Crop canopy sensors for Efficient Nitrogen management in the Indo-Gangetic plains

Progress Report

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Executive Summary

Large field-to-field variability of soil N supply restricts efficient use of N fertilizer when broad-based area general 'blanket' recommendations are used in rice and wheat. Innovative fertilizer management has to integrate both preventive and field specific corrective N management strategies to increase the profitability of irrigated rice and wheat. Hand-held GreenSeeker and Holland optical sensors offer distinct advantage over need based N management tools like SPAD meter and leaf color chart in that it can work out fertilizer N requirement of rice and wheat based on expected yields as well as achievable greenness of the leaves. As per nitrogen fertilizer optimization algorithm for using optical sensors, relationships of in-season estimate of yield (INSEY) defined as NDVI/day with grain yield (GY) of rice or wheat were developed for different stages of crops using data from field experiments conducted during 2004-2006 with different crop cultivars at Ludhiana, Karnal and Modipuram in the northwestern India. When INSEY-GY relationships were fitted to equation of the type $GY=a*(INSEY)^b$, R^2 values were 0.86 and 0.82 at Feekes 5/6 and Feekes 7/8 stages of wheat, respectively.

In puddled transplanted rice, the optical sensor did not work properly up to 3 weeks after transplanting due to interference of standing water in the field. But later on based on data from Karnal and Ludhiana, R^2 values worked out to be 0.54, 0.58 and 0.54 at 42, 49 and 55 days after transplanting. INSEY-GY relations developed by using Greenseeker and Holland sensors were similar and allowed prediction of yield potential that can be achieved without fertilizer N application. On the day of fertilizer N application using GreenSeeker, response index (RI) was calculated as ratio of NDVI in a N-rich strip and the test plot. Grain yield that can be achieved by applying fertilizer N was calculated by multiplying GY with RI. Difference in N uptake between predicted yields from plots with and without N fertilizer application allowed calculating the quantity of fertilizer N that should be applied. Results from both Karnal and Ludhiana trials indicated that 10-20% N can be saved without yield penalty in wheat if 'blanket' fertilizer N recommendation are replaced with GreenSeeker based N application at Feekes 7/8 stage. This N management scenario resulted in higher fertilizer N use efficiency and higher protein content in wheat grains. In rice, GreenSeeker based N management invariably resulted in total N application less than the blanket dose of 120 or 150 kg N ha^{-1} but in several treatment combinations it was possible to produce grain yields of rice equal to or more than that obtained with recommended doses. The studies carried out so far suggest that GreenSeeker can be an important tool for rational management of fertilizer N in the rice-wheat system of the Indo-Gangetic plains.

Initial studies have indicated that there are distinct possibilities of integrating the handheld optical sensors for NDVI measurements with the remotely sensed satellite IRS- LISS-III data

In rice season 2005, the relationship between GS-NDVI and Spectroradiometer NDVI (NIR: 770-860 nm, Red: 620-680 nm, corresponding to the IRS-LISS-III satellite bands) was: Y= 0.093055 + 0.80036 X (r = 0.8622)**,** where **Y** refers to GS-NDVI and **X** to SAT- NDVI (from Spectroradiometer). During the same period, relationship between GS-NDVI and Spectroradiometer NDVI (NIR: 780 nm, Red: 670 nm, the specific wave lengths of the GS) was found to be **Y= 0.114961 + 0.7582 X (r = 0.9664).**
For winter wheat 2005-06, the relationship between GS-NDVI and Spectroradiometer NDVI (NIR: 770-860 nm, Red: 620-680 nm, corresponding to the IRS-LISS-III satellite bands) was: **Y= 0.1793 +0.7443X (r= 0.8667)**

These results suggest that GS-NDVI indices can be effectively used as a tool for monitoring the integrated plant response to variations in agronomic and crop management conservation agricultural practices.

1. Introduction

Decisions regarding improvements in fertilizer N use efficiency begin at the field scale where farmers have to deal with variability in soils, climates, and cropping patterns. One of the most important factors governing any improvement in N use efficiency relates to fertilizer-N substitution value of soil N. Therefore, it is important to know about the amounts and variations in the indigenous N supply during crop season to determine the optimal timing and amount of fertilizer N applications. Since indigenous N supply is highly variable over time in same as well as different fields in any given agro ecological region, it is not easy to precisely manage N requirements of the crop plants. Significant temporal and spatial variability in soils makes it difficult to accurately estimate indigenous soil N supply for enhancing fertilizer N use efficiency in rice and wheat.

Current fertilizer N recommendations on the amounts and timing of N applications are typically general recommendations applied to very large area of rice and wheat growing tracts. Such broad-based 'blanket' recommendations of fertilizer N restrict efficient use of N fertilizer. In order to ensure high crop yields, many a times, ignorant farmers apply fertilizer N in doses much higher than the blanket recommendations. Over application of N in cereal crops is known to reduce fertilizer recovery. Innovative fertilizer management practices aimed at managing N efficiently must integrate both preventive and corrective strategies to sustain the soil resource base and increase the profitability of irrigated rice and wheat crops grown in the Indo-Gangetic plains. Successful strategies need to provide principles that can be developed into a range of management options based on location specific fertilizer N requirements of crops according to (i) seasonal / year-to-year variations in climate (particularly solar radiation) and (ii) the spatial and temporal variations of indigenous soil N supplies.

In order to improve fertilizer N use efficiency, it is crucial to reduce losses of N from the soil-plant system by synchronizing N applications with crop demands. Since rice-wheat systems have contrasting edaphic requirements, soil test based N fertilizer recommendations generally have not been successful. Therefore, dynamic N management calls for plant need–based application of N for achieving high yield and N use efficiency. Dynamic N management requires rapid assessment of leaf N content, which is closely related to photosynthetic rate and biomass production and is sensitive indicator of changes in crop N demand within the growing season. The chlorophyll or SPAD meter, and its inexpensive and simple alternative, the leaf colour chart (LCC) can quickly and reliably monitor relative greenness of leaf as an indicator of leaf N status. These tools have provided an excellent opportunity in terms of developing real-time N management strategies for rice but these tools do not take into account photosynthetic rates or the biomass production and expected yields for working out fertilizer N requirements. Whereas chlorophyll or SPAD meter and LCC have been used successfully in used particularly in rice, their utility is often constrained in wheat and other upland crops. Due to continuous wet soil moisture regimes in rice crop, fertilizer N can be applied at any time which is not true for many upland crops. In upland crops, fertilizer applications, to be effective, must be synchronized with irrigation cycles.

Recently, methods based on measurements of reflectance in the red (defined by chlorophyll content) and near infrared (defined by living vegetation) region of the electro-magnetic spectrum for estimating N requirement of crops using early season estimates of N uptake and potential yield have been developed. Normalized difference vegetative index based on in- season sensor reading can predict biomass, plant N concentration and plant N uptake. The strategy based on optical sensors hold promise in developing N management options because it offers distinct advantage of working out the fertilizer N requirement of rice and wheat crop based on expected yields as well as achievable greenness of the leaves.

In above context, this report is based on the work carried out using two optical sensors - GreenSeeker™ (hand held optical sensor Model 505, NTech Industries, Ukiah, CA, USA) and Holland sensor. Since Holland sensor was available only at Karnal, most of the work at Ludhiana, Karnal, Modipuram and Lucknow was carried out using GreenSeeker optical sensor. At Karnal, some comparisons in terms of efficiency of the two sensors for managing N in rice and wheat were made and have been included in this report.

2. Nitrogen fertilization optimization algorithm for optical sensors

2.1. Predicting Mid-Season Yield Potential (YP_0)

N-Rate Field Experiments: At Ludhiana, Karnal and Modipuram, on-station experiments were set up in field locations where a response to applied N was likely or at least probable. At each site, 3 to 5 N rates (all N applied as pre-plant as well as in two splits) were evaluated with the highest N rate being chosen in order to be "non-limiting" throughout the growing season, but not in excess. For wheat, N fertilizers were applied basal and along with first irrigation event. A typical experiment with wheat consisted of following treatments.

T1: No-N control
T2: 60 kg N/ha applied all basal
T3: 120 kg N/ha applied all basal
T4: 180 kg N/ha applied all basal
T5: 240 kg N/ha applied all basal
T6: 60 kg N/ha applied in 2 split doses (basal and CRI stage)
T7: 120 kg N/ha applied in 2 split doses (basal and CRI stage)
T8: 180 kg N/ha applied in 2 split doses (basal and CRI stage)

For rice, whole N was applied basally or in two splits – half basal and half at 21 days after transplanting (DAT)

NDVI readings using the GreenSeeker/ Holland handheld sensor: NDVI stands for "Normalized Difference Vegetation Index" and it is the "sensor" value displayed on the optical sensor. NDVI is computed by the following formula:

$$\mathbf{NDVI = (NIR_{ref} - Red_{ref}) / (NIR_{ref} + Red_{ref})}$$

where NIR_{ref} or Red_{ref} represent reflectance in the near infrared and red bands. Many researchers have shown that NDVI is an excellent measure of total biomass. Sensor readings from each of the plots in the above experiments were taken at weekly intervals but making sure that readings were taken near the physiological growth stage where mid-season N applications are made. For example, in wheat, Feekes 5/6 and Feekes 7/8 stages which generally coincide with 2^{nd} and 3^{rd} irrigation events were designated as stages for GreenSeeker based N management. For rice, 49 DAT and 56 DAT were the stages earmarked for mid-season fertilizer N applications when optical sensors can provide guidance.

