STUDIES ON SPECTRAL REFLECTANCE UNDER NORMAL AND NITROGEN - PHOSPHORUS STRESS CONDITION IN SOYBEAN (*GLYCINE MAX.* L.) CROP

By

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DISSERTATION

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PARBHANI 431 402 (M. S.) INDIA

2003

Affectioinately

Dedicated to

My Beloved

Aai, Appa

And Brothers

CANDIDATE' S DECLARATION

I hereby declare that the dissertation or part thereof

has not been previously submitted by me

to any other University or Institution

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Date : 25/ 06 / 2003

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Certificate - I

This is to certify that **Shri. GOLE ROHIDAS SUBHEDAR** has satisfactorily prosecuted his course of research for a period of not less than two semesters and that the dissertation entitled "**STUDIES ON SPECTRAL REFLECTANCE UNDER NORMAL AND NITROGEN - PHOSPHORUS STRESS CONDITION IN SOYBEAN (*GLYCINE MAX.* L.) CROP**" submitted by him is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination.

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Place : PARBHANI

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Certificate - II

This is to certify that dissertation entitled **"STUDIES ON SPECTRAL REFLECTANCE UNDER NORMAL AND NITROGEN - PHOSPHORUS STRESS CONDITION IN SOYBEAN (*GLYCINE MAX.* L.) CROP"** submitted by **Shri. GOLE ROHIDAS SUBHEDAR** to the Marathwada Agricultural University, Parbhani in the partial fulfillment of the requirement, for the award of the Degree of **MASTER OF SCIENCE** (AGRICULTURE) in the subject of **"AGRICULTURAL CHEMISTRY AND SOIL SCIENCE"** has been approved by the student's Advisory Committee after viva-voce examination in collaboration with the external examiner.

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ABBREVIATIONS

C	=	Carbon
CIR	=	Colour Infra Red
DAS	=	Days After Sowing
EMR	=	Electro Magnetic Radiation
g	=	Gram
GIS	=	Geographic Information System
IRS	=	Indian Remote Sensing Satellite
Kg ha^{-1}	=	kilogram per hectare
LAI	=	Leaf Area Index
LIDAR	=	Light Detection And Ranging
LISS	=	Linear Image Self Scanning
MSS	=	Multi Spectral Scanner
nm	=	nano meter
N	=	Nitrogen
NDVI	=	Normalized Difference Vegetation Index
NIR	=	Near Infra Red
NRI	=	Nitrogen Reflectance Index
NVI	=	Normalized Vegetation Index
P	=	Phosphorus
P_0	=	Plant Protection
P_1	=	Without Plant Protection
P_2	=	With Plant Protection
PAR	=	Photosynthetically Active Radiation
PRI	=	Photochemical Reflectance Index
PRI	=	Physiological Reflectance Index
PNSI	=	Plant Nitrogen Spectral Index
PVI	=	Perpendicular Vegetation Index
R	=	Red
RS	=	Remote Sensing
RVI	=	Ratio / Relative Vegetation Index
TVI	=	Transformed Vegetation Index
VI	=	Vegetation Index
YI	=	Yellowness Index
μm	=	Micrometer

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Introduction

Chapter 1

INTRODUCTION

Agricultural resources are important renewable dynamic natural resources, to feed the ever increasing population the pressure exerted on the natural resources to produce more and more food per unit area is increasing tremendously and has resulted in constant shrinking of our finite natural resources. Increase in Agricultural productivity has been the main concern since scope for increasing area under agriculture is rather limited. This demands judicious and optimal management of both land and water resources.

Remote sensing is the acquisition and interpretation of spectral measurement made at a distant location to obtain information about the earth surface. It is a multi-disciplinary activity which deals with the inventory, monitoring and assessment of natural resources through analysis of data obtained by observations from a remote platform. It have a greater application potential in agriculture and proven its applicability in crop acreage estimation, crop identification, crop yield estimation, monitoring soil moisture and water stress, land use and land degradation mapping. The integration of remote sensing with the accurate and conventional system of mapping and monitoring provides reliable information in a timely and cost effective manner.

Every object on the earth's surface yields distinctive "Finger prints" called "Spectral signatures". Scientific remote sensing is based on the spectral signatures. Spectral reflectance of crops is a basic prerequisite for monitoring crop growth and evaluating its productivity. Therefore, knowledge of leaf canopy spectral response affected by the environmental and cultural factors which alter crop growth and development is important one. The spectral quality and intensity of crop reflectance and emittance depends on such factors as leaf morphology, and pigmentation, canopy geometry, crop maturity, soil background, canopy cover, management and cultural practices and weather.

Remote sensors utilizes the solar radiation. Electromagnetic energy emitted by sun may be transmitted, reflected, absorbed, emitted or scattered by matter. Leaf reflectance is important stress indicator of water, nutrient and disease and pest stress. The leaf materials that affect reflectance and emmittance are common to all agricultural plants (Gates *et al.*, 1965). However, it changes as per environmental factors. Nutrient and moisture availability affect the optical and radiation properties of plant. The limitation of water supply and nutrient deficiencies in plants affects the colour, moisture content and internal structure of leaves and as a result of which their reflecting power also changes (Ajay *et al.* 1984, Das *et al.* 1992). Differences in Leaf Area Index are useful for spectrally discriminating healthy crop canopies from stressed crop canopies (Knipling, 1970). Spectral parameters have been used to estimate important crop canopy variables such as LAI, chlorophyll content and biomass of crop species (Ajay *et al.* 1983; Kamat *et al.* 1982; Duncan *et al.* 1993, Verma *et al.* 2002; Patil and Kolte, 2002).

Evaluation of soil productivity potential and constraints to crop growth are basic requisites for proper land use planning. Nutrient stress is one of the important growth and yield limiting factor. Which affects plant metabolic process particularly chlorophyll synthesis is badly affected and results in yellowing or low chlorophyll symptoms (Patil, 1994, Patil *et al.* 1994). Nitrogen, an essential element, is required for the plant growth and it directly influences the vegetative growth of the plants. Most of the studies on nutrient deficiency have, therefore, been concentrated on spectral responses in relation to nitrogen supply. Since in a nitrogen deficient crop, because of low chlorophyll content, the red reflectance is much higher compared to that in the infrared region, different vegetation indices based on red and IR reflectance have been developed as spectral parameters for distinguishing crop canopy under fertilized and nutrient stressed condition. Much lower values of NIR / Red reflectance ratio and the Normalized Difference Vegetation Indices for N deficient wheat crop were reported and compared to that of nitrogen fertilized crop over the complete growth cycle (Ajay *et al.,* 1984; Das *et al.,* 1985; Rao *et al.,* 1997). Phosphorus is another major nutrient, the effects due to which is limiting the crop production. The stresses caused by N and P deficiencies could be detected and differentiated using spectral behaviour of crop. So use of spectral data in nutrient deficiency detection will help in delineating the nutrient stress areas and for recommending the corrective measures in time. This technique is rapid, non destructive and economical on large scale. However, very limited work is carried out on this aspect. Hence, the project was formulated with following objective.

1. To determine the spectral response under disease pest and nutrient (Nitrogen and Phosphorus) stress condition in soybean

2. To study the temporal changes in physiological parameters of soybean under disease-pest stress and normal condition of crop

3. To study the changes in chlorophyll content and LAI under various growth stages under the influence of different stress and normal condition of crop

Review of Literature

Chapter 2

REVIEW OF LITERATURE

Use of spectral parameter information to detect field nutrient situations and crop vigor requires a thorough knowledge of what affects nutrient variations can have on the plant and soils. Several research workers have made efforts to study the effect of various types of stresses on canopy reflectance in different areas of the country and abroad. The observations documented on this aspect and associated areas of spectral parameters are reviewed from various sources like CAB abstracts, Internet, Periodicals, Books, Journals, Personal communication, etc.

The reviewed literature is presented in this chapter under the following heads

2.1 Effects of Nitrogen, Phosphorus, and Plant Protection on Growth, Yield and Physiological Parameters of Soybean

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2.1 Effects of Nitrogen, Phosphorus, and Plant Protection on Growth, Yield and Physiological Parameters of Soybean

Application of nitrogen and phosphorus under rainfed as well as irrigated condition influences the growth, yield and chlorophyll synthesis in soybean. Sekhon (1969) observed that the plant height of soybean was increased due to nitrogen application but phosphorus did not influence the height of plant where as Karim *et al.* (1981) found that soybean plant height was significantly greater at higher doses of phosphates Krishnamoorthy *et al.* (1983) studied the effect of various levels of phosphorus (0, 40, 80 and 120 kg ha^{-1}) on soybean at Bhavanisagar and recorded highest seed yield at 120 kg ha^{-1} phosphorus level. Similarly, Laddha *et al.* (1984) in their pot culture experiment (sandy loam soil) on soybean found that application of increasing levels of (0-90 kg P_2O_5 ha^{-1}) show increased the yield of soybean.

Application of nitrogen in general caused significant increase in growth and yield of soybean (Sharma and Dixit, 1987), whereas (Kailash kumar and Rao, 1991) in their study reported that dry matter yield of soybean per plant increased significantly by increased levels of nitrogen dose at all the growth stages. The P uptake was significantly increased by all the nitrogen levels. They further reported that application of phosphorus upto 100 kg P_2O_5 ha^{-1} increased the dry matter yield.

Reddy *et al.* (1990) found that nitrogen uptake by soybean increased significantly with each increment in nitrogen level and N uptake at 60 kg N ha^{-1} was significantly superior over all other levels. Further, application of P significantly increased N uptake with successive increments in levels of P from 0-90 kg P_2O_5 ha^{-1}. Highest P uptake recorded at 90 kg P_2O_5 ha^{-1} and was significantly superior over all other P_2O_5 levels.

Warade *et al.* (1992) observed that application of 40 kg N ha^{-1} to soybean significantly increased the number of pods per plant, weight of hundred seeds and straw yield over 20 kg N ha^{-1} and control. Among the different P_2O_5 levels, 90 kg P_2O_5 ha^{-1} produced maximum seed and straw yields.

Prasad *et al.* (1993) found that application of 60 kg P_2O_5 ha^{-1} significantly influenced the number of pods $plant^{-1}$, dry matter $plant^{-1}$, 100 seed weight and grain yield of soybean when compared with other levels. Similarly Hajare *et al.* (1994) reported that application of P upto 34 kg P ha^{-1}, with or without 20 kg N ha^{-1} or *Rhizobium* inoculation increased the biomass and yield of the soybean.

Patil and Makewar (1994) observed that chlorophyll content was maximum between 55 to 60 DAS in wheat crop.

2.2 Vegetation Spectral Indices

The earliest attempts were by Birth and McVey (1968) who attempted to relate the reflectance ratio at wavelengths 745 and 675 nm to the colour of turf. Jordan (1969) related the ratio of reflectance at 800 nm to that at 675 nm with the leaf area index of a forest floor. One of the first successful investigations into vegetation indices based on band ratio was developed by Rouse *et al.* (1973, 1974). They computed the NIR / R ratio (reflectance in Near Infrared or MSS 7 (Multi Spectral Scanner) band to reflectance in Red or MSS 5 band) and found it suitable when applied to satellite data (LANDSAT MSS) for the estimation of crop characteristics owing to partial correction for the solar position and atmospheric influence. This ratio is called simply the Vegetation Index (VI) or Relative Vegetation Index (RVI). They also used Normalized Difference Vegetation Index [NDVI= (NIR-Red) / (NIR + Red)] for the same purpose. Often this type of vegetation index is called the Normalized Difference Vegetation Index, NDVI = (NIR – Red) / (NIR + Red). To avoid impracticable negative values a Transformed Vegetation Index (TVI = [$(NDVI + 0.5)^{1/2}$] was developed.

Wiegand *et al.* (1974) for the first time related spectral data to LAI (Leaf Area Index). They concluded that LANDSAT (MSS-7) – (MSS-5) and (MSS-5 / MSS-7) in combination with MSS-7 and MSS-6 bands were suitable, in practice, as indicators of soil cover and plant density. Simulations by Bunnik (1978, 1981) show this kind of index as suitable for estimating the degree of cover, but slightly sensitive to variations of LAI after the soil is completely covered.

Spectral reflectance data from the field of wheat (*Triticum aestivum* Linn. emend. Thell) collected during the growing seasons were correlated with its yield. Infrared / red reflectance ratio and the Normalized Difference Vegetation Index were found highly and linearly correlated with total dry-matter production and grain yield. The correlation was maximum during a period of 40 days to 55 days after sowing (Kamat *et al.* 1983).

Jadhav (1992) concluded that remotely sensed data can meet many of the information needs for proper forest management in a short time, at low cost and in the format desired by forest department. Methodologies have been developed for forest type and density mapping as well as monitoring afforestation, deforestation and encroachments. The results show that Indian Remote Sensing Satellite (IRS - 1A) with 36.5 and 73 m resolution data at 22 days interval and vegetation specific bands serve as a powerful and monitoring tool for forest related studies.

Carlson *et al.* (1997) used a simple radiative transfer model with vegetation, soil and atmospheric components to show how the Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI) and fractional vegetation cover are dependent.

Gamon *et al.* (1997) derived the Photochemical Reflectance Index (PRI) from narrow-band reflectance at 531 and 570 nm, and explored as an indicator of photosynthetic radiation use efficiency for 20 species including field crops, forage crops and forest trees representing three functional types; annual, deciduous perennial and evergreen perennial.

Yang – Chwenming *et al.* (1997) analyzed reflectance spectra (350 – 1100 nm) of rice canopies grown in the field in the first and second growing seasons of 1996, and changes in reflectance in different wavelengths during the growing seasons. Using wavelengths of 674 and 756 nm to calculate vegetation indices, it is shown that curves of the Normalized Difference Vegetation Index, Relative Vegetation Index, Soil Adjusted Vegetation Index and Difference Vegetation Index were bell - shaped after transplanting. Differences in Vegetation Index between the 2 crops were attributed to different growth rates. Reflectance at 756 nm was suitable for estimating Leaf Area Index.

Krishnan *et al.* (1998) used ground-based remote sensing techniques for discriminating *Kharif* (monsoon) rice cultivars. The crop biometrics like LAI, chlorophyll content, leaf nitrogen content and biomass production were responsible for the cultivar discrimination. The discrimination was well pronounced in red and infrared bands and also in Vegetation Indices like IR / R and IR- R / IR + R.

Casanova *et al.* (1998) calqulated Vegetation Indices, Perpendicular Vegetation Index (PVI), Normalized Difference VI (NDVI), Weighted Difference VI (WDVI) and Relative VI (RVI) from rice crop reflectance. He observed that estimation of biomass from remote sensing data appear more reliable than estimation of LAI.

Semebiring *et al.* (1998) identified the optimum wavelength for detection of N and P status in winter wheat and observed that NDVI (NIR - R / NIR + R) and RVI (NIR / R) ratio were good indices to predict biomass and N and P uptake by wheat crop.

Toulios and Toulios (1998) reported that a relationship between a spectral index, viz. Normalized Differential Vegetation Index and biophysical parameters, could be useful in upland cotton (*Gossypium hirsutum* L.) for utilizing RS data.

Adams *et al.* (1999) discussed Yellowness Index (YI) as a measure for chlorosis of leaves in stressed plants. YI provides a measure of the change in shape of the reflectance spectra between the maximum near 0.55 μm and the minimum near 0.65 μm. Quantitatively, YI is a simple, three-point approximation of the second derivative of the spectra calculated using a finite divided difference approximation. YI is compared with two vegetation indices based on spectral changes in the region of the red edge, VI and NDVI.

2.3 Nutrient Stress and Leaf Reflectance

Nutrient stress is another factor that significantly affects the reflectance, transmittance and absorptance in both visible and near infra red wavelength. Light reflected from soil or plant surfaces that have a characteristic frequency and energy. The visible portion of light can be separated into red, orange, yellow, green, blue and violet. The yellow-green colour that associate with nitrogen deficiencies is characterized by having more violet light absorbed by the plant material or, alternatively, the intensity of green in plant is characterized by the amount of red light absorbed. Plant leaf greenness can be related to plant leaf chlorophyll content. Chlorophyll is directly related to plant nitrogen content. While, phosphorus deficiencies in plants theoretically result in increased absorbance of green light since increased purple coloring of leaf maturings and stem is expected. What is actually being measured in sensor based systems is spectral radiance from plant and soil surfaces.

Initial, leaf reflectance measurements at 550 (green) and 675 nm (red) were used to estimate the N status of sweet peppers. (Thomas and Oerther, 1972).

Al-Abbas *et al.* (1974) compared the spectral characteristics of normal maize leaves and leaves deficient in N, P, K,S, Mg and Ca. The nutrient deficiencies caused reduction in chlorophyll concentration and absorptance at 0.53 and 0.64 μm. Positive correlation were found between moisture content and absorptance at 1.45 and 1.93 μm. And leaves from P and Ca deficient plants absorbed less energy than those from normal plants in the NIR wavelengths, while leaves from the S, Mg, K and N deficient plant absorbed more than the normal.

In mustard spectral response was studied under irrigated, water stressed and nitrogen deficient conditions. The visible and infrared reflectivity were affected by the fertilizers treatment (Subba Rao *et al.* 1997). A field experiment was conducted in which spectral and agronomic measurements were collected from corn (*Zea mays* L.) canopies grown under four N treatments levels (0, 67, 134 and 202 kg ha^{-1}) on a Kaub silt long (Aquic Argiudoll soil). The spectra of four N treatments were significantly different. Early and late in the season only two spectral classes were resolved. Out of the spectral variables examined the near infrared / red reflectance ratio most effectively separated the treatments. Discrimination results for both years were similar in spite of larger treatment differences in 1979 than in 1978. Differences in spectral response between treatments were attributable to varying soil cover, leaf area index and leaf pigmentation values, all of which changed with N treatments (Walburg *et al.* 1982).

