PRECISION NITROGEN MANAGEMENT IN IRRIGATED WHEAT

BY

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CERTIFICATE – I

This is to certify that this thesis entitled **"Precision nitrogen management in irrigated wheat",** submitted for the degree of **Master of Science** in the subject of **Agronomy** of the **Chaudhary Charan Singh Haryana Agricultural University, Hisar**, is a bonafide research work carried out by Miss. **Rekha Ratanoo,** Admn. No. **2013A11M** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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This is to certify that this thesis entitled **"Precision nitrogen management in irrigated wheat",** submitted by Miss. **Rekha Ratanoo,** Adm. No. **2013A11M** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** in partial fulfillment of the requirements for the degree of **Master of Science** in the subject of **Agronomy**, has been approved by the Student's Advisory Committee after an oral examination on the same.

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CHAPTER-I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is world's number one cereal crop and is grown on the largest area among all the foodgrain crops. Wheat is grown on an area of 217.3 million hectares with the production of 653.3 million tonnes and productivity of 3.0 tonnes per hectare (FAO, 2013). In India, it is second most important cereal crop after rice. The area coverage under wheat has increased from 26.38 million hectares in 2004-05 to 30.21 million hectares in 2012-13. The production of wheat in the country has increased from 68.64 million tonnes in 2004-05 to 94.88 million tonnes in 2012-13. The productivity of wheat increased from 2.60 tonnes per hectare in 2004-05 to 3.14 tonnes per hectare in 2012-13 (Anonymous, 2014). India occupies second place in world as regards production and area under wheat but its productivity is much lower as compared to developed countries.

In India, wheat cultivation is mainly confined to North-Western plains, comprising Haryana, Punjab, Delhi, Rajasthan and Uttar Pradesh that cover nearly 37% of area and contribute about 45% in total production in country. In Haryana, wheat is grown on area of 2.50 million hectares. The total production in 2012-13 was 11.11 million tonnes with an average yield of 4.45 tonnes per hectare (Anonymous, 2014a).

Yield gains have stagnated/declined in recent years in major cereals particularly in regions with early adoption of green revolution technology. In India, average growth rate in yield of wheat was 2.87 during 1990-91 to 1999-2000 while it was only 0.73 during 2000-01 to 2010-11. This suggests the need for renewed research to boost production and productivity. More knowledge-intensive forms of soil and crop management have to be used that increase the efficiency of input use and, at the same time, do not harm the local and global environment. Wheat crop is a heavy nutrient feeder. Immediate and high response of this crop to applied nutrients, mainly nitrogen, has led to increased use of chemical fertilizers which in turn leads to imbalanced use of nutrients generally indicated by wider NPK ratio i.e. 8.3:2.7:1. Thus efficient and effective means of nutrient application are required for sustainable resource management in the world's most intensive cereal systems.

Nitrogen is one of the most important growth factors for growth and development of plants and most limiting nutrient in crop production particularly in irrigated cereal-based cropping systems and is applied by farmers with priority to get profitable yields. During 2011-12, total fertilizer N consumption of India and world was 17.3 and 107 million tonnes, respectively. Nitrogen consumption by cereals is 60% and 72% of total N consumption in world and India, respectively (Raun and Johnson, 1999; FAI, 2010).

In the soil-plant-atmosphere system, nitrogen undergoes various processes of the N cycle before becoming available to plant. Being a most dynamic nutrient, it is more prone to escape from root zone through volatilization, denitrification, surface run-off and leaching. Such losses are affected by many factors. Plant available nitrogen i.e. nitrate-N is more susceptible to leaching in coarse-textured soils (Chaudhary and Katoch, 1981). Loss of nitrogen leads to less proportion of applied N taken up by the crop i.e. lower N use efficiency. Generally 50% of the N applied is not taken up by the crop plants (Tilman *et al.*, 2002; Dobermann and Cassman, 2004).

N losses from soil-plant system are large due to lack of synchrony between crop N demand and N supply from soil or fertilizer, poor soil conditions or inappropriate fertilizer source. Therefore, all nitrogen management strategies are based on ensuring the presence of N in soil in plant available form during peak requirement of crop. Prasad (2007) reported that split application is the best method of increasing nitrogen use efficiency (NUE) in most irrigated crops since crops take up very small amount of N/ha/day. For example, Prasad (2006) reported that rice crop takes up only 1-1.2 kg N/ha/day and excess nitrogen is subjected to various losses so split application is highly desirable. Generally split application in two equal doses is recommended. Nitrogen use efficiency is less than 50% and averages 33% worldwide (Johnson and Raun, 2003). N recovery efficiency is around 30% in rice and wheat (Krupnik *et al.*, 2004). Further, alluvial soils of Indo-Gangetic plains are characteristically deficient in nitrogen.

Farmers have a tendency to apply N in excess of the requirement of crop to avoid risk of N deficiency. Overall farmers use about 10.5 to 24.5% (166 to 187 kg ha^{-1}as against recommended dose of 150 kg ha^{-}1) higher N dose in rice-wheat cropping system of Haryana (Singh *et al.*, 2012; Erenstein *et al.*, 2007). Over-application of N fertilizer in cereal crops lead to further lowering of N recovery efficiency and increasing the cost of production. Its application in excess of crop requirement also leads to increased attack of pest and diseases as well as possibility of nitrate pollution of ground water and emission of gases like nitrous oxide, which can attack ozone layer that protects earth from harmful ultra-violet radiations. Global warming potential of nitrous oxide gas is also very high, around 300 times higher than that of $CO_{2.}$ Therefore, cost-effective and well-organized nitrogen management plays a key role to reduce losses of nitrogen to soil water and atmosphere thus saving N fertilizer requirement.

Nitrogen management in India includes blanket recommendations developed for large area having similar climate and land forms. In the Indo-Gangetic Plains, these recommendations are generally 120-150 kg N ha^{-1} in two equal split doses at planting and crown root initiation stage of wheat crop. These have served the purpose very well but could not help in increasing the nutrient use efficiency beyond a limit (Bijay-Singh, 2008). For efficient fertilizer management, it is important to know about amount and variation in indigenous N supply during crop season. But significant temporal and spatial variability in soils makes it difficult to accurately estimate indigenous N supply. Cassman *et al.* (1996) observed that indigenous N supply of soils was variable among fields and seasons and was not related to soil organic matter content. That's why soil test based blanket recommendations limit efficient use of N fertilizer.

Site- specific N management can be prescriptive, corrective management (real time N management) or a combination of both (Dobermann and Cassman, 2004). In the prescriptive method of site-specific N management, supplying capacity of soil, expected crop demand, targeted yield, efficiency of fertilizer and risk from weather and pest infestation are taken into account. Real-time corrective nitrogen management is based on rapid assessment of leaf N content- a sensitive indicator of changes in crop N demand during the growing season. This approach revolves around quick and reliable diagnostic tools which are based on measurement of spectral characteristics of the radiation reflected, transmitted or absorbed by the leaves to estimate the chlorophyll content. Since most of the plant N is found in chloroplasts and chlorophyll protein, the N status of the plant could be assessed.

A number of scientific methods/tools such as leaf colour chart, chlorophyll meter etc. have been provided by the scientists to increase N-use efficiency in field crops. The scientific basis for need based N management was developed with the introduction of chlorophyll meter (SPAD), which allows estimating leaf N status or chlorophyll content through measurement of intensity of green colour of the leaves. Although chlorophyll meter helps in deciding the most appropriate time of N application during the crop growth period, recognizing its high cost, leaf colour charts (LCC) have been developed to guide farmers in assessing the crop demand for N. Critical colour shade on the LCC needs to be determined to guide N application. Leaf colour chart has been found successful in rice. In case of these both devices, the leaf N status is periodically assessed on the basis of chlorophyll content or colour of the leaf and application of fertilizer N is delayed until leaf greenness is reduced below a critical value.

These tools have provided an excellent opportunity in terms of developing real-time N management strategies but do not take into account photosynthetic rates or the biomass production and expected yields for working out fertilizer N requirements (Bijay-Singh *et al.*, 2011). In upland crops, fertilizer applications have to be synchronized with irrigation cycles.

Reflectance by growing plants in near-infrared region of the radiation (NIR 800-1000 nm) can be correlated with plant N status (Sui *et al.*, 1998). Evolution of optical sensing technology for N fertilizer management through measurement of early season red and NIR reflectance in wheat has been thoroughly described by Raun *et al.* (2001).

The GreenSeeker® (Trimble Navigation Ltd., Sunnyvale, CA, USA) system combines optical sensor measurements to calculate yield potential, response to additional fertilizer and to determine the N fertilizer application rate (Raun *et al.*, 2011). The sensor unit is designed to be hand held and measurements are taken as the sensor is passed over the crop surface. (Raun *et al.*, 2005). This unit provides a normalized difference vegetative index (NDVI) which is computed by the following formula:

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

Where, NIR_{ref} or Red_{ref} represent reflectance in the near infrared and red bands. Normalized difference vegetative index can predict biomass, plant N concentration and plant N uptake. NDVI values of in-season crop are recorded and In Season Estimates of Yield (INSEY) are made (Gupta, 2006).

To study the corrective nitrogen management based on GreenSeeker® optical sensor in irrigated wheat the present investigation entitled "PRECISION NITROGEN MANAGEMENT IN IRRIGATED WHEAT" was planned with the following objectives:

i. To find out the effect of nitrogen splitting with and without GreenSeeker guided nitrogen application on growth and quality of wheat.

ii. To find out the most suitable time of nitrogen application using GreenSeeker.

iii. To find out the economics of various treatments.

CHAPTER-II

REVIEW OF LITERATURE

Nitrogen is a key element for plant growth and development. Adequate supply leads to vigorous growth while its deficiency results in yellowing and stunted plant growth thereby adversely affecting the quantity and quality of produce. On the other hand, excess application of N is not only costly but also leads to pest-disease incidence and favors weed growth as well as lowers N-use efficiency. Therefore, judicious use of N is of vital importance to exploit the full potential of wheat crop. Effect of N on growth, quality and yield as well as ways to increase congruence of available N and peak demand of wheat for N are being reviewed under the following heads:-

2.1 Importance of N application

2.2 Effect of rate and time of N application

- 2.2.1 Growth parameters
- 2.2.2 Yield attributes and yield
- 2.2.3 Quality parameters of wheat
- 2.2.4 N uptake and N-use efficiency
- 2.2.5 Economics

2.3 Alternate devices for Precision N management

2.1 Importance of nitrogen application

Due to the challenge of feeding our vast population soon after independence and the experience of food shortage in pre-independence era, self reliance in food grains has been the cornerstone of our policies in the last 60 years. Food grain demand is estimated to increase to about 300 mt/yr by 2025. In the tropics, wheat yields with naturally available nitrogen can be sustained only up to 1-1.5 Mg/ha. Additional N will be needed to increase the productivity level to alleviate the ever increasing food insecurity (Ladha *et al.,* 2005).

Nitrogen is the basic nutrient and makes up 1-5% of dry weight of plants. It is present in many compounds of great physiological importance in plant metabolism e.g. nucleotides, phosphatides, alkaloids, enzymes, hormones, vitamins etc. It also influences growth, development, yield and protein content of crop. A number of mechanisms, *viz.* at cellular level, N increases the cell number and cell volume, whereas at leaf level, it increases the photosynthetic rate and efficiency (Lawlor *et al.*, 1988). Increased N percentage in the plant tissue at higher N supply was attributed to increased metabolic activities leading to higher protein synthesis (Greenwood *et al.,* 1991).

Development of disease and lodging resistant varieties having high input response and chemical weed and insect-pest control have led to high water supply and fertilizer as key inputs in agriculture particularly in intensive cereal based cropping systems. Area under irrigation for rice and wheat is more than 58% and 91.3%, respectively. To harness the potential of such HYV's under the favorable level of other inputs application of fertilizer N becomes more important because in Indian soils N deficiency is more prevailing as compared to other nutrients.

During a site- specific nutrient management study, Dobermann *et al.* (2003) found that N was most yield limiting nutrient among all three primary nutrients and that in some cases, higher N rates and better timing of N applications in 0-K and 0-P plots exceeded the yields, those obtained in plots where all three primary nutrients (NPK) were applied according to farmer's practice. This study indicated that N deficiency is a general feature in irrigated agro ecosystems of tropical and sub-tropical Asia. Almost 59% of Indian soils are low in N as depicted by GIS based soil fertility maps of soil nitrogen status of Indian soils given by Indian Institute of Soil Science, Bhopal.

Response of applied N to wheat in terms of increase in yield over unfertilized plots remains higher as compared to other major cereals indicated by relatively higher agronomic efficiency of nitrogen in wheat (Prasad *et al.,* 2000). This fact reveals that wheat yield levels are lowest in N unfertilized conditions and N fertilization is of immense importance to realize the full potential yield of crop. Wheat is grown in winter season in indo-gangetic plains when soil N supplying capacity (SNSC) is lower due to poor rates of native N mineralization due to low soil temperature and moisture conditions. Therefore, the accumulation or uptake of N from fertilizer was relatively more important than that N from soil (SNSC) (Adhikari *et al.*, 1999).

2.2 Effect of rate and time of N application

2.2.1 **Growth parameters:-**

Dhuka *et al.* (1991) reported that N applied as half basal + one-fourth top dressed (21 DAS) + one-fourth top dressed (35-40 DAS) gave significantly higher plant height as compared to full as basal, half basal + half (21 DAS) and half (21 DAS) + half (35-40 DAS).

Singh (1996) observed maximum dry matter accumulation at 60 and 81 DAS with nitrogen application in two equal splits and it was statistically at par with three splits. However, during later stages of crop development, three split, application produced significantly higher dry matter than two splits at 120 DAS. Where, dry matter continued to increase significantly when one-third dose of nitrogen was applied at flag leaf emergence instead of one-fourth dose of nitrogen. Pandey *et al.* (2003) reported highest plant height (99.3 cm), when nitrogen was applied half (basal) + half (CRI), compared to half basal + half (at 1st node stage), one-third basal + two-third (Ist node stage) and one-fourth basal + three-fourth (1st node stage).

Jakhar *et al.* (2006) reported that crop physiological parameters (LAI and LAD) increased with increasing dose of N from 100 to 125 kg/ha. However, the higher dose of 150 kg/ha remained statistically at par with 125 kg/ha. Relative Growth Rate remained statistically at par with the application of 100 to 150 kg/ha nitrogen levels.

2.2.2 Yield attributes and yield

Singh and Singh (1991) observed that application of nitrogen in 3 splits (25%) at CRI, 50% at tillering and 25% at jointing stage) gave significantly more (4.61 q/ha) grain yield as compared to two splits (1/2 N at sowing and 1/2 at first irrigation). They further stated that application of N in 3 splits significantly increased the yield contributing characters such as grain/ear and grain weight/ear.

Dhuka *et al.* (1992) reported that application of nitrogen in 3 splits viz, half basal + one fourth (21-20 DAS) + one fourth (35-40 DAS) increased the grain and straw yields by 49.9 and 23.9%, respectively over no split and 9.0 and 11.0% over half nitrogen top dressed at 21-25 DAS + half top dressed at 35-40 DAS.

Patel (1999) investigated that wheat grain yield was higher with split application than when all nitrogen was applied as basal, ranging from 2.44 tonnes with basal application to 3.43 tonnes with 50% basal and the rest split between 21 and 45 days after sowing. Krishnakumari *et al.* (2000) reported the highest grain yield of 4428 kg/ha when N was applied in three splits of 25, 25 and 50% at sowing, tillering and flowering stages, respectively. The straw yield was highest (5825 and 5827 kg/ha) when N dose applied was higher at early growth stages either in 100% applied as basal or in two equal splits at sowing and at tillering stages. Wagan *et al.* (2002) found that ear length, grain and straw yield were higher with three split application compared to two split application.

Coventry *et al.* (2011) reported from experiments conducted on wheat with different rotations and at different locations in Haryana that the 3 way split application generally gave highest yield where N was applied as basal, early tillering (22 DAS) and first node stage (65 DAS) in equal amounts. Treatments having N application at 22 DAS performed better than that without N application at 22 DAS. They also reported that the treatment where there was higher input of N fertilizer (200 kg/ha) the number of fertile tillers was increased compared to treatment with recommended doses but there was no difference in dry matter yield, grain yield or 1000 grain weight.

Gupta *et al.* (2011) reported that application of N in three equal splits (33:33:33) as basal dose, crown root initiation and ear initiation stage resulted in significantly higher grain and biological yield, no. of spikes/m^2, grain/spike than other splits (0:50:50 and 50:50:0) but was at par with 50:25:25 and 20:40:40 split doses.

Kaur *et al.* (2010) reported that nitrogen application in three splits (68 kg /ha as basal + 75 kg/ha at I^{st} irrigation + 7 kg/ha as foliar spray at anthesis) showed highest grain yield, biological yield, no. of spikelets/spike, no. of grains/spike and test weight which was at par with other treatments (50 kg/ha as basal + 50 kg/ha at Ist irrigation + 43 kg/ha at anthesis + 7 kg/ha as foliar spray at milk stage and 37.5 kg/ha as basal + 68 kg/ha at Ist irrigation + 37.5 kg/ha at anthesis + 7 kg/ha as foliar spray at milk stage). However, these parameters were significantly lower in treatments without N application during reproductive stages. Grain yield was 4.14% higher in three split application over recommended schedule. Effective no. of tillers/mrl was highest in treatment having moderate N doses at early stages (37.5 kg/ha as basal and 68 kg/ha at CRI) as compared to higher doses at these stages.

2.2.3 Quality parameters

Mellado and Granger (1996) observed that grain quality was not affected by basal nitrogen application, but application of supplementary nitrogen at heading or anthesis showed the greatest improvement in grain quality.

Singh *et al.* (1999) from Ludhiana reported that the application of nitrogen fertilizer in three split doses starting from sowing to flag emergence stage improved grain hardness, protein content and sedimentation value. Krishnakumari *et al.* (2000) reported that late application of N at tillering and flowering stages in two equal split doses gave the highest grain protein (14.73%). Lowest level of grain protein was received when whole N dose was applied as basal or in splits which ended up to tillering while treatments receiving later application of N were superior in grain protein.

Uppal *et al.* (2002) found that the increasing level and delayed application of nitrogen increased the grain hardness, protein content, β-carotene content and sedimentation value. Pandey *et al.* (2003) reported that when N treatment comprised of split doses applied as 1/2 basal + 1/2 at CRI, it resulted in highest N uptake (104.7) than 1/2 basal + 1/2 at first node, 1/3 basal + 2/3 at first node stage and 1/4 basal + 3/4 at first node stage. Lestache *et al.* (2004) reported that application of half or one third of total fertilizer nitrogen at stem elongation improved grain protein content with respect to application at sowing alone or both at sowing and tillering.

Coventry *et al.* (2011) reported that highest protein level was achieved (range 11.8-12.5%) with 3-way split in N application (basal, 22 and 65 DAS) and lowest level protein corresponded with 50:50 split (basal and 22 DAS). Highest N dose (200 kg/ha) resulted into significant (8-10%) increase in grain protein and a similar increase in grain hardness and chapatti score. Jat *et al.* (2014) reported significant increase in protein content, β-carotene and sedimentation value and significant decrease in hectoliter weight by raising rate of N application from 60 to 90 and 120 kg/ha in durum wheat.

2.2.4 N uptake and N-use efficiency

The yield response to N is typical following the law of diminishing returns and in general agronomic efficiency (AE_n: Kg grain increased over control/kg N applied) and recovery efficiency (RE_n: % N recovered in above ground plant parts) decline as the rate of application is increased as yield increment continuously declines at increasing the level of fertilizer N (Prasad, 2007a; Johnson and Raun, 2003).

Preplant N must be carefully managed to optimize grain yield, but adding excess N at that time reduces NUE, whereas late-season application can be adjusted to increase grain protein concentration and NUE (Wuest and Cassman, 1992b). Recovery of N applied at planting ranged from 30-55% while that applied at anthesis ranged from 55 to 80% (Wuest and Cassman, 1992a).

Dhuka *et al.* (1992) investigated that application of nitrogen in three splits (half basal + one-fourth at 21-25 DAS + one-fourth at 35- 40 DAS) increased the nitrogen uptake in grain and straw by 46.4 and 72.0 per cent, respectively over no split. They further reported that delayed application of nitrogen (half at 21-25 DAS + half at 35-40 DAS) decreased the uptake of nitrogen in grain and straw compared to three splits. Alcoz *et al.* (1993) found highest nitrogen uptake efficiency with 75 kg nitrogen applied in splits. They further observed increase in apparent recovery under split application of nitrogen. Khalil and El-Aref (1999) reported that splitting the nitrogen fertilizers into three equal applications significantly increased the uptake of nitrogen, phosphorus and potassium in grains and grain protein yield.

Prasad *et al.* (2000) analyzed several studies on rice-wheat cropping system including various groups of fertilizer N levels (40-60, 61-120, 121-180 kg/ha). They reported that total N uptake increased from 54.9 kg/ha to 145.8 kg/ha at increasing the N level from 0 to 121-180 kg/ha. AE_n, RE_n and physiological efficiency (PE_n: kg grain increased over control/kg N uptake) decreased from 28.8 to 15.9, 73.8 to 61.8 and 115.15 to 26.7 at increasing the N level from 40-60 to 121-180 kg/ha.

Coventry *et al.* (2011) reported that values for apparent recovery of N were significantly higher in 3 way split application of N in equal amounts ($1/3^{rd}$ each at sowing, 22 and 45-65 DAS) followed by 2 way split application that did not include a basal application. Kaur *et al.* (2010) reported that nitrogen recovery, N use efficiency and agronomic efficiency was 15.7, 8.0 and 12% more in treatment (F_4) having 68 kg N/ha as basal, 75 kg N/ha at I^{st} irrigation and 7 kg N/ha as 3% foliar spray at anthesis when compared with recommended schedule (F_1- 50:50 split at sowing and I^{st} irrigation). Whereas, 6% decrease in physiological efficiency was recorded in F_4 from F_1 treatment.

Singh *et al.* (2012) conducted a survey in rice-wheat belt of Haryana state and reported that present on-farm N use pattern in wheat gives overall N use efficiency of 27.9 kg grain/kg N applied and that reduction in NUE was 29, 52, and 80% while increase in the dose was 34, 63 and 94% due to 120-150, 150-180 and >180 kg N/ha categories over <120 kg N/ha category, respectively.

2.2.5 Economics

Gupta *et al.* (2011) reported that treatments receiving three splits recorded more net returns than those receiving two splits of N due to higher grain yield in former. Kaur *et al.* (2010) recorded highest cost of cultivation ($\times 10^3$ Rs /ha) at 26.27 in four split applications and highest net monetary return ($\times 10^3$ Rs/ha) at 12.10 and B-C ratio (0.46) in three split applications as compared to two way splits. There was a significant increase in net returns (Rs 47,770) and B-C ratio (3.44) by raising the rate of N application from 60 to 90 and 120 kg /ha (Jat *et al.*, 2014).

2.3 Alternate devices for precision N management

Traditionally, soil testing, plant tissue analysis and long-term field trials have been used for assessing N availability for crops which are laborious, time consuming, and costly. Such procedures have limited use as a diagnostic tool for optimizing N top dressing because of extensive time delay between sampling and obtaining results. For precision N application, non-destructive, instant and reliable methods for assessing N status and requirements of N of field crops are needed.

Monitoring of plant N status is important in improving the balance between crop N demand and N supply from soil and applied fertilizer (Cassman *et al.*, 1994). Because leaf N content is closely related to photosynthetic rate (Peng *et al.*, 1995) and biomass production (Kropff *et al.*, 1993), it is a sensitive indicator of the dyanamic changes in crop N demand within a growing season. Greater synchrony between crop demand and nutrient supply is necessary to improve NUE. Thus, for greater precision in N management, leaf and canopy characteristics are being increasingly used with the help of different tools/devices, some of which are as following:-

2.3.1 Chlorophyll or SPAD meter

2.3.2 Leaf colour chart

2.3.3 Optical sensors

2.3.1 Chlorophyll or SPAD meter

The chlorophyll meter also known as soil plant analysis development (SPAD) meter, can quickly and reliably assess the N status by determining the relative amount of chlorophyll content by measuring leaf greenness (Peterson *et al.,*1993). It has been used successfully for rice (Balasubramanian *et al.*, 1999, Hussain *et al.*, 2000, Bijay-Singh *et al.*, 2002), maize (*Zea mays* L.) (Peterson *et al.*, 1993) and wheat (Follett *et al.*, 1992).