<u>Days from Emergence/ Transplanting:</u> In order to generate an equation that functions over sites and years (multiple sites, planted at different times and sensed on different dates), planting dates and emergence dates were recorded. These dates were then used to compute the number of days from planting to sensing or emergence to sensing (site and crop specific). In regions where severe winter conditions are prevalent during crop season, it is important to compute days where GROWING DEGREE DAYS (GDD) were more than 0. GDD = $[(Tmin + Tmax)/2] - 4.4°C$. The value -4.4 °C will change as a function of the crop's minimum heat requirement for active growth, so this value works for many "cool season" crops, but will be somewhat higher for warm season crops) where Tmin and Tmax are minimum and maximum daily temperatures, respectively.

<u>Estimating Yield Potential:</u> By dividing NDVI (estimate of total biomass) by the number of days from planting to sensing (or emergence to sensing), we basically ended up with an estimate of biomass produced per day (note that to count a day, GDD must be >0). This index (NDVI/days from planting to sensing or emergence to sensing) which is called INSEY (In Season Estimated Yield) is an excellent predictor of yield potential or the yield (grain or forage depending on the system) that is likely to result with no added inputs. This estimate of yield or yield potential is essentially the YIELD GOAL with no added fertilizer N.

<u>Generating the Yield Prediction Equation:</u> Once actual harvest data was collected from each of the plots in the above described experiments, and placed in the same data file and for the same corresponding plots where NDVI, planting date, sensing date, and INSEY, an X-Y plot of yield versus INSEY were made. Power functions were found to describe the INSEY-GY relations in a better manner.

<u>Recording the Response Index (RI) at each Site:</u> At each location where the N-rate experiments defined above were conducted, it was critical that mid-season RI's were recorded. To do this, average NDVI readings from the high N plots were divided by the average NDVI readings in the check plots (0-N preplant). Depending on the year, location and crop, RI's can be expected to range from 1.0 to 3.0. This information will be used to later document 'responsiveness' to fertilizer N by site.

Determination of % N in the Grain or Forage of the Crop Investigated: Percent grain and straw N were determined following standard procedures

2.2. Predicting the Potential Response to Applied N

Nitrogen Rich Strips (NRS): A critical component of the algorithm is being able to precisely predict whether or not there will be an in-season response to applied fertilizer N and the magnitude of that response. The only way to do this is to place" Nitrogen-Rich Strips (NRS) in each and every farmer field where FERTILIZER N RATE RECOMMENDATIONS are to be made. NRS were created by applying three or more split doses of N fertilizers. Preferably, the NRS should be placed from one end of the field to the other (somewhere in the middle and not on the outer edges where fertilizer applicator error can be problematic…. turning, double planting, etc).

Computing the Response Index (RI): The Response Index (RI) or the potential responsiveness to added fertilizer N expected is calculated by dividing the average NDVI in the Nitrogen Rich Strip (NRS) by the average NDVI in the test plot. This will generally range somewhere between 1.0 and 3.0. If for example the Response Index were 1.5, it would mean that we can likely achieve a 50% increase in yield if added fertilizer N is applied. It says nothing about how much N should be applied, but it does indicate the likelihood of obtaining a response and how much of a response can be expected. What we are doing here is "Predicting the Potential Responsiveness of the Crop to Applied N" for that year, that field, that crop, under those growing conditions, planted on x-date and sensed on x-date. This information is also highly tailored to the response expected to N and only N. Because the Nitrogen Rich Strip compared to the test plots only evaluates the difference between "N non-limiting" or the NRS and the test plot "N possibly limiting", the only thing that this RI can be used for is N fertilization.

2.3. Yield Potential Achievable with Added N Fertilization (YP_N)

Predicting YP_N: The predicted attainable yield with added nitrogen is calculated as:

$$YP_N = YP_0 * RI$$

where the response index was calculated as previously described. As was noted earlier, this could be for different nutrients, but as specified here it is for nitrogen. It should be noted that two limits are preferably imposed on this calculation, namely: 1) RI generally cannot exceed 3.0; and 2) YP_N cannot exceed YP_{MAX} where YP_{MAX} is the biological maximum for a specific crop, grown within a specific region, and under defined management practices. The value of 3.0 for maximum RI, is arbitrary and may vary for a specific crop, grown in a specific region under different conditions.

Keeping YP_0 and RI Separate: It is important to understand that the Yield Potential Achievable with no added N fertilization (YP_0) needs to be understood independent of the Response Index (RI). The responsiveness to applied fertilizer N has nothing to do with the "expected yield" unless of course it was tied into how much fertilizer N was applied. For this reason, these two components were treated as independent inputs. Many researchers have used the sufficiency concept whereby N fertilizer is applied whenever the "Check" plot shows up as "lighter green" (lower NDVI or chlorophyll meter reading) than the Nitrogen Rich Strip. While useful, this approach still says nothing about exactly "how much" fertilizer N should be applied, but rather that "some" needs to be applied. The approach delineated here keeps RI and YP_0 apart, simply because we apply N based on responsiveness, but with the specific yield potential in mind.

Yield Potential and Response Index Change from Year to Year: Whether it is due to planting date, timely or untimely rainfall, etc., yield potential in the same field will vary from one year to the next even when "managed" the same way. The Response Index (RI) changes in the same field from one year to the next simply because of the marked influence of "environment" on N availability. N mineralized from soil organic matter can be quite high one year (warm and wet) and quite low the next (cool, and dry). The environmental conditions conducive to the mineralization of soil organic matter are quite variable and as such the demands for fertilizer N should be expected to be variable from one year to the next as well. In others words the ability of the environment to supply N (via mineralization of soil organic matter and/or deposited in rainfall) are quite variable and we need to take this amount of N supplied by the environment into consideration when making mid-season fertilizer N recommendations. .

2.4. Generating a Fertilizer N Rate Recommendation

Computing Grain N Uptake at YP_0 and YP_N: The predicted amount of N that will be removed in the grain at harvest (using our equation generated from 1E) is computed as follows:

Grain N uptake, YP_0 = Grain Yield (YP_0) * expected % N in the grain
$GNUP\_YP_0 = YP_0 * 0.018$
$GNUP\_YP_N = YP_N * 0.018$

where 0.018 represents 1.80%N in the grain for wheat grown in Punjab.

Computing the Final Fertilizer N Rate:
The fertilizer N rate to be applied was computed by subtracting the predicted amount of N to be removed in the grain at YP_0 from the predicted amount of N to be removed in the grain at YP_N, divided by some level of expected use efficiency. In the example below, we used 50% or 0.50 as the divisor, but this value can range anywhere from 50% to 80%. In north-western India we took this factor as 50% as most appropriate. Why do we subtract $GNUP\_YP_0$ from $GNUP\_YP_N$? The best estimate of projected N removed in the grain (with and without fertilizer) come from $GNUP\_YP_0$ and $GNUP\_YP_N$, respectively. Because of this, N requirement (based on projected N removed in the grain with and without N fertilizer) should theoretically be the difference between the two divided by an efficiency factor.

3. Results

3.1. INSEY-Grain Yield (GY) relations

Wheat

For wheat INSEY-GY relations were developed for Feekes 5/6 and Feekes 7/8 stages. Data from Karnal, Ludhiana and Modipuram generated in different years using different cultivars and by applying fertilizer N levels either as whole basal or in two split doses were plotted as X-Y graph between INSEY and grain yield. Figure 1a shows the INSEY-GY relation for wheat for Feekes 5/6 stage as developed by using data from experiments conducted at Ludhiana and Karnal. A value of R^2 as high as 0.86 suggest that wheat yields can be predicted fairly accurately as early Feekes 5/6 stage when first node appears on the wheat plant. The relationship was even more robust at Feekes 7/8 stage when data were available from a large number of wheat cultivars grown in different years at Ludhiana, Karnal and Modipuram (Fig. 1b).