Ajay *et al.* (1983) made the spectral measurement in red (648 – 692 nm) and infrared (818 – 883 nm) bands over wheat (Sonalika)using a hand held radiometer. The experiment was conducted at Indian

Agricultural Research Institute, New Delhi on sandy loam soil. Spectral and plant growth measurements were made on a complete growth cycle of the crop under normal, water stress and nutrient deficiency conditions. The spectral measurements were found to be significantly different for fertilized crop compared to nutrient stressed crop. The stress degree for the normal crop is always lower compared to the nutrient deficient wheat. These results indicated that remote sensing technique, using the spectral data is useful tool for detecting nutrient deficiencies in wheat.

Spectral reflectance of maize crop was studied under six different plant densities ranging from 0.058 to 0.4 million per hectare and also under nitrogen stress and no stress conditions. The vegetation index values showed an increase with the increase in plant density which are attributable to increase in biomass. The day of peak value attainment was delayed under optimum plant density by nine days relative to low plant densities. (Sundara Sarma *et al.* 1985).

In summer mung leaf and canopy temperatures (LT and CT) decreased with increasing levels of nitrogen and irrigation supply. The canopy air temperature difference (CATD) decreased with increase in nitrogen and irrigation levels. The IR/Red reflectance ratio and normalised difference (ND) of summer mung increased with increase in irrigation and nitrogen treatments. Higher IR/Red and ND values were found at 40 and 48 days after sowing in mung in irrigated and fertilized treatments. (Suresh Kumar, 1986).

Blackmer *et al.* (1994) conducted a experiment to compare light reflectance from corn leaves with other parameters used to detect N deficiencies. Light reflectance (400-700 μm) as measured from corn leaves in the laboratory with a Hunter tristimulus colourimeter was compared with minolta spad 502 chlorophyll meter readings (Light transmittence at 650 and 940 μm), leaf N concentrations, and specific leaf

N (N content per writ urea). Measurements were made on individual ear leaves collected from an irrigated corn N response trial with four hybrids and five N treatments. Light reflectance near 550 μm was the best wavelength to separate N treatment differences. Reflectance at 550 μm provided a stronger relationship with both leaf N concentration and chlorophyll meter readings than between chlorophyll meter readings and leaf N concentrations. The measurement of light reflectance near 550 μm has promise as a technique to detect N deficiencies in corn leaves.

Spectral radiance measurements for red (660 nm) and near infrared (NIR 780 nm) wavelengths have been measured in wheat from December to February using photodiode based sensors (Stone *et al.*, 1996, Soile *et al.*, 1996). The Plant Nitrogen Spectral Index (PNSI) was highly correlated with N uptake at several locations, using a wide range of varieties. PNSI is the inverse of the Normalized Difference Vegetative Index (NDVI), commonly used in remote sensing. This is important since several researchers have shown that wheat forage total N uptake during the winter months can be a predictor at top dressed N needs (Roth *et al.* 1989, Vaughan *et al.* 1990). Because N uptake can be predicted indirectly using spectral radiance measurements, sensors can reliably provide measurements equivalent to 'on-the-go 'chemical analyses. Using the PNSI, fertilizer N has been top dressed from January to February using prescribed amounts' based on the spectral radiance measurements (Stone *et al.* 1996).

Bausch *et al.* (1996) estimated plant N in irrigated maize using a previously developed N Reflectance Index (NRI) calculated from measured green (G) and near-infrared (NIR) canopy reflectance. The field study site consisted of contiguous plots with four imposed N fertilizer treatments. Chlorophyll meter measurements, whole plant sampling for N analysis, and canopy reflectance measurements were made throughout the 1995 growing season of maize cv. Pioneer 3790. Measured plant total N (all leaves) and estimated plant total N based on the NRI compared favorably as long as the soil background was obscured. Consequently, the NRI is assumed to be a better indicator of N sufficiency than the N sufficiency Index calculated from chlorophyllmeter measurements, because a plant community consisting of many plants is monitored instead of a single point on a single maize leaf. Furthermore, assessment of plant N status by the NRI is rapid and can be easily mapped with GIS tools to show areas that are N deficient.

In experiments in Colorado in 1996, two indices were tested to determine their usefulness for estimating crop water use and N status of irrigated maize. Results showed that it is feasible to estimate daily crop water use and plant N status from canopy reflectance data acquired in discrete wavebands in the green, red, and near infrared. Spatial assessment and mapping of the two variables were rapid. (Bausch, 1997).

Gopala *et al.* (1998) used high-resolution Colour Infrared (CIR) aerial images for detecting in-field spatial patterns, especially due to nitrogen stress in corn. Aerial remote sensing proved to be a promising tool for obtaining spatial and temporal in-field variability in the crop field for site-specific crop management and yield prediction.

Morales *et al.* (1998) showed photosynthetic induction of sugar beet leaves affected by Fe deficiency was characterized using the Tau – LIDAR (Light Detection and Ranging) apparatus, which can monitor stress conditions at a distance using photosynthesis related remote sensors. Fe deficiency increased the chlorophyll fluorescence lifetime in illuminated leaves. This effect could be measured at distance with a Tau – LIDAR device, supporting the view that laser instrumentation in combination with remote sensors can monitor the photosynthetic effects of stress on plants at a large spatial scale.

Shadchina *et al.* (1998) found the correlation between chlorophyll and leaf nitrogen contents. Leaf chlorophyll content, leaf nitrogen content and grain yields were closely correlated and during grain ripening, these correlations were cultivar-specific and were maintained although leaf chlorophyll and nitrogen contents were declining.

Semebiring *et al.* (1998-b) identified optimum wavelengths for dual detection of N and P status in winter wheat (*Triticum aestivum*) given 0, 56, 112 and 168 kg N ha $^{-1}$ and 0, 14.5 and 29 kg P ha $^{-1}$. A wide range of spectral radiance measurements were obtained from each plot using a PSD 1000 Ocean Optics Fiber Optic Spectrometer. At each reading date, 78 bands and 44 combination indices were generated to test for correlation with forage biomass and N and P uptake. Additional spectral radiance reading were collected using an integrated sensor which has photodiode detectors and interference filters for red and NIR. For this study, simple numerator / denominator indices were useful in predicting biomass, and N uptake and P uptake. Numerator wavelengths that ranged between 705 and 735 nm and denominator for wavelengths between 505 and 545 nm provided reliable prediction of forage biomass, and N and P uptake over locations using the photodiode sensor. NDVI (NIR – Red / NIR + Red) and NIR ratio (NIR / Red) were also good indices to predict biomass, and N and P uptake.

Semebiring *et al.* (1998-a) evaluated spectral radiance measurements to identify optimum wavelengths for dual detection of N and P status in Bermuda grass (*Cynodon dactylon*) given 0, 112, 224 and 336 kg N and 0, 29 and 58 kg P/ha. A wide range of spectral radiance measurements (276 – 831 nm) was obtained from each plot using a PSD 1000 Ocean Optics Fiber – Optic Spectrometer. The resulting spectra were partitioned into 10 nm bands. Added indices were generated to test for correlation of N and P content with spectral radiance. The 435-nm band (430 – 440 nm) was independent of N and P applications and as a covariate. It was found that biomass, N uptake, P uptake, and N concentration could be predicted using 695 / 405 nm. No index reliably predicted Bermuda grass forage P concentration. It was concluded that spectral radiance has the potential to be used for predicting N and P nutrient status, but further work is needed to document response in different environments.

Adams (1999) reported that for manganese – deficient soybean leaves, YI, VI and NDVI were all closely related to leaf chlorophyll concentrations. YI is calculated from wavelengths in the visible that are thought to be less sensitive to changes in leaf structure or water content. Because YI is an approximation of a spectral second derivative, it should be less sensitive to atmospheric effects than many other vegetation indices. It is suggested that as the results reported are based on leaf-level observations, they must be verified at the canopy level for remote sensing applications.

Fouche (1999) reported the results obtained from cotton, tobacco and wheat experiment conducted on different N treatments. Nitrogen rates for tobacco and cotton were 0, 50, 100, 150 and 200 kg N ha $^{-1}$. While on a wheat experiment the rates of N were 0, 60, 120 and 180 kg N ha $^{-1}$ with 4 splits of applications after sowing. Infrared aerial photographs and multispectral videography were taken of the experiments at certain times using remotely piloted aircraft. These images were processed on a computer and classified into high and low – N categories using image processing software. A portable spectrometer operating in the 770 mm to 920 nm range was also used to asses N deficiency by measuring the reflected radiation of wheat canopies 70 days after sowing. Interception of Photosynthetically Active Radiation (PAR) was used to assess the biomass of wheat over time. Light reflection in the near infrared wavelengths from air-borne IR photography and the 853 nm band from multispectral videography correlated well with the N rates on the different crops. Spectrometric reflection provided the best detection of N deficiency at the 779 nm wavelength. The PAR measurements followed the same correlation with N rates.

Kalpana *et al.* (1999) conducted an experiment in New Area Farm of Tamil Nadu Agricultural University, during 1998 study the influence of different levels of organic manures (Vermicompost and FYM at 5 t ha^{-1} each) and inorganic fertilizer N (20 kg and 40 kg N ha-1) on spectral reflectance and the relationship between spectral data and leaf N content in forage at (*Avena sativa*) Reflectance was measured with hand held radiometer at fortnightly interval. Significant relationship was observe between spectral parameters and N content of leaf at 45 DAS. The leaf N content of forage oat was found to be correlated with spectral bands (blue, green, red and infra red) and spectral vegetation indices like perpendicular vegetation Index (PVI) and greenness index (GI). Among the spectral parameters green band recorded highest correlation coefficient (r=0.953**) with leaf N content of forage out. Regression equation (prediction models) for estimating the leaf N content in forage oat using spectral variables were also developed.

Hannelie Botha (2000) found that individual spectrometer values as well as ratios of those values were a good indicator of leaf nitrogen status. Ratios of red and near infrared reflectance of both the infrared and multi-spectral video images indicated that symptoms of nitrogen deficiency are much more acute in the juvenile growth stage than in the adult stage.

2.4 Health of Crop and Leaf Reflectance

Colwell (1956) first demonstrated that infrared aerial photography could be used to differentiate healthy and rust-infected small grain. Several other investigations have shown that many crop disease and other stresses can be detected from remotely sensed spectral measurements. Studies with positive results include of those by Meyer and Calpouzos (1968) involving cercospora leaf spot disease of sugar beets and the previously mentioned work by Manzer and Cooper (1967) with late blight furgus of potatoes.

Thomas et al. (1966) and Wiegand *et al.* (1968) have shown that the effects of excessive soil salinity on crop growth are readily detectable in remotely sensed imagery.

Hart *et al.* (1971) and Payne *et al.* (1971) indicates that aerial infrared colour photography may be useful for the detection and survey of insect infestations, host plant ecology, and the evaluation of insect control efforts.

The most extensive surveys utilizing remote sensing methods to detect crop diseases and classify their severity were two experiments performed in 1970 and 1971 by the U.S. Department of Agriculture, the National Aeronautics and Space Administration and several universities remote Sensing showed that three classes of corn, healthy to slightly infected mild to moderate levels of infection and severe, could be differentiated using either small scale colour infrared aerial photography or multispectral scanner data (Bauer *et al.* 1971). These results were verified in 1971 over a much longer area (MacDonald *et al.* 1972).

Leaf colour can be an important variables yielding information about photosynthetic efficiency. Another measure of viability of crop besides chlorophyll content may be offered by the so called red edge index (blue shift) (Horler *et al.* 1983).

Sinha and Karale (1992) had preliminary investigations on area and health assessment of orange plantations using IRS data. The studies demonstrate the capability of remote sensing in general and IRS data in particular, for precise and faithful record of orange orchards. Among LISS-I (Linear Image Self Scanning) and LISS –II, the former facilitates broad inventory, where as the later favours precise locational details and extent as well as invaluable information about health status of the orange growing stock.

Dudka *et al.* (1999) used remotely sensed spectral data to assess the incidence of sclerotinia stem rot of soybean caused by *S. sclerotirum* and to determine its effect on soybean. Multispectral data were obtained with an ATLAS sensor (Airborne Terrestrial Applications Sensor), yields were mapped with a combine – mounted yield monitor and field disease assessments were made both visually and by means of spectral reflectance observations obtained with a hand held radiometer. Limitations in data obtained during the ground truth survey prevented use of multispectral data for disease assessment. However, the results suggested that disease incidence and crop yield could be estimated from spectral reflectance data, that plant disease could explain a high percentage of yield variability in a soybean field and that diseased area could be mapped using precision agricultural techniques.

A field experiment on detection of nutrient deficiencies in soybean (*Glycine max* L.) crop by remote sensing was conducted at Departmental farm of Marathwada Agricultural University, Parbhani, during Monsoon 2001-2002 to find out the feasibility of nutrient deficiency diagnosis by studying the spectral reflectance. There were sixteen treatment combinations of four main plot treatments (Two moisture levels – no irrigation and irrigation and two plant protection levels – no plant protection and plant protection) and four sub-plot treatments of fertility levels viz. No N and P, N @ 30 kg N ha^{-1}, P @ 60 kg P_2O_5 ha^{-1}, and N and P. The experiment was laid out in split plot design with three replication. Spectral reflectance in four bands i.e. visible blue green (0.45 – 0.52 μm), visible green (0.52 – 0.59 μm), visible red (0.62 – 0.68 μm) and near infra red (0.77 – 0.68 μm) were recorded between 1000 to 1500 hrs IST in direct sunlight by multi-band radiometer. The physiological changes in canopies (Leaf area, biomass and chlorophyll content of leaves) caused by irrigation, plant protection and N, Ca and P deficiency resulted in detectable reflectance variation. Reduced LAI, chlorophyll content and biomass were among the effects seen in N, P and N and P deficient canopies. RVI and NDVI ratios found better indiscriminating stressed soybean and normal soybean crop. RVI established positive relationship with total biomass and LAI (Kolte, 2002).

2.5 Chlorophyll and Caroteinoid Pigments and Leaf Reflectance

Thomas and Gausman (1977) reported the leaf reflectance vs. leaf chlorophyll and carotenoids concentrations for eight crops and observed that leaf reflectance in the 0.40 to 0.75 μm wavelength interval is influenced primarily by the pigments chlorophyll and carotenoid. The objectives in their study were to determine which three wavelengths in the visible spectral region best related leaf reflectance to total chlorophyll and carotenoid concentrations and the relative effect of these pigments on reflectance. Hemispherical reflectances (*Cucumis melo* L. cv. reticulantus Naud), corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), Cucumber (*Cucumis sativus* L.), Head lettuce. (*Lactuca sativa* L. cv. Capitata L.), Grain sorghum (*Sorghum bicolur* L. moench) and Tobacco (*Nicotiana tobacum.* L) were regressed on each crops leaf total chlorophyll and carotenoids concentrations. The crops were grown in sand culture, and their leaf pigment concentrations were varied by supplying N at rates of 14, 28, 84, 140 and 196 ppm to a basic nutrient solution. Hemispherical reflectance of leaves was inversely related to each crops leaf chlorophyll and carotenoid concentrations. However, of the three wavelengths tested the 0.55 μm wavelength seemed superior for individually relating the two pigments to leaf reflectance. The independent effects of carotenoids on hemispherical reflectance were small and generally statistically non significant, whereas the independent effect of chlorophyll while small were generally significant. The combined effects of these variables were highly significant and accounted for 39 to 95 % of the reflectance variability. This study indicated that even though including carotenoids with total chlorophyll measurements improved the correlation of reflectance with pigment concentration.

Kamat *et al.* (1982) and Ajay *et al.* (1983), from the field experiment observed that spectral parameters can be used to estimate the chlorophyll content, LAI and biomass of crop species.

Penuelas *et al.* (1993) examined a Water Band Index (WBI) defined as R 950 / R 900, because the reflectance spectrum was associated with a water absorption band. They reported that normalized total pigment to chlorophyll a ratio index was highly correlated with chlorophyll content and was a rough estimate of the ratio of total pigments to chlorophyll a, decreasing in healthy plants and rising in stressed or senescing plants.

NDVI was sensitive to chlorophyll absorption. Filella *et al.* (1995) indicated that leaf chlorophyll 'a' content is mainly determined by N availability. They found improved correlation between measured chlorophyll 'a' and leaf reflectance at 550 and 680 nm, whereas, Gamon *et al.* (1992) used a Physiological Reflectance Index (PRI) to track diurnal changes in photon efficiency (CO_2 uptake / absorbed photosynthetically active radiation = Rref – R 531 / Rref + R 531, where Rref was a reference wavelength and R 531 represented spectral radiance at 531 nm).

Bhavanarayana (1996) in a review reported that the carotenoid pigments are masked by chlorophyll and once chlorophyll breaks down later in the growth period, they become prominent and affect the light reflectance. Young leaves contain less water than mature leaves because immature cells in young leaves are primarily protoplasmic with little vacuolate water storage. The correlation of leaf water content with reflectance is strongest in the near infrared region of the spectrum. Effects of pigment changes and leaf moisture are closely related and sometimes cannot be separated. Changes in leaf moisture affect the pigments in the leaf within a very short period of time. As leaves senesce, their light reflection usually increases markedly in the green visible light wavelength region peaking at 0.55 μm, because of chlorophyll degradation. Leaf senescence decreases near infrared light reflectance over the 0.75 to 1.35 μm wavelength interval. Further he reported that the effects of structural components of plant leaves on reflectance are varied. To facilitate interpretation, the 0.5 to 2.5 μm wavelength interval can be divided into three categories:

1 The 0.5 to 0.75 μm visible light absorbance region, dominated by pigments primarily chlorophyll's 'a' and 'b' (chlorophyll 'c' occurs in brown algae.), carotenes and xanthophylls;

2 The 0.75 to 1.35 μm near-infrared region, a region of high reflectance and low absorptance affected considerably by internal leaf structure; and

3 1.35 to 2.5 μm region influenced by leaf structure, but affected greatly by water concentration in the tissue with strong water absorption bands occurring at both 1.45 and 1.95 μm.