The most recent fully expanded leaf is usually considered the index leaf to reflect N status of the plant. The SPAD uses a silicon photodiode to derive the ratio of transmittance through the leaf tissue at 650 nm compared with transmittance at 940 nm, and a value is given based on that ratio (Schepers and Francis, 1998). SPAD meter readings should be measured from the uppermost, fully expanded leaf at a point one-half the distance from the leaf tip to the collar, and one-half the distance between the leaf margin and the midrib (Bijay-Singh *et al.*, 2002, Peterson *et al.*, 1993).

Two approaches have been used to apply fertilizer N in rice and wheat using chlorophyll meter: (i) when sufficiency index (defined as SPAD value of the plot in question divided by that of a well- fertilized reference plot or strip falls below 0.90 (Hussain *et al.*, 2000) and (ii) when SPAD value is less than the set critical reading. N application based on the calculated sufficiency index has been used in rice. An index of 90% was found to guide fertilizer N management which resulted in high NUE and rice yields in Asia (Hussain *et al.*, 2000).

Bijay-Singh *et al.* (2002) found that wheat responded to N application at maximum tillering (MT) when SPAD value fell below 44. Wheat yield increased by 20% when 30 kg N/ha was applied at SPAD value of 42 at MT. Species and varietal differences can influence N management using chlorophyll meter when following critical value approach.

Maiti and Das (2006) reported that SPAD-treated plots saved 57.5 -72.5 kg N /ha and increased N-use efficiency significantly over fixed timing N treatment where 150 kg N/ha was applied in three splits without reduction in yield. They further reported that critical value of 37 was best N management in wheat in an inceptisol of West Bengal. Using critical SPAD value of 42 in wheat, Khurana *et al.* (2008) showed significant increases in agronomic (63%) and apparent recovery efficiency (59%) of N compared with farmer's fertilizer (fixed-time N fertilizer) practices. Compared with farmer's practice average grain yield increased from 4.2 to 4.8 t/ha.

In wheat chlorophyll meter has not been so successful because SPAD meter cannot be used until the crop develops fully expanded leaves i.e., after approximately one month of planting and generally fertilizer N should be applied in wheat in the initial stages. Therefore, SPAD meter can decide only one top dressing of N after 30 days after sowing. Besides, N application in wheat is linked with irrigation (Bijay-Singh, 2008). The chlorophyll meter has been proven to determine accurately when fertilization is needed, but is limited in that it is not able to estimate the amount of fertilizer needed (Varvel *et al.*, 1997).

2.3.2 Leaf Colour Chart

Leaf colour chart (LCC) is a high quality plastic strip with different shades of green colour ranging from light yellowish green to dark green. A six-panel leaf colour chart (IRRI-LCC, six-panel) was developed through collaboration of the International Rice Research Institute (IRRI) with agricultural research systems of several countries in Asia (IRRI, 1996). The LCC is simple, easy to use and inexpensive. It is an ideal tool for individual farmers to optimize N use in rice at medium to high yield levels, irrespective of the source of N applied. Like the chlorophyll meter the critical color shade on the leaf colour chart needs to be determined to guide N applications.

LCC threshold values were determined and compared with fixed time N-splitting for rice and wheat by Shukla *et al.* (2004).They started readings 21 DAS in wheat. Maintenance of LCC ≤4 required 120 kg N/ha, which produced higher grain yield, N uptake, and NUE than that of recommended N splits. Net returns were 19 to 31% higher in LCC-based N management than in fixed-time recommendations. A group of 107 farmers compared the LCC method with their own N management practices and found that the LCC reduced N requirements from an average of 154 to 122 kg/ha, a net savings of 32 kg/ha or 25% of applied N (Shukla *et al.*, 2004).

On-farm experiments were conducted on rice in 2002 in Punjab (north-western India) to evaluate LCC based N management with the farmer's practice. It was revealed that identical average yield was recorded by applying about 40 kg N/ha less fertilizer in LCC based (critical shade 4) real-time N management as compared to farmer's practice. A basal dose of 20 kg N/ha was applied in all the LCC-plots. It is very effective in avoiding over application of N fertilizers that ensures minimum pollution of the environment (Bijay-Singh *et al.*, 2002; Yadvinder-Singh *et al.*, 2007). Maiti and Das (2006) reported saving of 40-67.5 kg N/ha over fixed-time 150 kg N/ha applied in 3 splits and critical shade of 5 on LCC for corrective N application combined with basal 20 kg/ha as best N management strategy in wheat in terms of yield.

2.3.3 Optical sensors

Application of remote sensing in N management is a new approach. Use of remotely sensed indices like NDVI (Normalized Difference Vegetative Index) is emerging as a potential method for efficient N management through crop growth monitoring using on the go optical sensors. There was a very promising relationship between NDVI indices derived from satellite data and Green Seeker optical sensor (R^2 =0.86) as revealed in the progress report of Rice- wheat consortium by Gupta (2006).

In –season assessment of crop nutrient need by measuring canopy reflectance in red and near-infrared (NIR) bands of wavelength is basic principal of optical sensor technology (Filella *et al.*, 1995; Stone *et al.,* 1996; Afanasyev *et al.,* 2001; Raun *et al.,* 2005). Optical sensor based variable rate application systems designed to sense N needs late in season can take advantage of early history (insect, disease and weather) of the growing season. A second advantage of a late season application is that the probability of N loss either to the atmosphere or through leaching or runoff is reduced as the time between application and plant needs is reduced.

GreenSeeker® (Trimble Navigation Ltd., Sunnyvale, CA, USA) is an integrated optical sensing and application system that measures crop status and variably applies the crop's nitrogen requirements. Yield potential for a crop is identified using NDVI and an environmental factor. Nitrogen (N) is then recommended based on yield potential and the responsiveness of the crop to additional nitrogen. The sensor uses light emitting diodes (LED) to generate red (671±6 nm) and near infrared (NIR) (780±6 nm) light. The light generated is reflected off of the crop and measured by a photodiode located at the front of the sensor head. GreenSeeker sensors have a 24 inch approx. field of view when height is 32-48 inches above the plant.

2.3.3.1 Mechanism of Working

Canopy reflectance is determined by leaf surface properties, internal structure, and the concentration and distribution of biochemical components (Penuelas and Fillella, 1998).

Chlorophyll contained in the palisade layer of the leaf controls much of the visible light (400-700 nm) reflectance. Chlorophyll absorbs between 70 to 90% of all incident light in the blue and red wavelength bands while reflecting light in the green band (Campbell, 2002). Reflectance of the NIR electromagnetic spectrum (720–1,300 nm) depends upon the structure of mesophyll tissues, which reflects as much as 60% of all incident NIR radiation (Campbell, 2002). Absorbance of visible light in blue and red wavelength by chlorophyll molecules and reflectance of NIR by mesophyll cells (Fig. 1) is indicator of high amount of chlorophyll content and more vegetative biomass and on the basis of these spectral characteristics NDVI is also calculated. Higher is the NDVI value, more is the plant vigour and health.

Ercoli *et al.* (1993) reported a strong linear relationship between leaf chlorophyll and leaf N concentration (R^2=0.83). Therefore, it has been postulated that the relative greenness of a leaf can be used as an index of N content. Pradhan *et al.* (2013) reported that the canopy reflectance in the visible region (400-700 nm) decreased from CRI to booting stage and thereafter increased till harvesting stage as chlorophyll content increases and decreases, respectively during these periods. The reflectance in the near-infrared region increased from CRI to booting stage and thereafter decreased progressively till harvesting stage. This was attributed to increase in leaf area index (LAI) (subsequently increased light scattering by leaves and stems) from CRI to booting and thereafter, to decrease in LAI till harvesting.

2.3.3.2 NDVI: as predictor of growth parameters and yield (INSEY) and its timing

Potential of spectral reflectance of crop canopy for predicting biomass, plant N content and growth traits has been evaluated by several workers (Ma *et al.,* 1996; Aparacio *et al.*, 2002; Lukina *et al.*, 2001; Freeman *et al.*, 2007; Mullen *et al.*, 2003; Pradhan *et al.*, 2013).

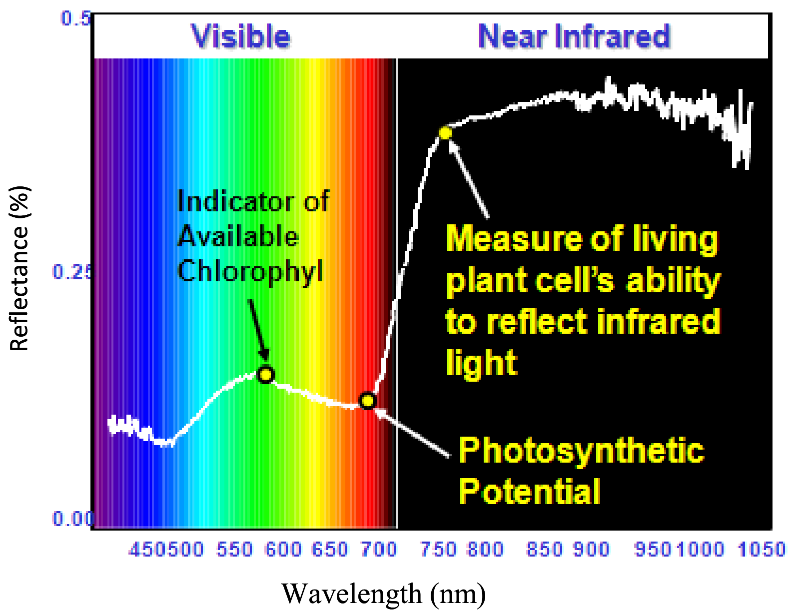

Fig. 1: Electro-magnetic spectrum of light showing reflectance of light in the visible and near-infrared regions

Normalized Difference Vegetative Index (NDVI) is one of the most extensively used indices for morphophysiological study and eventually for predicting the yield. Limon-Ortega (2009) reported that NDVI readings were correlated with grain yields (r=0.65) and heads/m^2 (r=0.59). The correlation between yield and NDVI were among the largest (R^2=0.7-0.8) in magnitude and positive when several types of reflectance indices were compared (Ma *et al.*, 2001).

Reflectance measurements have an advantage over transmittance measurements (chlorophyll meter readings) in assessing the leaf N concentration and grain yield because reflectance measurements may not be as sensitive to leaf thickness as transmittance measurements (Blackmer *et al.,* 1994). When the crop does not cover the entire soil surface, reflectance measured from a certain height above ground level will represent the reflectance of canopy and the soil surface, rather than just the crop itself. Therefore, determination of timing for sensor based N fertilization is quite essential. The percentage of soil covered by wheat was highly correlated with NDVI at Feekes Growth Stages 4 and 5, and both NDVI and coverage were correlated with vegetative biomass (Lukina *et al.*, 1999). In these trials, plant coverage was generally >50% at Feekes 4 and 60% at Feekes 5.

NDVI measurements in winter wheat between Feekes physiological growth stages 4 and 5 can provide a reliable prediction of both N uptake and biomass (Stone *et al* 1996). Experiments conducted at Karnal, Modipuram and Ludhiana under Rice-Wheat consortium funded project for Indo-gangetic plains showed robust relationship between in-season estimated yield (INSEY)-grain yield at Feekes 5/6 and Feekes7/8. The high R^2 values were obtained confirming that INSEY-grain yield based on several soils and cultivars can be very effective in predicting potential yield from in-season NDVI measurements of wheat over a vast region (Bijay-Singh *et al.,* 2011).

Cabrera-Bosquet *et al.* (2011) reported that growth traits (above ground biomass, total green area) and above ground nitrogen were significantly and positively correlated with NDVI measurements performed at stem elongation (Feekes 7.0) and anthesis (Feekes 10.5), however, these correlations considerably improved when the traits measured were compared with NDVI measurements performed closer to anthesis. Raun *et al.* (2001) conducted trials at nine locations for 2 years and reported that grain yield and estimated yield (EY) were significantly related (R^2 =0.50, P>0.0001) when EY was computed using post dormancy NDVI values. Further they improved it and showed that NDVI divided by the total number of days from planting to sensing was better correlated (R^2=0.64) with grain yield (Raun *et al.,* 2002).

Pradhan *et al.* (2013) reported that significant and positive correlations between grain yield and NDVI and biomass and NDVI at all growth stages except at CRI and maturity. The correlation coefficients were highest at milking stage indicating that this stage can be successfully used for the prediction of grain yield and biomass yield.

NDVI measurements in winter wheat between Feekes physiological growth stages 4 and 5 can provide a reliable prediction of both N uptake and biomass (Stone *et al.*, 1996). Lukina *et al.* (2001) reported that between feekes physiological stage 4 and 6, NDVI values and plant N uptake; NDVI values and final grain yield; in-season estimated yield and final grain yield were highly correlated.

2.3.3.3 GreenSeeker technology as a diagnostic tool for N management and yield response

Nitrogen fertilizer optimization algorithm i.e. procedure for calculating fertilizer N requirement by crop using NDVI readings has been thoroughly described by Raun *et al.* (2002) and Bijay-Singh *et al.* (2011). GreenSeeker optical sensor can be used only in combination with appropriate preventive N management, as it cannot work properly when crop is too young. This is evident from work of several researchers (Bijay-Singh *et al.*, 2011; Raun *et al.*, 2002; Pradhan *et al.*, 2013).

Raun *et al.* (2002) observed highest grain yield when preplant fixed rate (45 kg N/ha) was combined with NFOA based on greenseeker, followed by N application in two equal splits as preplant and mid-season. They further reported that yield reduced significantly when N was not applied preplant and that even mid-season higher dose and sensor based application could not compensate the yield loss. N fertilization based on mid-season estimates of yield potential increased NUE by more than 15% when compared to traditional practices which applied N at uniform rates.

Results from experiment conducted at Karnal, Modipuram and Ludhiana indicated that 10-20% N can be saved without yield reduction in wheat if blanket recommendation was replaced with GreenSeeker based N application. N application at the rate of 90 kg/ha at planting or in 2 equal splits at planting and crown root initiation stage were appropriate prescriptive nitrogen management strategies and sensor guided nitrogen was applied at Feekes 5-6 or 7-8 stages of wheat (Bijay-Singh *et al.*, 2011).

Coventry *et al.* (2011) used GreenSeeker instrument in wheat rotated with rice to determine the amount of N-fertilizer required at early node growth stage (second irrigation) in combination with 2 doses (1/3rd of recommended each) applied as basal and at 22 DAS. This gave a saving of 21 to 25 kg N/ha with similar grain yield. Consequently apparent N recovery of the N fertilizer was much higher (70-75%) compared with 60% and 50% for the two fixed time N treatments at the rate of 150 and 210 kg/ha applied 3 splits, 1/3rd each at sowing, first irrigation and second irrigation.

CHAPTER-III

MATERIAL AND METHODS

The present investigation entitled "**Precision nitrogen management in irrigated wheat"** was conducted during *Rabi* (winter) season of 2013-14. The details of materials used and methods adopted during the course of investigation are described below:

3.1 Material

3.1.1 Experimental site and location

The experiment was carried out at the Agronomy Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar. The experimental site is situated at an elevation of 215.2 m above mean sea level with latitude 29º10' N and longitude of 75º46' E in the sub-tropical zone.

3.1.2 Climate and weather conditions

The experimental site has a semi-arid sub-tropical climate with hot and dry desiccating winds and frequent dust storms during summer, severe cold during winter and warm humid conditions during monsoon months. The average annual rainfall is 450 mm most of which (80-90 per cent) is received between July to September from South-West monsoon and few showers of cyclonic rains are received in winter or late spring season. The mean maximum and minimum temperature shows a wide degree of fluctuation during summer and winter months. The maximum temperature around 48ºC with hot desiccating winds in summer to a minimum of 0ºC or even below accompanied by frost in winter is the common characteristic of this region. The mean relative humidity remains nearly constant at about 80 to 90 per cent from July to March and in April steadily decrease and remains around 40-50 per cent for the remaining part of the year.

The mean weekly meteorological data during the crop growing season recorded at the meteorological observatory located in the Agronomy Research Area of University Farm, Hisar are presented in Appendix-I and depicted in Fig. 2. Perusal of data showed that 77.9 mm rainfall was received during crop growing season. The mean weekly maximum and minimum temperature ranged between 16.9 to 37.6ºC and 2.4 to 18.6ºC, respectively. The mean weekly values for morning and evening relative humidity ranged between 57 to 99 and 22 to 84 per cent respectively, while sunshine ranged between 2.0 to 15.0 hrs during crop season.

3.1.3 Cropping history

The cropping history of the experimental field is given in Table 1.

Table 1: Cropping history of the experimental field

Year	Crop season	
	Kharif	**Rabi**
2011-12	Fallow	Wheat
2012-13	Mungbean	Wheat
2013-14	Fallow	Wheat (experimental crop)

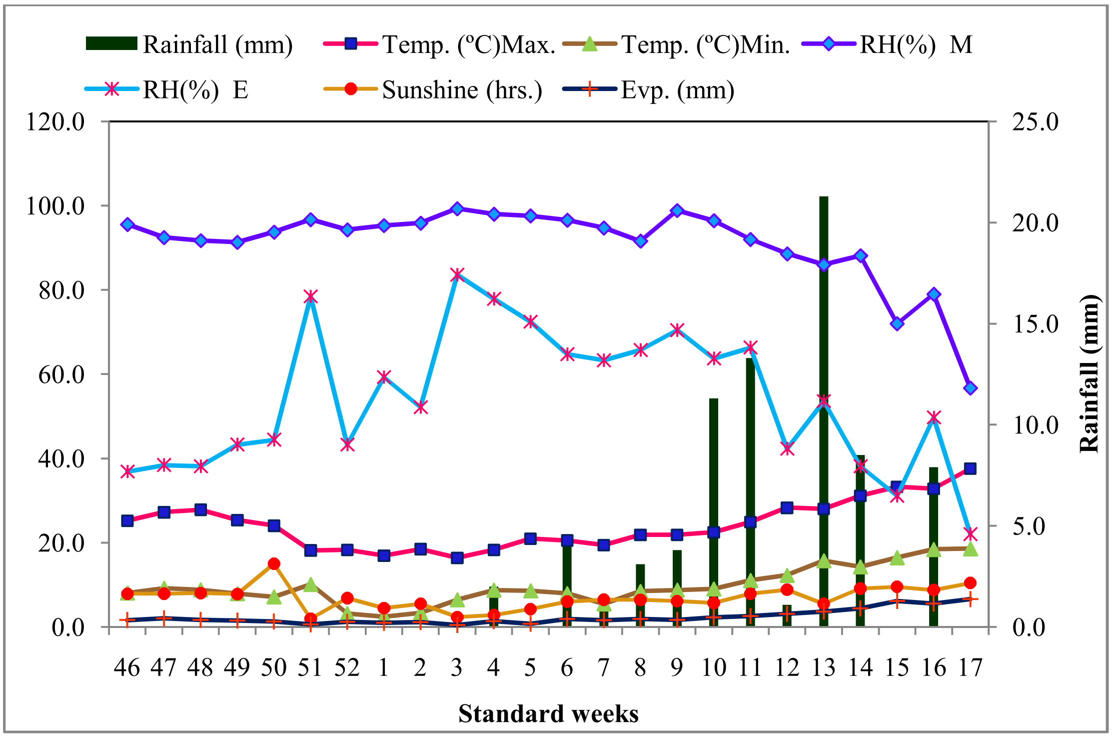

Fig. 2: Mean weekly values of weather parameters during cropping season 2013-14

3.1.4 Soil analysis

Soil samples from 0 to 15 cm and 15 to 30 cm depths from the experimental field were collected randomly before sowing. The composite sample was prepared by mixing all the soil samples from different depths. After proper grinding and sieving, samples subjected to both mechanical as well as chemical analysis and respective results are given in Table 2.

The results of mechanical and chemical analysis indicate that the soil of the experimental site was sandy loam in texture, slightly alkaline in reaction, low in organic carbon and available nitrogen, medium in available phosphorus and high in available potassium.

Table 2: Physico-chemical analysis of the soil of experimental field

Parameters	Soil Depth (cm)		Method of determination
	0-15	15-30	
Sand (%)	60.5	60.1	International Pipette method (Piper, 1966)
Silt (%)	22.2	21.7	
Clay (%)	17.3	18.2	
Texture	Sandy loam		
pH (1:2)	8.3	8.2	Glass electrode pH meter (Jackson, 1973)
EC (dSm^{-1} at 25ºC)	0.31	0.22	Conductivity bridge method 1:2 soil water suspension USDA Hand Book No. 60 (Richards, 1954)
Organic carbon (%)	0.33	0.29	Walkley and Black's rapid titration method (Walkley and Black, 1934)
Available N (kg/ha)	135.4	127.3	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	16.3	12.5	Olsen's method (Olsen *et al.,* 1954)
Available K (kg/ha)	351.3	322.2	Flame photometric method, USDA Hand Book No. 60, 1954 (Jackson, 1958)

3.2 Methods

Experimental details and layout

The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker. N application without using GreenSeeker consisted of two treatments having recommended dose (150 kg/ha) in two (75 kg/ha each) and three (50 kg/ha each) equal splits. GreenSeeker guided N application was combined with fixed rate (75, 100 and 125 kg/ha) and fixed time N application (nine treatments) as basal and at 25 DAS. GreenSeeker was used with each fixed level of N application at 2nd (50 DAS) and/or 3rd irrigation (65 DAS). One treatment was control where no fertilizer N was applied. Layout of the experiment is shown in Fig. 3 and the description of treatments is given below (Table 3):-

Table 3: Detail of treatments

Treatment	N application (kg ha^{-1})			
	Basal (at sowing)	20-25 DAS	45-50 DAS	60-65 DAS
T_1	75	75	_	_
T_2	50	50	50	_
T_3	25	50	GS	_
T_4	25	50	_	GS
T_5	25	50	GS	GS
T_6	25	75	GS	_
T_7	25	75	_	GS
T_8	25	75	GS	GS
T_9	50	75	GS	_
T_{10}	50	75	_	GS
T_{11}	50	75	GS	GS
T_{12}	Control(No N)			

GS indicates GreenSeeker guided nitrogen application

Design : Randomized Block Design

Replication : Three

Variety : WH711

Fertiliser : Nitrogen as per treatment.