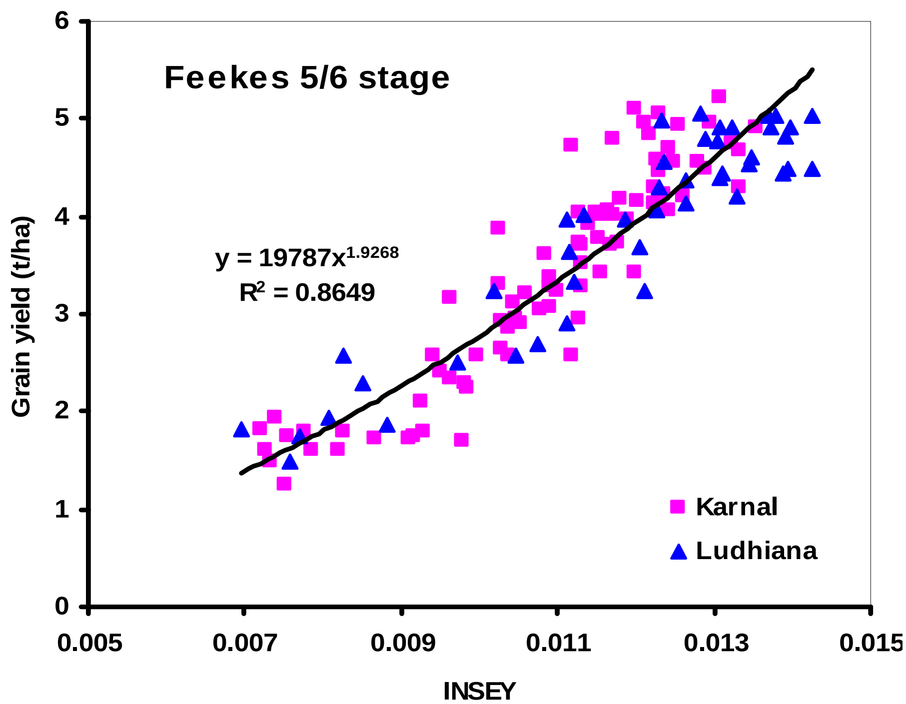


Fig. 1a. INSEY-GY relationship for wheat at Feekes 5/6 stage for north-western India based on data obtained from Karnal and Ludhiana during 2004-05 and 2005-06

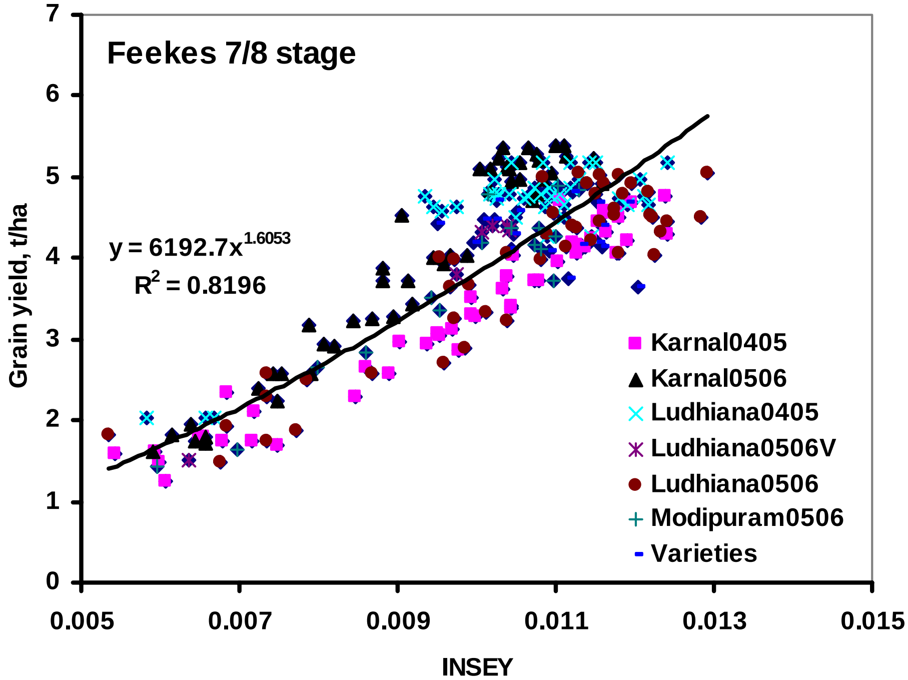


Fig. 1b. INSEY-GY relationship for wheat at Feekes 7/8 stage for north-western India based on data obtained from Karnal, Ludhiana and Modipuram during 2004-05 and 2005-06. Cultivars used to develop the relationship were: Ludhiana – PBW 343, PDW 291; Modipuram - PBW 343, HD 2687; Karnal – PBW 343, HD 2687, PBW 502, PBW 373, UP 2425, RAJ 3765

Transplanted Rice

Standing water on the soil surface can interfere with measurements of NDVI made with optical sensors. However, 3 to 4 weeks after transplanting of rice when there is enough development of the crop canopy, the optical sensors can work for rice as well. Prescriptive fertilizer N applications to rice are therefore proposed to be made during 6 weeks after transplanting and thereafter optical sensors can be used for corrective N management. INSEY- GY relationships for transplanted rice were therefore developed for 42, 49 and 56 DAT stages of the crop. As depicted in Fig. 2, satisfactory relationships were observed for all the three stages. The relationships have been developed using data generated at Karnal and Ludhiana by growing a number of rice cultivars. During 2005 and 2006. The INSEY-GY relationships depicted in Fig. 2 suggest that rice yields can be predicted fairly accurately by mid-season measurements of NDVI using hand-held optical sensors.

3.2. INSEY-GY relationships developed by GreenSeeker and Holland sensors

At Karnal, INSEY-GY relationships for both rice and wheat were developed by using both GreenSeeker and Holland sensors. Coefficients of correlation between

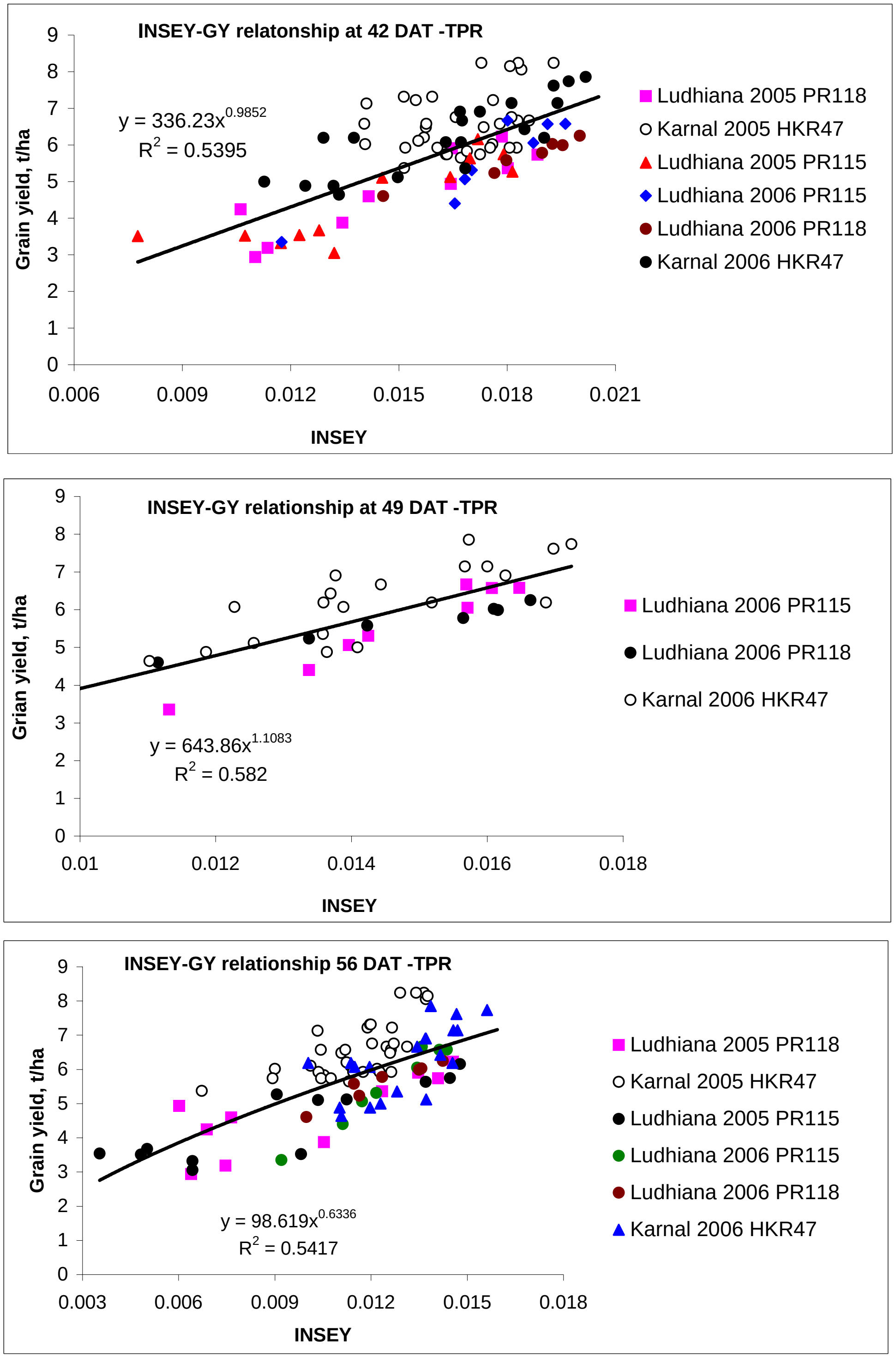


Fig. 2. INSEY-GY relationships for rice based on data from Karnal and Ludhiana

INSEY measured by the two sensors and grain yield of wheat and rice at different stages are shown in Figs. 3 and 4. In general, the two sensors were behaving equally well for developing the INSEY-GY relationships for both rice and wheat.

