Bacolor, Pampanga ranged from 0.07 to 0.46 from May 09, 2019 to December 10, 2019. These were fertilized based on the N fertilizer recommended rate (7 to 9 bags 46-0-0 ha⁻¹) last July 2019. After the application of N fertilizer last July 16, 2019, it was observed that NDVI values gradually increased from late July to early October 2019. Maximum NDVI values were observed during October 4 and 27, 2019 then significantly decreased on December 10, 2019. Since sites B2, B3 and B4 were harvested last December 4, 2019; remaining sites B1 and B5 have higher NDVI values due to the presence of sugarcane vegetation (Fig 3.3).

3.5 Green Normalized Difference Vegetation Index (GNDVI)

The GNDVI of sampling sites in SRA-LAREC ranged from 0.03 to 0.42 across capturing dates (Fig 4.1). The fertilizer regimes on these sampling sites were indigenous (L1, control), full dose (L2) and half dose (L3) N recommended rate. Minimum GNDVI was observed on the day of fertilizer application last February 22, 2019 then gradually increased until it peaked last June 23, 2019 and decreased afterward.

The GNDVI values of sampling sites in Porac, Pampanga ranged from 0.05 to 0.31. These sampling sites have excessive N application with most are 2nd ratoon canes. The maximum GNDVI was observed between July to October 2019 while the lowest was during May 2019 (Fig 4.2).

The GNDVI values of sampling sites in Bacolor, Pampanga ranged from 0.05 to 0.27. These sampling sites have sufficient N application with most were 1st ratoon canes. Only B3 and B5 sites have positive GNDVI on May 09, 2019. Because sites B2 to B4 were harvested last December 04, 2019 earlier than image capturing dates December 10 and 22, 2019; these have smaller GNDVI values due to absence of sugarcane vegetation. Lowest GNDVI was observed during July 2019 while the highest GNDVI was recorded during October 2019 (Fig 4.3).
Fig 3.1 NDVI values in SRA-LAREC from February to October 2019.

N fertilizer applied (PC): L1 – no N, L2 – sufficient N, L3 – deficient N

Fig 3.2 NDVI values of sampling sites in Porac, Pampanga from May to December 2019.

N fertilizer applied: P1 (PC) – excessive N, P2 (1st RC) – excessive N, P3 to P7 (2nd RC) – excessive N

Fig 3.3 NDVI values of sampling sites in Bacolor, Pampanga from May to December 2019.

N fertilizer applied B1 (PC) – sufficient N, B2 to B4 (1st RC) – sufficient N, B5 (3rd RC) – sufficient N

Fig 4.1 GNDVI values in SRA-LAREC from February to October 2019.

N fertilizer applied (PC): L1 – no N, L2 – sufficient N, L3 – deficient N

Fig 4.2 GNDVI values of sampling sites in Porac, Pampanga from May to December 2019.

N fertilizer applied: P1 (PC) – excessive N, P2 (1st RC) – excessive N, P3 to P7 (2nd RC) – excessive N

Fig 4.3 GNDVI values of sampling sites in Bacolor, Pampanga from May to December 2019.

N fertilizer applied B1 (PC) – sufficient N, B2 to B4 (1st RC) – sufficient N, B5 (3rd RC) – sufficient N
3.6 Correlation Analysis of Variables

The following presents the correlation coefficients with a significance of 5% for the mean data per sampling date. It was observed that plant N and SPAD were indeed correlated. The highest correlation coefficient was observed at 6 to 13 DAF (0.86) as high positive while the lowest correlation coefficient at 147 to 154 DAF (0.57) as moderate positive. Research supported that there is a positive significant linear relationship between SPAD meter readings and leaf N content in rice. However, correlation coefficients vary according to sampling dates [28].

Soil moisture has a moderate positive (0.59) correlation with plant N at 6 to 13 DAF. The significant correlation of soil moisture and plant N indicates that drought stress restricts N uptake; therefore, it can cause N deficiency in sugarcane. Also, the application of nitrogen fertilizer improves the larger root system at early stage; hence it can develop more shoots and higher total biomass either in full irrigation or drought condition [23].

Vegetation indices NDVI and GNDVI were also highly correlated. The highest correlation coefficient was observed at 6 to 13 DAF (0.88) as high positive while the lowest correlation coefficient was observed at 36 to 43 DAF (0.32) as low positive.

Plant N and NDVI have a negligible negative correlation across sampling dates. Oppositely, plant N and GNDVI have a moderate positive (0.56) correlation at 21 to 28 DAF.

Meanwhile SPAD, a highly correlated parameter with plant N, has a high positive (0.73) at 147 to 154 DAF and low positive correlation (0.48) at 36 to 43 DAF with NDVI. It has also high positive (0.80) at 147 to 154 DAF and a low positive correlation (0.43) at 21 to 28 DAF with GNDVI.