Phosphorus and Potassium at recommended rates i.e. 60 and 40 kg/ha, respectively in all treatments

Plot size : 5 m X 4 m

Net plot size : 3.8 m X 4 m

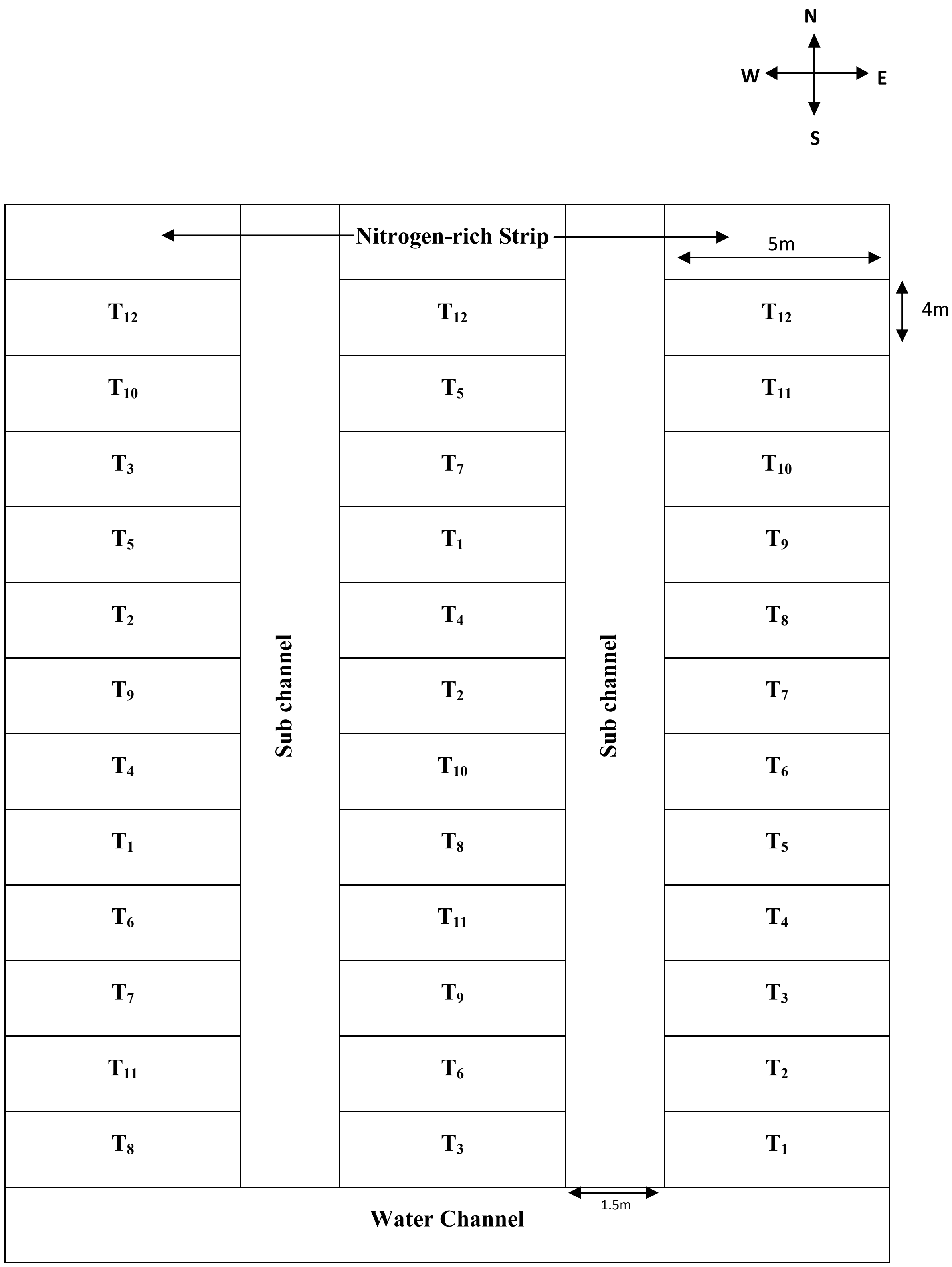

Fig. 3: Layout plan of experimental field

3.3 Cultural operations

The details of cultural operations carried out during pre and post sowing of wheat in the experiment field are presented in Table 4.

Table 4: Schedule of cultural operations carried out in the experimental field

Sr. No.	Nature of operations	Date of operations	Details of operations
A. Pre-sowing operations:			
1.	Pre-sowing irrigation	08.11.2013	Irrigation was done with canal water.
2.	Seed bed preparation	15.11.2013	At proper moisture condition, the field was ploughed twice by disc harrow and once by cultivator followed by planking with tractor.
3.	Layout	18.11.2013	Layout was performed.
4.	Sowing and fertilizer application	19.11.2013	Sowing of variety WH711 was done by seed-cum fertilizer drill as per treatments at 5-6 cm depth using 125 kg seed/ha. Phosphatic and potassic fertilizers were drilled @ 60 kg/ha and 40 kg/ha, respectively. Nitrogen was applied as per treatments.
B. Post Sowing operations:			
1.	Final layout	20.11.2013	Final layout, channels and bunds were prepared.
2.	Weeding/herbicide application	28.12.2013	The weeds were controlled by application of clodinafop @ 40 g a.i./ha at 40 DAS in all the plots.
3.	Nitrogenous fertilizer application	—	Nitrogenous fertilizer i.e. urea was applied as per the treatments with and without using GreenSeeker (GS).
4.	Irrigation	06.12.2013 30.12.2014 15.01.2014 17.02.2014	Ist irrigation at CRI stage was done. IInd irrigation was done at tillering stage. IIIrd irrigation was done at jointing stage. IVth irrigation was done at flowering stage.
5.	Harvesting	24.04.2014	Harvesting was done manually with the help of sickles by cutting the plants just above the ground level from the net area of each plot separately. Bundles were made and left in the field for drying in sun.
6.	Threshing	01.05.2014	Before threshing the biological yield (grain + straw) was recorded for each net plot. Threshing was done with the help of miniplot thresher. The grains collected from each net plot were weighed

3.4 Growth studies

The growth observations in terms of plant height, dry matter accumulation, tillers, leaf area index (LAI), radiation characteristics of crop were recorded during vegetative and reproductive phases of wheat crop. The details of various growth observations recorded are given as under:

3.4.1 Plant population

Plants were counted metre^{-1} row length from three randomly selected places from each plot at 15 days after sowing (DAS) and the average was reported.

3.4.2 Plant height

Five plants were tagged at random from each plot for recording plant height at 30, 60, 90, 120 DAS and at harvest and average of the five plants was reported. The plant height was recorded from ground surface to the base of the fully opened last leaf before the ear emergence and up to the base of earhead after heading.

3.4.3 Dry matter production

Plants were harvested from 25 cm row length at 30 days interval from two places in the second row on either side in each plot starting from 30 DAS till crop harvest. Samples were sun dried and then oven dried at 70ºC to a constant weight. Then dry weight of plants per metre row length was worked out.

3.4.4 Crop growth rate (CGR)

It represents dry weight gained by a unit area of crop in a unit time. The samples taken for dry matter accumulations, were also used for calculating CGR, at different stages by using formula:

$$\mathrm{CGR} = \frac{W_2 - W_1}{A(T_2 - T_2)}$$

Where W_2 and W_1 are dry weight of plant at times T_2 and T_1, respectively; T_2 and T_1 are the time interval between two observations and A is land area from which the sample was taken.

3.4.5 Relative growth rate (RGR)

It is an index of the amount of dry weight accumulated per unit weight of plant per unit time. The samples taken for dry matter accumulations, were also used for calculating RGR, at different stages by using formula:

$$\mathrm{RGR} = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

3.4.6 Leaf area index (LAI)

Plants from 25 cm row length removed from two places in the second row on either side in each plot were also used for recording leaf area. The leaves were separated from the base of lamina. Leaf area was measured at 30, 60, 90 and 120 DAS with the help of leaf area meter (LI 3000 Area meter LICOR ltd. Nebraska, USA). The leaf area index was worked out with the help of the following formula:

$$\text{Leaf area index} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Land area(cm}^2\text{)}}$$

3.5 Yield attributes

3.5.1 Effective tillers

Effective tillers/meter row length were counted from three randomly selected marked rows from each plot at harvest and the average was reported.

3.5.2 Spike length

Five representative spikes were harvested from marked rows. The spike length (cm) was measured from the base of the peduncle (lower spikelet) to the top of the spikelet and the average was reported.

3.5.3 Number of grains per spike

From the spikes selected for measuring spike length, the grains were separated from spikelets and the total numbers of grains were counted and the grains/spikes were worked out.

3.5.4 1000-grain weight

A composite sample of grains was taken from the produce of each net plot and 1000 grains were counted at random with the help of automatic seed counter and weighed.

3.6 Yield studies

3.6.1 Grain yield

Grains were separated with the help of mini-plot thresher from biological yield obtained from each net plot area. The grain yield thus obtained from net plot area was converted into kg/ha.

3.6.2 Straw yield

Straw yield was worked out by subtracting the grain yield from total biological yield of net plot area and expressed in kg/ha.

3.6.3 Biological yield

After harvesting the net plot area, the bundles of wheat crop were sun dried and then weight was recorded and converted into kg/ha.

3.6.4 Harvest index

Harvest index, which is the ratio of economic yield to biological yield and expressed in per cent was worked out by following formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.7 Quality studies

3.7.1 Protein content

Protein content in grain was calculated by multiplying the percentage of nitrogen in grains with 6.25. The protein yield was computed as:

$$\text{Protein yield (kg/ha)} = \frac{\text{Protein content x Grain Yield (kg/ha)}}{100}$$

3.7.2 Sedimentation value

Sedimentation value was calculated by using following reagents and procedure:

(A) Reagents:

Lactic acid-sodium dodecyl sulphate (SDS) solution was prepared by dissolving 20 g SDS in 1 litre of distilled water, 20 ml of stock dilute lactic acid was added to it (1 part by volume of 88% lactic acid+8 part by volume of distilled water).

(B) Procedure:

Sedimentation value in wheat flour and blends was determined according to procedure given by Mishra *et al.* (1998). A weighed sample (5 g) was transferred into 100 ml stoppered graduated cylinder. Distilled water (50 ml) was added to it and cylinder shaken horizontally i.e. left-right, for time specified in table and then kept for few minutes. After this lactic-acid-sodium dodecyl sulphate (SDS) solution (50 ml) was added and again mixed. The volume of sediments left was noted after 5 minutes and was reported as sedimentation value (ml).

3.7.3 Hectoliter value (hl)

Hectoliter weight of grain samples was measured with the help of test weight instrument developed at DWR, Karnal.

3.7.4 Grain appearance score

It is exclusively a visual test. This parameter was judged based on three characters, which include grain size, shape and colour. Bold grains with attractive shape, amber golden colour and the lustre of the grain are major criteria for scoring. Size, shape and colour of the whole grains threshed from each net plots, were observed visually and scoring was recorded ranging from 1 to 10 (Mishra and Gupta, 1995).

3.8 Nutrient studies

3.8.1 NPK content and uptake

NPK content in grain and straw at harvest was determined. For analysis of NPK, oven dried plant materials (grain and straw at harvest) from each plot were grinded separately with grinder. Nitrogen (Nessler's reagent method, Lindner, 1944), phosphorus (Vanadomolybdo-phosphoric acid yellow colour method, Jackson, 1973) and potassium (Flame photometer method, Richards, 1954) contents in sample were analyzed.

The uptake of each nutrient was computed as:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Per cent nutrient content x Yield (kg/ha)}}{100}$$

3.8.2 Soil analysis

Soil pH, EC, OC, available N, P, K in soil samples in 0-15 and 15-30 cm soil layers and available N, P, K in 0-15 cm soil layers after harvesting were determined as per standard methods reported in Table 2.

3.9 Nitrogen use efficiency

The N use efficiency measurements from applied N were calculated. The RE_n (Recovery efficiency), AE_n (Agronomic efficiency), PE_n (Physiological or internal efficiency) and PFP_n (Partial factor productivity) as follows:

i. $RE_n(\%) = \frac{\text{Total N uptake in N−fertilzed plot−Total N uptake in zero−N plot}}{\text{N−fertilizer rate in N−fertilizer plot}}$; (Dilz, 1988)

ii. $AE_n\ (\text{kg grain /kg N applied}) = \frac{\text{Grain yield in N fertilized plot − Grain yield in zero−N plot}}{\text{Quantity of N fertilizer applied}}$; (Novoa and Loomis, 1981)

iii. $PE_n(\text{kg grain/kg N uptake}) = \frac{\text{Grain yield in N fertilized plot − Grain yield in zero N plot}}{\text{Total N uptake in N fertilzed plot−Total N uptake in zero N plot}}$; (Isfan, 1990)

iv. $PFP_n\ (\text{kg grain/kg N applied}) = \frac{\text{Grain yield in N fertilized plot − Grain yield in zero−N plot}}{\text{Quantity of N fertilizer applied}}$; (Cassman *et al.*, 1998)

3.10 Economics

Cost of cultivation and gross returns (Rs./ha) of various treatments were calculated on the basis of approved market rates for inputs and outputs fixed by Directorate of Farm, CCS HAU, Hisar. Net returns (Rs./ha) were worked out by subtracting the total cost of cultivation of each treatment from the gross income of respective treatment. Benefit-cost ratio was also worked out by following formula:

$$B:C = \frac{\text{Gross returns}}{\text{cost of cultivation}}$$

3.11 Energy analysis

Energy input was calculated as the summation of energy requirement for human, diesel, seed, herbicide, and chemical fertilizers used for crop production. For calculating energy output main product and by-product were converted into energy equivalents by using conversion factors (Devsenapathy *et al.*, 2009). The data were converted into suitable energy units and expressed in MJ/ha. The formulae for calculating energy use efficiency are given below:-

i. $\text{Energy use efficiency} = \sum_{i=1}^{n}\ (EU \div EI)$; (Datta *et al.*, 2014)

ii. $\text{Energy − output efficiecy(MJ/ha/day)} = \frac{EU}{\text{Duration of system}}$; (Singh and Kumar, 2014)

iii. $\text{Specific energy(MJ/kg)} = \sum_{i=1}^{n}(EU \div GY)$; (Datta *et al.*, 2014)

iv. $\text{Energy productivity(kg/MJ)} = \sum_{i=1}^{n}(GY \div EI)$; (Datta *et al.*, 2014)

v. $\text{Net energy(MJ/ha)} = \sum_{i=1}^{n} EU - EI$; (Datta *et al.*, 2014)

Where, EU is energy output (MJ/ha); EI is energy input (MJ/ha); GY ic grain yield (kg/ha) and duration of system is time taken to days from sowing to harvesting.

3.12 Calculation of fertilizer N requirement using GreenSeeker instrument

45-50 DAS and 60-65 DAS which generally coincide with 2nd and 3rd irrigation events and Feekes 5/6 and Feekes 7/8 stages (Bijay-Singh *et al.*, 2011) were designated as stages for GreenSeeker based N management.

3.12.1 GreenSeeker® Optical Sensor

GreenSeeker® hand held optical sensor (Fig. 4) was used as a tool that provides precision measurement and data logging of the Normalized Difference Vegetative Index (NDVI) and a ratio of reflectance of red to near infrared (NIR) radiation from the crop canopy. These data points were used in conjunction with other agronomic references to index basic nutrient response, crop condition and yield potential in a quantitative manner. Absorbance of visible light in blue and red wavelength by chlorophyll molecules and reflectance of NIR by mesophyll cells is indicator of high amount of chlorophyll content and more vegetative biomass and on the basis of these spectral characteristics NDVI is also calculated.

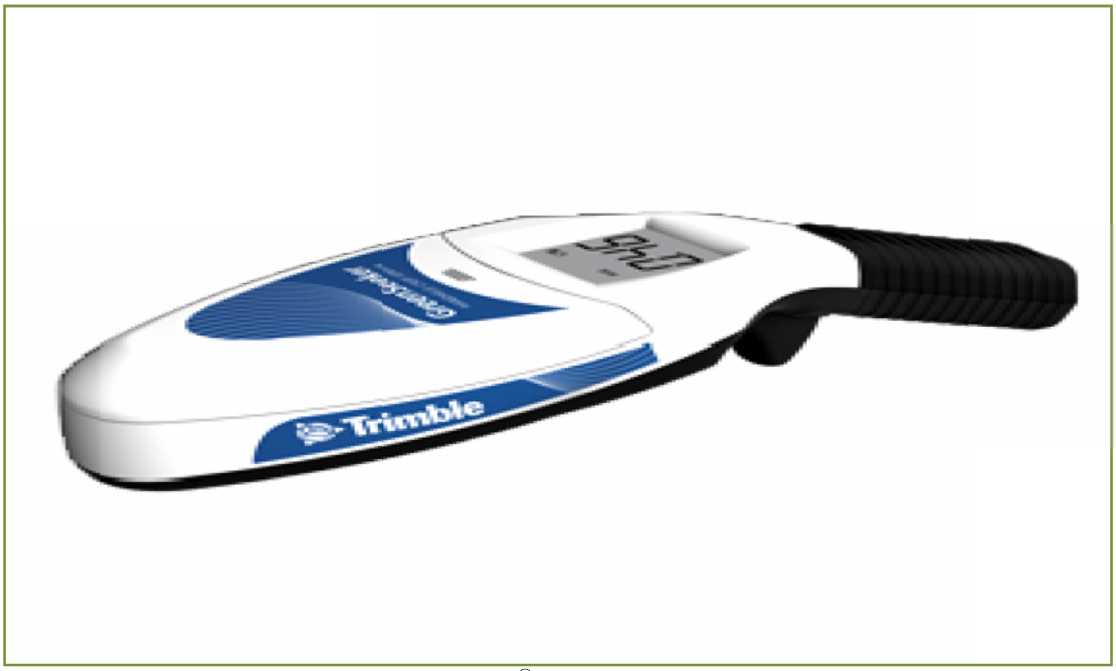

Fig. 4: GreenSeeker® hand held optical sensor

The GreenSeeker hand held optical sensor uses high intensity light emitting diodes (LED's) that emit light at 660±10 nm (red) and 780±10 nm (NIR) as light source. Sensor is held 24"–48"(60–120 cm) above the crop when the trigger is pulled (Fig. 5). The sensor's field of view is an oval; the field of view widens as the height of the sensor above the ground increases (Fig. 6). Upon pulling the trigger, the sensor turns on, emits brief bursts of red and infrared light. The light generated is reflected off of the crop and measured by a photodiode located at the front of the sensor head. The sensor continues to sample the scanned area as long as the trigger remains engaged. The strength of the detected light is a direct indicator of the plant's vigour. The sensor displays the measured value in terms of an NDVI reading on its LCD display screen. NDVI readings can range from 0.00 to 0.99. Yield potential for a crop is identified using NDVI and an environmental factor. Nitrogen (N) is then recommended based on yield potential and the responsiveness of the crop to additional nitrogen.

The two middle crop rows in each plot were sensed by passing the sensor while holding at a height of approximately 0.7 m above the crop canopy and oriented so that the sensed width was perpendicular to the rows and centered over the rows. Normalized difference vegetation index measurements made by Green Seeker were computed by the following formula:

$$NDVI = (NIR_{ref} – Red_{ref}) / (NIR_{ref} + Red_{ref})$$

where, NIR_{ref} or Red_{ref} represent reflectance in the near infrared and red bands. Normalized difference vegetation index is a measure of total biomass and greenness of leaves and is used for mid season prediction of final grain yield.

Fig. 5: GreenSeeker hand held optical sensor's position during sensing the crop

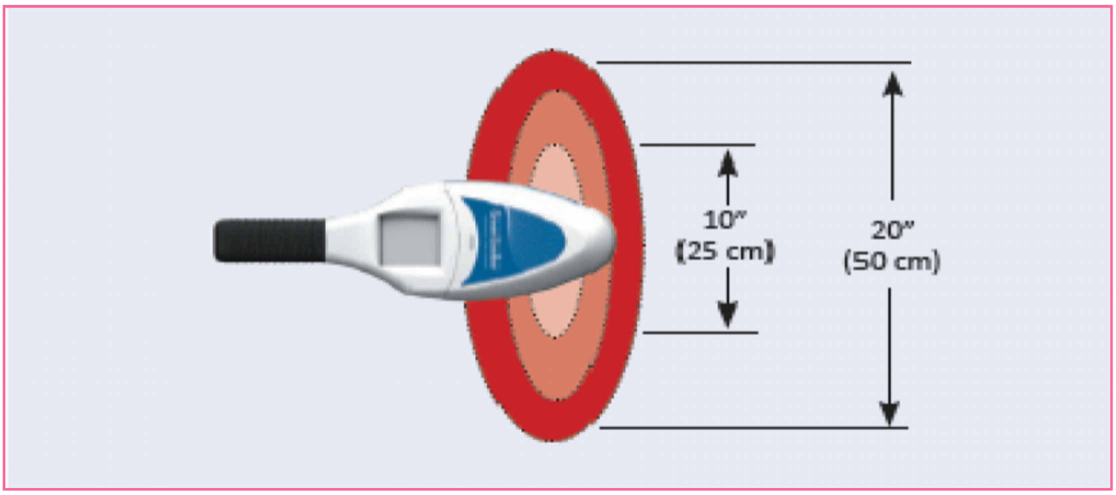

Fig. 6: GreenSeeker hand held optical sensor's field of view

3.12.2 N fertilization optimization algorithm (NFOA)

Nitrogen fertilizer optimization algorithm i.e. procedure for calculating fertilizer N requirement by crop using NDVI readings has been thoroughly described by Raun *et al.* (2002); Raun *et al.* (2005) and Bijay-Singh *et al.* (2011). The NFOA may be separated into several discrete components:

i. NDVI
ii. Mid-season prediction of grain yield (INSEY)
iii. Yield potential with no added inputs (YP_0)
iv. Response Index (RI_{NDVI})
v. Establishing one N- rich strip
vi. Yield potential achievable with applied N Fertilizer (YP_N)
vii. Generating Fertilizer N recommendation

i. Normalized difference vegetation index

Normalized difference vegetation index is a measure of total biomass and greenness of leaves and is used for mid season prediction of final grain yield. NDVI measurements by optical sensing of wheat with GreenSeeker were made on different dates. NDVI values recorded at 50 DAS and 65 DAS were used to find out the Fertilizer N requirements as per treatments. Normalized difference vegetation index (NDVI) measurements made by Green Seeker were computed by the following formula:

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

where, NIR_{ref} or Red_{ref} represent reflectance in the near infrared and red bands.

ii. Mid-season prediction of grain yield (INSEY)

Dividing NDVI (estimate of total biomass) with the number of days from planting to sensing provided an estimate of biomass produced per day. This index (NDVI/days from planting to sensing) is called an in- season estimate of yield or INSEY. It was calculated by using the following formula:-

$$\text{INSEY} = \frac{\text{NDVI}}{\text{Days from planting to sensing,}}$$

iii. Yield potential with no added inputs (YP_0)

Potential yield (YP_0) was predicted with no added fertilizer N from the equation for grain yield and in season estimates of grain yield (INSEY):

$$YP_0 = a\,(\text{INSEY})^{b} \text{ or exponential function}$$

Where the values of constants a and b were used as depicted from graphs showing relationship between grain yield and INSEY. Data from Karnal, Ludhiana and Modipuram generated in different years using different cultivars of wheat grown in tilled or zero-tilled soil and by applying fertilizer N levels either as whole basal or in two split doses, were used to develop these relationships (Bijay-Singh *et al.*, 2011).

Thus, at 2nd irrigation stage: $YP_0 = 602.47\ (INSEY)^{1.1348}$ and

at 3rd irrigation stage: $YP_0 = 2581\ (INSEY)^{1.4072}$

iv. Establishing one N- rich strip

Identifying the specific yield potential does not necessarily translate directly to a recommendation for N. Determining the extent to which the crop will respond to additional' N is equally important. A critical component of the nitrogen fertilizer optimization algorithm is to precisely predict whether or not there will be an in- season response to applied fertilizer N and the magnitude of that response. One N rich plot was established in a way that nitrogen was non-limiting throughout the growing season in the field where fertilizer N rate recommendations were to be made. Applying three or more split doses of N fertilizers created an N rich plot.

v. Response Index (RI_{NDVI})

The Response Index (RI) or the potential responsiveness to added fertilizer N expected was calculated by dividing the average NDVI in the N rich plot (NRS) by the average NDVI in the test plot. Response index indicated the likelihood of obtaining a response and how much of a response can be expected. It is equivalent to predicting the potential responsiveness of the crop to applied N for that year, that field, that crop, under those growing conditions, planted and sensed on particular date. The formula for computing RI is as follows:

$$\text{Response Index } (RI_{NDVI}) = \frac{NDVI_{NRS}}{NDVI_{\text{Test plot}}}$$

vi. Yield potential achievable with applied N Fertilizer (YP_N)

The predicted attainable yield (YP_N) with added nitrogen was based on YP estimated from INSEY-grain yield relation and response index. It was calculated as:

$$YP_N = YP_0 \times RI$$

vii. Generating Fertilizer N recommendation

The predicted amount of N that was removed in the grain at harvest is computed as follows:

$GNUP\_YP_0$ (Grain N uptake, YP_0) = Grain Yield (YP_0)× average % N in the grain

$GNUP\_YP_N$ (Grain N uptake, YP_N) = Grain Yield (YP_N) × average % N in the grain

Average percentage (%) N in grain used in these calculations were 1.8%. The fertilizer N rate to be applied was computed by subtracting the predicted amount of N to be removed in the grain at YP_0 from the predicted amount of N to be removed in the grain at YP_N divided by level of expected use efficiency:

$$[(GNUP\_YP_N) - (GNUP\_YP_0)] / 0.5$$

where, $GNUP\_YP_N$ is N uptake in grain at YP_N and $GNUP\_YP_0$ is N uptake in grain at YP_0. The divisor 0.5 represents the fertilizer N use efficiency factor of 50% for wheat. The best estimate of projected N removed in the grain (with and without fertilizer) come from $GNUP\_YP_N$ and $GNUP\_YP_0$ respectively. Because of this, N requirement (based on projected N removed in the grain with and without N fertilizer) should theoretically be the difference between the two divided by an efficiency factor. It can also be written as:

$$\text{Fertilizer N dose} = \frac{1.8 \times (YP_N - YP_0)}{100 \times 0.5}$$

$$\text{Fertilizer N dose} = \frac{1.8 \times YP_0 (RI_{NDVI} - 1)}{100 \times 0.5}$$

In this equation, YP_N and YP_0 are expressed in kg/ha so as to calculate fertilizer dose in kg N/ ha.