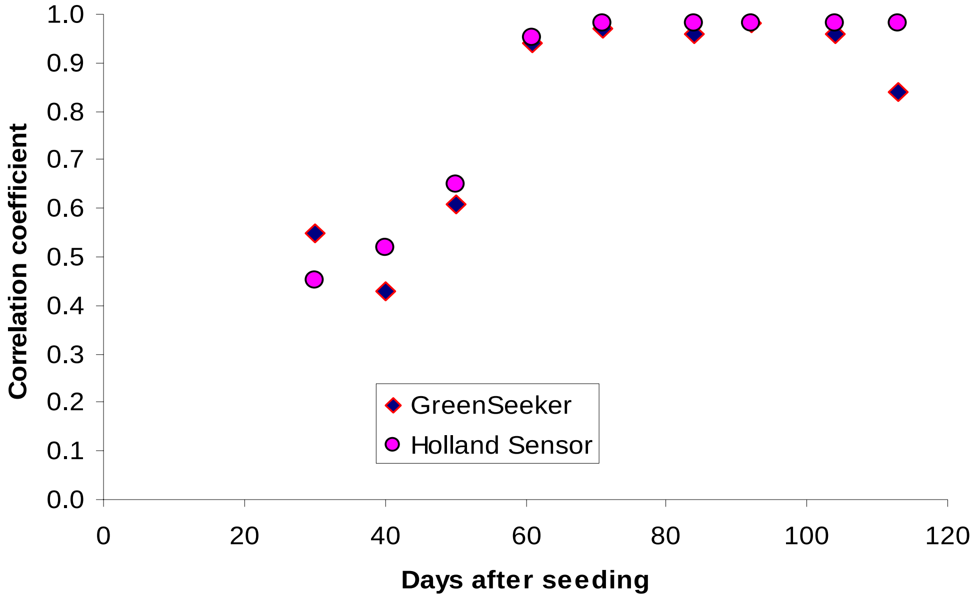


Fig. 3. INSEY-GY relationships in wheat (2004-05) developed using GreenSeeker and Holland optical sensors.

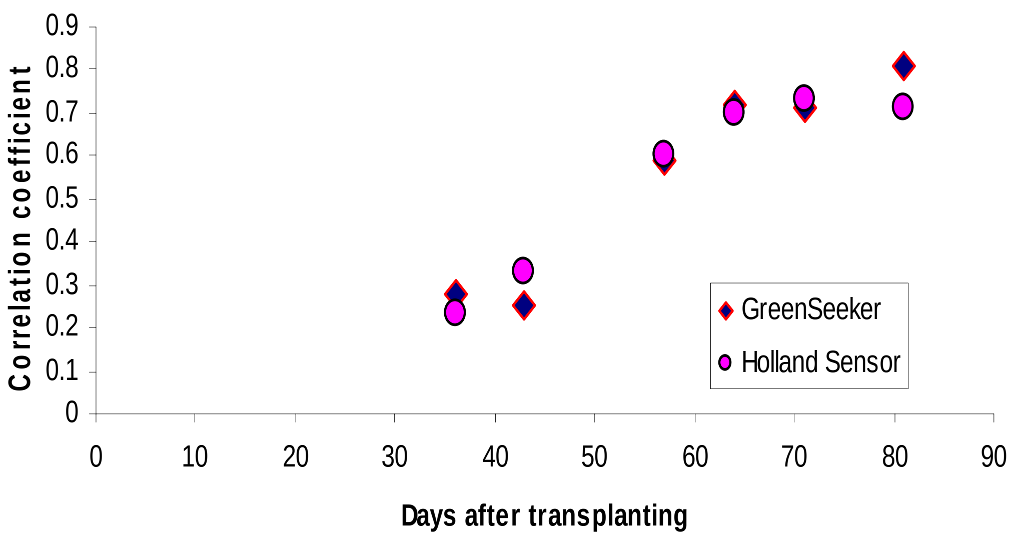


Fig. 4. INSEY-GY relationships in rice (2005) developed using GreenSeeker and Holland optical sensors.

3.3 Evaluation of Greenseeker based N management in irrigated wheat

Blanket recommendation for N management in wheat consists of applying 1/3rd to half of the total dose of 120 to 150 kg N/ha as basal at sowing and at crown root initiation stage which coincides with first irrigation event around 21 days after sowing. There also exist reports that application of all N as basal at sowing can be efficiently utilized by wheat. Also because fertilizer N application to wheat has to coincide with an irrigation event, experiments on evaluating GreenSeeker based n management in wheat were planned keeping in view the following:

- Greenseeker can be used to work out fertilizer N applications to wheat at Feekes 5/6 and Feekes 7/8 stages which almost coincide with 2nd and 3rd irrigation events

- Moderate doses of N can be applied as prescriptive N management at sowing and at crown root initiation stages when GreenSeeker cannot be used

- Robust INSEY-GY relations were observed at both Feekes 5/6 and Feekes 7/8 stages of wheat

Two experiments were conducted at Karnal and Ludhiana during 2005-06 wheat season. The results from these experiments are given in Tables 1 and 2. At both Karnal and Ludhiana, grain yield of wheat similar to that produced by applying blanket dose of 120 or 150 kg N/ha were obtained by applying 20 to 50 kg less N per hectare when GreenSeeker was used to guide fertilizer N application after a moderate application of N at sowing and crown root initiation stages. Some salient outcomes of wheat experiments can be summed up as:

- At low basal N application level, GreenSeeker based N management is inadequate for all Feekes stages
- With low basal N application supplemented with a low dose at crown root initiation stage and coupled with GreenSeeker based N use at Feekes 7/8 stage is most likely to significantly improve NUE at higher yield levels
- Using single basal N application and/or coupling it with a top dress with GreenSeeker based N application can also lead to higher NUE.
- Sensor based N management helps in saving up to 20% nitrogen
- GreenSeeker based N application at Feekes 7/8 stage improves protein content and grain quality.
- These are significant outcomes of this study because on the practical side they allow us to move forward in the direction of mulch based agriculture. Surface mulches retain the top dressed fertilizer nitrogen nutrient immobilizing it to release slowly subsequently. This imply that if 80% of the total N is applied as basal and the balance 20 % N is applied using sensor or using a LCC value of 4, it may not only improve yield of wheat and other crops but also improve protein content in the grain.

Optical sensor based N management in irrigated wheat as it is grown in north-western India holds promise and with some more refinements in terms of prescriptive N application at basal and crown root initiation stages.

Table 1. Performance of GreenSeeker based N management in wheat (cultivar PBW 343) at Ludhiana, 2005/06

Treat-ment	Fertilizer N applied ,(kg N ha^{-1}) at							
	Basal at sowing	Crown root initiation stage, 1st irrigation	Feekes 5-6 stage, 2nd Irrigation	Feekes 7-8 stage, 3rd irrigation	Total N applied	Grain yield of wheat (t/ha)	%N in wheat grain	Total N uptake (kg/ha)
1	0	0	-		0	1.52	1.47	32
2	60	60	-		120	4.35	1.75	103
3	75	75	-		150	4.41	1.81	110
4	60	0	17^{GS}		77	3.66	1.51	73
5	80	0	12^{GS}		92	3.80	1.67	88
6	100	0	10^{GS}		110	4.20	1.64	95
7	40	40	3^{GS}		83	3.81	1.65	89
8	50	50	0^{GS}		100	4.32	1.64	99
9	60	60	0^{GS}		120	4.39	1.73	105
10	60	0	-	29^{GS}	89	3.99	1.77	94
11	80	0	-	24^{GS}	104	4.13	1.72	98
12	100	0	-	21^{GS}	121	4.29	1.81	102
13	40	40	-	18^{GS}	98	4.27	1.73	101
14	50	50	-	12^{GS}	112	4.35	1.85	109
15	60	60	-	15^{GS}	135	4.40	1.92	115
LSD (p=0.05)			0.367				0.148	11

^{GS}GreenSeeker guided N application

Table 2. Performance of GreenSeeker based N management in wheat at Karnal, 2005/06

Treatment	Fertilizer N applied (kg N ha^{-1}) at					Grain yield wheat (t/ha)
	Basal at sowing	Crown root initiation stage, 1st irrigation	Feekes 5-6 stage, 2nd Irrigation	Feekes 7-8 stage, 3rd irrigation	Total N applied	
1	0	0	-		0	2.03
2	60	60	-		120	5.33
3	75	75	-	-	150	5.69
4	80	0	16 ^{GS}	-	96	5.45
5	100	0	14 ^{GS}	-	114	5.50
6	40	40	16 ^{GS}	-	96	5.18
7	50	50	13 ^{GS}	-	113	5.41
8	60	60	8 ^{GS}	-	128	5.85
9	80	0	-	20 ^{GS}	100	5.05
10	100	0	-	12 ^{GS}	112	5.23
11	40	40	-	17 ^{GS}	97	5.19
12	50	50	-	13 ^{GS}	113	5.18
13	60	60	-	8 ^{GS}	128	5.87
LSD (p=0.05)						0.703

^{GS}GreenSeeker guided N application

3.4 Evaluation of GreenSeeker based N management in transplanted rice

In 2006, three experiments were conducted at Ludhiana, Karnal and Modipuram to evaluate Greenseeker based N management in transplanted rice. The details of the treatments and yield data are recorded in Tables 3, 4 and 5. As already indicated, Greenseeker guided N applications were made only after 40 DAT because up to this time standing water in the field interferes with the NDVI measurements and good INSEY-GY relations are not observed. As it is well established that N should be applied to transplanted rice in at least three split doses so as to curb losses via leaching, ammonia volatilization and denitrification, in the reported experiments different combinations of N doses were applied at 0, 7, 21, 28 and 35 DAT and GreenSeeker was used to find the third application of N at 42 or 49 DAT.