Rundquist *et al.* (1996) measured algal – chlorophyll concentrations in surface waters, this provides hyperspectral signatures, in the visible and near infrared, associated with two experiments conducted out doors in large water tanks. One involving relatively low amounts of chlorophyll over a narrow range and a second involving relatively high amounts over a wide range. The principle finding was that the commonly used Near Infrared / Red ratio is best for estimating pigment amounts when the concentration of chlorophyll is relatively low, and the first derivative of reflectance around 690 nm is best when the concentration is relatively high.

Gitelson and Merzlyak (1997) formulated indices for the non-destructive estimation of chlorophyll content using various instruments to measure reflectance and absorption spectra in visible and near-infrared ranges, as well as chlorophyll contents from several non-related species from different climatic regions. The proposed new algorithms are simple ratios between percentage reflectance at spectral regions that are highly sensitive (540 to 630 nm and around 700 nm) and insensitive (near infrared) to variations in chlorophyll content (RNIR / R 700 and RNIR / R 550). The algorithms developed for predicting leaf chemistry from the leaf optics were validated for 9 plant species with a range of chlorophyll contents from 0.27 to 62 μg cm $^{-2}$. The use of green and red (near 700 nm) channels increases the sensitivity of NDVI to chlorophyll content by about 5 fold.

Blackburn (1998) investigated the effectiveness of a range of hyperspectral approaches for estimating the concentrations of chlorophyll 'a', chlorophyll 'b' and carotenoids at the plant canopy and leaf scales. The results indicated that narrow-band reflectance indices can be developed, such as the pigment specific simple ratio, which have extremely strong relationships with the concentration per unit area of individual pigments at the canopy scale. Spectral derivative approaches, particularly these based on pseudoabsorbance (log 1/R), are also closely related to canopy pigment concentration per unit area, but are more useful for deriving estimates of the concentration per unit mass of photosynthetic pigments at both canopy and leaf scales.

Choubey *et al.* (1999) showed that the period between 66 to 70 DAP (days after planting) was most suitable for the assessment of rice crop yield, based on chlorophyll 'a' concentration.

Datt (1999) studied the visible / near infrared reflectance properties of leaves from 21 *Eucalyptus spp.* to determine appropriate indices for remote sensing of chlorophyll content. A scatter correction technique was applied to reflectance spectra, which gave improved calibrations for the estimation of chlorophyll content. Reflectance near 710 nm wavelength showed maximum sensitivity to chlorophyll content with reflectance near 550 nm a less sensitive indicator. Among several reflectance indices tested, the ratio (R 850 – R 710) / (R 850 – R 680) performed best, and is proposed as a new index for the remote estimation of chlorophyll content in higher plants. From the first derivatives of reflectance, the ratio D1 (754) / D1 (704) and the wavelength position of the red edge were best correlated with chlorophyll content. The ratio D2 (712) / D2 (688) from the second derivative of reflectance was also an equally good indicator of chlorophyll content.

Gitelson *et al.* (1997) presented a remote sensing technique to estimate the chlorophyll content in higher plants. The ratio between chlorophyll fluorescence at 735 nm and in the range 700 – 710 nm, F 735

/ F 700 (measured in detached intact leaves using a spectrofluorometer), was found to be linearly proportional to the chlorophyll content and thus this ratio can be used as a precise indicator of chlorophyll content in plant leaves. This new chlorophyll fluorescence ratio indicates chlorophyll levels with high precision.

Subhash *et al.* (1999) indicated that changes in photosynthetic activity due to senescence and chlorophyll breakdown can easily be detected and qualified via fluorescence ratios that are based on the UV – A excited fluorescence bands F440, F520, F690 and F740. These ratios provide a solid basis for the laser – induced remote sensing of the state of health and chlorophyll content of vegetation. The fluorescence ratios green / red and green / far-red were found to be very suitable complementary indicators of early stress events in plants.

2.6 Crop Acreage Estimation

Phonologic events, which may related to yields of economic plant species in humid and sub-humid temperate regions are difficult and expensive to observe and measure. Sequential multispectral reflectance data obtained by an orbiting satellite (LAND SAT 7-1) cover 14 pre-selected sites in central and eastern United State during a 14 month period were examined. Analysis of data from four reflectance and regrowth differences among hardwood timber stands can be detected and quantified. The results suggest the need for continued development of these monitoring techniques for use in detecting and quantifying conditions of economic plants which may effect yield (Blair *et al.* 1977).

Aase *et al.* (1980) estimated that RS would be a valuable tool to decision making and crop forecasting groups to gain knowledge of winter wheat acreage, extent of winterkill, and the potential acreage that may be reseeded to spring crop. To simulate winterkill, seven winter wheat

(*T. aestivum* L.) stand variables of 0, 10, 20, 40, 60, 80 and 100 per cent of full stand (full stand = seeding rate of 67 kg ha^{-1}) were established by seeding to stand. The plots,20 x 20 m, were located on Williams loam (Fine loamy mixed, Typic Argiborolls) near Sidney, Mont. An Exotech. Model 100 A ground truth radiometer, corresponding to LANDSAT multispectral scanner (MSS) bands 4, 5, 6, 7, (0.5 to 0.6, 0.6 to 0.7, 0.7 to 0.8 and 0.8 to 1.1 nm) was used to measure reflected radiation at 0.930 hrs. MST on clear or nearly clear days. We chose the comparatively simple, but physically meaningful normalized difference vegetation index, V-17 =, (MSS 7 - MSS 5) / (MSS 7 + MSS 5), with the variant of substituting MSS 6 for MSS 7 to illustrate crop cover differences. In an attempt to better distinguish soil background from crops and to improve on the crop vegetation index relationship, we included the more complex, but also physically meaningful, perpendicular vegetation index, PVI. = [(Rgg 5 – Rp 5)2 + (Rpp 7 – Rp 7)] ½ with the variant of substituting MSS 6 for MSS 7, Early in the season. V17 delineated stand $\geq$ 40 per cent from those < 40 per cent allowing a judgment at to weather or not a field would need to be reasonably good stand if plants are properly spaced. The 10 and 20 per cent plots became distinguishable from the ,sold background at a biomass accumulation of about 30 kg ha^{-1} (LAI=0.06). There was no advantage of using either variant of the PVI over the V17 when plotted against leaf area index (LAI) or leaf dry matter (LDM). Both yielded a family of straight lines, with indices of determination ranging from 0.796 to 0.942 and slopes decreasing from the 10 per cent plot to similar slopes for the 80 and 100 per cent plots.

Relationships between crop canopy variables such as leaf area index (LAI) which might be used in large scale applications of growth and yield models of wheat and other crops and their multispectral reflectance properties are not well defined. The objective of this investigation was to identify these relationships and asses the potential for estimating selected canopy variables from remotely sensed reflectance measurements. The treatments in the experiment included planting date, N fertilization, cultivar and soil moisture correlation and regression analyses were used to relate the agronomic variables to reflectance factor and percent soil cover, LAI, biomass, and plant water content. A near infrared wavelength band, 0.76 to 0.90 nm, was most important in explaining variation in green LAI and percent soil cover, which a middle infrared band, 2.08 to 2.25 nm, explained the most variation fresh and dry biomass and plant water content. The canopy variables couls be accurately predicted using measurements from three to five wavelength bands. The reflective wavelength bands of the thematic mapper sensor were more strongly related to and better predictors of the canopy variables than the landsat MSS bands (Ahlrich, 1982).

Daughtry *et al.* (1982) in his experiment develop method for combining spectral and meteorological data in crop yield models that capable of providing accurate estimates of crop condition and yield Reflectance factor data were acquired with a Landsat sand radiometer throughout two growing seasons for corn (*Zea mays* L.) canopies differing in planting dates, populations, and soil types (Typic Argiaquoll and Udollic orchraqualf). The spectral variable greenness was associated with 76 per cent of variation in LAI over all treatments. Single observations of LAI or greenness were found to have limited value in predicting corn yields. The proportions of solar radiation Intercepted (SRI) by these canopies were estimated using either measured LAI or greenness. Both estimates, when accumulated over the growing season, accounted for approximately 65 per cent of the variation in yields. We concluded that solar radiation using spectral data represents a viable approach for merging spectral and meteorological data in crop yield models.

2.7 Yield Potential Estimation by Remote Sensing

Thomas *et al.* (1967) and Stanhill *et al.* (1973), respectively, showed that reflectance from cotton and from wheat fields is greatly affected by the amount of vegetation and the percentage of ground covered by the vegetation. In their experiments, optical density measurements of colour infrared photography accounted for 75 and 49 per cent of the variation in cotton lint and wheat grain yields, respectively.

Steen *et al.* (1969) found statistically significant correlations among pre-harvest yield indicates (e.g. open bolls, number of plants, percentage of ground cover, plant height, and plant dry weight) and optical density of aerial infrared film for cotton grain sorghum, carrots, cabbage, and onions.

Mac Donald *et al.* (1972) found a high correlation between the corn leaf slight severity classes they identify using remote sensing and yield samples from several hundred fields.

Das *et al.* (1989) developed prediction models for wheat to asses crop growth in terms of leaf area index, dry matter production and grain yield from remotely sensed temperature and spectral indices. The cumulative stress degree days for the period of flowering to grain formation stage showed significantly higher correlation with dry matter (r=0.940) and grain yield (r=0.0939). Whereas that for the period grain formation to harvest stages, showed significantly higher correlation (r=0.967) for crop water use.

Bashford *et al.* (1995) develop a yield maps for corn and soybeans were developed using data obtained from a simple yield monitor and by using a GPS for sit location. A yield monitor was installed in these exist portion of the clean grain elevator of a combine. A series light emitters and receivers were used for the yield monitoring. Such that the greater the flow rate, the smaller the amount of light seen by the receivers. The flow rate and voltage changes from the monitor appeared to linearly related in a laboratory study. The monitor had to be calibrated with the dynamics that correlated location data were obtained in real time. It was found that others were not good, with large deviations from the actual path. The combine speed as measured by the GPS was not adequate and a radar or other link to the combine speed sensor is necessary in order to calculate instantaneous yield data.

Zhang *et al.* (1999) estimated relationship between remotely sensed Normalized Difference Vegetation Index (NDVI) and yield was best at 9 in spatial resolution. Preliminary results indicates that it is possible to use NDVI to estimate the potential yield for soybeans and maize when canopy reaches full cover.

2.8 Relationship between Spectral Parameters and Physiological Parameters

Field experiment conducted during 1978 and 1979 under four N treatment levels. Red reflectance was increased and NIR reflectance was decreased from N deprived canopies. The results confirm the potential of remote sensing for monitoring the growth and development of crops (Walburg *et al.* 1982).

Das (1998) stated that the visible and infrared reflectivity were affected by the fertilized treatment. Considerable differences were also observed by the spectral indices between irrigated and water stress crop conditions.

Spectral reflectance data from the field of wheat crop was managed under two irrigation levels collected during the growing season were correlated with its yield. Infra red : red reflectance ratio normalized difference vegetation index were found highly and linearly correlated with total dry matter production and grain yield, establishing the potential of remote sensing for predicting grain and biological yields (Kamat *et al.* 1983).

Yield is function of various biotic and abiotic factors. Some of the important physiological parameters that influences the growth and development of crop are leaf area index, chlorophyll content, total biomass, etc. produced during the growth period. This parameter affects the yield of the crop. Further, the response of leaf area index, chlorophyll content, biomass and nutrient content of the leaves towards the spectral indices varies. It was observed that there is relationship between spectral indices and growth parameters of the crop (Patil and Kolte, 2002).

The spectral ratios like Relative Vegetative Index (RVI) and Normalised Difference Vegetative Index (NDVI) established positive and significant relationship with some of the important physiological parameters like LAI, chlorophyll content, total biomass and nitrogen content of the leaves. From the review it is inferred that the spectral parameters can be related to the physiological parameters to arrive at a good confidence level in discriminating the crop population against pest and disease stress, water stress and nutrient stress.

Material and Methods

Chapter – 3

MATERIALS AND METHODS

A field experiment was conducted to study the **"Spectral Reflectance under Normal and Nitrogen – Phosphorus Stress Condition in Soybean (*Glycine max.* L.) Crop"**. The objective of the project entitled was to find out the spectral response under different pathological (pest and disease), nutrient stress and temporal changes in physiological parameters of soybean influenced due to N and P levels and plant protection measures. To meet these objectives a field experiment was carried out during the *kharif* (Monsoon) 2002. The details of the materials used and methods adopted are presented in this chapter.

3.1 Experimental Site and Climate

3.2 Experimental Soil

3.3 Crop Weather Parameters Prevailed during Field Experimentation.

3.4 Field Experimentation and Observations

3.5 Spectral Observations

3.6 Collection of Soil and Plant Samples and Analysis

3.7 Spectral Indices and Statistical Analysis

3.1 Experimental Site and Climate

The experiment was conducted at Research Farm, Department of Agricultural Chemistry and Soil Science, Marathwada Agricultural University, Parbhani (Plate 1), during the *kharif* (Monsoon) season of 2002-2003. Parbhani is situated geographically at 19°16′ North latitude and 76°74′ East longitude. The height is 409 M above mean sea level. It has tropical climate with hot and dry summer and area comes under semi-arid tropics. The rainy season (South-West monsoon) starts from June and ceases in September. The rainfall received during the monsoon season during experimentation period was 295.5 mm.

3.2 Experimental Soil

The soil of the selected site for the experiment was almost plain. It had a dark brown colour (10 YR 4/3) with depth more than 90 cm. The soil belongs to Vertisols order formed from weathering of basalt(trap)rock rich in iron and manganese. The soil is having clay texture and taxonomically classified as Fine, smectitic (calcarious) isohyperthermic Typic haplusterts. The experimental soil was clay in texture (55.1 per cent clay), alkaline in reaction (pH 8.27), safe in total soluble salt concentration (EC 2.5 – 0.4 dSm^{-1}) and calcareous in nature ($CaCO_3$ 7.2 g kg^{-1}). Among the fertility constituents, organic carbon was 4.08 g kg^{-1}, available nitrogen, phosphorus and potassium content were 17.5, 14.16 and 397 Kg ha^{-1}, respectively.

3.3 Crop Weather Parameters Prevailed during Field Experimentation

3.3.1 Rainfall and Temperature

Data on weekly weather parameters from August 2002 to November 2002 are presented in Appendix I. It revealed that during growth period of soybean total rainfall of 295.5 mm was received in 7 rainy weeks. Its distribution during the month of August, and September was 215.5 and 80.00 mm respectively. There were no rains in the month of October and November. The data on maximum and minimum temperature showed that maximum temperature was prevailed in the month of August and September. The major feature of the rainfall was that there were heavy rains in 34^{th} meteorological week (112.4 mm), whereas only 80 mm rainfall was received in the month of September. The other climatic parameters were conducive for crop growth and were fluctuating as per the normal values for the season.

3.3.2 Weather Parameters Prevailed on Observation Days

The spectral observations were recorded during the growth period of soybean on September 26, October 11, October 23, November 1 and November 13, 2002. The weather parameters viz. temperature, relative humidity, leaf wetness, radiation, soil temperature and wind speed prevailed during observation time (10 hrs to 13 hrs) that may influence leaf reflectance were recorded. They are presented in Appendix II as a ready reference for the interpretation of experimental results.

3.4 Field experimentation and observation

The experiment was laid out in Randomized Block Design (Factorial experiment) on Soybean (Var. JS-335) during *kharif* season of 2002-2003. Fig. 1 shows the lay out of field experiment. There were 16 combinations consisting two plant protection levels and eight soil fertility levels as detailed below.

Treatments : 16 combination of plant protection level (2) x fertility level (8)

First factors : Two levels of plant protection

D1 No spraying for pest and disease control

D2 Recommended spraying for pest and disease control.

Second factor : Eight levels of soil fertility

F1 No N application and no P application.

F2 Recommended N application and no P application.