As shown on correlation analysis, plant N was correlated with SPAD meter readings while not correlated with NDVI across sampling dates. Nonetheless, plant N was correlated with GNDVI at 21 to 28 DAF. Based on results, 6 to 13 DAF should be the best sampling date in the evaluation of N using SPAD meter because of its high positive correlation (0.86). However, since plant N was correlated with SPAD (0.76) and with GNDVI (0.56) at 21 to 28 DAF, it can be considered as best sampling date for evaluation of plant N. The relationship of GNDVI with SPAD meter readings shows that vegetation index can be used in rapid assessment while SPAD meter can be used as a ground-truth instrument for plant N. Also, under Pampanga mill district condition, fertilizer is usually applied 7 months after planting or ratooning due to dependence on rainfall for soil moisture. Sampling at 6 to 13 DAF is too early to manifest the progress on vegetation indices while at 147 to 154 DAF will only coincide either maturity or harvesting of canes. Sampling at 21 to 28 DAF using GNDVI with SPAD meter coincides at stalk elongation stage (7 to 8 MAP) when nitrogen is vital for millable stalk production and yield development; hence monitoring is critical.

4. Conclusion

The current study was conducted to evaluate the relationship of vegetation indices (NDVI and GNDVI) and SPAD meter readings with sugarcane leaf N and to introduce the best sampling date for the evaluation of plant N. Results presented that SPAD meter readings (SMR) are higher in sampling sites with plant canes or with an excessive application of N fertilizer than sampling sites with ratoon canes or with sufficient and deficient N fertilizer. Insufficient soil moisture was experienced when permanent wilting point was reached during early to middle days after fertilization in Porac, Pampanga (6 to 43 DAF) while during late days after fertilization in Bacolor, Pampanga (100 to 154 DAF). Conversely, ample soil moisture was present in SRA-LAREC due to availability of irrigation facility. Meanwhile, there was adequate average plant N for sampling sites with plant cane and 1st ratoon cane applied with excessive (P1 and P2) or enough (L2) N fertilizer. As ratooning continues, even excessive N application has no influence on plant N and the latter remained deficient. Based on correlation analysis, plant N has a high positive correlation with SMR, negligible correlation with NDVI, and moderate positive correlation with GNDVI. Additionally, SMR is also correlated with GNDVI hence these technologies can be used for field validation and rapid assessment, respectively. It was recommended that 21 to 28 DAF using GNDVI and SPAD meter is the best sampling date for evaluation of plant N status.
Table 1.1 Correlation coefficient of parameters at 6 to 13 DAF (α = 0.05).

|       | SPAD | Soil moisture | Plant N | NDVI | GNDVI |
|-------|------|---------------|---------|------|-------|
| SPAD  | 1    | 0.22          | 0.86*   | 0.01 | -0.04 |
| Soil Moisture | 1    | 0.59*         | -0.51   | -0.73| -0.34 |
| Plant N | 1    | -0.16         | 0.88*   | 1    |
| NDVI  |      |               |         |      |
| GNDVI |      |               |         |      |

Table 1.2 Correlation coefficient of parameters at 21 to 28 DAF (α = 0.05).

|       | SPAD | Soil moisture | Plant N | NDVI | GNDVI |
|-------|------|---------------|---------|------|-------|
| SPAD  | 1    | 0.04          | 0.76*   | 0.02 | 0.43  |
| Soil Moisture | 1    | 0.28          | -0.22   | -0.15|       |
| Plant N | 1    | 0.01          | 0.56*   | 0.62*| 1     |
| NDVI  |      |               |         |      |
| GNDVI |      |               |         |      |

Table 1.3 Correlation coefficient of parameters at 36 to 43 DAF (α = 0.05).

|       | SPAD | Soil moisture | Plant N | NDVI | GNDVI |
|-------|------|---------------|---------|------|-------|
| SPAD  | 1    | 0.37          | 0.58*   | 0.48 | -0.18 |
| Soil Moisture | 1    | -0.27         | 0.58*   | 0.20 |       |
| Plant N | 1    | -0.18         | -0.68   | 0.32 |       |
| NDVI  |      |               |         |      |
| GNDVI |      |               |         |      |

Table 1.4 Correlation coefficient of parameters at 100 to 107 DAF (α = 0.05).

|       | SPAD | Soil moisture | Plant N | NDVI | GNDVI |
|-------|------|---------------|---------|------|-------|
| SPAD  | 1    | 0.34          | 0.59*   | -0.40| -0.01 |
| Soil Moisture | 1    | 0.27          | 0.26    | 0.72*|       |
| Plant N | 1    | -0.54         | -0.20   | 0.20 |       |
| NDVI  |      |               |         |      |
| GNDVI |      |               |         |      |

Table 1.5 Correlation coefficient of parameters at 147 to 154 DAF (α = 0.05).

|       | SPAD | Soil moisture | Plant N | NDVI | GNDVI |
|-------|------|---------------|---------|------|-------|
| SPAD  | 1    | 0.79*         | 0.57    | 0.73*| 0.80* |
| Soil Moisture | 1    | 0.29          | 0.67*   | 0.81*|       |
| Plant N | 1    | -0.01         | 0.33    | 0.81*|       |
| NDVI  |      |               |         |      |
| GNDVI |      |               |         |      |

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