The data in Tables 3, 4 and 5 reveals that GreenSeeker guided N management always resulted in total N application less than the blanket dose of 120 or 150 kg N ha^{-1} but in several treatment combinations it was possible to produce grain yields of rice equal to or more than that obtained with recommended doses. Fertilizer N applications guided by GreenSeeker were influenced by the amount and time of N applications already applied. For example at Ludhiana, in treatments 4 and 5 because of application of 30 and 60 kg N ha^{-1} at 21 DAT, GreenSeeker guided to apply 32 and 12 kg N ha^{-1} resulting in total N application of 92 kg N ha^{-1} in both the treatments. Obviously due to lower N dose at 21 DAT in treatment 5 GreenSeeker advised to apply more N than in treatment 4. However, the grain yield of rice in the two treatments was significantly different; perhaps a lower dose of N at 21 DAT adversely influenced tillering and resulted in low grain yield than in the treatment receiving 60 kg N ha^{-1}. Similar results were obtained when GreenSeeker guided N doses were applied at 49 DAT. Delaying the application of first N dose to 15 DAT also had a negative effect on the yield of rice and GreenSeeker guided N applications did not help. As a matter of fact when second dose of N was delayed to 35 DAT, GreenSeeker did not recommend application of more fertilizer although the treatment yielded better only than the no-N control. It confirms that GreenSeeker takes care of both the greenness and expected yield in guiding application of fertilizer N.

At Karnal (Table 4), GreenSeeker guided N applications helped to achieve grain yields of rice similar to that obtained by blanket recommendations of 150 kg N ha^{-1} but with total N application to the extent of almost 50%. These data convincingly proves that GreenSeeker results in need based N applications and can help avoid over application of fertilizer N. At Modipuram (Table 5), while application of first two doses of N at 0 and & DAT resulted in savings of fertilizer as compared to blanket recommendation (120 kg N ha^{-1}). Only exception was when only 30 kg N ha^{-1} was applied at 21 DAT. But when the first two doses of N were applied at 7 and 28 DAT, GreenSeeker guided N applications at 49DAT always resulted in total fertilizer N applications more than the recommended dose of 120 kg N ha^{-1}. These data suggest that more experimentation is needed to work out appropriate management of fertilizer prior to application fertilizer N guided by GreenSeeker at 42 DAT.

Table 3. Evaluating GreenSeeker based N management in rice (cultivar PR 118) at Ludhiana, 2006

	Fertilizer N applied (kg N/ha) days after transplanting									Total N applied (kg N/ha)	Rice grain yield (t/ha)
	0	7	15	21	28	35	42	49	56		
1										0	3.85
2	40			40			40			120	6.19
3	20			40			28^{GS}			88	6.23
4	20			60			12^{GS}			92	6.83
5	30			30			32^{GS}			92	5.63
6	30			50			14^{GS}			94	6.28
7	40			40			24^{GS}			104	6.34
8	30				50			29^{GS}		109	6.29
9		20			40			29^{GS}		89	5.97
10		20			60			19^{GS}		99	6.59
11		30			30			32^{GS}		92	5.66
12		30			50			17^{GS}		97	6.25
13		40			40			20^{GS}		100	6.50
14			40		40			20^{GS}		100	5.80
15			40			40			1^{GS}	81	4.97
16	50	50		50	50		50	50		300	5.73
LSD (p=0.05)											0.774

^{GS}GreenSeeker guided N application

Table 4. Evaluation of GreenSeeker based N management in rice (cultivar HKR 47) at Karnal, India, 2006

Treatments	Fertilizer N applied, kg/ha 0 DAT	7 DAT	21 DAT	28 DAT	39 DAT	50 DAT	Total N applied	Yield, t ha^{-1}
T1	0		0		0			5.63
T2	50		50		50		150	7.42
T3	20		40		13 ^{GS}		73	7.70
T4	20		60		4 ^{GS}		84	7.66
T5	30		30		22 ^{GS}		82	7.74
T6	40		40		9 ^{GS}		89	7.70
T7	25		75		3 ^{GS}		103	7.62
T8		20		40		21 ^{GS}	81	7.58
T9		20		60		12 ^{GS}	92	6.39
T10		30		30		13 ^{GS}	73	6.75
T11		40		40		18 ^{GS}	98	7.58
T12		25		75		28 ^{GS}	128	7.42
LSD (p=0.05)								0.722

DAT = Days after transplanting

^{GS}GreenSeeker guided N application

Table 5. Evaluation of GreenSeeker based N management in transplanted rice (cultivar PHB 71) at Modipuram, India, 2006

Treat-ments	Fertilizer N applied, kg/ha 0 DAT	7 DAT	21 DAT	28 DAT	42 DAT	49 DAT	Total N applied	Yield, t ha^{-1}
T1	0	0	0	0	0	0	0	4.90
T2	40	0	40	0	40	0	120	8.85
T3	20	0	40	0	25 ^{GS}	0	85	8.23
T4	20	0	60	0	30 ^{GS}	0	110	8.18
T5	30	0	30	0	40 ^{GS}	0	100	7.92
T6	40	0	40	0	36 ^{GS}	0	116	8.75
T7	0	20	0	40	0	79 ^{GS}	139	8.23
T8	0	20	0	60	0	54 ^{GS}	134	7.71
T9	0	30	0	30	0	76 ^{GS}	136	8.94
T10	0	40	0	40	0	63 ^{GS}	143	9.06
LSD (p=0.05) for yield = 1.66								

4. Integration of NDVI from Greenseeker with Satellite Remote Sensing

The hand-held Green Seeker (GS) optical sensor^{TM} is emerging as a potential tool for efficient N management through monitoring crop growth with remotely sensed indices like NDVI (Normalized Difference Vegetation Index) in rice-wheat cropping system. Optimization of nitrogen application using Greenseeker for rice and wheat crops have yielded encouraging results for improved nitrogen use efficiency (NUE) without any yield loss as described in the previous sections. Since rice-wheat system in IGP is spread over more than 10 m ha, it is practically not possible to guide N management in each field using hand-held Greenseeker sensors. Therefore, a key issue before us is how can we upscale the technology from field to large tracts and boost production in areas where crop yields suffer due to varying levels of Nitrogen deficiencies. Many of these areas are remotely located and farmers usually do not have facilities for getting their soils tested and area general recommendations are often followed by these farmers.
Therefore, we made an attempt to integrate the NDVI data obtained using a hand-held optical sensor such as Greenseeker with the NDVI data collected through satellite remote sensing systems to identify N deficient areas and then advocate the use of chemical N

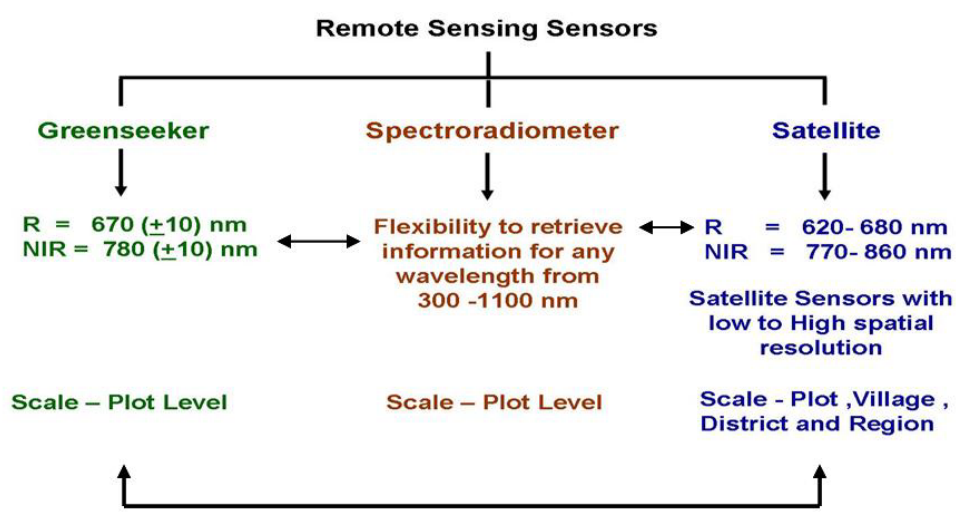


Fig.5. Description of different remote sensing sensors used for integration of GS with Satellite image.

fertilizers to improve crop production. In order to test this hypothesis, a pilot scale experiment was set up In Karnal district, Haryana state to test the confidence limits of determining the NDVI values derived from the satellite data for rice and wheat crops grown under varying farming situations and its relationship with the hand-held Green Seeker Optical sensor.