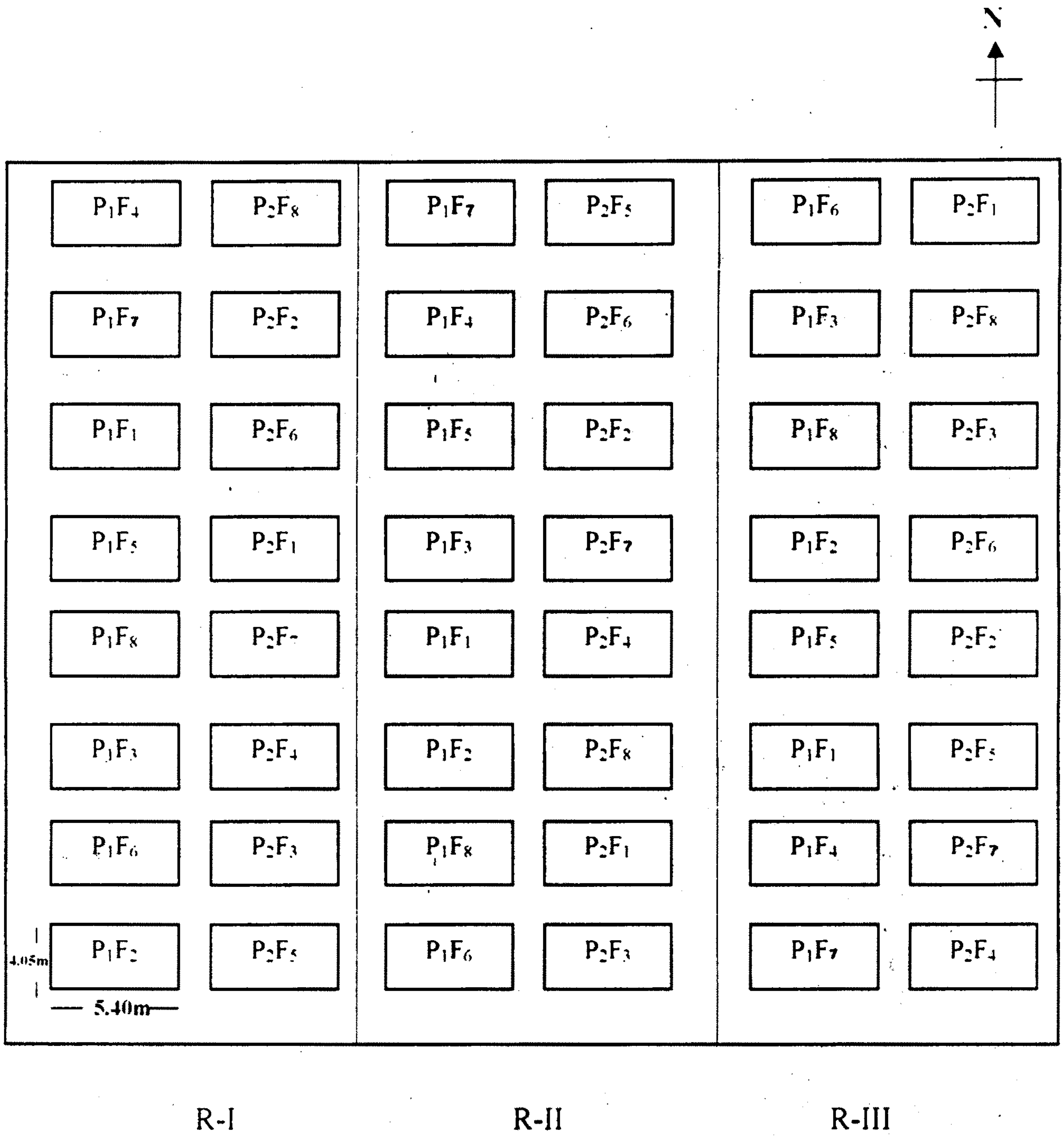

Fig. 1 : PLAN OF LAYOUT

Plate 1. *Experimental View of Soybean crop*

Plate 2. *Opto -Mech Multiband Ground Truth Radiometer*

F3	Recommended P application and no N application.
F4	Recommended N and P application
F5	Only 45 kg N/ha (1.5 times than the recommended dose of N).
F6	Only 60 kg N/ha (2 times than the recommended dose of N)
F7	Only 120 kg P/ha (2 times than the recommended dose of P)
F8	60 kg N + 120 kg P kg ha^{-1} (2 times than the recommended dose of N and P).

Soil type : Taxonomically classified as fine, smectitic (calcareous) isohyperthermic Typic haplusterts.

Other details

Replications	:	3
Plot size (GROSS)	:	5.40 x 4.05 M^2
(NET)	:	4.05 x 3.90 m^2
Sowing date	:	18[th] August 2002
Harvesting date	:	25[th] December 2002
Crop spacing	:	45 x 5 cm^2

Recommended fertilizer dose (basal) :

30 : 60 (kg N, P_2O_5 ha^{-1}) Total fertilizer dose of N (30 kg N) and P (60 kg P_2O_5) applied as basal dose, through urea and single super phosphate.

The details of the intercultural operations and plant protection schedule (as per treatment) followed during the experimentation are presented in Appendix-III. Two sprayings for pest and disease control treatment were received during the growth cycle.

Observations were recorded during the growth period of soybean on cloud free days between 10.30 to 12.30 hours. The biometric parameters like height, number of leaves, biomass, chlorophyll content, leaf area and spectral reflectance in four different bands were recorded by the Opto-mech Multiband Ground Truth Radiometer. In addition to this visual nutrient deficiency diagnosis was also made during the crop growth. The initial germination count, final plant population and economic yield were recorded. The plant samples and soil samples were analysed for nitrogen and phosphorus.

3.5 Spectral Observations

Opto-Mech Multiband Ground Truth Radiometer (Plate 2) having four spectral bands similar to Indian Remote Sensing Satellite (IRS-1C) were selected for collecting the data on canopy reflectance in Visible and Near Infra Red (NIR) region of Electromagnetic Radiation (EMR). The spectral bands selected were :

1.	Visible (blue-green)	:	0.45-0.52 μm
2.	Visible (green)	:	0.52-0.59 μm
3.	Visible (red)	:	0.62 – 0.68 μm
4.	Near Intra Red (NIR)	:	0.77 – 0.86 μm

The radiometric measurements were carried out using four band radiometer on cloud free days throughout the growing season. Keeping approximately 15 days interval in two observations. The radiometer was kept one meter above the canopy. All spectral data were collected in between 10.00 to 12.30 hrs Indian standard time in direct sunlight. Irradiance from Barium sulphate standard was measured after each radiance measurements and it was used to calculate the canopy reflectance.

3.6 Collection of Soil and Plant Samples and Analysis

The soil samples were collected from 0-20 cm depth and dried in shade. The samples were processed, labeled and kept in clean cloth bag for further analysis. For each observation, two-soybean plants were up rooted to record biomass, Leaf Area and chlorophyll content. Same plant samples were dried and processed for chemical constituent analysis.

Methods adopted for soil and plant samples are listed in Table 1.

Table 1. Methods of soil and plant analysis

Soil Property/Nutrient	**Method**	**Reference**
Soil analysis		
pH	1:2.5 (Soil:water)	Jackson, 1973
$EC_{2.5}$	1:2.5 (Soil:water)	Jackson, 1973
$CaCO_3$	Rapid titration	Puri, 1949
Organic carbon	Wet digestion	Walkely and Black, 1934
Available nitrogen	Alkaline potassium permanganate	Subbiah and Asija, 1956
Available phosphorus	0.5 M Sodium bicarbonate.	Olsen *et al.*, 1954
Plant analysis		
Nitrogen	Micro-kjeldahls	AOAC, 1965
Phosphorus	Vanado – molybdo phosphoric acid/ spectrophotometer	Jackson, 1973
Total Chlorophyll	Acetone / Spectrophotometer.	Arnon, 1949

3.7 Spectral Indices and Statistical Analysis

3.7.1 Calculations for Spectral Indices

Two spectral indices viz. Relative Vegetative Index (RVI), and Normalized Difference Vegetative Index (NDVI) were computed for all observations. The Red (R) and Near Infrared (NIR) spectral reflectance for each treatment were transferred into RVI and NDVI ratio's.

Relative Vegetation Index (RVI)

Relative Vegetation Index is a corrected ratio of canopy reflectance in NIR (Band – B_4) over canopy reflectance in Red (Band – B_3) radiation.

Calculation of corrected NIR and R reflectance

NIR = NIR_c / NIR_b

Where, NIR_c = Canopy radiance in NIR band.

NIR_b = Irradiance on barium plate in NIR band

R = R_c / R_b

Where, R_c = Canopy radiance in red band.

R_b = Irradiance on barium plate in red band.

Relative Vegetation Index i. e. **RVI** = NIR / R

Normalized Difference Vegetation Index i. e. **NDVI** = NIR – R / NIR + R

Leaf Area Index i. e. **LAI**= Leaf Area Per Plant in cm^2 / Spacing per plant in cm^2.

3.7.2 Statistical Analysis

The data emerged out from the field experiment on spectral reflectance, biometric parameters, chlorophyll content, available soil nutrients, plant nutrient concentration, RVI ratio and NDVI were computed and exposed for design analysis and correlation regression studies. (Panse and Sukhatme 1985).

Results

Chapter 4

RESULTS

Nutrient status influences the characteristics of plant, spectral reflectance and transmittance by changing the leaf geometry, morphology, physiology and biochemistry. Excess or deficiency of an essential element such as nitrogen and phosphorus may cause visible abnormalities in pigmentation, size and shape of the leaves. Similarly, insect, pest and disease attack also influences the leaf chlorophyll content, leaf area and soil cover by leaf canopy. Considering the immense potential of Remote Sensing technique, an attempt has been made to study the spectral reflectance in relation to normal and nitrogen – phosphorus stress condition in soybean (*Glycine* max.) crop. The results obtained on various growth parameters and spectral parameters are presented in this chapter under following sub heads.

4.1 Effect of Plant Protection and Soil Fertility Levels on Physiological Parameters and Chlorophyll Content of Soybean

4.1.1 Effect of Plant Protection and Soil Fertility Levels on Germination and Final Plant Population of Soybean

4.1.2 Effect of Plant Protection and Soil Fertility Levels on Height of Soybean

4.1.3 Effect of Plant Protection and Soil Fertility Levels on Leaf Area Index (LAI) of Soybean

4.1.4 Effect of Plant Protection and Soil Fertility Levels on Total Biomass Production by Soybean

4.1.5 Effect of Plant Protection and Soil Fertility Levels on Total Chlorophyll Content of Soybean

4.2 Effect of Plant Protection and Soil Fertility Levels on Spectral Parameters of Soybean

4.2.1 Effect Plant Protection and Soil Fertility Levels on Spectral Radiance in Visible Blue - Green (B_1 : 0.45 - 0.52 μm) and Visible Green (B_2 : 0.52 – 0.59 μm) Region

4.2.2 Effect Plant Protection and Soil Fertility Levels on Relative Vegetation Index (RVI) of Soybean

4.2.3 Effect Plant Protection and Soil Fertility Levels on Normalized Difference Vegetative Index (NDVI) of Soybean

4.3 Effect of Plant Protection and Soil Fertility Levels on Chemical Constituents of Soybean

4.3.1 Effect of Plant Protection and Soil Fertility Levels on Plant Nitrogen Concentration at Various Growth Stages of Soybean

4.3.2 Effect of Plant Protection and Soil Fertility Levels on Plant Phosphorus Concentration at Various Growth Stages of Soybean

4.4 Effect of Plant Protection and Soil Fertility Levels on Available Nitrogen and Phosphorus Status of Soil after Harvest of Soybean

4.5 Effect of Plant Protection and Soil Fertility Levels on Grain Yield of Soybean

4.6 Relationship (' r ' values) and Multiple Regression (R^2) between Spectral Parameters and Physiological Parameters and Leaf Nutrient Concentrations

4.6.1 Relationship (' r ' values) between RVI and Physiological Parameters and Leaf Nutrient Concentrations

4.6.2 Relationship (' r ' values) between NDVI and Physiological Parameters and Leaf Nutrient Concentrations

4.6.3 Relationship (' r ' values) between Soybean Grain Yield and Spectral Indices

4.6.4 Multiple Regression Equations between RVI and Growth Parameters, NDVI and Growth Parameters and Grain Yield and Spectral Indices (RVI and NDVI)

4.7 Visual Effects of Various Stresses on Soybean

4.1 Effect of Plant Protection and Soil Fertility Levels on Physiological Parameters and Chlorophyll Content of Soybean

4.1.1 Effect of Plant Protection and Soil Fertility Levels on Germination and Final Plant Population of Soybean

The data on mean values of germinated seeds per plot and plant population at harvest per plot are presented in Table 2.

Table 2. Effect of plant protection and soil fertility levels on germination and final plant population of soybean

Treatments	Germinated seeds (per plot)	Plant population (per plot)
Plant protection levels		
P_1 (Without Plant protection)	872.75	857.88
P_2 (With Plant protection)	873.42	858.42
S. E. ±	0.76	0.78
C. D. at 5 %	NS	NS
Fertility levels		
F_1 N_0 P_0	870.50	855.50
F_2 N_{30}	871.00	856.00
F_3 P_{60}	871.33	856.33
F_4 N_{30} P_{60}	873.17	858.33
F_5 N_{45}	873.50	858.50
F_6 N_{60}	874.33	859.33
F_7 P_{120}	874.83	860.00
F_8 N_{60} P_{120}	876.00	861.17
S. E. ±	1.73	1.77
C. D. at 5 %	NS	NS
Interaction (P x F)		
S. E. ±	2.04	2.09
C. D. at 5 %	NS	NS
Mean	873.00	858.15

The effect of plant protection and fertility levels on germination and final plant population of soybean were found non-significant. However final plant stand was numerically higher when crop was grown under plant protection and fertilizer application.

The non significant difference in germination and final plant population of soybean suggested that the due care was taken in carrying out experimentation and no effect of germination and plant population was recorded on various physiological and spectral parameters studies in the present investigation.

4.1.2 Effect of Plant Protection and Soil Fertility Levels on Height of Soybean

The data pertaining to the effects of plant protection and soil fertility levels on plant height are presented in Table 3. It was noticed that plant protection and soil fertility levels significantly increased the plant height. The effect of plant protection levels on height of soybean showed the significant treatment differences at all growth stages. Highest plant height was recorded at 88 Days After Sowing (DAS). The plant height was increased from 13.62 cm (20 DAS) to 32.6 cm (88 DAS) in without plant protection treatment. While plant height was increased from 14.07 to 33.5 cm in plant protection treatment.

The data on effect of fertility levels on plant height are presented in Table 3 showed significant increase in height with increase in fertilizer dose. The observations recorded at 39, 55, 67, 76 and 88 DAS showed that the phosphorus application @ 60 and 120 kg P_2O_5 recorded less height as compared to 30, 45 and 60 kg nitrogen application. The results showed that nitrogen played important role in increasing plant height than phosphorus. However application of N and P in combination (N_{60} P_{120} kg ha^{-1}) found beneficial.

Table 3 Effect of plant protection and soil fertility levels on height (cm) of soybean

Treatments	Days After Sowing (DAS)					
	20	39	55	67	76	88
Plant protection levels						
P_1 (without Plant protection)	13.6	22.7	29.6	28.5	31.9	32.6
P_2 (with Plant protection)	14.0	24.5	27.6	29.7	32.6	33.5
S. E. ±	0.14	0.25	0.17	0.14	0.22	0.17
C. D. at 5 %	0.42	0.73	0.50	0.40	0.66	0.51
Fertility levels						
F_1 N_0 P_0	9.9	15.6	21.1	22.4	25.2	26.2
F_2 N_{30}	11.7	20.9	24.1	26.4	29.2	30.4
F_3 P_{60}	12.7	20.3	23.5	24.4	27.7	30.0
F_4 N_{30} P_{60}	14.0	24.2	27.1	29.3	32.4	32.9
F_5 N_{45}	14.8	26.0	28.5	30.4	35.0	35.9
F_6 N_{60}	16.0	20.3	29.4	33.5	36.5	36.4
F_7 P_{120}	15.6	25.0	29.3	31.4	34.6	35.0
F_8 N_{60} P_{120}	16.5	30.8	35.0	34.8	37.0	37.3
S. E. ±	0.29	0.51	0.35	0.28	0.45	0.35
C. D. at 5 %	0.85	1.48	1.02	0.81	1.32	1.02
Interaction (P x F)						
S. E. ±	0.41	0.72	0.49	0.40	0.64	0.50
C. D. at 5 %	NS	NS	NS	NS	NS	NS
Mean	13.84	23.6	27.2	29.7	32.2	33.1

The interaction effects of plant protection and fertility levels were significant at 88 DAS (Table 4).

It was observed that height of soybean was found to be influenced due to interaction of N and P with and without plant protection. The interaction P_2 F_8 was showed maximum height of soybean over rest of the interactions except P_2F_5, P_2F_6 and P_2F_7.

Table 4. Interaction effects of P x F on height (cm) of soybean (88 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Mean
P_1	26.13	30.2	29.6	32.46	35.5	36.0	34.5	36.7	32.6
P_2	26.36	30.7	30.4	33.2	36.3	37.9	35.6	37.9	33.5
Mean	26.2	30.4	30.0	32.8	35.9	36.9	35.0	37.3	33.1
	SE ±	0.50			CD at 5 %		1.44		

4.1.3 Effect of Plant Protection and Soil Fertility Levels on Leaf Area Index (LAI) of Soybean

The effects of plant protection levels and soil fertility levels on leaf area index were recorded from 39 DAS to 88 DAS. The computed data are presented in Table 5.

It was evidenced that leaf area index of soybean was increased at all growth stages due to plant protection measures. The increase was to the extent of 7 to 10 per cent. However the treatment difference could not reach to the level of significance.

Application of various doses of nitrogen and phosphorus alone and in combination showed increase in LAI of soybean. The minimum LAI was observed in control treatment at 39 DAS while maximum LAI recorded at 88 DAS in the treatment consisting both nitrogen and phosphorus (60 kg and 120 kg P_2O_5 ha^{-1}). Further scrutiny of data revealed the steady increase in LAI with increase in N and P levels alone and in combination.

Table 5 Effect of plant protection and soil fertility levels on Leaf Area Index (LAI) of soybean

Treatments	Days After Sowing (DAS)				
	39	55	67	76	88
Plant protection levels					
P_1 (without Plant protection)	0.91	1.39	2.48	2.85	2.88
P_2 (with Plant protection)	0.98	1.49	2.58	2.92	3.08
S. E. ±	0.005	0.007	0.11	0.19	0.14
C. D. at 5 %	NS	NS	NS	NS	NS
Fertility levels					
F_1 N_0 P_0	0.65	0.99	1.86	2.18	2.21
F_2 N_{30}	0.82	1.12	2.21	2.47	2.35
F_3 P_{60}	0.88	1.20	2.33	2.54	2.63
F_4 N_{30} P_{60}	0.92	1.27	2.39	2.86	2.79
F_5 N_{45}	0.94	1.46	3.42	3.03	2.96
F_6 N_{60}	1.00	1.60	2.70	3.25	3.32
F_7 P_{120}	1.14	1.81	2.70	3.26	3.51
F_8 N_{60} P_{120}	1.25	2.06	3.62	4.08	3.68
S. E. ±	0.10	0.14	0.23	0.39	0.29
C. D. at 5 %	0.29	0.40	0.67	1.13	0.84
Interaction (P x F)					
S. E. ±	0.14	0.19	0.32	0.55	0.41
C. D. at 5 %	NS	NS	NS	NS	1.19
Mean	0.95	1.44	2.53	2.88	2.98

Final observation showed that N_{60} P_{120} treatment was statistically superior over rest of the treatments. The application of 60 and 120 kg P_2O_5 and 45 and 60 kg nitrogen per hectare alone were statistically on par with each other.