3.13 Statistical analysis of data

a) The experimental data for various growth, yield attributing characters, yield, quality parameters and nutrients uptake was statistically analyzed by the methods of analysis of variance (ANOVA) as described by Panse and Sukhatme (1985). The significance of treatment effects were computed with the help of 'F' (variance ratio) test (Fisher, 1958) and to judge the significance of differences between means of two treatment, critical differences (CD) was worked out as described by Gomez and Gomez (1983) as follows :

$$CD = \sqrt{\frac{2 \text{ x EMS}}{n}} \text{ x t-value for error d.f. at 5\% level of significance}$$

Where,

CD : Critical difference

n : Number of observations of that factor for which CD is to be calculated

t at 5% : Value of Fisher's table for error degree of freedom at five per cent level of significance

b) To measure the degree of association between the variables, correlation analysis was done with the help of linear correlation coefficient.

CHAPTER-IV

RESULTS

The details of results obtained from present investigation entitled, **"Precision nitrogen management in irrigated wheat"** conducted during *Rabi* season of 2013-14 are presented in this chapter with the help of suitable tables and figures.

4.1 Calculating Fertilizer N doses using GreenSeeker (GS) optical sensor

4.1.1 Normalized Difference Vegetative Index (NDVI)

The data pertaining to NDVI values at different crop growth stages (from 50 DAS to 120 DAS) are presented in Fig. 7. In general, NDVI readings were influenced by different initial fixed N doses and time of GS guided N application. The values increased with advancement in crop age upto 73 DAS or 90 DAS and thereafter decreased. NDVI increased upto 73 DAS in all the treatments except control, whereas increased values of NDVI at 90 DAS were generally observed when fertilizer N was applied at 65 DAS i.e. 3rd irrigation stage while at next crop growth stage i.e. at 120 DAS, NDVI decreased in all the treatments, irrespective of the rate and time of N application. No N application (Control) recorded much lower values of NDVI than other treatments (not more than 0.48) and the maximum average values of NDVI was 0.477 that was obtained at 58 DAS, thereafter NDVI decreased, the minimum being at 120 DAS.

At 50 and 58 DAS the treatment having recommended schedule of N application (@ 150 kg/ha) recorded highest NDVI values, followed by treatments where initially 125 kg N/ha had been applied i.e. T_9, T_{10} and T_{11}. However, beyond 65 DAS N application in three splits i.e. T_2 (total N@ 150 kg/ha) was higher in NDVI values than T_1.

At 73 DAS and beyond that NDVI values tended to be more in treatments having N applied into more number of splits and higher doses of total N. At 90 and 120 DAS, T_{11} recorded highest NDVI followed by T_2 and T_9. Among the treatments having same level of fixed rate N application, single stage GS guided N at 3rd irrigation recorded lowest value of NDVI from 58 DAS till end. Changes in NDVI values (11.6 to 13.5%) between the second (50 DAS) and third irrigation (65 DAS) stages were large in treatments where N was applied at 2nd irrigation as compared to changes (2.6 to 5.9%) in treatments having no N application at 2nd irrigation.

4.1.2 Estimating the response to applied N

Average RI_{NDVI} values computed for different treatments at different growth stages are presented in Table 5. The values were generally more than 1.0. RI_{NDVI} at 50 and 65 DAS were used for calculating fertilizer N doses in wheat. Higher doses of N were applied in treatments with higher values of response index. The highest dose of 34 and 36 kg N/ha was applied in wheat at 2nd (50 DAS) and 3rd irrigation (65 DAS) when the response index were 1.25 and 1.26, respectively.

Fig. 7: Effect of time and rate of GreenSeeker based N application on NDVI values of wheat

Table 5: Average RI_{NDVI} and $RI_{HARVEST}$ computed at different crop growth stages in wheat

Treatments	Nitrogen application (kg/ha)					RI_{NDVI}						$RI_{HARVEST}$
	Days after sowing				Total	Days after sowing						
	Basal	25	50	65		50	58	65	73	90	120	
T_1	75	75	0	0	150	1.07	1.08	1.08	1.10	1.18	1.13	2.81
T_2	50	50	50	0	150	1.12	1.09	1.07	1.08	1.15	1.09	2.93
T_3	25	50	34	0	109	1.25	1.26	1.17	1.19	1.19	1.16	2.46
T_4	25	50	0	36	111	1.22	1.26	1.26	1.26	1.22	1.16	2.33
T_5	25	50	33	31	139	1.24	1.21	1.21	1.13	1.18	1.12	2.94
T_6	25	75	29	0	129	1.20	1.18	1.16	1.14	1.18	1.12	2.52
T_7	25	75	0	33	133	1.15	1.20	1.23	1.21	1.21	1.13	2.41
T_8	25	75	28	23	151	1.19	1.17	1.15	1.12	1.16	1.11	2.58
T_9	50	75	20	0	145	1.13	1.11	1.10	1.10	1.15	1.16	2.55
T_{10}	50	75	0	28	153	1.12	1.16	1.19	1.17	1.16	1.09	2.53
T_{11}	50	75	19	18	162	1.12	1.11	1.11	1.09	1.11	1.14	2.88
T_{12}	Control (no nitrogen)					1.56	1.64	1.72	1.81	2.07	1.97	1.00

The perusal of data for effect of rate and time of N application on RI values revealed that at 50 DAS, T_1 recorded minimum RI_{NDVI}, whereas, treatments having fixed rate of N application @ 75 kg/ha into two splits of 25 kg N/ha and 50 kg N/ha as basal and at 25 DAS, respectively, were found most likely to be responsive to additional fertilizer N. Generally, the increase in level of fixed doses of N led to decrease in RI_{NDVI} at all growth stages, irrespective of the dose of GS guided N. The maximum value of RI_{NDVI} was recorded in T_{12} (control) at all growth stages. Pattern of change in RI_{NDVI} values with advancement of crop age varied as the time of N application varied. When N was applied on 2^{nd} irrigation (50 DAS) with or without using GS, generally the RI_{NDVI} decreased upto 73 DAS. Somewhat the same pattern was observed when N was applied both at 2^{nd} and 3^{rd} irrigation stages. Avoiding the N application at 2^{nd} (50 DAS) and application at 3^{rd} irrigation (65 DAS) using GS recorded increase in RI_{NDVI} values upto 65 DAS. Then after 3^{rd} irrigation RI_{NDVI} values decreased in these treatments also. Minimum RI_{NDVI} values were observed at 120 DAS, irrespective of the treatments. Treatment T_1 showed RI_{NDVI} value less than 1.1 initially but at later stages (beyond 73 DAS) the values increased and reached at 1.13 at 120 DAS. In general, the lowest value of RI_{NDVI} at 120 DAS was observed when N was applied both at 2^{nd} and 3^{rd} irrigation stages.

4.1.3 Estimation of fertilizer N dose using YP_0 and RI_{NDVI}

Fertilizer N doses using yield potential without additional fertilizer (YP_0) and potential responsiveness to applied N (RI_{NDVI}) and an N-use efficiency factor (0.5) were calculated at 50 DAS and 65 DAS as per treatment (Table 6). In case of single stage GS guided N application, generally the amount of N turned out to be less at 50 DAS than at 65 DAS whereas YP_0 followed the reverse pattern at these stages. However, in case of GS guided N application both at 50 DAS and 65 DAS, YP_0 increased at 65 DAS as compared to 50 DAS whereas amount of N was less at 65 DAS as compared to 50 DAS. More was the amount of fixed rate N application at sowing and 25 DAS, less was the amount of GS guided N, irrespective of the stage of using GS. However, total dose of N applied increased as the level of fixed rate N application increased. Total N applied was slightly higher when GS guided N was applied at 65 DAS than that at 50 DAS, irrespective of the level of fixed rate N application. Whereas at same level of fixed rate N application, higher amount of total N was applied when GreenSeeker was used at both the stages to recommend the required dose of N.

Table 6: Calculating N fertilizer doses using yield potential and response index

Treatments	N application (kg/ha)	50 DAS		65 DAS		Estimated Fertilizer N dose (kg/ha)		TOTAL N (Kg/ha)
		YP_0	RI_{NDVI}	YP_0	RI_{NDVI}	50 DAS (2^{nd} irrigation)	65 DAS (3^{rd} irrigation)	
T_3	25-50-GS*-0	3.97	1.24	-	-	34	-	109
T_4	25-50-0-GS**	-	-	3.90	1.26	-	36	111
T_5	25-50-GS*-GS**	3.98	1.24	4.13	1.21	33	31	139
T_6	25-75-GS*-0	4.11	1.20	-	-	29	-	129
T_7	25-75-0-GS**	-	-	4.04	1.23	-	33	133
T_8	25-75-GS*-GS**	4.17	1.19	4.45	1.15	28	23	151
T_9	50-75-GS*-0	4.41	1.13	-	-	20	-	145
T_{10}	50-75-0-GS**	-	-	4.25	1.19	-	28	153
T_{11}	50-75-GS*-GS**	4.44	1.12	4.69	1.11	19	18	162

*indicates GreenSeeker guided N application at 2^{nd} irrigation; ** indicates GreenSeeker guided N application at 3^{rd} irrigation; YP_0 = yield potential without additional fertilizer N; Fertilizer N Requirement = 1.8 YP0 (RI_{NDVI}-1)*10/ 0.5

4.2 Relationship between different parameters

4.2.1 Relationship between RI_{NDVI} and $RI_{HARVEST}$

Possible extent of crop to respond to application of additional N i.e. Response Index (RI_{NDVI}), calculated using the NDVI values of test plot and N rich plot (as described in section 3.12.2) were plotted against actual response of crop to total N applied i.e. response index at harvest ($RI_{HARVEST}$), computed by dividing the mean grain yield of N applied test plot with mean grain yield of control plots are presented in Fig. 8. The values of RI_{NDVI} were significantly negatively correlated with $RI_{HARVREST}$ and the highest value of correlation coefficient (0.97) was found at 73 DAS. The values of correlation coefficient increased from 50 DAS (0.89) to 73 DAS (0.97) and thereafter, decreased upto 120 DAS (0.92).

4.2.2 Relationship between total N uptake and NDVI

Total N uptake (straw and grain) of wheat plotted against NDVI at different crop growth stages using linear function, is shown in Fig. 9. The amount of N taken up in wheat was highly correlated with NDVI and the values of coefficient of determination were more than 0.7. The early and later stages showed less correlation than middle stages. Coefficient of determination increased from 50 DAS to 73 DAS and then decreased upto 120 DAS.

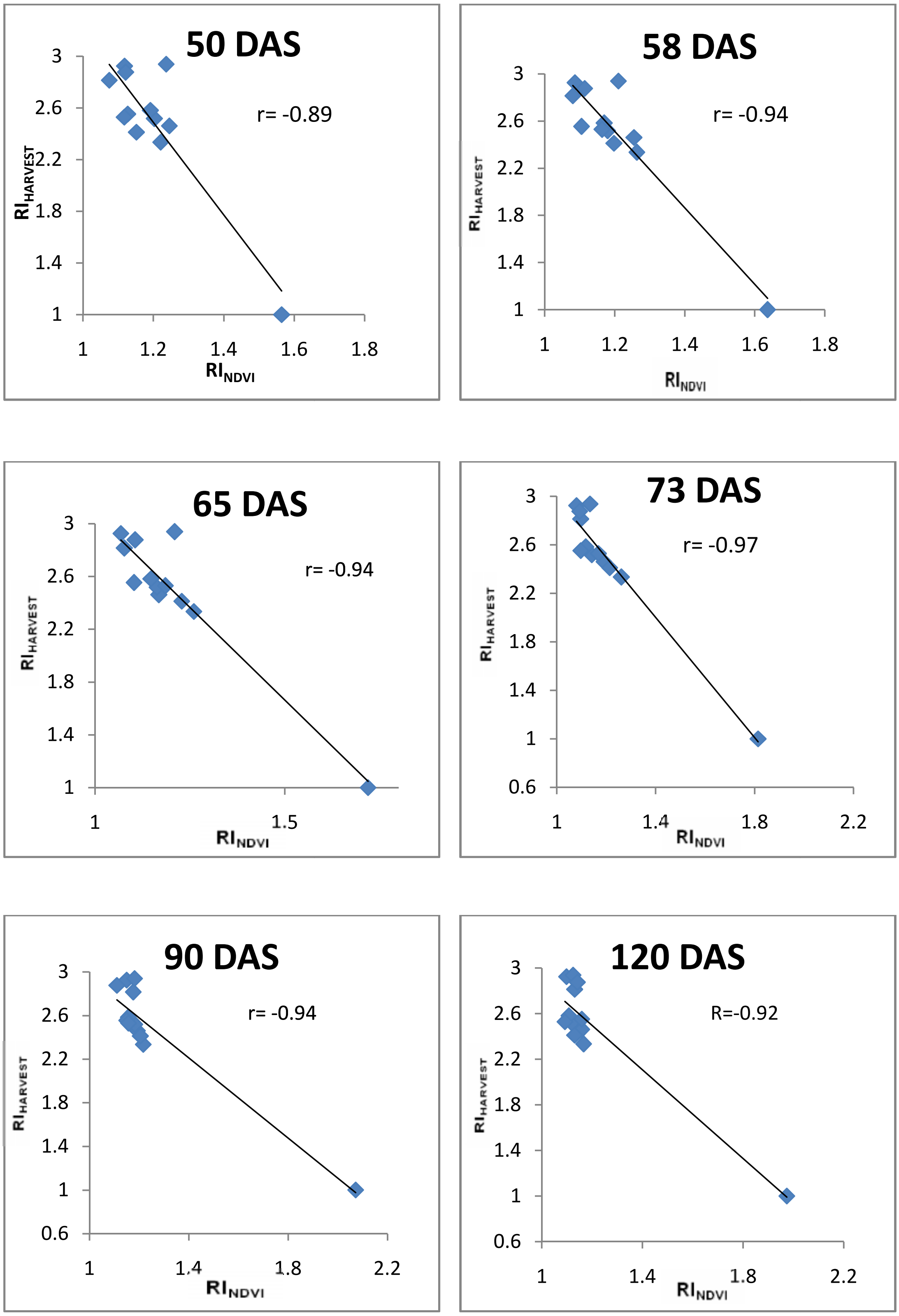

Fig. 8: Relationship between RI_{NDVI} and $RI_{HARVEST}$ of wheat

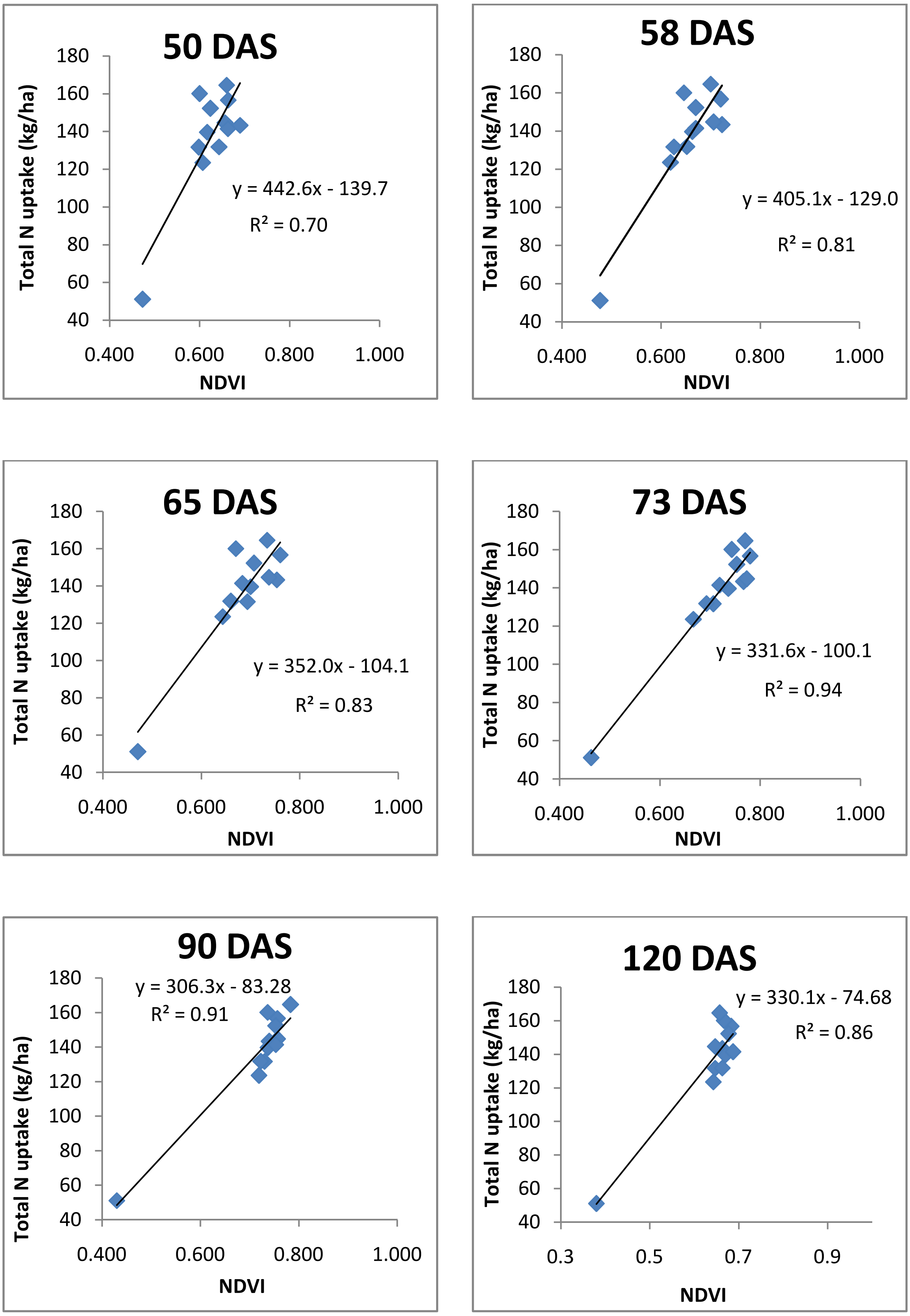

Fig. 9: Relationship between wheat total N uptake and NDVI values

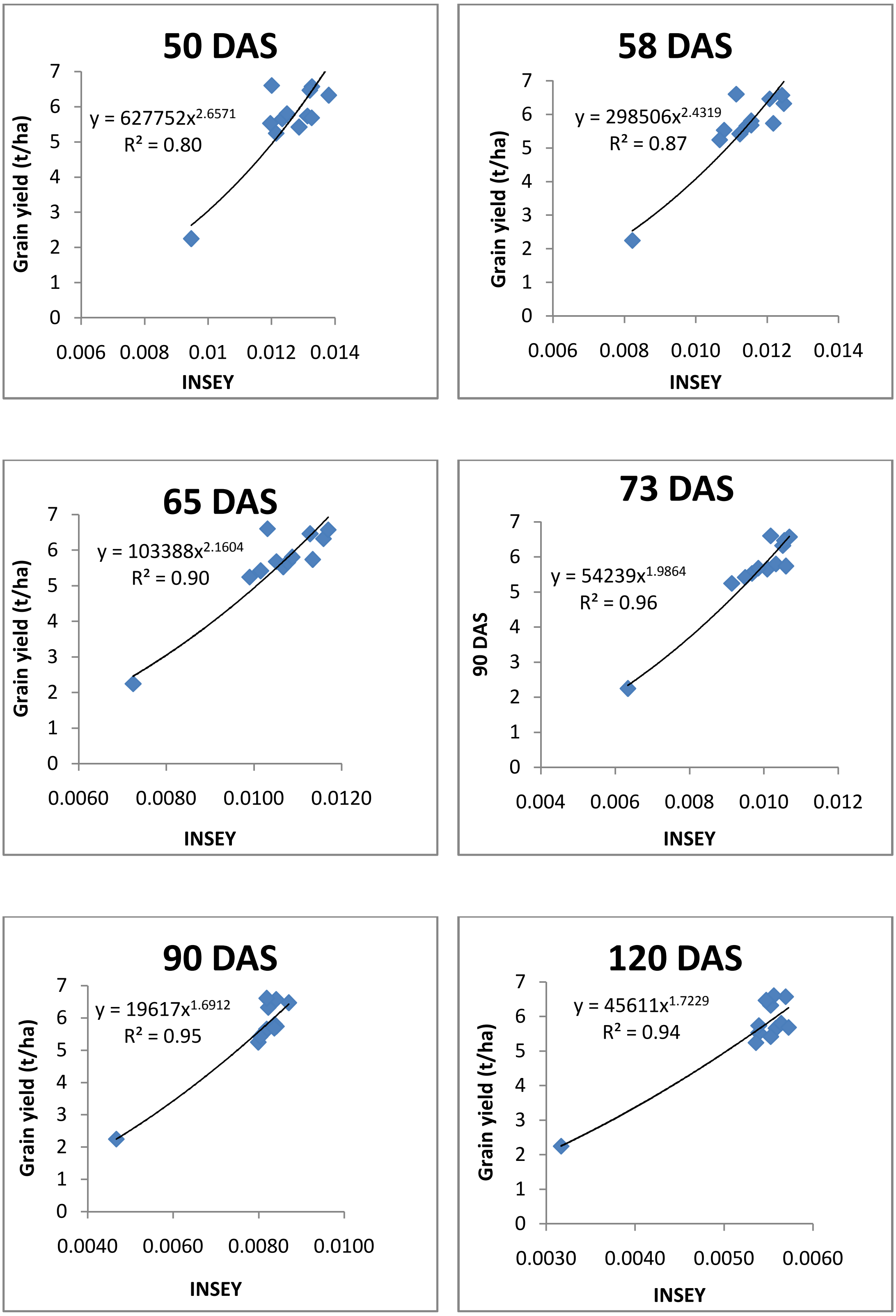

Fig. 10: **Relationship between grain yield and in- season estimation of yield (INSEY) based on NDVI values**

4.2.3 Relationship between INSEY and yield

The in-season estimates of yield, an estimate of biomass produced per day when growth was possible, was plotted against wheat grain yield (Fig. 10). Power functions were used to describe the INSEY and grain yield relation. For the INSEY and grain yield relationship, the coefficient of determination (R^2) values varied from 0.8 to 0.96. R^2 values were lowest at 50 DAS (0.8) then increased upto 73 DAS (0.96) thereafter, decreased to 0.94 at 120 DAS.

Table 7: Effect of time and rate of GreenSeeker based N application on initial plant population/meter row length (mrl) of wheat at 15 days after sowing

Treatments	N application (kg/ha)	Total N (kg/ha)	No. of plants/mrl
T_1	**75-75-0-0**	**150**	47
T_2	**50-50-50-0**	**150**	47
T_3	**25-50-34*-0**	**109**	40
T_4	**25-50-0-36****	**111**	48
T_5	**25-50-33*-31****	**139**	47
T_6	**25-75-29*-0**	**129**	47
T_7	**25-75-0-33****	**133**	45
T_8	**25-75-28*-23****	**151**	46
T_9	**50-75-20*-0**	**145**	47
T_{10}	**50-75-0-28****	**153**	48
T_{11}	**50-75-19*-18****	**162**	47
T_{12}	**Control**	**0**	37
SEm±			2.18
CD at 5%			NS

* indicates GreenSeeker guided N application at 2nd irrigation
** indicates GreenSeeker guided N application at 3rd irrigation

4.3 Crop growth studies

4.3.1 Initial plant population

The plant population of wheat recorded at 15 DAS was not significantly influenced by either of N application treatment (Table 7).