Both these systems (Green seeker and satellite) monitor NDVI at non-adjustable specific wavelengths (in Red and NIR and in different ranges; fig1. above) and hence it is not easy to compare the NDVI obtained by the two tools as such. Therefore, Spectroradiometer having the flexibility for adjustment in the wavelengths from 300 - 1100 µm) was used to monitor NDVI in the specific wavelengths of the GreenSeeker and also the specific bands (IR band 0.77-0.86 µm and R band (62-0.68 µm) of the IRS satellite. Spectroradiometer thus provides the necessary intermediate tool for developing valid correlations in the NDVI, / Reflectance data obtained using specific wavelengths of the GreenSeeker and the specific bands of the IRS satellite.

Rice

Using the GS sensor and the Spectroradiometer, NDVI measurements were taken on weekly basis and on the dates of satellite passes in the rice and wheat crop seasons. These data were used to develop basic relationships between the reflectance measured by ‘mimicking’ the GS and IRS satellite.

The data was used to develop relationships (i) between NVDI recorded by Green Seeker (NIR - 780 nm and R- 670 nm) and the Spectroradiometer simulating GS wavelengths, and (ii) the NDVI measurements with GS and Spectroradiometer simulating operational spectral bands of IRS satellite (NIR: 770-860 nm, Red: 620-680 nm, Green: 520-580 nm). The above mentioned relationships are shown in figure (6a and 6b), respectively. The NDVI measurements were collected in the farms of the Directorate of Wheat Research (DWR), Karnal and also in the nearby areas where farmer participatory trials of the RWC were underway in the Karnal district.

The NDVI data for the rice is presented in figure (6a and b) and for wheat (fig 6c). The results indicated to a very promising relationship between NDVI indices recorded by two respective instruments with R^2 values ranging from 0.86 to 0.96. The relationship for wheat crop was Y= 0.4307 +0.4211X (r^2 =0.8599)

Fig. 6 a

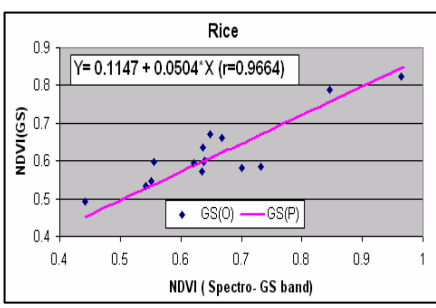


Fig. 6 b

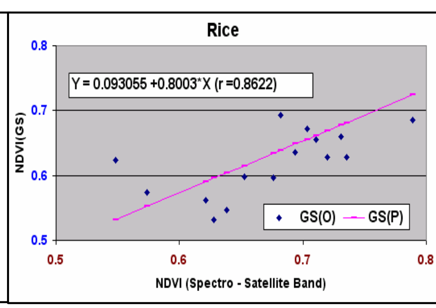
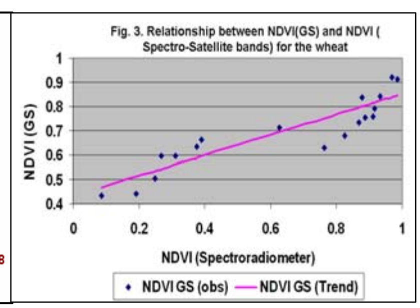


Fig. 6 c



5. Computation of NDVI from Satellite image

In order to calculate the satellite based NDVI Satellite images of LISS III (Linear Imaging Self-Scanning) sensor with 23.5 resolution were studied for the month of December 2005 and Jan 2006. Normalized difference vegetation index from a radiometric corrected image has been computed using the following equation and method;

$$\frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}}$$

Wherein Band 4 refers to IR band (0.77-0.86 µm) and Band 3 refers to Red Band (0.62-0.68 µm)

The methodology flow chart for computing the NDVI from multispectral LISS – III data is given below in figure (7).

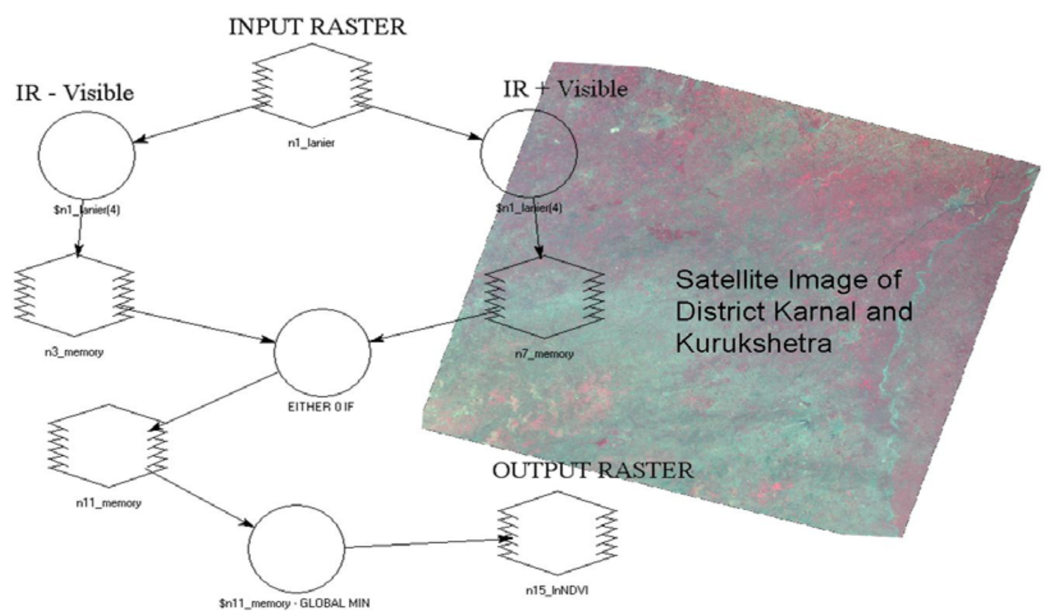


Fig.7. Schematic Methodology for computing NDVI from multi-spectral LISS-III sensor using ERDAS Imagine.

Satellite based NDVI information was extracted from the Imageries using above mentioned routinely used *ERDAS Imagine* procedures.

The GS-NDVI measurements were also collected for the satellite pass dates to spatially compare variations between SAT-NDVI and GS-NDVI.

6. Computation of the add-on Correction Factor

It was observed that the SAT-NDVI values on all the dates were invariably lower than the GS-NDVI for the reasons of loss in reflectance due to atmospheric errors. Hence an add-on correction factor was needed to precisely calculate Nitrogen Response Index from Sat-NDVI for assessing nitrogen requirement of the rice /wheat crops at different scales (field, farms, village, block and districts). Radiometric correction was applied using standard procedures to remove haze and atmospheric errors from the satellite image. In general a correction factor of .02 to .05 is needed for Karnal and Kurushetra districts (see fig 8.) in Haryana. It worth pointing it out the add-on correction factor is likely to vary from place to place depending upon the intensities of the noises mentioned above.

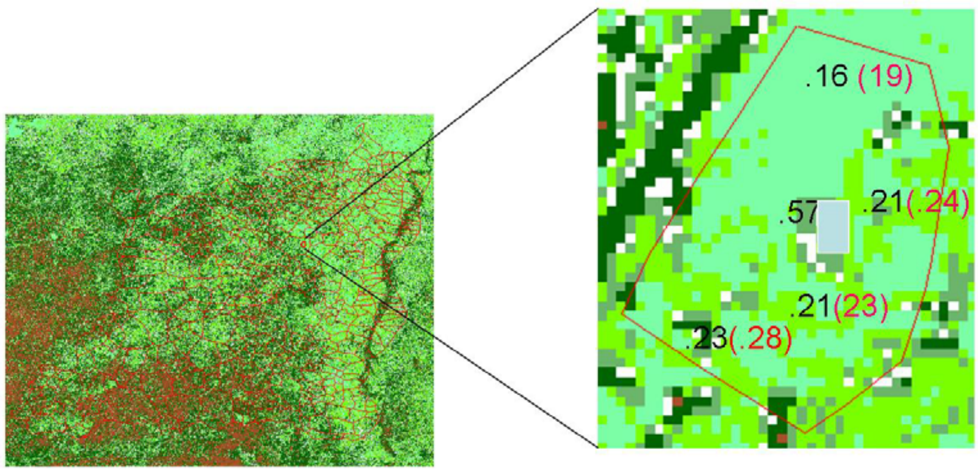


Fig.8. Difference between SAT-NDVI and GS -NDVI observation at village Ramba in Karnal. (In LHS picture, numbers in red are of GS-NDVI values whereas black numbers denotes Sat-NDVI values from satellite image.)