The interaction effects due to plant protection and fertility levels found significant at 88 DAS (Table 6). Significantly higher LAI was found in P_2F_8 treatment. However, it was at par with P_2F_6, P_2F_7, P_1F_6, P_1F_7 and P_1F_8 Interactions.

The graphical representation of effects of plant protection and fertility levels on leaf area index were depicted in Figure 2 and Figure 3, respectively.

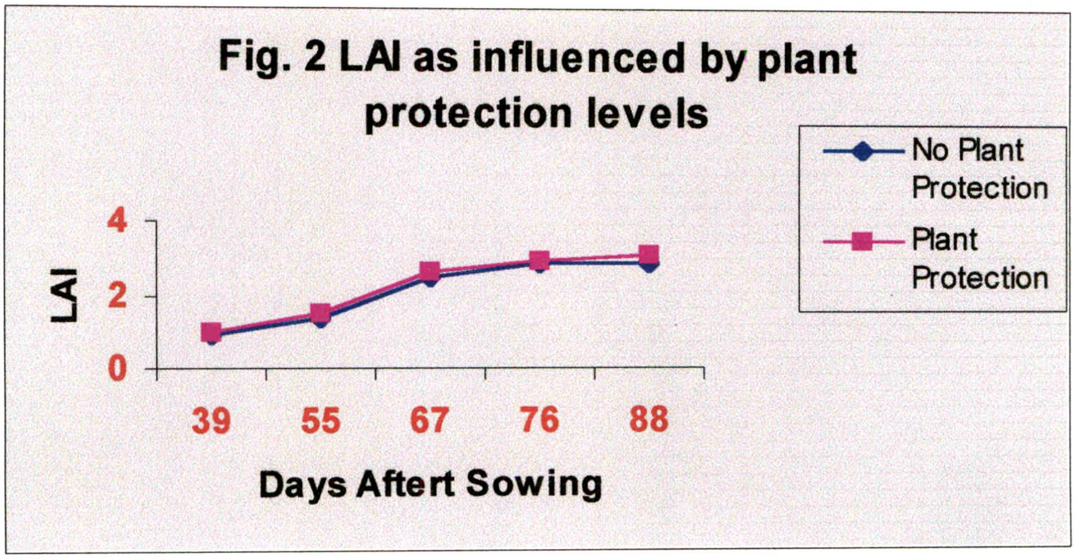

Fig. 2 LAI as influenced by plant protection levels
No Plant Protection
Plant Protection
LAI
4
2
0
39
55
67
76
88
Days Aftert Sowing

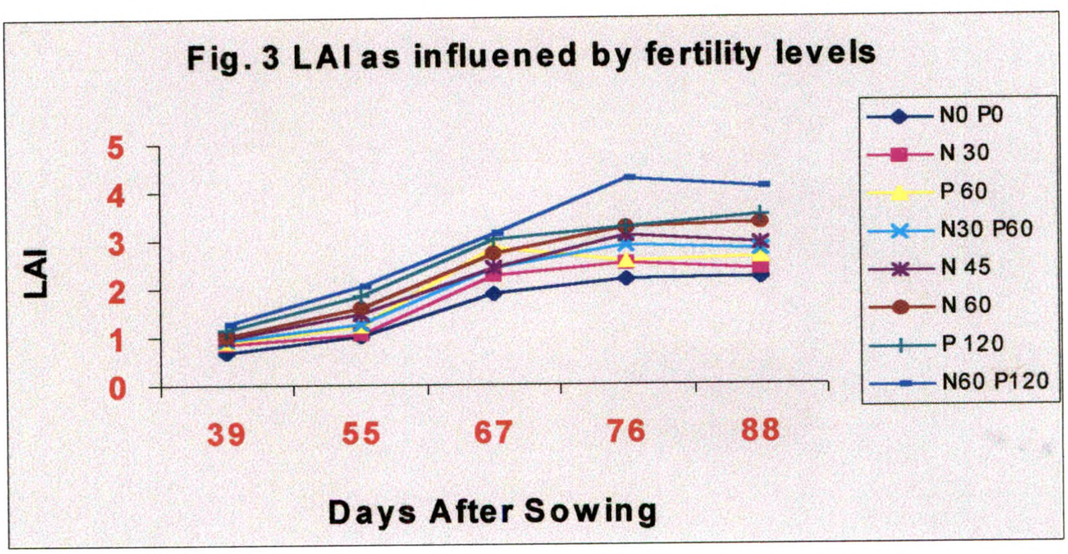

Fig. 3 LAI as influened by fertility levels
N0 P0
N 30
P 60
N30 P60
N 45
N 60
P 120
N60 P120
LAI
5
4
3
2
1
0
39
55
67
76
88
Days After Sowing

It was very clear that LAI was not much influenced due to plant protection levels up to 67 DAS (Fig. 2). This may be because of very low pest and disease incidence observed during the growth period of soybean. However at later growth stages i.e. 88 DAS application of plant protection out yielded the treatment without plant protection in leaf area index.

Table 6 Interaction effects of P_o x F on Leaf Area Index (LAI) of soybean (88 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Mean
P_1	2.15	2.27	2.55	2.77	2.86	3.29	3.37	3.79	2.88
P_2	2.27	2.44	2.71	2.81	3.05	3.35	3.64	4.36	3.08
Mean	2.21	2.35	2.63	2.79	2.96	3.32	3.51	4.08	2.98
	SE $\pm$	0.413			CD at 5 %		1.19		

Figure 3 shows the effect of fertility levels on LAI. The cluster of lines depicting various fertility levels showed higher leaf area index over control treatment at all growth stages. However the distinguishable differences among the treatments were observed at 55, 76 and 88 DAS. These growth stages are fall at shifting vegetative growth stages.

4.1.4 Effect of Plant Protection and Soil Fertility Levels on Total Biomass Production by Soybean

The data in Table 7 presents the effect of plant protection levels on total biomass production of soybean at various growth stages.

The total biomass produced by soybean crop was not affected due to plant protection levels up to 76 DAS. However there was numerical increase in biomass production at 39, 55 and 67 DAS. At pod filling stage (88 DAS) adoption of plant protection measures significantly increased the total biomass production over unprotected crop.

Table 7 Effect of plant protection and soil fertility levels on total biomass (g plant^{-1}) of soybean

Treatments	Days After Sowing (DAS)				
	39	55	67	76	88
Plant protection levels					
P_1 (without Plant protection)	8.5	14.6	42.2	78.6	94.1
P_2 (with Plant protection)	9.1	15.9	43.9	86.0	107.4
S. E. ±	0.46	0.81	3.00	4.30	2.20
C. D. at 5 %	NS	NS	NS	NS	6.30
Fertility levels					
F_1 N_0 P_0	5.5	9.7	29.9	39.5	64.6
F_2 N_{30}	6.8	13.3	33.5	55.0	77.3
F_3 P_{60}	7.4	13:6	34.1	64.8	82.7
F_4 N_{30} P_{60}	7.6	14.6	40.7	75.8	95.2
F_5 N_{45}	8.5	16.6	44.1	88.2	104.3
F_6 N_{60}	9.9	17.1	49.6	99.0	113.3
F_7 P_{120}	11.8	17.6	54.2	111.3	126.5
F_8 N_{60} P_{120}	13.2	20.3	58.4	112.3	132.1
S. E. ±	0.93	1.6	6.0	8.6	4.3
C. D. at 5 %	2.68	4.70	17.1	24.6	12.5
Interaction (P x F)					
S. E. ±	1.3	2.3	8.4	12.0	6.1
C. D. at 5 %	NS	NS	NS	NS	NS
Mean	8.8	15.2	43.1	82.3	100.2

Effect of soil fertility levels on total biomass production found statistically significant at all growth stages. The higher values of biomass production recorded at 88 DAS and the values were low in earlier growth stages. Further, higher values of biomass 1 32, 2 03, 5 84, 11 23 and 14 21 at 39, 55, 67, 76 and 88 DAS were observed in the treatment N_{60} P_{120}, respectively and the lowest in N_0P_0. The application of nitrogen and phosphorus in combination showed its superiority over single nutrient application.

The interaction effects observed at 88 DAS are presented in Table 8. It was revealed that the soybean crop received 60 kg nitrogen and 120 kg phosphorus per hectare with adoption of plant protection measures produced highest biomass.

Table 8 Interaction effects of P_0x F on total biomass (g plant^{-1}) production of soybean (88 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Mean
P_1	57.30	72.73	78.50	90.53	101.0	102.9	115.6	134.3	94.1
P_2	71.83	77.3	86.8	99.8	107.6	123.5	137.4	149.9	107.4
Mean	64.6	77.3	82.7	95.2	104.3	113.3	126.5	142.1	100.2
	SE ±	6.13			CD at 5 %		17.7		

4.1.5 Effect of Plant Protection and Soil Fertility Levels on Total Chlorophyll Content of Soybean

The Table 9 showed the effect of plant protection and N and P application on total chlorophyll content. It was noticed that at all growth stages except 76 DAS the treatment differences found non-significant. However numerical increase in chlorophyll was observed in P_2 (with plant protection) up to grand growth period (67 DAS) and decreased there after.

The effect of fertility levels on total chlorophyll content indicated that chlorophyll content was increased upto grand growth period. At 39 DAS the maximum chlorophyll content found in treatment $N_{60}P_{120}$. However treatment N_{60}, P_{120} and $N_{60}P_{120}$ found at par with each other. Though lowest chlorophyll was found in control it was at par with N_{30} and P_{60}. The treatment P_{60}, N_{30} P_{60}, N_{45} and N_{60} were equally effective in chlorophyll synthesis.

Table 9. Effect of plant protection and soil fertility levels on total chlorophyll content (mg g^{-1}) of soybean

Treatments	Days After Sowing (DAS)				
	39	55	67	76	88
Plant protection levels					
P_1 (without Plant protection)	1.71	2.19	3.54	2.39	2.03
P_2 (with Plant protection)	1.81	2.30	3.72	2.54	2.17
S. E. ±	0.00	0.00	0.10	0.00	0.00
C. D. at 5 %	NS	NS	NS	0.049	NS
Fertility levels					
F_1 N_0 P_0	1.39	1.45	2.89	1.85	1.60
F_2 N_{30}	1.56	1.96*	3.07	2.00	1.77
F_3 P_{60}	1.61	2.05	3.27	2.25	1.93
F_4 N_{30} P_{60}	1.66	2.28	3.51	2.45	2.03
F_5 N_{45}	1.77	2.38	3.75	2.54	2.17
F_6 N_{60}	1.84	2.47	3.90	2.69	2.23
F_7 P_{120}	2.03	2.63	4.16	2.81*	2.39
F_8 N_{60} P_{120}	2.22	2.77	4.50	3.13*	2.70
S. E. ±	0.074	0.12	0.21	0.034	0.16
C. D. at 5 %	0.21	0.33	0.60	0.098	0.47
Interaction (P x F)					
S. E. ±	0.10	0.16	0.29	0.00	0.22
C. D. at 5 %	NS	NS	NS	0.14	NS
Mean	1.76	2.25	3.63	2.47	2.10

At 55 DAS soybean crop with 60 kg nitrogen and 120 kg phosphorus recorded significantly higher chlorophyll content over rest of the treatments except P_{120}, N_{45} and N_{60}. The lowest chlorophyll content (1.45 mg g^{-1}) was observed in control treatment. It was further increased with application of N, P and N+P. There was sharp increase in chlorophyll content from 2.25 mg g^{-1} to 3.6 mg g^{-1} at 67 DAS and there after the chlorophyll content was decreased.

The chlorophyll value at 67 DAS and 88 DAS were found statistically non significant. The treatment N_0P_0, N_{30}, P_{60} and N_{30} P_{60} were at par with each other at both growth stages. The treatment N_{30} P_{60}, N_{45}, N_{60} and P_{120} were also on par with each other however significantly superior over control.

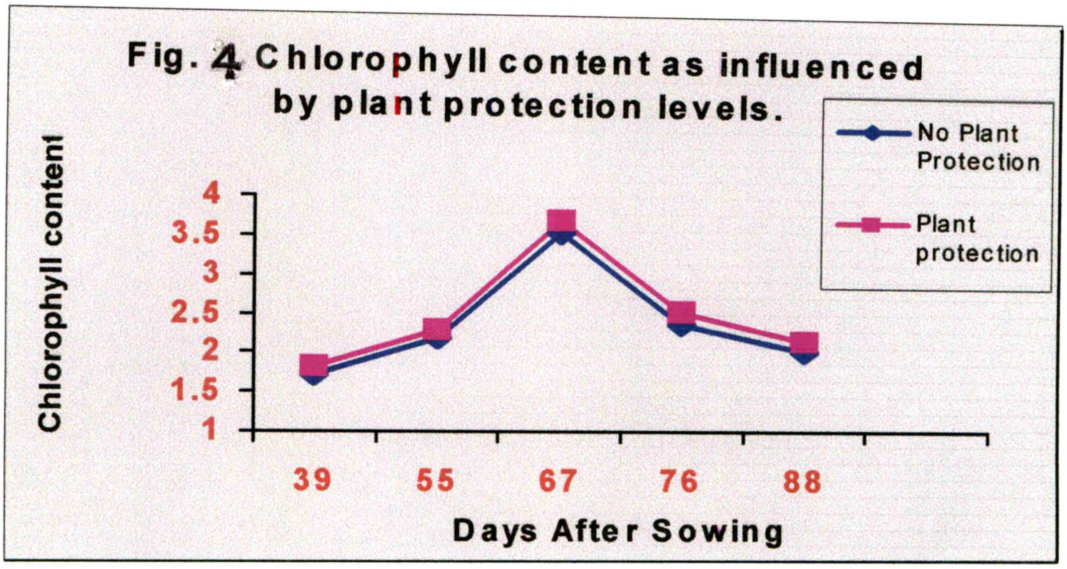

Fig. 4 Chlorophyll content as influenced by plant protection levels.

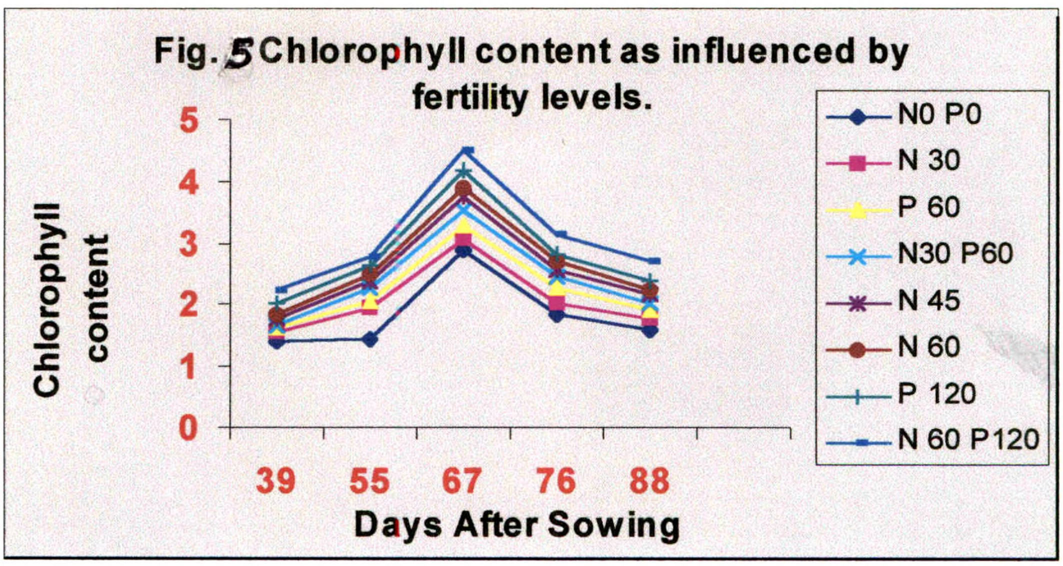

Fig. 5 Chlorophyll content as influenced by fertility levels.

The higher chlorophyll content was recorded by N_{60} P_{120} and was at par with P_{120}.

The interaction effects (Table 10) due to plant protection measure and fertility levels on total chlorophyll content at 67 DAS showed significant differences. Interaction P_2F_8 showed maximum total chlorophyll content (4.70 mg g^{-1}) over rest of the interactions except P_2F_3, P_2F_4, P_2F_5, P_2F_6, P_2F_7 and P_1F_4, P_1F_5, P_1F_6, P_1F_7 and P_1F_8 which were at par with each other.

Table 10 Interaction effects of P_o x F on total chlorophyll content of soybean (67 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Mean
P_1	2.77	3.07	3.09	3.42	3.74	3.82	4.14	4.30	3.54
P_2	3.00	3.08	3.44	3.61	3.76	3.97	4.17	4.70	3.72
Mean	2.89	3.07	3.27	3.51	3.75	3.90	4.16	4.50	3.63
	SE ±	0.29			CD at 5 %		0.85		

Effect of plant protection levels and fertility levels on total chlorophyll content was presented in Figure 4 and Figure 5. There is no much variation in chlorophyll content due to plant protection up to 55 DAS. However there after variation in chlorophyll content due to adoption of plant protection measures was noticed. Sharp increase in chlorophyll content was observed at 67 DAS and differences were more clear at 76 and 88 DAS.