4.3.2 Plant height (cm)

Plant height at different stages of crop growth and at maturity as influenced by different N application treatments is given in Table 8. The plant height increased with advancement in crop age. The different treatments failed to produce significant difference in height at 30 days after sowing (DAS); however, significant variation was recorded at later stages. Significantly shorter wheat plants were recorded in control treatment beyond 60 DAS as compared to other N application treatments. Irrespective of GreenSeeker (GS) guided N application doses, plant height increased with increasing the level of fixed rate N application at all growth stages starting from 60 DAS till maturity. At 60 DAS, N application as recommended schedule (T_1) resulted into significantly taller plants than all other treatments except the treatments having fixed rate application @ 125 kg/ha i.e. T_9, T_{10}, T_{11}. However, this treatment led to numerically lower plant height than all other treatments except T_3 and T_4 at 90 DAS and except T_4 at 120 DAS and at maturity. At 90, 120 and at maturity, GS guided N application proved more efficient when applied at two stages i.e. 2nd and 3rd irrigation as compared to single GS guided N application either at 2nd or 3rd irrigation, irrespective of different fixed rate N application levels. At maturity, at different fixed rates of N application i.e. 75, 100 or 125 kg/ha coupled with GS based N application at two stage (2nd and 3rd irrigation) improved plant height than GS based application either at 2nd or 3rd irrigation, however, GS guided N application at 2nd irrigation resulted into taller plants than N application at 3rd irrigation, irrespective of fixed rate N application rates.

Table 8: Effect of time and rate of GreenSeeker based N application on plant height (cm) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Days after sowing				At maturity
			30	60	90	120	
T_1	75-75-0-0	150	21.27	42.79	75.00	83.28	85.28
T_2	50-50-50-0	150	20.91	36.37	77.18	89.13	91.36
T_3	25-50-34*-0	109	19.80	34.34	73.43	84.27	87.16
T_4	25-50-0-36**	111	20.82	35.53	71.54	81.53	84.18
T_5	25-50-33*-31**	139	20.13	34.97	75.52	87.17	90.06
T_6	25-75-29*-0	129	20.40	37.02	77.32	86.16	89.05
T_7	25-75-0-33**	133	20.80	37.24	75.60	85.96	87.29
T_8	25-75-28*-23**	151	20.53	38.07	78.04	88.72	90.95
T_9	50-75-20*-0	145	20.67	40.03	78.73	86.60	89.14
T_{10}	50-75-0-28**	153	21.22	41.42	77.65	86.15	88.66
T_{11}	50-75-19*-18**	162	22.02	39.94	78.53	87.13	92.78
T_{12}	Control	0	16.46	28.6	50.07	62.49	67.23
SEm ±			0.97	1.26	1.90	2.20	2.37
CD at 5%			NS	3.73	5.60	6.51	6.99

* indicates GreenSeeker guided N application at 2nd irrigation;
** indicates GreenSeeker guided N application at 3rd irrigation

4.3.3 Dry matter accumulation

The perusal of data of Table 9 revealed that dry matter accumulation by wheat plant increased progressively with the advancement of crop age. The maximum dry matter was recorded at maturity in all the treatments. Dry matter accumulation varied significantly among various N application treatments from 60 DAS till maturity. At 60 DAS, recommended schedule of N application (T_1) produced significantly more dry matter than all other treatments except T_9, T_{10} and T_{11} which were at par with each other. However, from 90 DAS onwards T_1 was statistically at par with three N splits without using GreenSeeker (T_2).

Among all N application treatments, lowest dry matter accumulation was recorded in T_4 at all growth stages beyond 30 DAS and it was significantly lower than all other treatments except T_3 and T_7 at 90, 120 and at maturity. Dry matter accumulation increased with increasing the level of fixed rate N application, irrespective of GS guided N doses. Dry matter accumulation of wheat in treatments having fixed rate N application @ 75 kg/ha coupled with GS applied N was significantly lower than that in treatments having 125 kg N/ha as fixed rate coupled with GS applied N beyond 60 DAS whereas, increase in fixed rate N application by 25 kg/ha (i.e. 100 kg N/ha) failed to produce significant variation in dry matter

Table 9: Effect of time and rate of GreenSeeker based N application on dry matter accumulation (g/mrl) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Days after sowing				At maturity
			30	60	90	120	
T_1	75-75-0-0	150	11.31	54.70	166.00	280.40	339.20
T_2	50-50-50-0	150	10.63	50.03	164.23	282.53	342.73
T_3	25-50-34*-0	109	9.20	45.19	157.09	270.19	324.79
T_4	25-50-0-36**	111	9.27	44.80	147.10	256.60	307.05
T_5	25-50-33*-31**	139	9.35	45.93	158.13	276.63	330.88
T_6	25-75-29*-0	129	9.12	49.50	164.80	279.20	334.85
T_7	25-75-0-33**	133	9.56	48.26	155.75	265.75	318.10
T_8	25-75-28*-23**	151	9.00	48.73	166.02	285.46	342.51
T_9	50-75-20*-0	145	9.97	54.32	170.38	293.68	352.83
T_{10}	50-75-0-28**	153	10.41	52.92	160.86	281.16	335.96
T_{11}	50-75-19*-18**	162	10.27	53.13	171.76	298.72	353.22
T_{12}	Control	0	8.32	35.16	123.96	216.96	235.16
SEm±			0.58	0.92	3.69	6.67	7.72
CD at 5%			NS	2.72	10.88	19.68	22.78

* indicates GreenSeeker guided N application at 2nd irrigation
** indicates GreenSeeker guided N application at 3rd irrigation

accumulation of wheat at these growth stages. Treatments having GS guided N application at 2nd and 3rd irrigation were superior over treatments with GS guided N application only at 2nd irrigation followed by 3rd irrigation, irrespective of fixed doses of N application. In general, GS guided N application only at 3rd irrigation recorded significantly lower dry matter accumulation than its corresponding treatments (treatments having same level of fixed rate N) having GS guided N application both at 2nd and 3rd irrigation. Nitrogen applied @ 150 kg/ha in 2 or 3 splits produced statistically similar crop dry matter, however, both of these treatments produced significantly higher dry matter accumulation than control at maturity. 75

kg N/ha as fixed rate along with GS applied N at 2nd and 3rd irrigation produced significantly higher wheat dry matter than control and T_4 treatments but rest of the treatments were at par with each other in relation to crop dry matter production at maturity.

4.3.4 Crop growth rate

CGR of wheat as influenced by different treatments is presented in Table 10. CGR of wheat increased with the advancement of crop age upto 120 DAS and later on it decreased. The maximum crop growth rate was recorded between 91-120 DAS, the lowest being upto 30 DAS of wheat crop. Nitrogen applied at 150 kg/ha either in 2 or 3 splits failed to produce significant variation in CGR of wheat at all growth stages among themselves except at 31-60 DAS where 2 splits produced significantly higher CGR. The CGR increased with the increase in fixed rate of N application in different treatments. GS based N application at 3rd irrigation, irrespective of fixed rate N application numerically produced lower CGR than N application at 2nd irrigation. In general, GS indicated N application at 2nd and 3rd irrigation resulted into higher CGR values at all growth stages, irrespective of fixed rate N application. At fixed rate of N application coupled with GS indicated N failed to produce significant variation in CGR, however, higher the fixed N application, higher was the value of CGR.

Table 10: Effect of time and rate of GreenSeeker based N application on crop growth rate (g/mrl/day) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Days after sowing				
			0-30	31-60	61-90	91-120	121-156
T_1	75-75-0-0	150	0.38	1.45	3.71	3.81	1.63
T_2	50-50-50-0	150	0.35	1.31	3.81	3.94	1.67
T_3	25-50-34*-0	109	0.31	1.20	3.73	3.77	1.52
T_4	25-50-0-36**	111	0.31	1.18	3.41	3.65	1.40
T_5	25-50-33*-31**	139	0.31	1.22	3.74	3.95	1.51
T_6	25-75-29*-0	129	0.30	1.35	3.79	3.81	1.55
T_7	25-75-0-33**	133	0.32	1.31	3.58	3.67	1.45
T_8	25-75-28*-23**	151	0.30	1.31	3.91	3.98	1.58
T_9	50-75-20*-0	145	0.33	1.44	3.87	4.11	1.64
T_{10}	50-75-0-28**	153	0.35	1.42	3.60	4.01	1.52
T_{11}	50-75-19*-18**	162	0.34	1.47	3.95	4.23	1.51
T_{12}	Control	0	0.28	0.89	2.96	3.10	0.51
SEm±			0.02	0.03	0.13	0.20	0.07
CD at 5%			NS	0.10	0.38	NS	0.22

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

4.3.5 Relative growth rate (RGR)

Data pertaining to RGR of wheat are presented in Table 11 indicates that RGR of wheat was not significantly influenced by different treatments upto 120 DAS. The maximum values of RGR were recorded between 31-60 DAS and beyond this stage the values of RGR were reduced, the lowest being during 121 DAS to maturity. No nitrogen application (control) produced significantly lower values of RGR in between 121 DAS to maturity as compared to rest of the treatments which were at par with each other.

Table 11: Effect of time and rate of GreenSeeker based N application on relative growth rate (mg/g/day) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Days after sowing			
			31-60	61-90	91-120	121-156
T_1	75-75-0-0	150	52.93	36.99	17.73	5.40
T_2	50-50-50-0	150	51.78	39.63	18.10	5.52
T_3	25-50-34*-0	109	53.11	41.53	18.06	5.26
T_4	25-50-0-36**	111	52.52	39.61	19.15	5.47
T_5	25-50-33*-31**	139	53.10	41.21	18.13	5.19
T_6	25-75-29*-0	129	56.50	40.07	17.31	5.24
T_7	25-75-0-33**	133	54.17	39.03	18.42	5.41
T_8	25-75-28*-23**	151	56.41	40.86	17.83	5.24
T_9	50-75-20*-0	145	56.62	38.11	17.81	5.29
T_{10}	50-75-0-28**	153	54.24	37.07	19.29	5.33
T_{11}	50-75-19*-18**	162	54.88	39.10	18.22	4.78
T_{12}	Control	0	48.09	41.98	18.67	2.29
SEm±			1.92	1.05	1.25	0.16
CD at 5%			NS	NS	NS	0.47

* indicates GreenSeeker guided N application at 2^{nd} irrigation.
** indicates GreenSeeker guided N application at 3^{rd} irrigation

4.3.6 Leaf area index

Area of green (photosynthetically active) leaves was recorded at 30, 60, 90 and 120 DAS and then leaf area index (LAI) was calculated. The LAI of different stages are given in Table 12.

The data indicated that LAI increased with the advancement of crop age reaching peak value at 90 DAS and it decreased thereafter at 120 DAS. The increase in LAI was more remarkable from 30-60 DAS period as compared to 60-90 DAS. LAI showed increasing pattern with increase in level of fixed rate N. At 60 DAS, N application at initial stages as fixed dose @ 100 and 125 kg/ha, led to significantly higher LAI than that @ 75 kg/ha. However at 90 and 120 DAS, the varying levels of fixed dose did not produce significant difference among themselves. GS guided N application at two stages i.e. 2nd and 3rd irrigation was superior to single stage GS guided N either at 2nd or 3rd irrigation, though these differences were not statistically significant, except at 90 and 120 DAS when single stage GS guided N application at 3rd irrigation recorded significantly lower LAI than two stage GS guided N application, irrespective of the level of fixed rate N application. Recommended schedule of N application (T_1), being superior initially, recorded lower LAI at 90 and 120 DAS than treatment having same dose of N applied in three splits (T_2). At 30 DAS, different treatments were unable to influence LAI significantly. Significantly minimum LAI was recorded under control treatment.

Table 12: Effect of time and rate of GreenSeeker based N application on leaf area index of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Days after sowing			
			30	60	90	120
T_1	**75-75-0-0**	**150**	0.58	4.36	5.72	2.33
T_2	**50-50-50-0**	**150**	0.56	4.24	5.83	2.37
T_3	**25-50-34*-0**	**109**	0.45	4.07	5.69	2.30
T_4	**25-50-0-36****	**111**	0.42	3.98	5.51	2.26
T_5	**25-50-33*-31****	**139**	0.43	4.09	5.81	2.42
T_6	**25-75-29*-0**	**129**	0.47	4.32	5.77	2.36
T_7	**25-75-0-33****	**133**	0.48	4.26	5.59	2.27
T_8	**25-75-28*-23****	**151**	0.51	4.30	5.86	2.43
T_9	**50-75-20*-0**	**145**	0.57	4.34	5.79	2.41
T_{10}	**50-75-0-28****	**153**	0.58	4.31	5.63	2.32
T_{11}	**50-75-19*-18****	**162**	0.54	4.38	5.88	2.45
T_{12}	**Control**	**0**	0.40	3.60	4.81	1.09
SEm±			0.04	0.08	0.09	0.04
CD at 5%			NS	0.25	0.25	0.13

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

4.4 Yield attributes

4.4.1 Effective tillers/mrl

The data pertaining to effective tillers per meter row length are given in Table 13. Control treatment recorded significantly lower number of effective tillers than all other treatments. T_5 produced maximum no. of effective tillers followed by T_2, T_{11} and T_1, however, these treatments were statistically similar to each other in respect of number of effective tillers. Moreover, effective tillers were significantly less in rest of the treatments than T_5. Treatment having recommended dose of N as three split applications without using GS (T_2)

recorded 3.83% higher number of effective tillers than T_1, though both the treatments were statistically at par. Single N application using GS either at 2nd or 3rd irrigation failed to show any significant variation in number of effective tillers. But the values consistently decreased at avoiding the N application at 2nd irrigation, irrespective of the fixed N dose of 75, 100 and 125 kg/ha and the respective decrease in their number was 3.29, 2.24 and 1.28% over the treatment having single GS guided N application at 2nd irrigation. However, number of effective tillers increased to significant level when GS guided N was applied both at 2nd and 3rd irrigation in all such treatments except T_7 and T_8. Number of effective tillers was numerically more in T_8 than that in T_7 but both the treatments were statistically at par. Additionally, T_3 (GS guided N application at 3rd irrigation) was also significantly inferior to T_5 (GS N application at both stages) i.e. the number decreased by 11.3% in T_3 but at higher levels of fixed rate N application i.e. 100 and 125 kg/ha, the equivalent treatments failed to produce any significant variations; however two stage GS application achieved 0.84 and 5.6% higher number of effective tillers than its other corresponding treatments, respectively. Number of effective tillers increased at increasing the level of fixed rate N application, irrespective of the number and dose of N application using GS, though the increase was not significant. At each successive increase in fixed N dose, effective tillers increased by 0.54 and 1.9%; 1.6 and 2.95% in both types of single stage GS guided N application treatments (N application at 2nd irrigation; 3rd irrigation, respectively). T_8 was exceptionally inferior to T_5 and the difference was significant i.e. T_8 led to 10% decrease in effective tillers as compared to T_5 but T_{11} recorded 6.7% increase from T_8, yet T_{11} was numerically inferior to T_5.

4.4.2 Spike length (cm)

Average spike length as influenced by different treatments is given in Table 13. The perusal of data revealed that T_5 being at par with T_1 and T_2, recorded maximum length of spikes. There was no significant variation in treatments having GS guided N application either at 2nd or 3rd irrigation, however, longer spikes were recorded when N was applied only at 3rd irrigation, irrespective of the level of fixed rate N application. Similarly, in case of fixed rate N application @ 100 and 125 kg/ha, GS guided N application either once (2nd or 3rd irrigation) or twice (2nd and 3rd irrigation) achieved no significant variation in spike length. N applied @ 75 kg /ha as fixed rate, the two staged GS guided N application produced significantly longer spike as compared to GS guided N either at 2nd or 3rd irrigation stage. Control treatment produced minimum length of spike, significantly inferior to all other treatments. T_1 and T_2 (N splitting without using GS) recorded no significant variation among themselves; however, spike length was comparatively higher in T_2.

Table 13: Effect of time and rate of GreenSeeker based N application on yield attributes of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Effective tillers/mrl (No.)	Spike length (cm)	Grains/ spike (No.)	1000-grain weight (g)
T_1	75-75-0-0	150	106.34	10.09	46.23	43.10
T_2	50-50-50-0	150	110.42	10.95	46.31	43.52
T_3	25-50-34*-0	109	99.82	9.50	44.70	41.01
T_4	25-50-0-36**	111	96.53	9.95	44.07	40.90
T_5	25-50-33*-31**	139	112.51	11.53	46.50	43.85
T_6	25-75-29*-0	129	100.36	9.99	45.20	42.13
T_7	25-75-0-33**	133	98.11	9.89	44.80	41.32
T_8	25-75-28*-23**	151	101.21	10.21	45.10	42.81
T_9	50-75-20*-0	145	102.32	9.76	46.21	42.54
T_{10}	50-75-0-28**	153	101.01	10.47	45.02	42.48
T_{11}	50-75-19*-18**	162	108.02	10.55	46.42	43.16
T_{12}	Control	0	74.06	8.44	39.68	39.26
SEm±			2.36	0.32	2.36	0.60
CD at 5%			6.98	0.94	6.98	1.77

* indicates GreenSeeker guided N application at 2^{nd} irrigation.
** indicates GreenSeeker guided N application at 3^{rd} irrigation

4.4.3 Grains/spike (No.)

The data on no. of grain/spike are presented in Table 13. Each of treatments was significantly superior over control. Increase in no. of grains/spike due to N application in different treatments was 11.1 to 17.2% over control. However, among treatments other than control, the lowest no. of grain was recorded in T_4. T_1, T_2, T_5, T_9 and T_{11} were significantly superior to T_4. When treatments having same level of fixed doses were compared with each other, the highest number of grains/spike was recorded when N was applied at all the four stages except T_6 and T_8 where T_8 recorded numerically lower number of grains/spike and the lowest number of grains was recorded when N application was avoided at 2^{nd} irrigation, however, the differences among the treatments were not significant. Overall, highest number of grains was recorded in T_5, however, it was at par with remaining treatments except T_4 and control. Application of recommended dose in three equal splits (T_2) was better than that in two equal splits (T_1).

4.4.4 1000-grain weight

1000-grain weight (TW) followed the similar pattern as that obtained for other yield attributing characters. The relevant data is given in Table 13. T_5 recorded highest TW (43.85 g) and it was statistically at par with other treatments except T_4, T_7 and control. Control treatment was significantly lower in TW than other treatments. T_1 and T_2 were statistically similar but T_2 recorded numerically higher (by 1%) TW. Among GS guided N application doses combined with initial fixed doses, the lowest TW was recorded when N application was avoided at 2nd irrigation and the highest being at GS application N at two stages i.e. 2nd and 3rd irrigation, irrespective of fixed level N application doses. When level of fixed rate N application was increased, 1000-grain weight also improved in case of single stage GS guided N either at 2nd and 3rd irrigation, whereas, in case of two stage GS guided N application, 1000-grain weight decreased to 2.4% at first level increase in fixed dose (i.e. 75 to 100 kg/ha) but the increase from 100 to 125 kg/ha led to 0.8% increase in TW as a result T_{11} (43.16 g) was still inferior to T_5 (43.85 g), although both the treatments were statistically at par.

4.5 Yield

4.5.1 Biological yield

The data pertaining to biological yield as influenced by various treatments is given in Table 14 which revealed that minimum biological yield was obtained in T_{12} (control) and it was significantly inferior to all other treatments. The highest biological yield was recorded where recommended dose (150 kg/ha) was applied in three equal splits (T_2) and it was followed by treatment having application of recommended dose in 2 equal splits (T_1). Increase in yield due to treatment T_2 was 2.95% over T_1. When different levels of fixed rate N application were combined with GS guided N application, the highest biological yield was recorded in T_{11} (14460 kg/ha) followed by T_5 (14419 kg/ha); however T_1, T_2, T_5 and T_{11} were at par with each other.

Table 14: Effect of time and rate of GreenSeeker based N application on yield (kg/ha) and harvest index (%) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Biological yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
T_1	75-75-0-0	150	14591	6324	8267	43.38
T_2	50-50-50-0	150	15021	6573	8448	43.76
T_3	25-50-34*-0	109	12824	5530	7294	43.13
T_4	25-50-0-36**	111	11955	5245	6710	43.88
T_5	25-50-33*-31**	139	14419	6603	7816	45.82
T_6	25-75-29*-0	129	12971	5657	7314	43.62
T_7	25-75-0-33**	133	12213	5420	6793	44.39
T_8	25-75-28*-23**	151	13527	5803	7724	42.97
T_9	50-75-20*-0	145	13255	5737	7518	43.41
T_{10}	50-75-0-28**	153	12742	5683	7059	44.63
T_{11}	50-75-19*-18**	162	14460	6464	7996	44.73
T_{12}	Control	0	5541	2247	3294	40.56
SEm±			276	103	255	0.96
CD at 5%			814	305	751	NS

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

When treatments having same fixed level of N application were compared, it was observed that at fixed rate N application of 75 kg/ha, the yield variations were significant with each other. At higher levels, the significant increase was observed only when GS guided N was applied at two stages (2^{nd} and 3^{rd} irrigation) instead of single stage GS guided N application at 3^{rd} irrigation while the rest of the treatments failed to record significant variation with each other.

When these variations were quantified, the decrease in yield due to skipping the N application at 2^{nd} irrigation was found more (13.5 to 20.6%) than that due to skipping at 3^{rd} irrigation (i.e. 9.1 to 12.4%). In general, the biological yield improved as the level of fixed rate N application was increased and thoughtful perception of data revealed that in treatment having single GS guided N application at 2^{nd} irrigation, there was 1.14 and 2.19% more yield when fixed N application level was increased from 75 to 100 kg/ha and 100 to 125 kg/ha, respectively. Similarly, 2.16 and 4.33% more yields were recorded at each successive increase in level of fixed N application when GS guided N was applied only at 3^{rd} irrigation. However, yield decreased to 6.19% when N application level was increased from 75 to 100 kg/ha, in case of two stage GS guided N application but again increase in fixed N dose to next level led to 6.9% increase in biological yield as a result T_5 and T_{11} recorded statistically similar yield levels i.e. 14419 and 14460 kg/ha, respectively.

4.5.2 Grain yield

Grain yield of wheat as responded to 12 different treatments was recorded and relevant data are given in Table 14. Application of recommended dose of N i.e. 150 kg/ha in two (T_1) or three (T_2) equal splits, produced statistically similar grain yields but T_2 produced 3.94% higher grain yield (6573 kg/ha) than T_1 (6324 kg/ha). T_1 and T_2 both were significantly superior over control and increase in yield was 181.4% and 192.5% over control, respectively. T_5 (75 kg N/ha coupled with GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation) produced highest grain yield and it was at par with T_1, T_2 and T_{11} (125 kg N/ha as fixed rate coupled with GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation). T_5 was significantly superior to rest of the treatments. Lowest grain yield was recorded in T_{12} (control) and all the treatments produced significantly higher grain yield as compared to T_{12} (control). The range of yield increase due to N application was 146.1% to 193.8%.

A thorough understanding of data shows that GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation proved significantly superior to single N application (GS based) either at 2^{nd} or 3^{rd} irrigation, irrespective of the level of fixed rate N application; however, the decrease in yield was 0.83% to 4.3% more when N application was skipped at 2^{nd} irrigation as compared to N application skipped at 3^{rd} irrigation. In other words, yields were less when N application only at 3^{rd} irrigation was done as compared to N application only at 2^{nd} irrigation.

This study also emphasized that the grain yields improved generally at increasing the level of fixed rate N application, irrespective of the doses of GS guided nitrogen. When GS guided N was applied once at 2nd irrigation, the increase in yield was 2.29% and 1.41% at increasing the level of fixed rate N application from 75 to 100 kg/ha and from 100 to 125 kg/ha, respectively. Similarly, when GS guided N was applied once at 3rd irrigation, the respective increases in yields were 3.34% and 4.85%. However, in case of two stage GS applied N, the reverse trend was observed at first level increase in fixed rate N application (i.e. 75 kg/ha to 100 kg N/ha) as the yield decreased to 12.1% (from 6603 kg grain/ha in T_5 to 5803 kg grain/ha in T_7). However, the next level increase in fixed N rate resulted into 11.3% yield increase but the yield in T_{11} (6464 kg/ha) was still less than that in T_5 (6603 kg/ha).

4.5.3 Straw yield

Perusal of data (Table 14) showed that straw yield followed similar trend as that of biological yield. The highest straw yield was recorded in T_2 follwed by T_1 but the yield increased to only 2.19% in T_2 over T_1 and both the treatments were statistically at par. Whereas, T_1 and T_2 both achieved significantly higher straw yield than all other treatments except the treatments where the GS guided N was applied both at 2nd and 3rd irrigation stages, in combination with different fixed doses (i.e. T_5, T_8 and T_{11}). T_5, T_8 and T_{11} recorded 7.5, 8.6 and 5.6% decrease in yield as compared to T_2, respectively.