It is very important to mention here that Nitrogen Fertilization Optimization Algorithms (NFOA) are based on specific wavelengths, therefore Greenseeker instrument must be used as a ground truth tool for developing response index from satellite image for predicting N requirements for larger areas.

7. Correlation between sowing dates (DOS) and NDVI measurements

In order to develop an economical way out for yield estimation and identification of N deficient zones, we have used multispectral IRS LISS III satellite data for this study. But it is difficult to calculate the exact date of sowing through LISS III satellite data because of its 24 days revisit time. This problem can be resolved using any multi-spectral satellite data with revisit time of 7 days or less. Quickbird-2 satellite (which has 1-5 days revisit time , 2.8 m mulspectral resolution and swath 30 km) data can be very useful in estimation of planting dates with better accuracy.

To relate the SAT- NDVI to days after seeding in farmers' fields, a calibration curve was developed using relation between GS-NDVI and Number of days after seeding. This relationship was developed on the DWR experiment station and further populated from the observations collected on the farmers' fields to make it more robust. The curve was used to estimate / calculate the days after sowing (growth duration of the crop) from the 'corrected Sat-NDVI' observed on the satellite pass date. The correction procedure for SAT- NDVI has been described previously. It is mentioned that we observed in-spite of the calibration curve, there could be an error of 3 to 4 days in estimation of the DOS. However this small error does not seem to affect response index significantly.

After calculation of DOS, response index (Fig 9.) for each pixel has been calculated using the algorithm - NDVI $^{\text{Nrich}}$/NDVI $_{\text{Test plot}}$

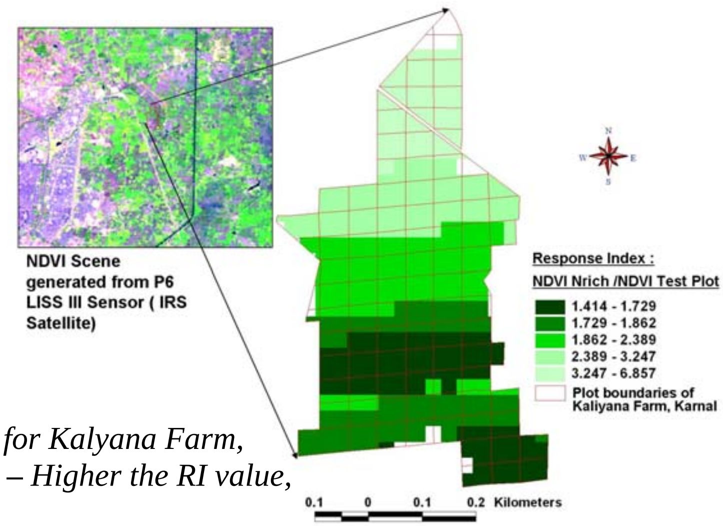


Fig. 9. Plot-wise responses index for Kalyana Farm, Karnal showing the RI variations – Higher the RI value, higher the N requirement.

8. Other Potential Applications of GreenSeeker in Agriculture

<u>8.1. Evaluation of crop performance under conservation Agriculture using GS</u>

Results of our field trials bring out that NDVI could serve as an excellent indicator of crop growth in the vegetative growth phase and biomass accumulation. Since integrated effects of the physico-chemical and biological properties of the soils vis –a-vis soil health reflect themselves through differential responses on the health of the crop plants as monitored by NDVI. Therefore, effects of specific tillage, agronomic or crop management practices on plant growth and vis-a-vis soil health can also be monitored using Greenseeker technology. GS-NDVI is very useful measurement for precisely measuring the effects of conservation agriculture (tillage, mulching practices etc.) on crop communities. As an

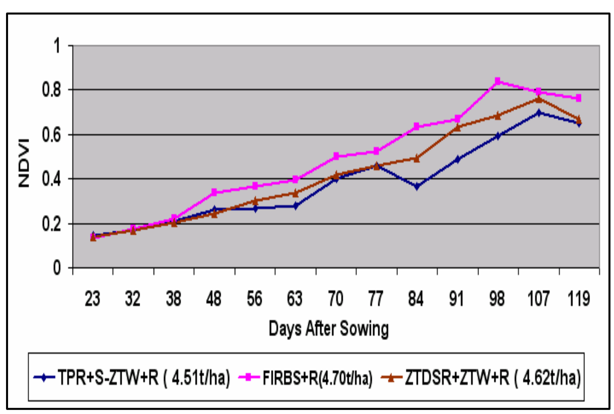


Fig. 10. NDVI of wheat with three tillage practices adopted in rice-wheat system.

example, we observed that practice of puddling in rice season destroys soil structure and also affects soil moisture storage for the succeeding wheat crop. Data in **Figure (10)** clearly brings out that puddled transplanted rice in the preceding season has adversely affected the growth and yields of the succeeding wheat crop grown in Rice-Wheat rotation. It is interesting to note from fig. (10) that wheat productivity was a little more with ZT-DSR (Direct seeded rice) - ZT wheat system than the Puddled transplanted rice-ZT wheat system. Performance of raised bed planted wheat (FIRB) was found best of three tillage systems.

Similarly we observed that the mulched wheat crop grows slowly but steadily to out yield the NDVI and yield of non-mulched crop. It seems that zerotill planted wheat crop with residue retained on the surface is less stressed for water and nutrients (due to reduced evaporation, lesser weeds and temperature moderation effects of the mulches) as compared with ZT wheat with out mulches. Fluctuating NDVI in ZT without residues plots only reflects to nutrient, water and cold stresses during the wheat season (fig.11).

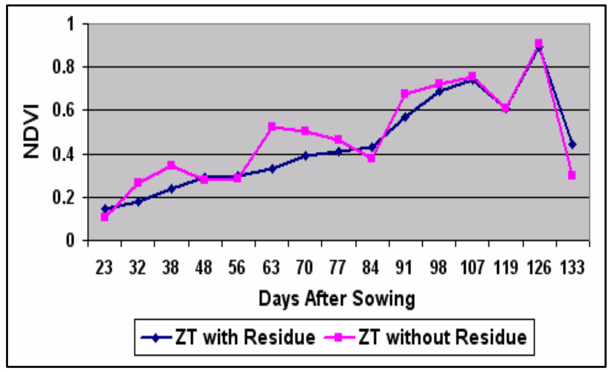


Fig.11. Effect of mulching on NDVI of wheat

8.2. Effect of temperature variations on growth of wheat

It was observed that abrasions from the long term trends in minimum and maximum temperatures affected the growth of wheat during 2005-06. The temperature fluctuations in Tmin and Tmax were effectively reflected on wheat crop growth at different stages. Data in figure (12) clearly illustrates that sudden rise in Tmin. And decrease in Tmax reduced the range of 'temperature comfort zone' for the wheat crop to grow effectively and consequently a deep plunge in the NDVI plot indicates only to a stressed crop.

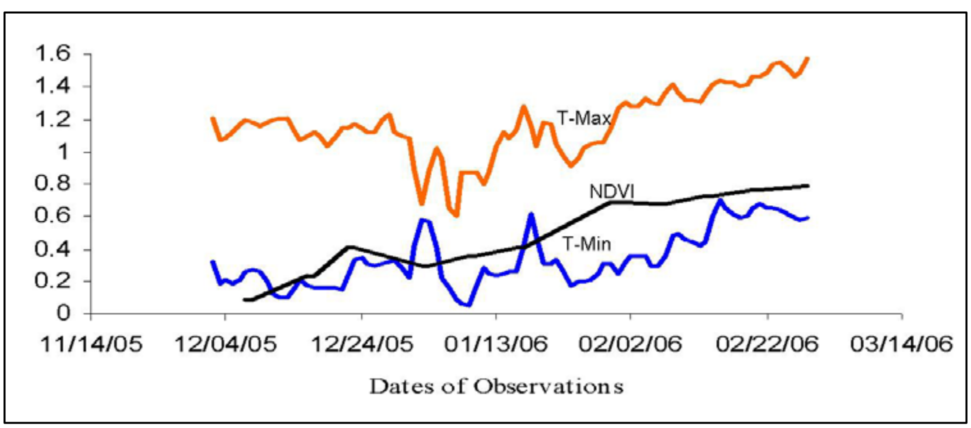


Fig. 12. – Effect of Temp fluctuations on crop performance

(Pl note: NDVI value always remains with in very low array of -1 to 1. Whereas temperature values in northern India in winter 2005-06 varied in between 0 to 32^o C. To bring the NDVI and temperature values on a common level, Min and Max. temperature values have been divided by 15).