Effect of various levels of fertility on chlorophyll content demonstrated in Figure 5. The soybean crop fertilized with nitrogen, phosphorus and nitrogen + phosphorus showed more chlorophyll content than control (i.e. no fertilizer application). The over all effect of fertilizer application over no application was more distinguishable at 55 DAS. Where as the treatment received 60 kg Nitrogen and 120 kg phosphorus produced distinguishable differences over rest of the treatments after 67 DAS.

4.2 Effect of Plant Protection and Soil Fertility Levels on Spectral Parameters of Soybean

4.2.1 Effect of Plant Protection and Soil Fertility Levels on Spectral Radiance in Visible Blue - Green Region (B_1 : 0.45 – 0.52 μm) and Visible Green (B_2 0.52 – 0.59 μm) Region

Table 11 indicate the effect of plant protection and soil fertility levels on spectral radiance in visible blue green band (0.45 – 0.52 μm).

The spectral radiance for P_1 (without plant protection) and P_2 (with plant protection) at various growth stages did not show variation. This suggest that visible blue green region of Electro Magnetic Region is not suitable to discriminate the effect of plant protection on vegetation.

Table 11 Effect of plant protection and soil fertility levels on spectral radiance (B : 0.45 – 0.52 μm)

Treatments	Days After Sowing (DAS)				
	39	**55**	**67**	**76**	**88**
Plant protection levels					
P_1 (without Plant protection)	0.090	0.104	0.124	0.114	0.097
P_2 (with Plant protection)	0.090	0.105	0.125	0.115	0.099
S. E. ±	0.003	0.001	0.002	0.003	0.001
C. D. at 5 %	NS	NS	NS	0.049	NS
Fertility levels					
F_1 N_0 P_0	0.078	0.090	0.102	0.104	0.090
F_2 N_{30}	0.080	0.095	0.102	0.108	0.088
F_3 P_{60}	0.083	0.102	0.108	0.112	0.092
F_4 N_{30} P_{60}	0.090	0.103	0.133	0.114	0.098
F_5 N_{45}	0.090	0.104	0.133	0.117	0.098
F_6 N_{60}	0.097	0.107	0.135	0.118	0.105
F_7 P_{120}	0.103	0.108	0.150	0.118	0.105
F_8 N_{60} P_{120}	0.121	0.108	0.158	0.120	0.108
S. E. ±	0.006	0.002	0.005	0.006	0.002
C. D. at 5 %	0.018	0.006	0.017	NS	0.007
Interaction (P x F)					
S. E. ±	0.008	0.003	0.008	0.009	0.003
C. D. at 5 %	NS	NS	NS	NS	NS
Mean	0.090	0.103	0.125	0.115	0.098

The effect of fertility levels on visible blue green spectral radiance presented in Table 12, revealed that at all growth stages except 76 DAS the spectral values were significantly affected due to application of nitrogen and phosphorus alone or in combination. The spectral values were increased upto 67 DAS and decreased there after. Adoption of plant protection measures and nitrogen and phosphorus application did not show any response for spectral parameter B_2 : 0.52 to 0.59 um (Table 12). Through out the crop growth cycle the results were non consistence. From these results it is inferred that these spectral regions of Electromagnetic radiation (0.45 – 0.52 µm and 0.52 – 0.59 µm) were not capable for detecting the effect of plant protection and nutrient stress exhibited by soybean crop.

Table 12 Effect of plant protection and soil fertility levels on spectral radiance (B_2 : 0.52 – 0.59 µm).

Treatments	**Days After Sowing (DAS)**				
	39	**55**	**67**	**76**	**88**
Plant protection levels					
P_1 (without Plant protection)	0.090	0.089	0.082	0.084	0.097
P_2 (with Plant protection)	0.090	0.093	0.089	0.086	0.101
S. E. ±	0.004	0.001	0.002	0.001	0.014
C. D. at 5 %	NS	NS	NS	NS	NS
Fertility levels					
F_1 N_0 P_0	0.070	0.078	0.073	0.068	0.083
F_2 N_{30}	0.083	0.084	0.075	0.075	0.085
F_3 P_{60}	0.092	0.093	0.080	0.080	0.095
F_4 N_{30} P_{60}	0.100	0.090	0.082	0.080	0.100
F_5 N_{45}	0.100	0.090	0.086	0.090	0.100
F_6 N_{60}	0.105	0.933	0.090	0.093	0.097
F_7 P_{120}	0.107	0.975	0.095	0.095	0.105
F_8 N_{60} P_{120}	0.115	0.100	0.102	0.097	0.105
S. E. ±	0.004	0.002	0.005	0.003	0.002
C. D. at 5 %	0.017	0.008	0.015	0.010	0.008
Interaction (P x F)					
S. E. ±	0.002	0.004	0.007	0.005	0.004
C. D. at 5 %	NS	NS	NS	NS	NS
Mean	0.090	0.090	0.085	0.085	0.099

4.2.2 Effect of Plant Protection and Soil Fertility Levels on Relative Vegetation Index (RVI) of Soybean

The relative vegetative index a spectral parameters was calculated by taking a spectral radiance for each treatment in red region Band 3 (0.62 to 0.67 μm) and near infra red region (Band 4 : 0.77 to 0.87 μm).

The infra Red/Red reflectance ratio (Relative Vegetation Index RVI) has been shown to be related to variations in plant protection levels (Table 13).

Table 13 Effect of plant protection and soil fertility levels on relative vegetation index (RVI) of soybean.

Treatments	Days After Sowing (DAS)				
	39	55	67	76	88
Plant protection levels					
P_1 (without Plant protection)	3.01	3.96	5.98	4.24	3.53
P_2 (with Plant protection)	3.20	4.23	6.50	4.69	3.79
S. E. ±	0.11	0.16	0.21	0.20	0.10
C. D. at 5 %	NS	NS	NS	NS	NS
Fertility levels					
F_1 N_0 P_0	1.73	2.87	3.75	3.00	2.76
F_2 N_{30}	2.17	3.07	3.98	3.42	2.92
F_3 P_{60}	2.44	3.29	4.96	3.77	3.12
F_4 N_{30} P_{60}	2.85	3.97	5.82	3.90	3.35
F_5 N_{45}	3.14	4.07	6.97	4.36	3.96
F_6 N_{60}	3.61	4.37	7.49	4.69	4.12
F_7 P_{120}	4.09	5.42	7.92	5.89	4.46
F_8 N_{60} P_{120}	4.80	5.70	9.06	6.66	4.56
S. E. ±	0.22	0.32	0.43	0.41	0.20
C. D. at 5 %	0.66	0.95	1.23	1.19	0.56
Interaction (P x F)					
S. E. ±	0.32	0.46	0.60	0.58	0.27
C. D. at 5 %	NS	NS	NS	NS	NS
Mean	3.10	4.09	6.24	4.46	3.65

There was numerical increase in RVI from 3.01 to 3.20, 3.96 to 4.23, 5.98 to 6.50, 4.24 to 4.69 and 3.53 to 3.78 at 39, 55, 67, 76 and 88 DAS. The maximum RVI under protected (6.50) and unprotected (5.98) crop was recorded at 67 DAS. However the effect of plant protection measures on RVI at all growth stages were not reached to the level of significance. The statistical non significance is the effect of low pest and disease attack on the soybean crop. However little variation in canopy due to plant protection measures also depicted by spectral parameter (RVI).

The Relative Vegetation Index as influenced by various fertility levels at various growth stages of soybean are presented in Table 13. It was indicated that nutrient deficient soybean crop (No N and No P) had much lower NIR/R ratio compared to the fertilized one, at all growth stages. It was also observed that application of nitrogen to soybean had relatively higher RVI values than P application. RVI values were progressively increased up to grand growth period of soybean i.e. up to 67 DAS and there after there was progressive decrease in RVI in all fertility levels. This may be because of higher red reflectance and lower IR reflectance for N and P deficient crop. Among the fertility treatments application of double dose of recommended N + P (N_{60} P_{120}) showed significantly higher RVI over rest of the treatments except the crop fertilized with P_{120} kg P_2O_5 ha^{-1}.

The interaction effects due to P_0 x F at on RVI grand growth stage (67 DAS) are presented in Table 14. The results revealed that the interaction P_2F_8 had maximum RVI followed by P_1F_8, P_2F_7, P_1F_7, P_2F_6 and P_2F_5, P_1F_6.

Table 14. Interaction effects of P_0 x F on RVI (67 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	Mean
P_1	3.68	3.95	4.68	5.58	5.59	7.28	7.72	8.91	5.98
P_2	3.81	4.00	5.22	6.05	7.94	7.68	8.11	9.20	6.50
Mean	3.75	3.98	4.96	5.82	6.97	7.49	7.92	9.06	6.24
	SE ±	0.60			CD at 5 %		1.74		

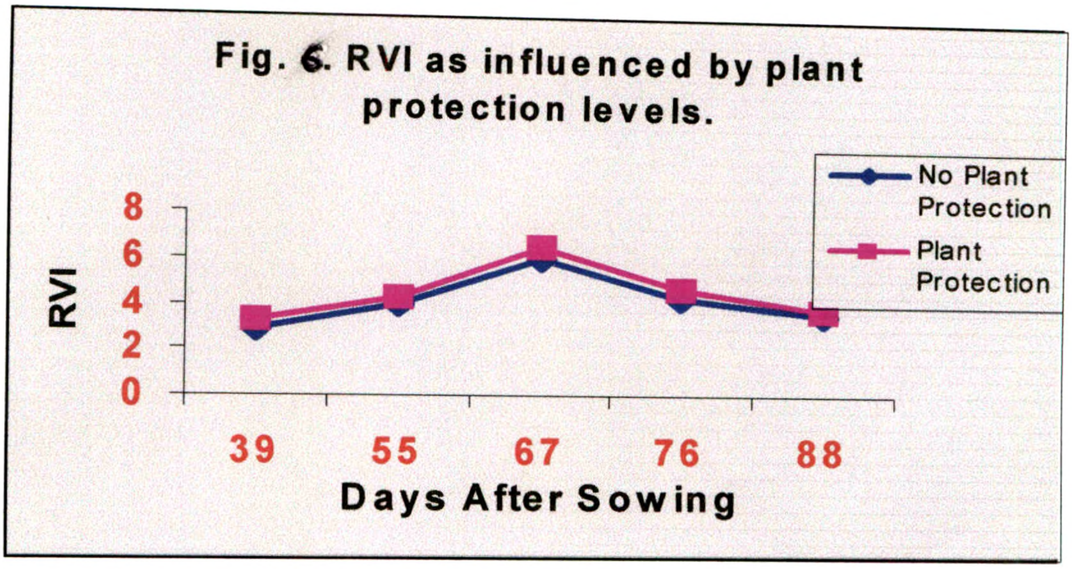

Fig. 6. RVI as influenced by plant protection levels.

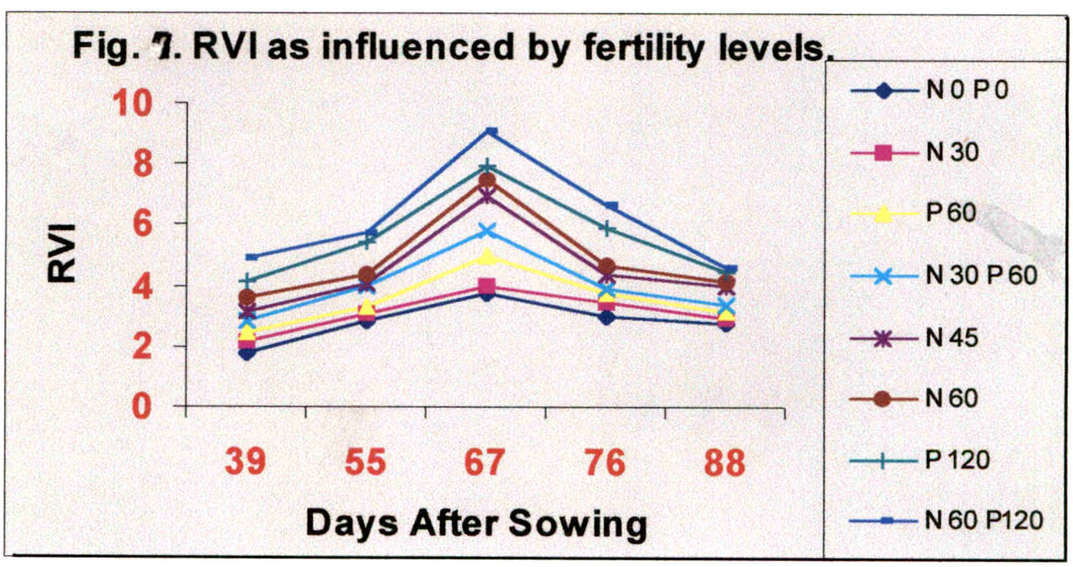

Fig. 7. RVI as influenced by fertility levels.

Effects of plant protection levels on RVI of soybean are visualized in Figure 6. Though the application of plant protection treatment recorded relatively higher RVI, the differences are not very clear. At senescence stage (88 DAS) both the treatments did not show variation due to plant protection.

Nitrogen, phosphorus and N + P fertilizer application to soybean and its effects on RVI are demonstrated in Figure 7 upto 76 DAS. Nutrient deficient crop had much lower NIR/R ratio compared to fertilized one. The variation in RVI due to nitrogen and phosphorus fertilized soybean was observable between 55 to 76 DAS. In all treatments RVI was declined after 67 DAS.

4.2.3 Effect of Plant Protection and Soil Fertility Levels on Normalized Difference Vegetative Index (NDVI) of Soybean

The Normalized Difference Vegetative Index computed from NIR and R radiance of soybean crop for normal and nutrient stress condition are presented in Table 15.

There was significant variation in NDVI due to plant protection at 88 DAS. Where in protecting the soybean crop against pest and diseases recorded significantly higher RVI (0.570) than unprotected soybean crop (0.528). While, rest of the growth stages the differences were non significant.

Data presented in Table 15 showed the effects of fertility levels on NDVI. It was very clear that application of N + P in combination (N_{60} P_{120}) out yielded NDVI in all observations. The second best position was acquired by treatment of phosphorus application @ 120 kg P_2O_5 ha^{-1} over other treatments. The NDVI values were minimum at 39 DAS and maximum up to 67 DAS. The significant variation in NDVI was attributed to role of N and P on growth parameters viz. Chlorophyll, LAI, biomass of soybean.

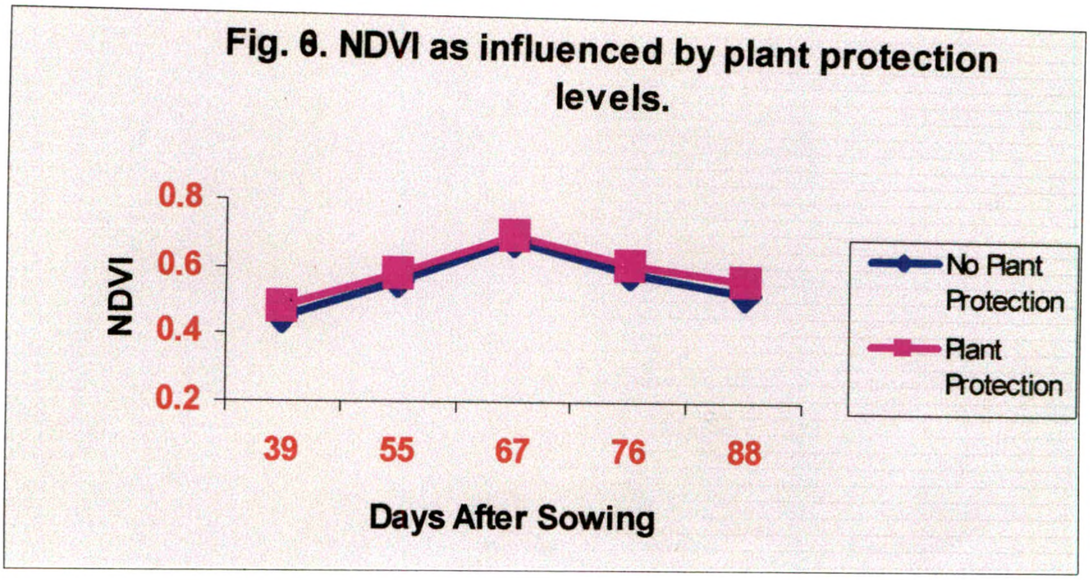
Fig. 8. NDVI as influenced by plant protection levels.
0.8
0.6
0.4
0.2
NDVI
39
55
67
76
88
Days After Sowing
No Plant Protection
Plant Protection

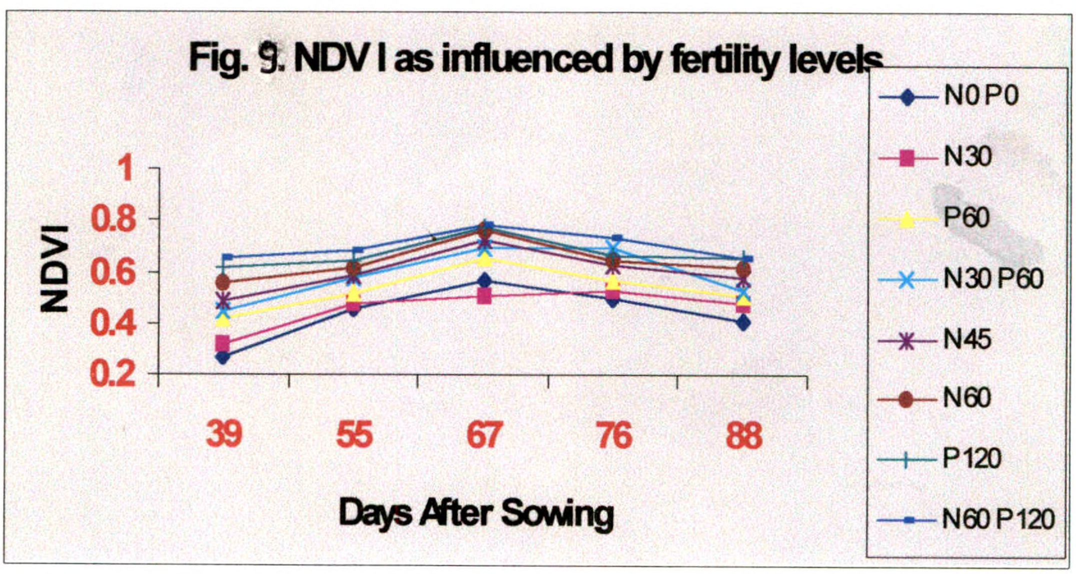
Fig. 9. NDV I as influenced by fertility levels
1
0.8
0.6
0.4
0.2
NDVI
39
55
67
76
88
Days After Sowing
N0 P0
N30
P60
N30 P60
N45
N60
P120
N60 P120

The interaction effects due to plant protection x fertility levels are presented in Table 16. The results showed non significant variation.