After careful perusal of data from the treatments having combined N application (fixed N dose as basal and at 25 DAS +GS guided N at 2nd and/or 3rd irrigation), it was revealed that avoiding N application at 2nd irrigation always led to minimum straw yield. GS guided N application at two stages i.e. at 2nd and 3rd irrigation proved significantly superior in straw yield; over single stage GS guided N application at 3rd irrigation. GS guided N application at two stages i.e. at 2nd and 3rd irrigation was also superior to single stage GS guided N application at 2nd irrigation, though the difference was not significant. Moreover, both single stage GS guided N application treatments were statistically at par with each other, irrespective of the level of fixed rate N application. The pattern of variation in straw yield was similar to that in biological yield when treatments having different levels of fixed rate N application were compared. The successive yield increments quantified were 0.27 and 2.85% and; 1.24 and 3,91% when treatments having same timing of N application (GS applied N at 2nd and 3rd irrigation, respectively) were compared. However, treatments having 2 stage GS guided N recorded some deviation in successive yield variations as the straw yield decreased to 1.17% at increasing the fixed N dose from 75 to 100 kg/ha but again the yield increased to 3.52% at next level of N application. Any of these treatments did not produce significant variation with each other. As usual, control treatment was significantly inferior to all other treatments.

4.5.4 Harvest Index

Harvest index was not significantly affected by either of N application treatment (Table 14).

4.6 Correlation studies

Correlation of grain yield per hectare with the physiological growth parameters and yield contributing characters were worked out and are presented in Table 15. A critical examination of the Table 15 revealed that all the yield attributing characters under study viz. number of effective tillers/mrl, number of grains/spike, spike length and 1000-grain weight were found significantly positively correlated with the grain yield at 1 per cent level of significance. Besides, grain yield, other yield attributes among themselves were also found to be positively related at 1 per cent level of significance.

All the growth parameters under study viz. plant height (cm), dry matter accumulation (g/mrl), CGR (60-90 DAS) and LAI were also significantly positively correlated with grain yield at 1% level of significance. Besides, all the growth parameters were also found significantly positively correlated with each other. Moreover, growth parameters and yield attributes among themselves were also significantly correlated.

4.7 Quality Parameters

The data on quality parameters like sedimentation value, protein content, grain appearance and starch content of wheat as influenced by different treatments is given in Table 16.

4.7.1 Sedimentation value

The highest sedimentation value was recorded in T_8 and T_{11} and these were at par with T_1, T_2, T_5, T_6, T_9 and T_{10}. Numerical values of sedimentation increased with increasing no. of splits and level of N dose. When related with time, avoiding the N dose tended to decrease the sedimentation values.

4.7.2 Hectoliter weight

The data on hectoliter weight showed that it was not influenced by different time and rate of N application with or without GS guided N doses.

4.7.3 Grain appearance

The minimum grain appearance score was recorded in control and T_3. T_8 and T_{11} scored highest in grain appearance and when compared, these treatments were at par with T_{10}, T_5, T_7, T_9 but significantly superior over rest of the treatments. A thorough understanding of data revealed that there was a combined effect of total dose and time of N application. N application at later stages (2^{nd} and/or 3^{rd} irrigation proved better in grain appearance than initial higher doses (T_1). More the number of split doses of N, higher was the grain appearance score.

Table 15: Correlation coefficient between different growth parameters and yield

Variables	Grain Yield	Effective tillers/mrl	Grains /spike	Spike length	1000-grain weight	Plant height	Dry matter accumulation	CGR (60-90 DAS)	LAI (90 DAS)
Grain Yield	1.000								
Effective tillers/mrl	0.990**	1.000							
Grains/spike	0.983**	0.975**	1.000						
Spike length	0.858**	0.897**	0.807**	1.000					
1000-grain weight	0.901**	0.928**	0.903**	0.893**	1.000				
Plant height	0.938**	0.908**	0.930**	0.782**	0.818**	1.000			
Drymatter accumulation	0.931**	0.897**	0.957**	0.693*	0.844**	0.956**	1.000		
CGR (60-90 DAS)	0.884**	0.858**	0.908**	0.644*	0.819**	0.938**	0.960**	1.000	
LAI (90 DAS)	0.957**	0.930**	0.958**	0.756**	0.854**	0.978**	0.973**	0.972**	1.000

* indicates significance at 5% level
** indicates significance at 1% level

Table 16: Effect of time and rate of GreenSeeker based N application on quality parameters and protein yield (kg/ha) of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Sedimentation value (ml)	Hectolitre weight (kg/hl)	Grain appearance score (0-10)	Protein content (%)	Protein yield (kg/ha)
T_1	**75-75-0-0**	**150**	35.3	81.42	6.1	10.81	683.3
T_2	**50-50-50-0**	**150**	36.0	80.33	6.2	11.13	731.5
T_3	**25-50-34*-0**	**109**	34.2	78.78	6.0	11.06	613.0
T_4	**25-50-0-36****	**111**	33.3	77.98	6.1	11.31	592.7
T_5	**25-50-33*-31****	**139**	36.0	79.87	6.3	11.63	767.4
T_6	**25-75-29*-0**	**129**	34.9	79.81	6.2	11.44	648.2
T_7	**25-75-0-33****	**133**	33.7	78.96	6.3	11.69	633.4
T_8	**25-75-28*-23****	**151**	36.7	80.37	6.5	12.19	707.0
T_9	**50-75-20*-0**	**145**	35.6	80.00	6.3	11.88	680.4
T_{10}	**50-75-0-28****	**153**	35.3	79.38	6.4	11.94	676.6
T_{11}	**50-75-19*-18****	**162**	36.7	80.72	6.5	12.06	779.7
T_{12}	**Control**	**0**	31.7	76.21	6.0	10.63	238.7
SEm±			0.7	2.52	0.1	0.43	24.5
CD at 5%			2.1	NS	0.3	NS	72.3

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

4.7.4 Protein content

No significant variation was observed in protein content of wheat due to different N application treatments. The lowest protein content in wheat grain (10.63 per cent) was recorded in control and the highest in T_8 (12.19 per cent).

4.7.5 Protein yield

N application at different time and rate in different treatments produced significantly higher protein yield as compared to control. Application of recommended dose of N in three equal splits (T_2) proved more efficient in yielding protein than that in two equal splits (T_1). Irrespective of the level of fixed rate N, GS guided N application at two stages i.e. at 2nd and 3rd irrigation was significantly superior over other two treatments having GS guided N application either at 2nd or 3rd irrigation exceptionally, the difference between protein yield of T_6 and T_8 was not statistically significant. Highest protein yield was recorded in T_{11} and all other treatments except T_2 and T_5 were significantly inferior to T_{11}. As the level of fixed rate N application increased protein yield also increased except T_8 where protein yield was less than T_5.

4.8 Nutrient Studies

4.8.1 Nutrient content in soil after harvest of crop

Table 17: Effect of time and rate of GreenSeeker based N application on available nutrients in soil after harvesting of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Available Nitrogen (kg/ha)	Available Phosphorous (kg/ha)	Available Potassium (kg/ha)
T_1	**75-75-0-0**	**150**	135.7	13.7	347.4
T_2	**50-50-50-0**	**150**	136.6	10.9	347.4
T_3	**25-50-34*-0**	**109**	128.5	16.8	349.7
T_4	**25-50-0-36****	**111**	131.0	15.4	340.4
T_5	**25-50-33*-31****	**139**	136.8	14.9	338.1
T_6	**25-75-29*-0**	**129**	132.6	15.8	350.8
T_7	**25-75-0-33****	**133**	132.3	14.6	339.2
T_8	**25-75-28*-23****	**151**	138.8	14.4	346.1
T_9	**50-75-20*-0**	**145**	131.2	15.2	344.9
T_{10}	**50-75-0-28****	**153**	137.4	14.0	341.4
T_{11}	**50-75-19*-18****	**162**	139.2	13.2	336.8
T_{12}	**Control**	**0**	126.8	16.8	341.6

* indicates GreenSeeker guided N application at 2nd irrigation
** indicates GreenSeeker guided N application at 3rd irrigation

Available N, P and K in different treatment plots after harvest of crop are presented in Table 17. Highest N was found in T_{11} and the lowest being in control (126.8 kg/ha). T_1 and T_2 had higher available N content as compared to combined N application treatments. Highest available P was observed in T_3 and T_{12} (16.8 kg/ha). The highest available K was observed in T_6 followed by T_1 and T_2 (347.4). Available N, P and K were not much influenced by different N application treatment, however, available N generally increased with increasing total applied N.

4.8.2 Nutrient content and uptake in grain and straw

4.8.2.1 N, P and K content in grain and straw

The different N application treatments failed to produce significant difference in N, P and K content of wheat grain and straw (Table 18).

Table 18: Effect of time and rate of GreenSeeker based N application on NPK content (%) in grain and straw of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	N (%)		P (%)		K (%)	
			Grain	Straw	Grain	Straw	Grain	Straw
T_1	75-75-0-0	150	1.73	0.41	0.33	0.06	0.43	1.80
T_2	50-50-50-0	150	1.78	0.47	0.33	0.07	0.45	1.79
T_3	25-50-34*-0	109	1.77	0.46	0.32	0.06	0.46	1.79
T_4	25-50-0-36**	111	1.81	0.43	0.29	0.05	0.45	1.66
T_5	25-50-33*-31**	139	1.86	0.48	0.33	0.06	0.46	1.85
T_6	25-75-29*-0	129	1.83	0.49	0.32	0.06	0.45	1.97
T_7	25-75-0-33**	133	1.87	0.45	0.29	0.05	0.43	1.86
T_8	25-75-28*-23**	151	1.95	0.51	0.33	0.06	0.46	1.90
T_9	50-75-20*-0	145	1.90	0.48	0.31	0.06	0.44	1.81
T_{10}	50-75-0-28**	153	1.91	0.47	0.31	0.05	0.43	1.83
T_{11}	50-75-19*-18**	162	1.93	0.50	0.34	0.06	0.43	1.83
T_{12}	Control	0	1.70	0.39	0.30	0.07	0.45	1.73
SEm±			0.07	0.03	0.01	0.00	0.02	0.09
CD at 5%			NS	NS	NS	NS	NS	NS

* indicates GreenSeeker guided N application at 2^{nd} irrigation.
** indicates GreenSeeker guided N application at 3^{rd} irrigation

4.8.2.2 N uptake in wheat grain and straw

The different treatments having different rates and time of N application influenced the N uptake in wheat grain and straw significantly (Table 19). N accumulation in grain and straw, without application of fertilizer N i.e. control, was significantly lower than that in treatments having N application.

N uptake by grain and straw due to N splitting without using GS was statistically similar in both the treatments (T_1 and T_2) but T_2 recorded 7.0 and 16.5% higher N uptake than T_1, in grain and straw, respectively. All the treatments having N application using GS only once (either at 2nd or 3rd irrigation) failed to produce significant difference in N uptake with each other and avoiding the N application 2nd irrigation always led to lower N uptake by grain and straw than other two treatments i.e. GS guided N application only at 2nd irrigation and GS guided N application both at 2nd and 3rd irrigation.

The N uptake by grain in treatment having GS guided N application at both the stages i.e. 2nd and 3rd irrigation was higher, irrespective of the fixed N dose as compared to N application alone either at 2nd or 3rd irrigation. Two stage GS guided N also led to highest N uptake by straw each fixed N rate (i.e. at 75, 100 and 125 kg N/ha as fixed dose) although significantly lower N uptake was recorded only when N was applied at 3rd irrigation and avoided at 2nd irrigation using GS, otherwise the differences were not significant. Highest N uptake by both grain and straw was recorded in T_{11} and it was at par with T_5, T_2 and T_8 in grain and with T_2, T_8, T_5, T_6 and T_9 in straw.

Table 19: Effect of time and rate of GreenSeeker based N application on NPK uptake (kg/ha) in grain and straw of wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Nitrogen uptake (kg/ha)		Phosphorous uptake (kg/ha)		Potassium uptake (kg/ha)	
			Grain	Straw	Grain	Straw	Grain	Straw
T_1	75-75-0-0	150	109.3	34.0	20.7	5.2	27.4	148.8
T_2	50-50-50-0	150	117.0	39.6	21.4	5.6	29.9	151.0
T_3	25-50-34*-0	109	98.1	33.6	17.7	4.4	25.5	130.0
T_4	25-50-0-36**	111	94.8	28.7	15.1	3.2	23.6	111.5
T_5	25-50-33*-31**	139	122.8	37.3	21.8	4.8	30.4	144.3
T_6	25-75-29*-0	129	103.7	35.9	17.9	4.5	25.4	144.1
T_7	25-75-0-33**	133	101.3	30.5	15.5	3.6	23.2	126.2
T_8	25-75-28*-23**	151	113.1	39.2	19.4	4.6	26.7	145.8
T_9	50-75-20*-0	145	108.9	35.8	18.0	4.6	25.2	135.1
T_{10}	50-75-0-28**	153	108.3	33.2	17.4	3.6	24.3	129.1
T_{11}	50-75-19*-18**	162	124.8	39.9	21.9	5.2	27.6	146.2
T_{12}	Control	0	38.2	12.9	6.7	2.2	10.1	56.7
SEm±			3.9	1.9	0.7	0.2	1.1	3.4
CD at 5%			11.6	5.6	2.0	8.9	3.2	10.1

* indicates GreenSeeker guided N application at 2nd irrigation
** indicates GreenSeeker guided N application at 3rd irrigation

4.8.2.4 P uptake in grain and straw

P uptake in wheat grain as well as straw varied significantly among the different N application treatments (Table 19). P uptake by grain and straw of wheat in control was significantly lower (by 69.6 to 55.8% and 60.2 to 31.1% in wheat grain and straw, respectively) than all other treatments. T_2 recorded 3.4 and 6.1% higher P uptake in grain and straw, respectively than T_1 and both these treatments were statistically at par with each other. When different GS combined N application treatments were compared, irrespective of the level of fixed N dose, P uptake by grain and straw was lowest when N application was avoided at 2nd irrigation stage, and the highest being in case of two stage GS guided N application i.e. at 2nd and 3rd irrigation. Comparisons of same fixed level N application treatments with each other revealed that avoiding the N application 2nd irrigation stage significantly reduced the P uptake by grain and straw as compared to other two treatments except T_9 and T_{10}. Avoiding the N application at 3rd irrigation also led to significant reduction in P uptake by grain as compared to N application at both stages i.e. 2nd and 3rd irrigation; however, P uptake by straw was not significantly affected due to GS guided N application either at 2nd irrigation alone and both at 2nd and 3rd irrigation stages. P uptake by grain and straw improved as the level of fixed N doses was increased except T_8 when P uptake by grain and straw decreased from that in T_5.

4.8.2.6 K uptake in wheat grain and straw

K accumulation in wheat grain and straw was significantly influenced by different treatments (Table 19). K uptake in grain and straw was not significantly influenced by N splitting without using GS, however, three times N splitting recorded comparatively higher values. Single GS guided N application combined with different fixed doses of N failed to produce significant difference in grain K uptake as compared to two stage GS guided N coupled with fixed doses of N. GS guided N alone at 3rd irrigation coupled with any of the fixed N dose was numerically lower in K uptake by grain than GS guided N applied at 2nd irrigation, irrespective of the level of level of fixed doses. Among treatments having GS guided N application at single stage, 2nd irrigation applied N led to significantly higher K uptake in straw at each level of fixed N dose except at 125 kg/ha. Two stage GS guided N application led to significantly higher K uptake by straw also, than other two treatments, at each level of fixed dose. However, T_6 and T_8 were not significantly different. K accumulation by grain and straw in the control was significantly lower than rest of the treatments. The highest K uptake by grain and straw was recorded in T_5 and T_1, respectively.

4.8.2.7 Total N, P and K uptake of wheat crop

The different N application treatments significantly influenced the nutrient uptake (NPK) in wheat crop (Table 20). The nutrient uptake was significantly lower in control than all other treatments. Application of recommended dose of N in three splits resulted in higher uptake of all N, P and K of wheat crop as compared to application of recommended dose of N in 2 split doses, however, the difference in these treatments was not significant. Increase in N, P and K uptake was observed with the increasing the fixed doses of N application, in case of single stage GS guided N application, however, N, P and K uptake decreased at increasing the level of fixed N doses from 75 to 100 kg/ha when GS guided N was applied at two stages i.e. 2nd and 3rd irrigation, however, at further increase in fixed doses led to higher N, P and K uptake in this combination.

Table 20: Effect of time and rate of GreenSeeker based N application on total NPK uptake (kg/ha) by wheat

Treatments	N application (kg/ha)	Total N (kg/ha)	Nutrient uptake (kg/ha)		
			N	P	K
T_1	**75-75-0-0**	**150**	143.3	25.9	176.2
T_2	**50-50-50-0**	**150**	156.7	26.9	180.9
T_3	**25-50-34*-0**	**109**	131.7	22.0	155.5
T_4	**25-50-0-36****	**111**	123.6	18.3	135.1
T_5	**25-50-33*-31****	**139**	160.1	26.6	174.7
T_6	**25-75-29*-0**	**129**	139.7	22.4	169.5
T_7	**25-75-0-33****	**133**	131.8	19.1	149.4
T_8	**25-75-28*-23****	**151**	152.3	24.0	172.6
T_9	**50-75-20*-0**	**145**	144.7	22.7	160.2
T_{10}	**50-75-0-28****	**153**	141.5	21.0	153.3
T_{11}	**50-75-19*-18****	**162**	164.6	27.1	173.8
T_{12}	**Control**	**0**	51.1	8.9	66.8
SEm±			3.9	0.6	3.6
CD at 5%			11.6	1.84	10.6

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

When treatments having same level of fixed doses were compared among themselves, total N uptake was not significantly influenced by single GS applied N, otherwise different time of GS guided N application generally produced significant variation in N, P and K uptake. Among treatments other than control, the lowest N, P and K uptake was recorded when single GS guided N was applied at 3rd irrigation. In general, N, P and K uptake by wheat increased at increasing the level of fixed dose N application, irrespective of the rate of GS guided N application.

4.9 Nitrogen-use efficiency

N-use efficiency measured in terms of Agronomic Efficiency (AE_n), Recovery Efficiency (RE_n), Physiological Efficiency (PE_n) and Partial Factor Productivity (PFP_n) is given in Table 21.

4.9.1 Agronomic Efficiency (AE_n)

Among different treatments the highest values of AE_n was recorded in T_5treatment. The value in T_5 was significantly superior to rest of the treatments. Application of same dose (150 kg/ha) of N in three splits instead of two splits proved better in improving the agronomic efficiency though it was statistically at par with two splits. AE_n was higher with 2nd irrigation applied N using GS than 3rd irrigation applied N using GS at all the fixed rates of N. Two times GS guided N proved better than single GS guided N at 3rd irrigation coupled with 75 and 125 kg N/ha fixed application rates.

Table 21: Effect of time and rate of GreenSeeker based N application on nitrogen use efficiency of wheat

Treatment	N application (kg/ha)		AE_n (kg grain increase/ kg N applied	RE_n (%)	PE_n (kg grain increase/ kg N uptake)	PFP_n (kg grain/ kg N applied
	Split doses	Total				
T_1	75-75-0-0	150	27.18	61.49	44.33	42.16
T_2	50-50-50-0	150	28.84	70.37	41.08	43.82
T_3	25-50-34*-0	109	30.18	74.05	40.82	50.83
T_4	25-50-0-36**	111	26.94	65.11	41.52	47.12
T_5	25-50-33*-31**	139	31.25	78.18	40.04	47.37
T_6	25-75-29*-0	129	26.33	68.37	38.96	43.67
T_7	25-75-0-33**	133	23.86	60.70	39.36	40.75
T_8	25-75-28*-23**	151	23.53	66.95	35.16	38.40
T_9	50-75-20*-0	145	24.04	64.48	37.43	39.52
T_{10}	50-75-0-28**	153	22.41	58.94	38.39	37.07
T_{11}	50-75-19*-18**	162	26.04	70.11	37.16	39.92
T_{12}	control	0	0.00	0.00	0.00	0.00
SEm±			0.77	2.94	1.83	0.76
CD at 5%			2.28	8.68	5.40	2.23

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

4.9.2 Recovery Efficiency (RE_n)

Maximum RE_n was achieved in T_5 and it was statistically at par with T_2, T_3 and T_{11} while rest of the treatments recorded significantly lower RE_n. Application of recommended dose of N in three splits (T_2) resulted in higher RE_n and T_2 recorded 14.4% higher RE_n than T_1. RE_n improved numerically when single GS guided N was applied at 2nd irrigation instead of N application at 3rd irrigation, irrespective of the level of fixed rate N application. Moreover, irrespective of the level of fixed rate N application, RE_n of two stage GS guided nitrogen improved from single stage GS guided nitrogen. Increased dose of fixed N application always led to decreased level of RE_n when treatment having same timing of GS guided N application with different fixed N levels were compared among themselves.

4.9.3 Physiological Efficiency (PE_n)

The maximum PE_n was recorded in T_1 followed by T_4 and it was significantly superior to T_9, T_{10} and T_{11}, whereas, rest of the treatments were at par with T_1. At the same level of fixed rate N application, irrespective of the dose, PE_n was higher in conjunction with the application of GS guided N at 3rd irrigation and it reduced if GS guided N was applied at 2nd irrigation, moreover, at all levels of fixed N levels alongwith two stages GS guided N resulted in lowest PE_n (Table 21). There was no much difference numerically at 125 kg N supplied/ha alongwith GS guided N.

4.9.4 Partial Factor Productivity (PFP_n)

PFP_n showed decreasing trend with increase in level of fixed rate N application doses (Table 21). At the same level of fixed N coupled with GS guided N application, the higher values of PFP_n were recorded when GS guided N was applied at 2nd irrigation as compared to 3rd irrigation, irrespective of the level of fixed N. application of N @ 150 kg/ha in three splits resulted in higher partial factor productivity as compared to two splits (Table 23).

4.10 Economics

Effect of different treatments on economics of wheat crop is presented in Table 22**.**

4.10.1 Cost of cultivation (Rs./ha)

Cost of cultivation of different rate treatments was calculated by cost of different inputs along with cultural practices rates. The highest cost of cultivation Rs. 46230 ha^{-1} was recorded in T_{11} while control recorded the lowest cost of cultivation Rs. 43248 ha^{-1}. Among N application treatments without using GS, application in 2 split doses resulted in lower cost of cultivation (Rs 45550) than 3 split applications (Table 22). When fixed doses of N were same, single use of GS in guiding N dose recorded slightly higher cost of cultivation when it was applied at 3rd irrigation as compared to 2nd irrigation. Two stage GS guided N application resulted into highest cost of cultivation among these three treatments, irrespective of the level of fixed rate of N application. Increasing trend in cost of cultivation was observed with increase in level of fixed rate N application (i.e. 75, 100 and 125 kg N/ha). Recommended dose of N applied in two splits incurred lower cost of cultivation as compared to other treatments except T_4 and control.

Table 22: Effect of time and rate of GreenSeeker based N application on economics of wheat production

Treatments	N application (kg/ha)		Cost of cultivation (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C
	Split doses	Total				
T_1	75-75-0-0	150	45550	108036	62486	2.37
T_2	50-50-50-0	150	45820	111522	65702	2.43
T_3	25-50-34*-0	109	45336	96920	51584	2.14
T_4	25-50-0-36**	111	45365	92930	47565	2.05
T_5	25-50-33*-31**	139	45965	111942	65977	2.44
T_6	25-75-29*-0	129	45579	98698	53119	2.17
T_7	25-75-0-33**	133	45620	95380	49760	2.09
T_8	25-75-28*-23**	151	46103	100742	54639	2.19
T_9	50-75-20*-0	145	45763	99818	54055	2.18
T_{10}	50-75-0-28**	153	45859	99062	53203	2.16
T_{11}	50-75-19*-18**	162	46230	109996	63766	2.38
T_{12}	Control	0	43248	50958	7711	1.18

* indicates GreenSeeker guided N application at 2^{nd} irrigation.
** indicates GreenSeeker guided N application at 3^{rd} irrigation

4.10.2 Gross returns (Rs. /ha)

Different N application treatments recorded much higher gross returns as compared to control treatment. Application of 150 kg N/ha in 3 equal splits (T_2) resulted in 3.2% higher gross return than that in 2 splits (T_1). Gross returns were lowest among different timings of GS guided N application when N application was avoided at 2^{nd} irrigation, the highest being with the use of GS both at 2^{nd} and 3^{rd} irrigation stages. Gross returns were highest with application of total N @ 139 kg/ha into four splits (25-75-33-31 kg/ha) i.e. followed by T_2, T_{11}, T_1 and T_8.