8.3. NDVI and Soil Health

The Normalised Difference Vegetation Index (NDVI) is widely used for monitoring, analysing, and mapping the temporal and spatial distributions of physiological and biophysical characteristics of vegetation. NDVI has indirect relation with soil parameters as soil health indirectly reflects in the plant health. GS NDVI takes the aggregate value of plant biomass, physical stress, diseases, and nutrient stress therefore, there is a possibility of development of indirect index for different soil parameters e.g. pH, EC, N, P, K, OC etc.

Based on last wheat season experiments, we have observed that organic carbon has positive spatial correlation with NDVI. However, for other parameters we need more observations to develop a database and then a quantitative equation for establishing spatial correlation.

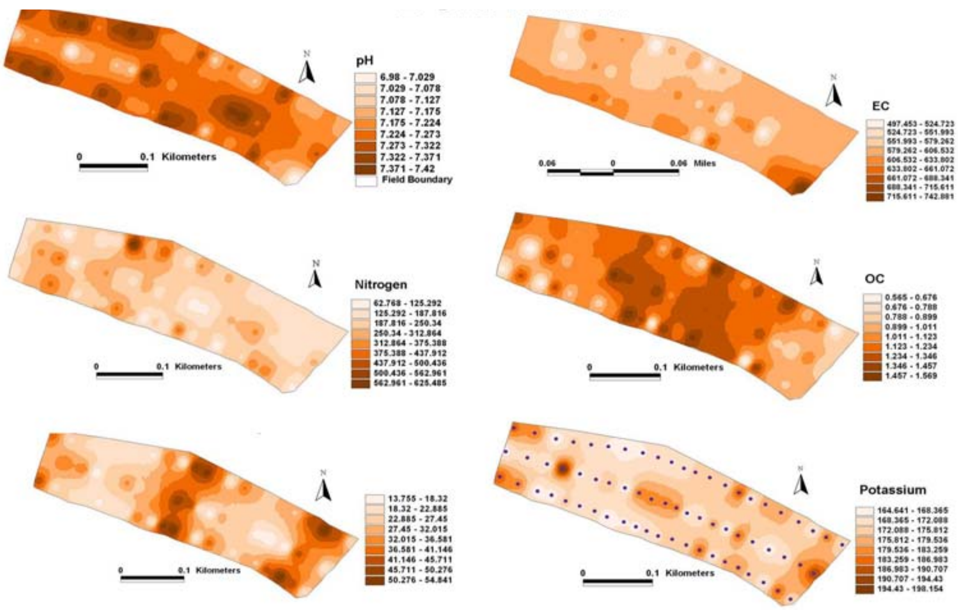


Fig. 13: Evaluating the effect of Spatial Variability of Soil on NDVI

8.4. Chlorophyll Estimation in sugarcane by SPAD Meter

In order to plan N applications efforts are on the way to calibrate the Leaf N and chlorophyll contents in sugarcane leaves using the chlorophyll meter (SPAD-502). A highly significant positive correlation (r= 0.9673) was obtained between SPAD reading and

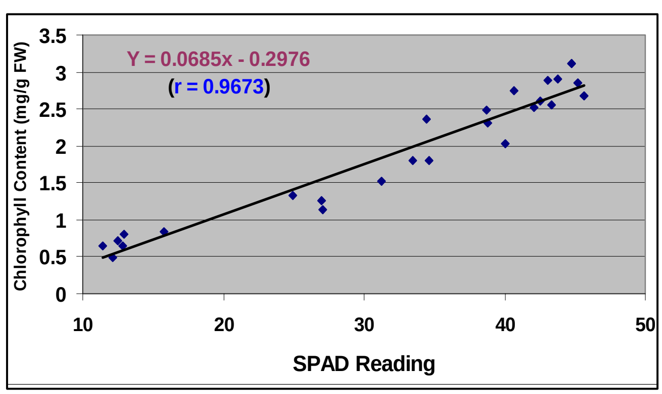


Fig. 14. Relationship between SPAD Reading and Chlorophyll Content

chlorophyll content. Chlorophyll content of the top fully expanded leaf correlated well the leaf N content of the cane leaf (data not presented here). SPAD meter and GS technology is being used to plan N management in raised bed planted wheat crop grown as an intercrop with sugarcane. Experiments are still in progress at Sugarcane institutes in Karnal (Haryana) and Lucknow (UP). Results will be available only after April 2007.

8.5. GS-NDVI in relation to canopy development in Sugarcane

The cane variety CoS 92423 was grown with recommended fertilizer dose (150 kg N /ha) in spring season 2006. The canopy development in terms of LAI (leaf area index) was recorded periodically at satellite pass dates along with GS-NDVI. The data is presented in table-6

Table-6 NDVI (GS) in relation to canopy development in sugarcane

Satellite Pass Dates	NDVI	LAI
15.05.06	0.376	0.32
08.06.06	0.642	1.34
02.07.06	0.750	2.87
26.07.06	0.769	4.15
19.08.06	0.769	5.32
12.09.06	0.776	5.79
06.10.06	0.752	6.23

Results will be available after April 2007.

9. Training Programs and Capacity Building

During the project period, six national and one international training program have been organized to train the researchers of working group and to build the capacity within NARs partners. A total number of 80 scientists/data collectors/field assistants have been trained for N management using the Greenseeker in Rice, Wheat and Sugarcane crops in India & Pakistan.

- Introduction & Training program on Handheld Optical Sensors for Nitrogen Management on July 2004 at DWR Karnal. Invited Lectures – Dr. James Schepers, ARS-USDA, Nebraska, Mr. Kent Martin, Department of Agronomy, Oklahoma State University, and Dr. Ryan Moore, United State Development Agency, USA.
- Training and planning meeting for “Calibrating GreenSeeker for predicting potential yield and fertilizer N management in rice” on May 26, 2005 at PAU Ludhiana.
- Workshop on “Sensor Based Nitrogen Fertilization” on August- 16-17, 2005 at PDCSR, Modipuram. Invited Lectures from Dr. Kent Martin, KSU, Soil Testing Laboratory, Department of Agronomy, Throckmorton Plant Sciences Center,

Manhattan, and Arnall Brain - Department of Agronomy, Oklahoma state University, Oklahoma.

- Review and Planning meeting for discussions on calibrating Greenseeker for Rice and Wheat using remotely sensed IRS data, Dec 5, 2005 at IISR Lucknow, UP.
- Training workshop for principle component analysis towards integrated evaluation of crop management practices using NDVI sensors data. 4th- 10th April 2006. NASC Complex, New Delhi. Invited Lectures - Bram Govaerts from Department of Land Management and Economics, K.U. Leuven, Belgium (Currently Posted in CIMMYT).
- "Greenseeker Workshop (Review and Planning)" from 6-7 June, 2006 at CIMMYT office, New Delhi.
- "Sensor Based Nitrogen Fertilizer Use Workshop" from 10 -14 July, 2006 at Karnal and Modipuram. Invited Lectures - Kent Martin, KSU Soil Testing Laboratory, Department of Agronomy, Throckmorton Plant Sciences Center, Manhattan, USA.
- Project review and Finalization workshop on 26th July 2006, Dr. Ryan Moore from USDA & Dr. Aleen Mukerjee from USAID –India.
- Training workshop on "Handheld Optical Sensors for Nitrogen Management" from 2- 6 November 2006, Wheat Research Institute and University of Faisalabad, Faisalabad, Punjab, Pakistan, organized by Professor Dr. Bijay Singh, National Professor, PAU Ludhiana and Parvesh Chandna, Affiliate Scientist - Remote Sensing & GIS, RWC.

10. Papers published/ presented

- Bijay-Singh, R.K. Sharma, M.L. Jat, Yadvinder Singh, Parvesh Chandna, Mahesh Gathala, O.P. Choudhary, S.C. Tripathi, R.K Gupta, Jaspreet Kaur, Arun Srivastava, Ishwar Singh and Raj Gupta 2006, In-season estimation of yield potential and nitrogen management using hand-held GreenSeeker^{TM} optical sensor in the rice-wheat system in the Indo-Gangetic plain. 2nd International Rice Congress. October 9-13, 2006. NASC Complex, New Delhi India.
- Ishwar singh, Arun. K. Srivastava, Parvesh Chandna and Raj Gupta 2006; Crop Sensors for Efficient Nitrogen Management in Sugarcane: Potential and Constraints. Sugar Tech. Vol 8 (4) 299-302.
- Parvesh Chandna, Arun Srivastava, R.K.Sharma, Bijay Singh, Samar Singh, M. Sethi, M.L Jat, Ajay Kumar, R.P. Singh, Yadvinder Singh, O.P Chaudhary, M.Gathala, S.C.Tripathi, Ishwar Singh, S.N Singh and Raj Gupta 2006, Integration of NDVI of Greenseeker handheld optical sensor^{TM} with satellite remote sensing. 2nd International Rice Congress. October 9-13, 2006. NASC Complex, New Delhi India.

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12. Collaborators and Institutions

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- Dr. ML Jat, Directorate of Cropping System Research, Modipuram, Meerut, UP
- Dr.Aquil Khan, Director, Wheat Research Institute, Faisalabad, Pakistan (co-opted)