Table 15 Effect of plant protection and soil fertility levels on Normalized Difference Vegetative Index (NDVI) of soybean.

Treatments	Days After Sowing (DAS)				
	39	55	67	76	88
Plant protection levels					
P_1 (without Plant protection)	0.452	0.560	0.682	0.591	0.528
P_2 (with Plant protection)	0.480	0.577	0.700	0.610	0.570
S. E. ±	0.015	0.011	0.008	0.009	0.009
C. D. at 5 %	NS	NS	NS	NS	0.026
Fertility levels					
F_1 N_0 P_0	0.267	0.461	0.567	0.493	0.408
F_2 N_{30}	0.320	0.485	0.583	0.525	0.483
F_3 P_{60}	0.412*	0.515	0.650	0.567	0.508
F_4 N_{30} P_{60}	0.440	0.585	0.695	0.587	0.523
F_5 N_{45}	0.483	0.583	0.723	0.617	0.580
F_6 N_{60}	0.553	0.603	0.752	0.633	0.602
F_7 P_{120}	0.602	0.638	0.755	0.658	0.642
F_8 N_{60} P_{120}	0.650	0.675	0.788	0.723	0.643
S. E. ±	0.031	0.022	0.016	0.019	0.018
C. D. at 5 %	0.090	0.063	0.047	0.056	0.053
Interaction (P x F)					
S. E. ±	0.044	0.030	0.023	0.027	0.025
C. D. at 5 %	NS	NS	NS	NS	NS
Mean	0.46	0.57	0.69	0.60	0.57

The variations in NDVI values over the complete growth cycle for protected and unprotected soybean are presented in Figure 8. It was observed that the protected and unprotected soybean crop could not be discriminated by NDVI ratio.

The spectral discriminability of the normal crop (fertilized) and nutrient stressed crop (unfertilized) varied over the season (Figure 8, 9). All the fertilized treatments showed higher NDVI than the control (No N and P application). Further it was maximum during the period corresponding to the stage of maximum vegetative development.

Table 16 Interaction effects of P x F on NDVI (67 DAS)

Plant protection	Fertility levels								
	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	**Mean**
P_1	0.56	0.58	0.64	0.69	0.71	0.75	0.73	0.79	0.68
P_2	0.57	0.59	0.66	0.70	0.74	0.77	0.78	0.78	0.70
Mean	0.56	0.58	0.65	0.69	0.72	0.76	0.75	0.78	0.69
	SE ±	0.023			CD at 5 %		0.069		

4.3 Effect of Plant Protection and Soil Fertility Levels on Chemical Constituents of Soybean

4.3.1 Effect of Plant Protection and Soil Fertility Levels on Plant Nitrogen Concentration at Various Growth Stages of Soybean

Data presented in Table 17 showed the effect of plant protection levels and soil fertility levels on plant nitrogen concentration at various growth stages.

The plant protection levels could not showed significant effect on N concentration of leaves at 39 DAS.

Where as significant difference in P_1 (without plant protection measure) and P_2 (with plant protection measure) were noticed at 67 and 88 DAS. Further it was observed that adoption of plant protection level increase the nitrogen uptake at later growth stages.

The effect of fertility levels on plant nitrogen concentration also found non significant at 39 DAS. As growth proceeds the treatment difference showed significant results. The concentration of nitrogen increased gradually with increase in level of N and P fertilizer application.

Table 17 Effect of plant protection and soil fertility levels on plant nitrogen concentration (%) at various growth stages of soybean.

Treatments	Days After Sowing (DAS)		
	39	67	88
Plant protection levels			
P_1 (without Plant protection)	0.558	0.80	0.95
P_2 (with Plant protection)	0.567	0.86	0.99
S. E. ±	0.013	0.004	0.005
C. D. at 5 %	NS	0.014	0.001
Fertility levels			
F_1 N_0 P_0	0.519	0.781	0.885
F_2 N_{30}	0.534	0.789	0.901
F_3 P_{60}	0.523	0.779	0.892
F_4 N_{30} P_{60}	0.550	0.822	0.931
F_5 N_{45}	0.575	0.850	0.967
F_6 N_{60}	0.584	0.865	1.013
F_7 P_{120}	0.594	0.866	1.074
F_8 N_{60} P_{120}	0.609	0.873	1.121
S. E. ±	0.026	0.009	0.010
C. D. at 5 %	NS	0.028	0.030
Interaction (P x F)			
S. E. ±	0.037	0.014	0.015
C. D. at 5 %	NS	NS	NS
Mean	0.562	0.830	0.970

Interaction effect of plant protection and fertility levels were non significant for leaf nitrogen concentration.

4.3.2 Effect of Plant Protection and Soil Fertility Levels on Plant Phosphorus Concentration at Various Growth Stages of Soybean

The data presented in Table 18 showed phosphorus concentration in soybean crop at various growth stages as affected by plant protection and fertility levels.

Table 18 Effect of plant protection and soil fertility levels on plant phosphorus concentration (%) at various growth stages of soybean.

Treatments	Days After Sowing (DAS)		
	39	67	88
Plant protection levels			
P_1 (without Plant protection)	0.134	0.169	0.203
P_2 (with Plant protection)	0.145	0.177	0.203
S. E. ±	0.001	0.001	0.004
C. D. at 5 %	0.004	0.004	NS
Fertility levels			
F_1 N_0 P_0	0.110	0.123	0.170
F_2 N_{30}	0.125	0.137	0.176
F_3 P_{60}	0.128	0.147	0.190
F_4 N_{30} P_{60}	0.134	0.173	0.201
F_5 N_{45}	0.143	0.186	0.208
F_6 N_{60}	0.152	0.192	0.211
F_7 P_{120}	0.162	0.211	0.223
F_8 N_{60} P_{120}	0.167	0.216	0.243
S. E. ±	0.002	0.003	0.008
C. D. at 5 %	0.008	0.009	0.023
Interaction (P x F)			
S. E. ±	0.004	0.004	0.012
C. D. at 5 %	NS	NS	NS
Mean	0.140	0.173	0.203

It was noticed that adoption of plant protection measure showed significant treatment differences over control for phosphorus concentration in soybean crop. The phosphorus concentration recorded higher at 88 DAS (0.203 per cent) however there is no change in phosphorus concentration in P_1 and P_2 treatment.

Application of nitrogen and phosphorus alone or in combination significantly increased the phosphorus concentration at all growth stages. The highest values of phosphorus concentration was recorded at 88 DAS (0.243 and 0.170 in treatment N_{60} P_{120} and No N + P application, respectively).

The interaction effects (P_o x F) on phosphorus concentration were non significant.

4.4 Effect of Plant Protection and Soil Fertility Levels on Available Status of Nitrogen and Phosphorus in Soil after Harvesting of Soybean Crop.

The data on effect of plant protection and soil fertility levels on available status of nitrogen in soil after harvesting of soybean crop are presented in Table 19.

The data showed that adoption of plant protection measure increased the available nitrogen in soil (up to 164.0 kg ha^{-1}). The treatment difference due plant protection measure could not reach to significant level.

The data on effect of fertility levels on available nitrogen are presented in Table 19. It was observed that each level of increment of N and P increased the available status of nitrogen in soil.

Table 19 Effect of plant protection and soil fertility levels on available nitrogen in soil after harvesting of soybean.

Treatments	Nitrogen kg ha^{-1}
Plant protection levels	
P_1 (without Plant protection)	160.50
P_2 (with Plant protection)	164.00
S. E. ±	2.64
C. D. at 5 %	NS
Fertility levels	
F_1 N_0 P_0	109.12
F_2 N_{30}	125.67
F_3 P_{60}	148.06
F_4 N_{30} P_{60}	150.92
F_5 N_{45}	163.95
F_6 N_{60}	175.21
F_7 P_{120}	178.58
F_8 N_{60} P_{120}	249.53
S. E. ±	5.29
C. D. at 5 %	1.52
Interaction (P x F)	
S. E. ±	7.48
C. D. at 5 %	NS
Mean	162.6

The interaction effect of P_ox F found non significant for available nitrogen status in soil after harvesting of soybean crop.

The data on effect of plant protection levels on available phosphorus in soil after harvesting of soybean crop are presented in Table 20.

It was indicated that adoption of plant protection measures significantly increased the available phosphorus over control (without plant protection).

The effect of soil fertility levels on available phosphorus in soil showed that available phosphorus increased with application of nitrogen and phosphorus alone or in combination.

Table 20 Effect of plant protection and soil fertility levels on available phosphorus in soil after harvesting of soybean.

Treatments	Phosphorus (kg ha^{-1})
Plant protection levels	
P_1 (without Plant protection)	6.78
P_2 (with Plant protection)	7.73
S. E. ±	0.29
C. D. at 5 %	0.84
Fertility levels	
F_1 N_0 P_0	2.41
F_2 N_{30}	3.50
F_3 P_{60}	4.58
F_4 N_{30} P_{60}	6.44
F_5 N_{45}	6.41
F_6 N_{60}	7.95
F_7 P_{120}	10.82
F_8 N_{60} P_{120}	15.93
S. E. ±	0.59
C. D. at 5 %	1.69
Interaction (P x F)	
S. E. ±	0.82
C. D. at 5 %	NS
Mean	7.26

4.5 Effect of Plant Protection and Soil Fertility Levels on Grain Yield of Soybean

Table 21 showed the effect of plant protection on grain yield of soybean. It was noticed that adoption of plant protection measures significantly increased the grain yield over plant managed without plant protection. The effect of fertility levels on grain yield of soybean presented in Table 21.

Table 21 Effect of plant protection and soil fertility levels on grain yield of soybean.

Treatments	Phosphorus (kg ha^{-1})
Plant protection levels	
P_1 (without Plant protection)	1069.94
P_2 (with Plant protection)	1143.10
S. E. $\pm$	12.80
C. D. at 5 %	35.66
Fertility levels	
F_1 N_0 P_0	832.00
F_2 N_{30}	951.00
F_3 P_{60}	1024.4
F_4 N_{30} P_{60}	1115.6
F_5 N_{45}	1133.8
F_6 N_{60}	1152.2
F_7 P_{120}	1173.6
F_8 N_{60} P_{120}	1481.4
S. E. $\pm$	24.68
C. D. at 5 %	71.32
Interaction (P x F)	
S. E. $\pm$	34.74
C. D. at 5 %	101.48
Mean	1106.52

The treatment $N_{60}P_{120}$ produced significantly higher grain yield (1481.40) followed by P_{120} (1173.6 kg ha^{-1}). The lowest grain yield was obtained in control. Application of nitrogen and phosphorus @ 60 and 120 kg ha^{-1} significantly increased the yield of soybean over rest of the treatment.

The combined effect of plant protection and soil fertility levels on grain yield of soybean showed significant results.

4.6 Relationship (r-Values) Between RVI and Physiological Parameters and Leaf Nutrient Concentration

Correlation coefficients ('r' values) were worked out to determine the relationship between Relative Vegetation Index (RVI) and other parameters. The obtained 'r' values are presented in Table 22. It was observed that Leaf Area Index (LAI). Total Biomass, Total Chlorophyll, Leaf Nitrogen and Leaf Phosphorus had positive and significant correlation with RVI. Further, it was recorded that total chlorophyll and nitrogen content of soybean established highly significant correlation (r=0.870 and 0.880, respectively) with RVI, confirming prominent role of nitrogen in chlorophyll synthesis. Secondly, chlorophyll absorption band's are also centered in the blue and red region i.e. between 0.45 to 0.65 μm respectively. In present study red band wavelength was 0.62 to 0.68 μm because of which RVI showed highly significant correlation with plant nitrogen content. It is noticed that even though RVI established significant correlation with leaf phosphorus, it is at its lower magnitude.

Table 22. Correlation coefficient ('r' values) between RVI and physiological parameters and leaf nutrient concentration.

Parameters	'r' values
RVI Vs LAI	0.708*
RVI Vs Total biomass	0.720*
RVI Vs Total chlorophyll	0.870*
RVI Vs Leaf nitrogen	0.880*
RVI Vs Leaf phosphorus	0.617*

* Significant at 5 %

4.6.2 Relationship (' r ' Values) Between NDVI and Physiological Parameters and Leaf Nutrient Concentrations

Table 23 showed positive and significant relationship. NDVI had highly significant and positive relationship with total biomass (r=0.874) Production followed by LAI (r=0.823). Many documented evidences suggests that NDVI is a better Index for estimation of biomass and LAI of vegetation.

Table 23. Correlation coefficient ('r' values) between NDVI and physiological parameters and leaf nutrient concentration.

Parameters	'r' values
NDVI Vs LAI	0.823*
NDVI Vs Total biomass	0.874*
NDVI Vs Total chlorophyll	0.787*
NDVI Vs Leaf nitrogen	0.712*
NDVI Vs Leaf phosphorus	0.512

* Significant at 5 %

4.6.3 Relationship (' r ' Values) Between Soybean Grain Yield and Spectral Indices

The correlation ' r ' values (Table 24) between grain yield and spectral parameters NDVI and RVI depict positive and significant correlation. Further, it was noted that NDVI established more close association than RVI with respect to grain yield. This suggest that NDVI is better index for prediction of grain yield of soybean.

Table 24. Correlation coefficient ('r' values) between soybean grain yield with RVI and NDVI.

Parameters	'r' values
Grain yield Vs RVI	0.831*
Grain yield Vs. NDVI	0.862*

* Significant at 5 %

4.6.4 Multiple Regression Equations of Spectral Indices and other Parameters are

RVI = 10.28 – 0.60 Total chlorophyll – 0.75 LAI – 0.100 Total biomass + 7.77 Leaf N + 39.0 Leaf P (R^2 = 0.890) ------ 1

NDVI= 0.103 - 0.0060 Total chlorophyll + 0.039 LAI + 0.0059 Total Biomass + 0.012 Leaf N + 2.09 Leaf P (R^2 = 0.870) --- 2

$\hat{Y}$ = 0.685 + 90.12 RVI - 491.44 NDVI (R^2 = 0.744) ------ 3

The statistical relationship between RVI and NDVI with physiological parameters and leaf nutrients concentration were established by multiple regression equation of type $Y = a + b_1X_1 + b_2X_2$ --------- b_nX_n where 'a' is an intercept and b_n to X_n are regression coefficients of X_1 to X_n, respectively.

The equation 1 has R^2 value 0.890 to which showed relative contribution of various growth parameters and leaf nutrient concentration to the extent of 89 per cent in RVI of soybean. RVI of soybean found to be influenced nearly 0.60, -0.75, -0.100, +7.77 and 39.0 units changes in

Chlorophyll, LAI, Biomoass, Plant nitrogen and Plant phosphorus, respectively.

Equation 2 developed for NDVI showed nearly 87 per cent contribution of studied growth parameters and plant nutrient in influencing NDVI (R^2 = 0.870). It was observed that all studied parameters had influence on NDVI.

Grain yield of soybean ($\hat{Y}$ = predicted grain yield) was found to be influenced more due to NDVI than RVI the adaptability of this equation (equation number 3) was 74 %.

4.7 Visual Effects of Various Stresses on Soybean

From the initial stage growth of soybean crop was good. There was no pest and disease attack in early stage because of heavy rains The high intensity rains washed away the sucking complex. Hence, the effect of plant protection measures on plant physiological parameter was not very clear. However seed treatment applied to P treatment showed vigorus growth. At 13 September 1st spraying was given for treatment P_2, to prevent the crop against attack of pest and disease. This resulted in variation in chlorophyll content, LAI, biomass and spectral parameters. Second spraying was given at pod formation stage which further broadened the differences in P_1 and P_2.

The effect of nutrient stress on soybean crop observed through out growth period of crop. The nutrient stressed crop showed the less chlorophyll content, stunted growth and less vigorus as compared to fertilized crop. The crop with recommended dose of N + P showed better growth than individual application of N and P. It was also observed that application of N + P two times than the recommended dose resulted in better development of physiological parameters. The plant without N or without P showed the stunted growth, lower values of LAI, and Chlorophyll. The N_0P_0 plots shows yellowing of leaves.