4.10.3 Net returns (Rs./ha)

Different N application treatments recorded much higher net returns as compared to control treatment. Application of 150 kg N/ha in three equal splits (T_2) resulted in 5.1% higher net returns than that in two splits (T_1). Net returns were highest with application of total N @ 139 kg/ha into four splits (25-75-33-31 kg/ha) i.e. followed by T_2, T_{11}, T_1 and T_8. Net returns were lowest among different timings of GS guided N application when N application was avoided at 2^{nd} irrigation, the highest being with the use of GS both at 2^{nd} and 3^{rd} irrigation stages.

4.10.4 Benefit-cost ratio

Different N application treatments recorded significantly higher benefit-cost ratio (B-C ratio) as compared to control. Split application without using GS (T_1 and T_2) was higher in B-C ratio as compared to other treatments where GS guided N was applied except T_5 (2.43) and T_{11} (2.38). Highest B-C ratio was recorded in T_5 (2.44). Increase in level of fixed rate N application influenced B-C ratio in similar way as that influenced the gross returns. Application of N using GS only once resulted in lower B-C ratio as compared to N application using GS twice at 2nd and 3rd irrigation stages. There was decrease in B-C ratio by 4.2, 3.6 and 0.6% due to N application using GS at 3rd irrigation as compared to that at 2nd irrigation in treatments having 75 and 100 kg N/ha as fixed initial doses, respectively. The lowest B-C ratio was recorded in control (1.18). Application of 150 kg N/ha in three splits was superior to two splits (T_1).

4.11 Energy analysis

The data on energy analysis of experiment are given in Table 23 and Table 24. Total input energy requirement was lowest in control whereas application of 150 kg N/ha either in 2 or 3 splits (T_1 and T_2) required same energy level (15.3×10^3 MJ/ha). Energy input increased with increase in level of fixed rate N application. Energy input with 150 kg N/ha was 146.8% higher than control. Irrespective of fixed N energy input was lower when GS guided nitrogen was applied at 2nd irrigation as compared to 3rd irrigation (Table 23).

Table 23: Effect of time and rate of GreenSeeker based N application on energy input, output and net energy return of wheat production

Treatments	N application (kg/ha)	Total N (kg/ha)	Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Net energy ($\times 10^3$ MJ/ha)
T_1	75-75-0-0	150	15.3	196.3	181.0
T_2	50-50-50-0	150	15.3	202.2	186.9
T_3	25-50-34*-0	109	12.8	172.5	159.6
T_4	25-50-0-36**	111	13.0	161.0	148.0
T_5	25-50-33*-31**	139	14.7	194.8	180.1
T_6	25-75-29*-0	129	14.1	174.6	160.5
T_7	25-75-0-33**	133	14.3	164.6	150.3
T_8	25-75-28*-23**	151	15.4	181.9	166.4
T_9	50-75-20*-0	145	15.0	178.3	163.3
T_{10}	50-75-0-28**	153	15.5	171.8	156.2
T_{11}	50-75-19*-18**	162	16.1	195.0	178.9
T_{12}	Control	0	6.2	74.2	68.0

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

Table 24: Effect of time and rate of GreenSeeker based N application on energy use efficiency of wheat production

Treatments	N application (kg/ha)	Total N (kg/ha)	Energy-use efficiency	Energy-output efficiency (MJ/ha/ day)	Energy productivity (kg/MJ)	Specific energy (MJ/kg)
T_1	**75-75-0-0**	**150**	12.82	1.25	0.41	2.42
T_2	**50-50-50-0**	**150**	13.19	1.29	0.43	2.33
T_3	**25-50-34*-0**	**109**	13.43	1.10	0.43	2.32
T_4	**25-50-0-36****	**111**	12.39	1.03	0.40	2.48
T_5	**25-50-33*-31****	**139**	13.24	1.24	0.45	2.23
T_6	**25-75-29*-0**	**129**	12.39	1.11	0.40	2.49
T_7	**25-75-0-33****	**133**	11.51	1.05	0.38	2.64
T_8	**25-75-28*-23****	**151**	11.79	1.16	0.38	2.66
T_9	**50-75-20*-0**	**145**	11.85	1.14	0.38	2.62
T_{10}	**50-75-0-28****	**153**	11.06	1.09	0.37	2.73
T_{11}	**50-75-19*-18****	**162**	12.13	1.24	0.40	2.49
T_{12}	**Control**	**0**	12.01	0.47	0.36	2.75

* indicates GreenSeeker guided N application at 2nd irrigation.
** indicates GreenSeeker guided N application at 3rd irrigation

Energy output was slightly higher in T_2 than that in T_1 (Table 23). Among combined N application treatments highest output was obtained in T_{11} and other such treatments (i.e. N application using GS both at 2nd and 3rd irrigation) were superior to their corresponding treatments (same level of fixed doses) having single GS guided N. Split N application without using GS was better than rest of the treatments. Minimum energy output was recorded in control treatment.

Net energy gain (Table 23) followed the similar pattern as that obtained for energy output. T_3 recorded higher energy use efficiency (EUE) closely followed by T_5 and T_2. Energy use efficiency of 3 split N application (i.e. at basal + at 25 DAS + at 2nd irrigation as guided by GS) was higher than other two treatments having same level of fixed rate N application, in case of first two levels (75 and 100 kg N/ha), however, at fixed N application @ 125 kg/ha recorded higher energy use efficiency when it was combined with GS guided N application both at 2nd and 3rd irrigation stages (Table 24). Application of 150 kg N/ha in three equal split (T_2) resulted into higher EUE than that in two equal splits (T_1).

Energy output efficiency (EOE) was highest in T_2 followed by T_1 and both of these treatments were better than rest of the treatments (Table 24). EOE increased with the increase in total N application (fixed rate + GS guided N). The value of EOE was 0.47 in control treatment which was 62.4% lower than T_1. At the same level of fixed N the values of EOE was higher when fixed rate N application was coupled with GS guided N at 2nd and 3rd irrigation. However, lower values of EOE was recorded at 3rd irrigation applied N using GS as compared to 2nd irrigation applied N (GS based).

Energy productivity was highest in T_5 (0.45 kg/MJ) followed by T_2 and T_3 (Table 24). In contrast to other energy parameters, energy productivity generally decreased as the dose of fixed N application was increased.

Specific energy (Table 24) being reverse of energy productivity showed the reverse trend as followed by later as a result control recorded highest energy requirement in production of unit crop yield.

CHAPTER-V

DISCUSSION

During the course of present investigation entitled, **"Precision nitrogen management in irrigated wheat"** many significant variations were noted due to the treatments constituting the experiment. In this chapter, efforts have been made to differentiate the treatments and also to establish cause and effect relationship in the light of available scientific literature in support of findings of present investigation.

5.1 Effect of weather parameters

Cool and moist weather during vegetative phase and warm and dry weather during grain formation and maturity are the most ideal conditions for wheat growth. However, balance among different weather parameters must prevail during all the growth stages of wheat crop in order to set in timely onset and end of various yield determining processes. Evans and Wardlaw (1976) emphasized that seasonal environmental conditions under which the crop was grown played a major role determining the optimum balance of yield components.

Weekly maximum and minimum temperature remained under a suitable range for different crop growth stages (Appendix-I). Total rainfall received during the crop growing period was 77.9 mm and it was uniformly distributed throughout the period as a result favorable temperature and soil moisture conditions were created which were conducive to enhance the yield attributing characters *viz*. spike length, number of grains/spike, 1000-grain weight etc. and eventually to the higher yield.

5.2 Growth Studies

Growth in terms of plant height, dry matter accumulation and leaf area index at various stages of crop growth varied significantly under different treatments. Plant stand at 15 DAS was not affected by different treatments because at the time of seedling emergence and establishment of plant the principle source of nutrients is the storage organs of the seed in the presence of adequate soil moisture (Table 7).

Plant height and dry matter accumulation increased at a slow rate upto 60 DAS; thereafter, increased with a faster rate upto 120 DAS (Table 8 and 9). At 30 DAS, plant height and dry matter were not affected by different rates of N application because there is less competition for N during early stage of crop. Plant height and dry matter accumulation in treatment having N application (150 kg/ha) in two equal split doses (75 kg/ha basal and 75 kg/ha at 25 DAS) were significantly higher during early stages of crop and numerically lower during later stages of crop, as compared to the treatment having same dose of N in three equal splits (50 kg/ha as basal+50 kg/ha at 25 DAS+50 kg/ha at 2nd irrigation) without using GS.

Gupta *et al.* (2011) also recorded similar trend of dry matter accumulation at different crop growth stages when they applied N in either two or three equal split doses and this may occur due to excessively higher dose of N at sowing time i.e. 75 kg/ha, substantial part of which might had not been taken up by crop and subjected to leaching losses while N application at 2^{nd} irrigation better coincided with the demand of crop for N at that time.

Avoiding the N application at 2^{nd} irrigation generally led to significantly lower plant height and dry matter accumulation than two stage GS guided N application but it was not significantly lower than alone application of GS guided N at 2^{nd} irrigation throughout the crop growth stages. It may be due to the fact that 2^{nd} irrigation stage is the stage of maximum tillering and after this elongation phase is likely to start so this stage lies somewhere within vegetative log phase or grand growth phase and N being the important constituent of chlorophyll, nucleotides, proteins, enzymes which take part in various metabolic processes, is most needed to increase cell number and cell size by converting the carbohydrates into protoplasm during this stage so N applied at 2^{nd} irrigation is able to cause considerable positive change in growth.

Treatments having GS guided N application at 2^{nd} and 3^{rd} irrigation were also superior regarding to the LAI and CGR (Table10 and 12), over treatments with GS guided N application only at 2^{nd} irrigation followed by the treatments with GS guided N application at 3^{rd} irrigation, irrespective of fixed doses of N application. This situation indicates that four time N application (application of fixed dose into two splits and two stage GS guided N application) maintains the N availability during the grand period of growth i.e. active tillering and elongation phase. Besides, application of N at later stages also helps in retention of chlorophyll pigment for long time which leads to high photosynthetic rate even upto 120 DAS (Table 13). Pan *et al.* (1998) investigated that nitrogen top dressing at the jointing stage delayed the decline in photosynthetic rate of flag leaves and activity of roots and increased the rate of grain growth.

Treatments having different fixed rate N application combined with two stage GS guided N application were statistically at par with each other in plant height and dry matter accumulation inspite of considerable difference in total dose of N applied. This situation might occur due to leaching loss of initially applied higher N doses as crop takes up very less amount of N per day instead comparatively higher doses of N at later stages might be taken up by crop more efficiently as it coincided with peak demand of crop during active vegetative growth. This is clearly indicated by higher N-use efficiency in T_5 than that in T_8 and T_{11}. Moreover, root activity to absorb nutrient is also higher during late vegetative phases coinciding with 2^{nd} and 3^{rd} irrigation stages than early growth stages. Singh (1996) also observed that dry matter continued to increase significantly when one-third dose of N was applied at later stage instead of one-fourth dose of nitrogen.

5.3 Yield attributes and yield

Yield attributes/yield components are the morphological, reproductive and developmental features of plant which finally affect the yield. In other words, economic yield is expressed as function of yield attributes. The ultimate yield of crop plants is affected by both the source and sink and the capacity to translocate assimilates from one part to another when needed. In cereals, including wheat, the source component is the number of leaves, leaf area/unit ground area (LAI) and dry matter of plant, whereas, sink or storage organs are spike number, spike length, number of grains/spike and 1000-grain weight.

Application of recommended dose of N i.e. 150 kg/ha in three equal splits (1/3rd as basal+ 1/3rd at 25 DAS+1/3rd at 2nd irrigation) resulted into 3.94% higher wheat grain yield as compared to its application in two equal splits (½ as basal+½ at 25 DAS). Improvement of yield attributes i.e. effective tillers (3.83%) spike length (8.5%), grains/spike (0.2%) and 1000-grain weight (1%) in three splits led to higher grain yield in this treatment as compared to two equal splits i.e. ½ as basal+ ½ at 1st irrigation. Singh and Singh (1991); Kaur *et al.* (2010); Coventry *et al.* (2011); Gupta *et al.* (2011) also reported that three-way split application of N including basal and CRI as initial stages and 1st node stage to early flowering as third stage recorded higher growth, yield attributing characters and yield than two- way split application. Higher N-use efficiency in three equal splits of N application also clearly indicated proper utilization of nitrogen which ultimately reflected into higher wheat grain yield.

In general, yield components viz. no. of effective tillers/mrl, grains/spike, 1000-grain weight increased with increase in level of fixed rate N application (Table 13), irrespective of number and doses of GS guided N application because higher N application doses at sowing and 25 DAS fulfilled the peak requirement of crop at early stage of crop that resulted into higher plant height, more dry matter accumulation, higher CGR (Table 9 and 10) and as a result more photosynthates were produced at higher N levels which ultimately resulted in increase in yield. The sink capacity of a plant depends mainly on vegetative growth of the plant which is affected positively by application of nitrogenous fertilizers and supply of photosynthates for the formation of yield components (Patra, 1990; Patel and Upadhyay, 1993).

However, this trend was not followed when fixed level of N application was followed by GS guided N application both at 2nd and 3rd irrigation. N application @ 75 kg/ha with GS guided N application at 2nd and 3rd irrigation (T_5) proved superior in improving the yield attributes and achieved highest grain yield closely followed by T_{11}, T_2 and T_1. This may be due to the fact that GS guided N doses applied at later stages i.e. 2nd and 3rd irrigation were higher in T_5 and it is comprehended that competition is set between upper internodes (vegetative part) and the inflorescence at this stage of the crop since it is the period of elongation of stem as well as differentiation of inflorescence. Kaur *et al.* (2010) also reported highest number of effective tillers in treatments having moderate N doses at early stages as compared to higher doses at these stages.

Straw yield was highest in treatment having N application in three equal splits (T_2) and it was statistically at par with N application in two equal splits (Table 14). This may be due to the fact that N availability was more uniform throughout the vegetative growth of the crop plants in three split application. Moreover, high values of yield attributes have also contributed to higher yield. Wagan *et al.* (2002) found that ear length, grain and straw yield were higher with three split application compared to two split application. T_1 and T_2 both were superior but statistically at par with T_5, T_8 and T_{11} because N application made at different crop growth stages in T_5, T_8 and T_{11} made the plants to increase the CGR and green leaf area (photosynthesizing organs) till later stages of crop as a result dry matter and plant height continued to increase till maturity at a higher rate whereas in T_1 and T_2, CGR and LAI became almost stagnant (Table 10 and 12). However, this stagnation was observed after reaching at a level, sufficiently high to make these treatments (T_1 and T_2) significantly superior to rest of the treatments (i.e the treatments except T_5, T_8 and T_{11}) because total dose of nitrogen as well as level of fixed rate N application were considerably lower in rest of the treatments as compared to T_1 and T_2. Krishnakumari *et al.* (2000) and Dhuka *et al.* (1992) also showed the importance of higher N doses at early stages of crop (basal and 1st irrigation stage) in increasing the straw yield.

As far as single stage GS guided N application was concerned, its time (either at 2nd or 3rd irrigation) affected the biological, grain and straw yields (Table 14). The biological, grain and straw yields were less by 3.9 to 6.8, 0.94 to 5.1 and 6.1 to 8.0%, respectively when N application only at 3rd irrigation was done as compared to N application at 2nd irrigation. The possible reason may be traced back to lower dry matter, plant height and LAI (Table 8, 9 and 12) in GS guided N application only at 3rd irrigation as compared to that at 2nd irrigation. These results were found in confirmation with Mossedaq and Smith (1994).

In the present investigation, harvest index was not influenced significantly by any treatment (Table 14) since harvest index of any crop is more controlled by genetic factor rather than environment and management factors.

5.4 Quality parameters

Sedimentation value is the index of gluten strength. Higher the value, better is the quality of wheat. Highest value (36.7) was recorded when 100 and 125 kg N/ha as fixed dose combined with GS guided N application at both the stages (T_8 and T_{11}), whereas, application of 150 kg N/ha in two or three equal splits proved statistically at par with these treatments (Table 16). Sedimentation values increased at increasing the level of fixed rate N application as well as number of GS guided N splits. Recommended dose of N (150 kg/ha) improved sedimentation value when it was applied in three equal splits (T_2) as compared to same dose applied in two equal splits and it is duly supported by Uppal (1999).

N application at later stages (2nd and/or 3rd irrigation) proved better in grain appearance than initial higher doses (T_1). More the split application of N, higher was the grain appearance score (Table 16). The minimum score was obtained in control and when 75 kg N/ha as fixed dose was combined with GS guided N application at 2nd irrigation (T_3). So it is obvious that there was combined effect of total N dose and time of N application.

Protein content was not significantly influenced by different treatments though protein content was higher when N was applied at 3rd irrigation as compared to treatments lacking N application at 3rd irrigation.

Protein yield (kg/ha) was 7.05% higher with N application (150 kg/ha) in three equal splits (T_2) than that in two equal splits because both grain yield and protein contents were higher in T_2 than T_1 (Table 16). Singh (1996); Singh *et al.* (1999); Uppal (1999) and Coventry *et al.* (2011) also reported the similar results on grain protein. Irrespective of the level of fixed rate N application, GS guided N application at two stages was significantly superior over other two treatments having single stage GS guided N application either at 2nd or 3rd irrigation. GS applied N twice resulted into comparatively increased dose at later stage of the crop which resulted into higher N content in grain by ensuring the more translocation of photosynthates to developing grains and their utilization in protein synthesis and subsequently in higher protein content and yield. Krishnakumari *et al.* (2000); Ottman *et al.* (2000); Uppal *et al.* (2002) also reported significance of N application at later stages of crop.

5.4 Nutrient studies

5.4.1 N, P and K content and uptake by wheat crop

Total N uptake and N uptake by wheat grain and straw increased by 9.3, 7.0 and 16.5%, respectively, due to application of recommended dose of N in three splits as compared to that in two splits (Table 19 and 20). The reason may be that more frequent application of N resulted into increased availability of N throughout the active growth period when it was most needed. Dhuka *et al.* (1992) reported that application of N in three splits resulted into highest grain and straw N uptake. Generally, GS guided N application alone at 3rd irrigation combined with different fixed rate N application levels, led to significantly lower N uptake by grain, straw and total N uptake as compared to GS guided N application both at 2nd and 3rd irrigation. This might be due to increased total N availability in the two stage GS guided N application, resulting in higher N content in grain and straw and higher yield. Among single stage GS guided N application treatments, higher N uptake was recorded when N was applied at 2nd irrigation as compared to 3rd irrigation applied N. More production of dry matter in 2nd irrigation applied N led to better translocation of photosynthates to grains and finally it produced higher yield and higher N uptake than 3rd irrigation applied N. Moreover, single stage GS guided N application at

2^{nd} irrigation was significantly inferior in grain N uptake and total N uptake and numerically inferior in straw N uptake than two stage GS guided N application. This indicates that 3^{rd} irrigation applied N is more important regarding the grain N uptake.

P uptake by grain and straw and total P uptake of wheat in control was significantly lower (by 69.6 to 55.8 and 60.2 to 31.1% in wheat grain and straw, respectively) than all other treatments. Significantly lower grain and straw yields in control (without N application) caused lower P uptake inspite of uniform P application in all experimental plots.

K uptake was also affected by different fixed levels of N application coupled with different time and frequency of using GS guided N. GS guided N application at 2^{nd} and 3^{rd} irrigation had significantly higher K uptake by grain and straw than GS applied N alone at either 2^{nd} or 3^{rd} irrigation.

Total N, P and K uptake generally increased at increasing the level of fixed rate N application, when equivalent treatments (i.e. treatments having same time of GS guided N application) were compared. This might be due to higher dry matter accumulation and higher yields under increased N levels. However, increasing the fixed rate N level from 75 to 100 kg/ha had lower total N, P and K uptake when GS guided N was applied both at 2^{nd} and 3^{rd} irrigation.

5.5 Nitrogen-use efficiency

Nitrogen-use efficiency illustrates how well a crop has recovered applied N fertilizer and can highlight the pathways where N can be used more efficiently. The optimum use of N fertilizer will come from matching N supply with crop demand for N (Bhardwaj *et al.*, 2010) and losses of N can be large when the N application is not synchronized with crop growth and development. N-use efficiency measured in different ways is given in Table 21.

The yield response to N is typical following the law of diminishing returns and in general agronomic efficiency (AE_n: Kg grain increased over control/kg N applied) and recovery efficiency (RE_n: % N recovered in above ground plant parts) decline as the rate of application is increased as yield increment continuously declines at increasing the level of fertilizer N (Prasad, 2007a; Johnson and Raun, 2003). In this investigation different NUEs followed this pattern with increasing level of fixed rate N application.

RE_n indicates how much of total N applied was taken up by crop. Higher the RE_n, higher is the proportion of the applied N taken up by crop. A thorough understanding of data on RE_n revealed that crop was able to take up more N when small amounts were added, instead of higher doses in less number of splits. Application of recommended dose of N in three splits (T_2) resulted in significantly higher RE_n (by 14.4%) than T_1. The results were found in confirmation with Alcoz *et al.* (1993).

Adding more N as fixed level doses at sowing and 25 DAS, generally resulted into decreased RE_n because this caused the higher total dose of N and as a rule, higher the N dose, lower is the N- use efficiency. However, number of split application and time of N application also affected recovery efficiency. Among combined N application treatments, significantly higher RE_n was achieved when GS guided N was applied at both the stages as compared to single GS guided N application. More frequent application of N maintained the greenness of plant throughout the active growing period (higher LAI) that resulted into production of more photosynthates and subsequently higher uptake of N for utilization of these photosynthates in protoplasm formation. RE_n of combined N application having GS guided N at 3^{rd} irrigation was 8.6 to 12.1% lower than GS guided N at 2^{nd} irrigation due to lower yield levels though both the treatments were statistically at par. Ortiz-Monasterio and Raun (1994) and Bijay-Singh *et al.* (2011) also reported lower RE of N with delayed application of N beyond Feekes 5-6 stage.

Agronomic efficiency (AE_n) shows crop response to applied N in terms of grain yield increase to applied N over control. AE_n largely depends on crop yield in fertilized plots as well as that of control plot. Therefore, soils having low N supplying capacity have higher AE_n due to poor yield in control plot. Furthermore, number of N splits, total dose of N also significantly influenced agronomic efficiency of different treatments. Increasing the level of fixed rate N application, increased total dose of N as a result, AE_n successively declined. GS guided N application alone at 2^{nd} irrigation achieved significantly higher AE_n than 3^{rd} irrigation applied N because no N application at 2^{nd} irrigation led to lower dry matter and finally lower grain yield.

AE_n and RE_n both decreased when single GS guided N was applied at 3^{rd} irrigation instead of 2^{nd} irrigation but PE_n was reverse of that because comparative decrease in RE_n was higher (12.1, 11.2 and 8.6% at 75, 100 and 125 kg/ha as fixed N doses, respectively) while decrease in AE_n was lower (10.7, 9.5 and 6.8%, respectively) and RE_n being denominator caused increase in PE_n. This may be due to the fact that grain N uptake was not affected as much as straw N uptake. In other words, grain N uptake was affected only slightly (0 to 3.4%) whereas straw N uptake was more adversely affected (upto 14.6%) due to no N application at 2^{nd} irrigation (Table 19). Bijay-Singh *et al.* (2011) also reported similar results on PE_n from Karnal. Similarly, PE_n of three-split N application without using GS was numerically lower than that of two split N application without using GS. Kaur *et al.* (2010) also reported 6% decrease in PE_n when they applied split doses of N at sowing, 1^{st} irrigation and anthesis (foliar spray) as compared to split doses at sowing and 1^{st} irrigation.