Discussion

Chapter 5

DISCUSSION

In recent years the India's food situation imphasized need for timely information on Nation wise crop production. Remote sensing, aerospace platform can provide information about crops and soils that could be used crop production forecasting systems Remote Sensing is the technology to sense an object from distance without coming in contact with same. Every object on the earth's surface yields distinctive finger prints called "spectral signatures". Scientific Remote sensing is based on recording of spectral signatures by using spectral reflectance information. Spectral reflectance of crop is a basic prerequisite for monitoring crop growth, evaluating its productivity. Spectral characteristics of vegetation form the basis for identification and discrimination of crop, its condition assessment. Spectral reflectance of vegetation varies with wavelength influenced by the energy emitted by matter. The responses in visible and infra red region in plants depends on stage of crop growth, crop health, chlorophyll pigment, biomass, LAI, l eaf structure and water content. The spectral characteristics is an important property of vegetation and can be used to identify the vegetation of crop under defined condition. The stage of crop growth, health, vigour of plant can also be inferred by the spectral response (Badhawar and Henderson, 1981, Mack *et al.* 1980, Kolte, 2002, Patil, 2001).

Since, 1956 when Colwell first demonstrated that infra red aerial photography could be used to differentiate health and infected small grains. Several other investigation have shown that many crop diseases and other stresses, can be detected from remotely sensed spectral measurements (Meyer and Calpouzos, 1968, Mazer and Cooper, 1967; Tucker *et al.* 1980). The important stress that seriously affect the crop growth and development is due to nutrient deficiency. Nutrient stresses influenced characteristics of plant, spectral reflectance and transmittance by charging leaf geometry, morphology and physiology. Deficiency of essential element such as nitrogen cause visible abnormalities, in pigmentation, size and shape of leaves.

As revived in earlier chapter it was observed that stress due to pest and diseases and nutrient deficiencies in plants affect chlorophyll content, leaf area and leaf structure as a result reflecting power of leaf changes. So it was infered that charges in leaf reflectance are important stress indicators. Present research is an initial step in this field based on similar hypothesis. Original results obtained out of this research presented in previous chapter are discussed in this chapter.

Physiological Parameters :

Out come of field experiment is dependent on the germination of sown crop and its final plant stand at harvest. In the present study, in all treatments soybean germination was more than 90 per cent and hence various treatment showed non significant differences. The non significant differences in germination formed a homogeneous base for physiological and spectral observations. In last observation, treatment wise final plant population recorded presented in (Table 2). The statistically analysed data of various treatment revealed non significant difference. The results confirmed that experiment was conducted in appropriate manner which gave chance to different treatments to express their effects. The results of plant protection levels and fertility levels on various physiological parameters viz., height, LAI, total biomass and chlorophyll content are presented in Table 3, 4, 5, 6, 7, 8, 9 and 10 in chapter 4.

Use of plant protection measures recorded recognizable increase in plant height, LAI and total biomass in soybean over no plant protection treatment from 20 DAS to 88 DAS. Where as effect of plant protection on chlorophyll content in soybean leaves was seen from 39 DAS to 67 DAS.

The plant protection measure leads to healthy crop growth which reflected in to improvement in growth parameters. The increase in chlorophyll concentration in plant protection treatment was also govern by healthy growth of crop. However it was restricted to 39 to 67 DAS which was a grand growth period, this period crop grown under plant protection umbrella had more growth rate and nutrient absorption which might have resulted in increased chlorophyll content. Application of nitrogen and phosphorus alone or in combination exhibited considerable influence on height, LAI and total biomass production in all observations over no nitrogen and no N and P application. Each increment of N and P application over recommended dose of fertilizer improved these physiological parameters. Growth of soybean was restricted under nutrient stress condition i.e. no N and P application. In normal condition of crop i.e. crop receiving recommended and incremental nitrogen and phosphorus recorded maximum height, leaf area index, biomass production and total chlorophyll concentration. These physiological parameters were maximum in treatment receiving 60 kg nitrogen and 120 kg P_2O_5 ha^{-1}. The improvement in growth parameter and chlorophyll concentration was attributed to role of nitrogen in chlorophyll synthesis. Nitrogen being a part of chlorophyll molecule is involved in photosynthesis. Lack of nitrogen and chlorophyll means the crop will not utilize sunlight, as an energy source to carry an essential functions such as nutrient uptake. Application of recommended nitrogen to crop produced dark green colour in the leaves caused by a high concentration of chlorophyll. Nitrogen deficiency result in chlorosis (yellowing) of the leaves because of declining chlorophyll. Green pigment in chlorophyll absorb light energy (red), and convert carbon (C), hydrogen (H), oxygen (O) to simple sugars and these sugars and their conversion products are used for the growth and development of crop. Reduced LAI, height, biomass and chlorophyll are the indicators of N deficiency. The first sign of P deficiency was an overall stunted plant, leaf shape get distorted and dead areas develop on the leaves. A purple or reddish leaf colour seen on P deficient plants. However, visual deficiency symptoms are not clear as those of N. Similar observations recorded in this research project under No P application treatment. Observations recorded by Reddy *et al.* 1990, Warade *et al.* 1992, Sharma and Dixit, 1987 and Patil and Kolte 2002 are in same line.

These results showed that the adoption of plant protection measures and application of recommended nitrogen and phosphorus alone or in combination over no plant protection and no nitrogen and phosphorus application increase all growth parameters particularly height of soybean, leaf area and total biomass. Up to 88 days from sowing (last observation). While chlorophyll content was its maximum between grand growth period i.e. 39 to 67 days after sowing. The soybean crop received pest and disease stress and nutrient stress shows poor growth. Among the N and P nutrients more response was recorded with N + P followed by only N application. All these parameters in turn affect the spectral reflectance.

Spectral parameters

Spectral radiance measurement were carried out to find out the influence of stress due to pest and disease and nutrient on various spectral parameters (Table 11 to 16 and Figure 6 to 9) by Multi Band Ground Truth Radiometer. The effect of pest and disease stress and stress due to nutrient Vs normal crop showed no spectral variation in Band 1 (0.45 – 0.52 μm) and Band 2 (0.52 – 0.59 μm) the poor response in these bands might be because of Band 1 and Band 2 of radiometer which are suitable for soil and vegetation differentiation. These bands were not capable to discriminate stressed vegetation from normal vegetation. This is because, it is the band width of spectral band, that discriminate two different features. Band width narrower than 0.45 to 0.52 um may allow to discriminate stressed soybean crop from normal stressed crop. There is difference at 0.55 um indicating high reflectance due to green foliage. But became of broader band width of B1 and B2 the effect was narrowed, Dutt (1999), also reported that reflectance near 720 nm wavelength had maximum sensitivity to chlorophyll content, where as near 0.550 μm it was less sensitive. Thus from going discussion it is obivious that band, having 0.45 – 0.52 μm and 0.52 – 0.59 μm fails to identify stressed Vs normal crop. The data immerged out in Red (B3 0.62 –0.68 um) and NIR (B4 0.77 – 0.86 um) were transformed in to RVI and NDVI spectral ratios and the results are presented in chapter 4 (Table 13 to 16 and Figure 6 to 9). RVI to was found to discriminate the stressed vegetation Vs normal vegetation. In the present investigation effect of stress exhibited due to pest and disease and fertilizer on RVI were visiualised. The stresses magnitude observed by soybean crop due to plant protection level was less and hence the difference between stressed Vs normal crop were not very clear. However crop receiving plant protection measures always show high RVI values over unprotected crop. This is because of true fact that, there was no pest build up during crop growth, due to the heavy rains received during the investigation period. These high intensity rains washed out the pest complex even though differences were there, that are because of seed treatment and application of two spraying. Even though work of Collwell (1956) initiated the research on stress study. The work on health assessment and stress effect due to pest and disease on crop plant by remote sensing is very limited. However, Sinha and Karale (1992), demonstrated feasibility of remote sensing in health assessment.

In the present study spectral discriminability of the normal crop (fertilizer) and nutrient stressed crop (non fertilized) varied over season. All fertilizer treatments depicted higher RVI and NDVI than control (No N and P). The RVI and NDVI were progressively increased upto grand growth period of soybean (67 DAS). Thereafter, there was declining RVI and NDVI. Nutrient deficient soybean had much lower IR/R ratio compared to fertilizer one. This may be became of higher red reflectance and lower reflectance in NIR for nutrient stressed crop. Changes in Red and NIR reflectance have been attributed to LAI, total chlorophyll and total biomass (Collwell, 1974, Ajay, 1984 and 1983, Krishnan *et al.,* 1998, Semebiring, *et al.* 1998, Patil and Kolte, 2002).

Relationship of RVI and NDVI with physiological parameters and leaf nutrient concentration

Correlation ('r' values) as regression equations were worked out predicted that LAI, biomass, chlorophyll, leaf nitrogen and leaf phosphorus had positive and significant correlation with RVI and NDVI. Total chlorophyll and nitrogen content of leaves established highly significant correlation (r=0.870 and 0.880, respectively) confirming prominent role of nitrogen in chlorophyll synthesis. Chlorophyll absorption bands are also centered in the blue and red region i.e. between 0.45 to 0.65 μm that coincides with the red band wavelength (0.62 to 0.68 μm) which showed highly significant correlation with plant nitrogen content. Dutt, 1993; Gitelson *et al.,* 1997; Kolte, 2002 and Patil and Kolte, 2002, also revealed similar findings NDVI had highly significant and positive relationship with total biomass production (r=0.874) followed by LAI (r=0.823). Their findings are in accordance with the studies conducted by Casanova (1998). Further, NDVI established more close association than RVI with respect to grain yield. These suggest that NDVI is better index for prediction of grain yield of soybean. Multiple regression models computed for RVI, NDVI and Physiological parameters showed 89 and 87 present contribution of growth parameters towards the RVI and NDVI, respectively. There findings confirm RVI and NDI spectral indices hold good in discriminating the growth parameters (Patil and Kolte, 2002).

Summary and Conclusions

Chapter - 6

SUMMARY AND CONCLUSIONS

Research work was carried to study the effect of pest and disease stress and nutrient stress on soybean by Remote Sensing. The results emerged out of this original research work are summarized in this chapter. The germinated seed count and final crop stand of soybean were non affected due to various treatment employed.

Physiological parameters viz., height of soybean, LAI, total biomass and chlorophyll content were found to be influenced by both pest and disease stress and nutrient stress treatments applied to soybean crop.

Soybean crop with plant protection measures showed improvement over no plant protection in physiological parameters viz., height, LAI, biomass and chlorophyll. Chlorophyll content of soybean leaves was increased up to 67 DAS and there after decreased.

Application of N and P alone and in combination greatly influenced the crop physiological parameters. The crop with double dose of N + P than recommended dose of fertilizer found best followed by P_{120} treatment.

Effect of plant protection and fertilizer application on spectral reflectance in visible blue green (0.42 – 0.52 μm) and visible green (0.52 to 0.59 μm) were not consistent during growth period, suggesting that Band-1 were not suitable for vegetation canopy reflectance study.

The spectral indices RVI and NDVI greatly influenced due to plant protection and fertility levels. The RVI and NDVI values were progressively increased up to grand growth period (67 DAS) and thereafter there was progressive decrease in RVI and NDVI values. The nutrient stress crop showed lower RVI and NDVI values.

The effect of plant protection on RVI and NDVI were found statistically non significant at all growth stages this may be because of less pest and disease attack.

RVI established positive and significant correlation with all physiological parameters and plant nutrient concentration. Where as 'r' values of leaf nitrogen (0.880) and total chlorophyll (0.870) showed greatly closer association with RVI. NDVI also showed significant and positive correlation with all physiological parameters and plant nutrient concentration. But the values of LAI and total biomass had better correlation with NDVI values. Contribution of various growth parameters to RVI and NDVI were 89 and 74 percent, respectively.

Conclusion

The results emerged out of the project, "Studies on spectral reflectance under normal and nitrogen and phosphorus stress condition in soybean (*Glycine max* L.) crop" showed that growth parameters and physiological parameters viz. height, chlorophyll, leaf area index and total biomass influenced by pest and disease stress and nutrient stress resulted in detectable reflectance variation through RVI and NDVI. Poor crop growth, reduced canopy cover, chlorophyll content and biomass production are the effects observed in nutrient deficient crop canopies. These changes in soybean crop were related to spectral indices, (RVI and NDVI) that are resulted in to discrimination of stressed and normal soybean crop.

Future Research Needs

To measure even small physiological change in crop canopies, the future research must be planned with narrow band width data.

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APPENDIX - I

Weather data recorded during the course of investigation at Meteorological Observatory, M. A. U., Parbhani (2002-2003)

Months	Met. Week	Rainfall (mm)	Temperature (°C)		Humidity (%)		EVP (mm)	BSS (Hrs)	Wind velocity (km/ph)
			Max.	Min.	AM	PM			
Aug.	32	39.1	28.3	21.8	86	79	3.3	1.1	6.6
	33	5.8	29.6	22.1	88	66	3.6	2.1	7.1
	34	112.4	27.7	21.6	90	77	3.4	0.7	6.6
	35	58.2	29.0	21.9	89	74	4.7	5.3	6.5
Sept.	36	68.4	28.7	21.12	86	72	4.0	5.1	6.5
	37	3.2	31.8	20.3	87	53	5.8	9.6	5.2
	38	8.4	32.1	21.1	85	55	5.5	7.3	3.9
	39	0.0	34.1	21.1	79	43	6.2	9.6	3.6
Oct.	40	0.0	35.8	18.0	76	34	6.5	11.0	2.5
	41	0.0	33.5	20.6	75	45	5.6	7.8	3.9
	42	0.0	31.8	19.9	89	50	4.0	6.9	4.1
	43	0.0	33.3	14.4	73	26	5.7	10.9	4.3
	44	0.0	32.4	11.5	71	27	5.5	10.6	3.2
Nov.	45	0.0	32.1	14.1	74	33	5.2	10.2	3.8
	46	0.0	30.7	13.3	76	37	4.9	9.2	2.9
	47	0.0	31.2	9.1	79	26	5.2	10.9	3.5
	48	0.0	32.7	11.3	73	27	5.1	10.8	1.9
Dec.	49	0.0	31.4	12.1	76	28	4.4	10.2	2.8
	50	0.0	31.5	10.6	78	24	4.1	10.2	2.3
	51	0.0	31.7	11.2	79	23	4.3	10.3	2.2
	52	0.0	30.8	10.8	77	25	5.1	10.5	2.5

APPENDIX – II

WEATHER PARAMETERS PREVAILED ON DATES OF OBSERVATION

Time Hh:mm:ss	Temp. (°C)	RH (%)	Leaf wetness	Radiation (W/qm)	Soil Temp. (°C)	Wind speed (m/s)	Wind direction (°)	Rainfall (l/qm)
Sept. 26 - 2002								
10:00:00	29.3	87.0	253.4	451.2	26.0	1.7	225	0.0
11:00:00	31.0	79.5	253.9	626.8	26.4	1.2	202.5	0.0
12:00:00	32.5	72.0	254.2	731.4	27.0	1.3	202.5	0.0
13:00:00	33.5	63.5	254.3	646.4	27.5	0.8	225	0.0
14:00:00	34.4	58.0	254.4	634.9	28.0	0.8	225	0.0
Oct. 10 – 2002								
10:00:00	29.4	80.5	253.5	339.6	26.4	0.0	22.5	0.0
11:00:00	30.6	74.5	253.9	459.2	26.9	0.1	67.5	0.0
12:00:00	32.5	67.0	54.8	726.1	27.4	0.2	45.0	0.0
13:00:00	33.1	63.5	254.3	599.5	28.2	0.3	22.5	0.0
14:00:00	33.6	58.5	254.3	551.1	28.9	0.5	292.5	0.0
Oct. 23 - 2002								
10:00:00	30.5	52.5	254.3	534.6	24.6	0.1	247.5	0.0
11:00:00	32.1	46.0	254.4	631.8	26.3	0.4	225.0	0.0
12:00:00	33.4	39.0	254.5	678.5	28.1	0.6	225.0	0.0
13:00:00	34.1	31.5	254.5	658.6	29.7	1.9	292.5	0.0
14:00:00	34.4	27.5	254.5	572.5	30.8	2.2	315.0	0.0
Nov. 1 – 2002								
10:00:00	29.2	44.0	254.5	541.9	21.8	0.0	67.5	0.0
11:00:00	30.9	40.0	254.5	354.7	23.8	0.9	0.0	0.0
12:00:00	31.7	35.0	254.7	557.1	26.0	2.1	0.0	0.0
13:00:00	32.3	31.5	254.7	631.0	27.9	2.7	357.5	0.0
14:00:00	32.8	28.0	254.6	559.8	29.4	2.1	22.5	0.0
Nov. 13 – 2002								
10:00:00	25.9	72.5	254.2	436.6	23.4	0.8	337.5	0.0
11:00:00	27.9	66.5	254.3	519.6	25.9	0.9	337.5	0.0
12:00:00	29.2	62.0	254.4	567.5	27.0	1.1	315.0	0.0
13:00:00	30.5	56.5	254.5	555.3	28.8	0.8	337.5	0.0
14:00:00	30.3	55.5	254.5	332.0	30.0	0.7	315.0	0.0

APPENDIX - III

Work done in field experimentation

Date	Work done
14 Aug. 2002	Layout of field experimentation
18 Aug. 2002	Application of total fertilizer dose (30 : 60 N P kg ha^{-1})
18 Aug. 2002	Sowing of soybean
26 Aug. 2002	Thinning and gap filling
10 Sep. 2002	I^{st} Weeding
12 Sep. 2002	Hoeing
13 Sep. 2002	I^{st} spraying (for treatment P_2)
25 Sep. 2002	II^{nd} Weeding
06 Oct. 2002	II^{nd} spraying (for treatment P_2)
25 Dec. 2002	Harvesting of soybean

Dates of Spectral Observations

Date	Time
26 Sep. 2002	10.00 am to 12.00 am
11 Nov. 2002	10.00 am to 12.00 am
23 Nov. 2002	10.00 am to 12.00 am
01 Dec. 2002	10.00 am to 12.00 am
13 Dec. 2002	10.00 am to 12.00 am