5.6 Economics

The cost of cultivation was highest in treatment having maximum dose of N application i.e @ 162 kg/ha and it was 6.9% more than control (Table 22). This indicated that N application caused increase in cost of cultivation upto 6.9%. Highest gross return was recorded in T_5 due to highest grain yield and as a result net returns and B-C ratio were also highest in this treatment. Net returns and B-C ratio also improved due to three-split application of N (at recommended dose) without using GS as compared to two-split application because increase in gross return was 3.2% whereas cost of cultivation increased only slightly (by 0.6%). Gupta *et al.* (2011) also recorded higher net returns and B-C ratio in three splits than two splits. Application of N using GS only once resulted in lower B-C ratio as compared to N application using GS twice at 2^{nd} and 3^{rd} irrigation due to more increase in gross returns as compared to increase in cost of cultivation. B-C ratio decreased due to N application using GS at 3^{rd} irrigation as compared to GS applied N at 2^{nd} irrigation due to decrease in gross return as well as increase in cost of cultivation.

5.7 Evaluation of GreenSeeker based N management

5.7.1 Normalized Difference Vegetative Index (NDVI)

Fertilizer N doses using GS were calculated as described in section 3.12.2. According to the procedure NDVI values were calculated. The GreenSeeker optical sensor calculated the reflectance values i.e. the ratio of incident and reflected values in both red (671±6 nm) and near infrared (NIR) (780±6 nm) region of the electromagnetic spectrum and that is:

$$NDVI = [(NIR_{ref}/NIR_{inc})-(Red_{ref}/Red_{inc})]/ [(NIR_{ref}/NIR_{inc})+ (Red_{ref}/Red_{inc})]$$

where, NIR_{ref} and Red_{ref} = magnitude of reflected near infrared and red lights, and NIR_{inc} and Red_{inc} = magnitude of the incident near infrared and red lights. As absorbance of visible light in blue and red wavelength by chlorophyll molecules and reflectance of NIR by mesophyll cells is indicator of amount of chlorophyll content and vegetative biomass, NDVI serves as an excellent indicator of crop growth in the vegetative growth phase and biomass accumulation. In the present investigation NDVI values increased with advancement in crop age upto 73 DAS or 90 DAS and thereafter decreased till end. NDVI increased upto 73 DAS in all the treatments except control, whereas increased values of NDVI at 90 DAS were generally observed when fertilizer N was applied at 65 DAS i.e. 3^{rd} irrigation stage and at next crop growth stage i.e. at 120 DAS, NDVI decreased in all the treatments, irrespective of the rate and time of N application (Fig. 7). Pradhan *et al.* (2013) reported that the canopy reflectance in the visible region (400-700 nm) decreased from CRI to booting stage and thereafter increased till harvesting stage as chlorophyll content increases and decreases, respectively during these periods. The reflectance in the near-infrared region increased from CRI to booting stage and thereafter decreased progressively till harvesting stage. Among the treatments having same level of fixed rate N application, single stage GS guided N at 3^{rd} irrigation recorded lowest value of NDVI from 58 DAS till end. This may be attributed to lower LAI and dry matter accumulation in these treatments till end as compared to GS guided N application at 2^{nd} and 3^{rd} irrigation or alone at 2^{nd} irrigation (Table 9 and 12).

Total N uptake (straw and grain) of wheat plotted against NDVI at different crop growth stages using linear function, is shown in Fig. 9. The amount of N taken up in wheat was highly correlated with NDVI . The early and later stages showed less correlation than middle stages. Coefficient of determination increased from 50 DAS to 73 DAS and then decreased upto 120 DAS. Kaur (2007) also reported increasing values of R^2 from 49 to 80 DAS. Hence potential yield levels with GreenSeeker optical sensor can be estimated during the crop growth stage from 65 to 90 DAS.

5.7.2 Relationship between INSEY-grain yield of wheat

Although INSEY-grain yield relationship used for calculating fertilizer N dose in this experiment were adopted from Bijay-Singh *et al.* (2011), the actual grain yields were plotted against INSEY at different crop growth stages to investigate the effect of different rate and time of N application on predictive ability of GS for yield (Fig. 10). The highest value of coefficient of determination was observed at 73 and 90 DAS i.e. just after applying last dose of fertilizer N dose at 3rd irrigation. This may be attributed to comparatively more increase in LAI and CGR values at 90 DAS due to 3rd irrigation applied N and it indicates that grain yields can be improved by N application upto 3rd irrigation stage. As INSEY is estimate of biomass produced per day, higher values of R^2 at 120 DAS than 50 DAS indicated that N applied at 2nd and 3rd irrigation considerably contributes to increase in grain yield.

5.7.3 Responsiveness to applied N

Calculating the response index (RI_{NDVI}) means predicting the potential responsiveness of wheat to applied N for that year, that field, that crop, under those growing conditions, planted and sensed on particular date. The importance of in-season estimate of RI_{NDVI} lies in that it is indicative of the increase in grain yield that could be obtained via fertilization. However, RI_{NDVI} by itself does nothing in terms of determining an optimum in-season N dose. So in-season response index estimated using NDVI sensor readings helps to determine when and when not to apply in-season fertilizer N and how much of a response can be expected. If for example the response index were 1.23, it would mean that a 23% increase in yield was likely if fertilizer N was applied. A thorough understanding of data on RI_{NDVI} reveals that it was affected by fixed rate N application at planting and 25 DAS (Table 5). Higher the fixed rate N application, lower was the RI_{NDVI} value. Among treatments having N application without using GS, RI_{NDVI} was lower in two split application initially i.e. at 50 DAS, as compared to three split application. Thereafter, this pattern reversed as RI_{NDVI} values in two split applications continued to increase while in three split application RI_{NDVI} values decreased and reached at values < 1.1. This indicated that doses of 75 kg N/ha at planting and 25 DAS were in excess of crop needs and it was not efficiently utilized and subjected to leaching losses whereas small amount of N applied in more splits makes the crop sufficient in N status and crop doesn't need any additional fertilizer N.

Lower correlation coefficient between RI_{NDVI} and $RI_{HARVEST}$ at 50 DAS means lower predictability of RI_{NDVI} about $RI_{HARVEST}$ at that stage and it indicates that N doses at later stages i.e. at 2nd and 3rd irrigation also affected actual response of crop to N fertilizer i.e. $RI_{HARVEST}$. (Fig. 8). Correlation coefficient increased, the maximum being at 73 DAS and thereafter, decreased. Lower values of correlation coefficient at later stages may be due to overestimation of RI_{NDVI} because crop in test plot tended to attain maturity faster than crop in N-rich strip and due to this NDVI in test plot lowered down. The results were found in confirmation with Mullen *et al.* (2003).

5.7.4 Estimating N doses using Yield Potential (YP_0) and RI_{NDVI}

When fixed level of N application at sowing and 25 DAS was low, the total amount (fixed dose + GS guided) of N applied was low (for e.g. total N dose was 11 to 41 kg/ha lower than recommended dose at 75 kg N/ha as fixed dose) (Table 6). Doses similar to recommended dose were obtained only when 100 or 125 kg N/ha was applied at planting and 25 DAS. Bijay-Singh *et al.* (2011) also reported that total fertilizer remained low unless the 100 kg or more N was applied as prescriptive dose either at planting or both planting and CRI stages. In case of single stage GS guided N application, amount of N turned out to be slightly less at 50 DAS than 65 DAS. This might be due to the higher RI_{NDVI} values at 65 DAS than at 50 DAS. These results were found on confirmation with Bijay-Singh *et al.* (2011). Similarly, GS guided N was less at 65 DAS than at 50 DAS when GS was used at both of these stages so it can be interpreted that optical sensor underestimated the fertilizer N needs when it was used too close to a fertilizer N application event. More was the amount of fixed rate N application at sowing and 25 DAS, less was the GS guided N, irrespective of stages of using GS. This may be due to luxurious growth of plant in terms of biomass as well as green leaf area which resulted into higher NDVI values of test plots and lower probability of response to further addition of fertilizer N. These results were found in confirmation with Bijay-Singh *et al.* (2011).

Highest grain yield was obtained when N was applied in combination i.e. 25 and 50 kg/ha at sowing and 25 DAS, respectively, as fixed dose and 33 and 31 kg/ha at 2nd and 3rd irrigation stage, respectively, guided by GS and this treatment was statistically at par with N application at recommended dose either in two or three equal splits. Moreover, 11 kg N/ha was saved as compared to recommended N dose (150 kg/ha) and this resulted into higher N-use efficiency. Agronomic efficiency and recovery efficiency were 31.25 kg kg^{-1} and 78.2%, respectively, in this treatment as against 27-29 kg kg^{-1} and 61- 70% in recommended N application treatments. Similar findings on N fertilizer saving and increased N-use efficiency were reported by Bijay-Singh *et al.* (2011) from Karnal, Modipuram and Ludhiana; and by Coventry *et al.* (2011) from Haryana.

CHAPTER-VI

SUMMARY AND CONCLUSION

A field experiment entitled "**Precision nitrogen management in irrigated wheat**" was conducted during the winter season of 2013-14 at Agronomy Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker. N application without using GreenSeeker consisted of two treatments having recommended dose (150 kg/ha) in two (75 kg/ha each) and three (50 kg/ha each) equal splits. GreenSeeker guided N application was combined with fixed rate (75, 100 and 125 kg/ha) and fixed time N application (nine treatments) as basal and at 25 DAS. GreenSeeker was used with each fixed level of N application at 2^{nd} (50 DAS) and/or 3^{rd} irrigation (65 DAS). One treatment was control where no fertilizer N was applied. The data was recorded on growth parameters (plant height, dry matter accumulation and crop growth indices *viz*. leaf area index, crop growth rate and relative growth rate), yield attributes and yield, N, P and K content and uptake by wheat grain and straw, N-use efficiency, quality parameters (sedimentation value, hectoliter weight, grain appearance, protein content and protein yield) and energy analysis. The economics of various treatments was also worked out.

6.1 Growth studies

6.1.1 Plant count per meter row length was not affected significantly by different rates and time of N application.

6.1.2 Plant height increased with advancement of crop age and maximum rate of increase was observed between 60 to 90 DAS. Maximum plant height was recorded in treatment having fixed rate N application @ 125 kg/ha coupled with GS guided N application both at 2^{nd} and 3^{rd} irrigation. At maturity, different fixed rates of N application i.e. 75, 100 or 125 kg/ha coupled with GS based N at two stage (2^{nd} and 3^{rd} irrigation) improved plant height than GS based N application either at 2^{nd} or 3^{rd} irrigation, however, GS guided N application at 2^{nd} irrigation resulted into taller plants than N application at 3^{rd} irrigation, irrespective of fixed rate N application rates. Although treatment having N application @ 150 kg/ha in two splits had taller plants at early stages of crop, at later stages of crop growth three split application resulted into comparatively taller plants.

6.1.3 Dry matter accumulation was significantly higher when GS guided N was applied both at 2^{nd} and 3^{rd} irrigation as compared to GS guided N either at 2^{nd} or 3^{rd} irrigation, irrespective of the level of fixed rate N application. Maximum dry matter at maturity was recorded in treatment having fixed rate N application @ 125 kg/ha coupled with GS guided N application both at 2nd and 3rd irrigation.

6.1.4 At fixed rate of N application coupled with different time of GS guided N failed to produce significant variation in crop growth rate, however, higher the fixed N application, higher was the value of crop growth rate. GS based N application at 3rd irrigation, irrespective of the fixed rate N application numerically produced lower crop growth rate than N application at 2nd irrigation. In all GS indicated N application at 2nd and 3rd irrigation resulted into higher CGR values at all growth stages, irrespective of the fixed rate N application.

6.1.5 The maximum values of relative growth rate of wheat were recorded between 31-60 DAS and beyond this stage values of RGR reduced, the lowest being during 121 to maturity. No nitrogen application (control) produced significantly lower values of RGR in between 121 DAS to maturity as compared to rest of the treatments which were at par with each other.

6.2 Yield attributes and yield

6.2.1 The maximum number of effective tillers per meter row length was recorded when GS applied N at 2nd and 3rd irrigation was combined with fixed level of N application @ 75 kg/ha and treatments having N application at recommended dose and 125 kg/ha fixed level N combined with two stage GS guided N was statistically at par with this treatment. Number of effective tillers increased to significant level when GS guided N was applied both at the stages as compared to single stage GS guided N. Number of effective tillers increased at increasing the level of fixed rate N application.

6.2.2 In case of fixed rate N application @ 100 and 125 kg/ha, GS guided N application either once (2nd or 3rd irrigation) or twice (2nd and 3rd irrigation) achieved no significant variation in spike length. N applied @ 75 kg /ha as fixed rate coupled with the two staged GS guided N application produced significantly longer spike as compared to GS guided N either at 2nd or 3rd irrigation stage. N splitting without using GS recorded no significant variation among themselves, however, spike length was comparatively higher in three split application.

6.2.3 Increase in number of grains/spike due to N application in different treatments was 11.1 to 17.2% over control. Overall, highest number of grains was recorded in treatment having GS guided N both at stages with 75 kg/ha of fixed dose, however, it was generally at par with remaining treatments.

6.2.4 Application of 75 kg N/ha followed by GS guided N both at 2nd and 3rd irrigation recorded highest TW (43.85 g) and it was statistically at par with rest of the treatments except single stage GS guided N applications at 3rd irrigation, irrespective of the level fixed N dose and control.

6.2.5 The highest biological yield was recorded where recommended dose (150 kg/ha) was applied in three equal splits and it was followed by treatment having application of recommended dose in 2 equal splits and the increase in yield due to three split application was 2.95% over two split application. Among combined N application treatments, the highest biological yield was recorded in at 125 kg/ha with GS used both at stages (14460 kg/ha) followed by 75 kg N/ha with GS used both at stages (14419 kg/ha); however all of these treatments were at par with each other.

6.2.6 Application of recommended dose of N in three splits produced 3.94% higher grain yield (6573 kg/ha) than two splits (6324 kg/ha) and both of these treatments were significantly superior over control. 75 kg N/ha coupled with GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation produced highest grain yield and it was at par with recommended dose and 125 kg N/ha as fixed rate coupled with GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation. GS guided N application at two stages i.e. 2^{nd} and 3^{rd} irrigation proved significantly superior to single N application (GS based) either at 2^{nd} or 3^{rd} irrigation, irrespective of the level of fixed rate N application. Yields were less when N application only at 3^{rd} irrigation was done as compared to N application only at 2^{nd} irrigation. Grain yields improved generally at increasing the level of fixed rate N application.

6.2.7 Recommended dose of N application in three splits being superior over all other treatments, recorded 2.19% increase in straw yield over two split application. Both of these treatments recorded significantly more straw yield over all other treatments except the treatments where GS guided N was applied both at 2^{nd} and 3^{rd} irrigation stages, in combination with different fixed doses.

6.3 Quality parameters

6.3.1 Sedimentation value and grain appearance score were highest in treatments having 100 and 125 kg N/ha as fixed dose combined with two stage GS guided N application which were statistically at par with recommended dose, fixed dose of 125 kg/ha (all combinations i.e. T_9 and T_{10}), GS applied N at two stages combined with fixed dose of 75 kg/ha. Hectoliter weight was not influenced by different treatments.

6.3.2 No significant variation was observed in protein content of wheat due to different N application treatments. However, N application at 3^{rd} irrigation invariably recorded higher grain protein content than 2^{nd} irrigation applied N. Application of recommended dose of N in three equal splits proved more efficient in yielding protein (kg/ha) than that in two equal splits. Irrespective of the level of fixed rate N, GS guided N application at two stages i.e. at 2^{nd} and 3^{rd} irrigation was significantly superior over other two treatments having GS guided N application either at 2^{nd} or 3^{rd} irrigation. As the level of fixed rate N application increased protein yield also increased.

6.4 Nutrient Studies

6.4.1 The different N application treatments failed to produce significant difference in N, P and K content of wheat grain and straw.

6.4.2 Total N, P and K uptake as well as N, P and K uptake separately by grain and straw, generally increased at increasing the level of fixed rate N application, when equivalent treatments (i.e. treatments having same time of GS guided N application) were compared. Significantly higher N uptake by grain in two stage applied N using GS over 2nd irrigation applied N indicated that 3rd irrigation applied N is important regarding the grain N uptake.

6.5 Economics

6.5.1 Cost of cultivation was highest in treatment having maximum dose of N application i.e. @ 162 kg/ha and it was 6.9% more than control. Highest gross returns, highest net returns and highest B-C ratio was recorded in treatment having fixed N dose of 75 kg/ha coupled with two stage GS guided N application. Application of N using GS only once resulted in lower B-C ratio as compared to N application using GS twice at 2nd and 3rd irrigation due to more increase in gross returns as compared to increase in cost of cultivation.

6.6 Evaluation of N management in wheat with and without using GreenSeeker

6.6.1 Application of recommended dose of N in three splits proved better than two split application in terms of yield, N-use efficiency and grain quality.

6.6.1 When 25+50 kg N/ha was applied at sowing and 25 DAS, GS recommended highest doses of N at 2nd and 3rd irrigation, however, total dose of N applied was less by 11 kg/ha as compared to recommended dose i.e. 150 kg N/ha and the same treatment recorded highest grain yield, however, it was at par with recommended dose of N application either in two or three equal split doses. But saving in N application with improvement in yield resulted into highest agronomic and recovery efficiency and partial factor productivity.

6.6.2 At successive increase in level of fixed rate N application, GS guided N doses decreased; however, total dose of N applied increased at increasing the level of fixed rate N application. Successive increase in N dose was 7 to 19% whereas increase in yield was only 4.8 to 1.4% as a result, the decrease in agronomic efficiency and recovery efficiency was recorded.

6.6.3 GreenSeeker guided N both at 2nd and 3rd irrigation stage, resulted into significantly improved yield, N-use efficiency and better grain quality in terms of higher protein content.

6.6.4 Single stage GreenSeeker guided N at 2nd irrigation was better than single stage GreenSeeker guided N 3rd irrigation in terms of yield and N-use efficiency.

Conclusion

The experiment on precision N management using optical sensor should be conducted for at least two crop seasons, in order to better understand the impact of particular location, soil type and local climatic conditions on yield potential and probability of crop response to fertilizer N on the basis of which the optical sensor estimates the in-season N fertilizer requirements. However, keeping in view the objectives of present experiment, following inferences may be drawn based on one year data.

1. The treatment having 75 kg N/ha (25 kg/ha at sowing + 50 kg /ha at 25 DAS) as fixed dose coupled with GreenSeeker guided N both at 2nd and 3rd irrigation i.e. 33 and 31 kg N/ha, respectively, was significantly superior in terms of growth parameters, yield attributes and yield over all other treatments. In this treatment total N applied was also lower by 11 kg /ha than recommended.
2. Growth parameters**,** yield attributes and yield were superior when recommended dose of N (150 kg/ha) was applied in three equal split doses as compared to two equal split doses.
3. GreenSeeker guided N should be applied at 2nd irrigation instead of 3rd irrigation, if N is to be applied one time using GreenSeeker, irrespective of the fixed nitrogen doses applied at sowing and 25 DAS, however, GreenSeeker guided N applied at 2nd and 3rd irrigation was superior over single GreenSeeker guided N application.
4. Application of 75 kg N/ha (25 kg/ha at sowing + 50 kg /ha at 25 DAS) coupled with two stage GreenSeeker guided N was found most economical among different treatments based on B-C ratio and net returns.

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APPENDIX-I

Mean weekly meteorological data during crop growing season (2013-14) recorded at experimental station

Standard weeks	Temperature (^oC)		Relative humidity (%)		Sunshine (hrs.)	Evp. (mm)	Rainfall (mm)
	Max.	Min.	M	E			
46	25.2	8.0	96	37	7.9	1.7	0.0
47	27.2	9.2	92	38	7.9	2.1	0.0
48	27.8	8.8	92	38	8.0	1.7	0.0
49	25.4	7.9	91	43	7.8	1.6	0.0
50	24.1	7.2	94	44	15.0	1.4	0.0
51	18.2	10.1	97	78	2.0	0.6	0.0
52	18.3	3.2	94	43	6.8	1.3	0.0
1	16.9	2.4	95	59	4.4	1.0	0.0
2	18.5	3.3	96	52	5.5	1.2	0.0
3	16.4	6.5	99	84	2.3	0.5	0.0
4	18.3	8.8	98	78	2.8	1.4	2.0
5	21.0	8.6	98	72	4.2	0.8	0.0
6	20.6	7.9	97	65	6.0	1.9	4.1
7	19.5	5.5	95	63	6.5	1.6	1.5
8	21.9	8.5	92	66	6.4	1.9	3.1
9	21.9	8.7	99	70	6.1	1.7	3.8
10	22.5	9.0	96	64	5.7	2.3	11.3
11	24.9	11.0	92	66	7.9	2.6	13.3
12	28.3	12.3	89	42	8.8	3.2	1.1
13	28.0	15.7	86	54	5.5	3.7	21.3
14	31.2	14.3	88	38	9.1	4.4	8.5
15	33.3	16.4	72	31	9.5	6.2	0.0
16	32.8	18.4	79	50	8.8	5.6	7.9
17	37.6	18.6	57	22	10.4	6.6	0.0

ABSTRACT

Title of thesis	**:**	Precision nitrogen management in irrigated wheat
Full Name of Degree Holder	**:**	Rekha Ratanoo
Title of degree	:	Master of Science in Agronomy
Name and Address of Major Advisor	:	Dr. Satish Kumar Professor (Agronomy) & Associate Dean, PGS, CCS HAU, Hisar-125004
Degree awarding University/ Institute	:	Chaudhary Charan Singh Haryana Agricultural University Hisar -125004
Year of award of degree	:	2015
Major subject	:	Agronomy
Number of words in abstract	:	418
Total number of pages in thesis	:	77 + vii +I

Key words: Wheat, precision nitrogen management, GreenSeeker (GS), optical sensor, fixed level of N application, GS guided N, growth parameters, yield attributes, yield, nutrient uptake, N-use efficiency, economics

A field experiment entitled "**Precision nitrogen management in irrigated wheat**" was conducted during the winter season of 2013-14 at Agronomy Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. The experiment was laid out in randomized block design with three replications. There were 12 treatments comprising N application with and without using GreenSeeker optical sensor. N application without using GreenSeeker consisted of two treatments having recommended dose (150 kg/ha) in two (75kg/ha each) and three (50 kg/ha each) equal splits. GreenSeeker guided N application was combined with fixed rate and fixed time N application (nine treatments) as basal and at 25 DAS with three levels 75, 100, and 125 kg/ha. GreenSeeker was used with each fixed level of N application at 2^{nd} (50 DAS) and/or 3^{rd} irrigation (65 DAS). One treatment was control where no fertilizer N was applied.

Growth parameters *viz*. plant height, dry matter accumulation and crop growth rate increased with increase in level of fixed rate N application, whereas, within the same level of N application growth parameters significantly improved in two stage GS guided N application. Yield attributes as well as yield, improved significantly with increase in level of fixed rate N application. The highest yield was recorded in treatment having fixed dose of 75 kg N/ha (25 kg/ha as basal + 50 kg/ha at 25 DAS) combined with GS guided N application both at 2^{nd} and 3^{rd} irrigation stages i.e. 33 kg/ha and 31 kg/ha, respectively; and it was at par with recommended dose of N either in two or three splits and treatment having fixed dose of N @ 125 kg/ha combined with GS guided N both at 2^{nd} and 3^{rd} irrigation. Application of recommended dose of N in three splits proved better than two split application in terms of yield, N-use efficiency and grain quality. The highest N-use efficiency was recorded in treatment having fixed dose of 75 kg N/ha (25 kg/ha as basal + 50 kg/ha at 25 DAS) combined with two stage GS guided N application. Nutrient uptake improved with increasing the number of splits and total N dose. N-use efficiency decreased with increase in level of fixed rate N application. A saving of 11 kg N/ha was recorded without reducing the yield in treatment having fixed rate N application @ 75 kg/ha (25 kg/ha as basal + 50 kg/ha at 25 DAS) combined with two stage GS guided N. This treatment also led to highest B-C ratio closely followed by three split application of recommended dose.

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I, **Rekha Ratanoo,** Admn. No. **2013A11M**, undertake that I give copy right of my thesis entitled, **"Precision nitrogen management in irrigated wheat"** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar.

I also undertake the patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of Chaudhary Charan Singh Haryana Agricultural University, Hisar.

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