SPECTRAL CHARACTERIZATION TO DISCRIMINATE GRASS WEEDS FROM WHEAT CROP USING REMOTE SENSING AND GIS FOR PRECISION AGRICULTURE AND ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

The study entitled, Spectral characterization to discriminate grass weeds from wheat crop using remote sensing and GIS" was carried out to find out the optimum time span to distinguishing major grass weeds i.e. *Phalaris minor* and *Avena ludoviciana* from wheat crop based on their spectral characteritics. The study was conducted at Student's Research Farm, Department of Agronomy during 2006-07 and 2007-08. The experimental sites during both the seasons were sandy loam in texture, with normal soil reaction and electrical conductivity, low in organic carbon and available nitrogen and medium in available phosphorus and potassium. The investigation consisted of two experiments each having twelve treatments with different population levels of *Phalaris minor* in Experiment I and *Avena ludoviciana* in experiment II viz 0, 10, 15, 25, 50, 75, 100, 125, 150, 200, 250 plants m^{-2} and a pure weed plot. In addition to the various agronomic parameters, the remote sensing parameters such as Red reflectance (%), Infrared reflectance (%), Radiance ratio (RR) and NDVI were recorded periodically during the crop growing season for both the years. The results showed that the highest RR and NDVI values were recorded under pure wheat treatment (T_0) and minimum under pure weed plots (T_{max}). It was observed that by using remote sensing indices like RR and NDVI, pure wheat can be distinguished from pure populations of *P. minor* and *Avena ludoviciana* just after 34 DAS and various levels of weed populations can be discriminated amongst themselves from 68 DAS upto 107 DAS. From Such type of study it is concluded that we can discriminate the grass weeds from Wheat crop based on their spectral characterization and in future, weed prescription mapping can be used for forecasting the weed infestations in crops, on the basis of which farmers can be advised to take the preventive control measures to manage the weeds precisely/need based without going for blanket spraying of herbicides and weed maps can be used in yield forecasting models.

Key Words: Multispectral, Wheat, Little seed canary grass precision weed management, remote sensing spectral characteristics.

INTRODUCTION

Wheat (*Triticum aestivum* L. emend Fiori and Paol) is the most important and widely cultivated cereal crop in the world. In Punjab it is cultivated over an area of 3.52 million hectares with a total production of 15.7 million tones and an average yield of 4.5 tones/hectare (Anonymous, 2010). Major detriments to higher productivity of wheat are stiff competition from weeds, multiple nutrient deficiencies, insect-pests and incidence of diseases. Severe weed competition has resulted from the change in morphological characteristics of wheat varieties and shift in sowing paradigm over a period of four decades. Moreover, high initial soil moisture and low temperature at sowing leads to severe infestation by grassy and non-grassy weeds. (Anjuman and Bajwa, 2010) reported that selected wheat varieties incurred 60-65 per cent biomass losses due to weed infestation. The effect was evident on tillering capacity that decreased by 41.6 per cent and consequently, the crop yield. In various plots, the reduction in total grain weight was as high as 83 per cent compared with weed free control. Among different weed species, the infestation by little seed canary grass (*Phalaris minor*) in wheat is rampant and it alone divests the crop of 42.2 kg N, 6.5 kg P and 71.6 kg K per hectare (Walia and Gill, 1985a) and lowers the crop yield by 30-50 % (Pandey and Singh, 1997).

Generally weed-crop competition is complicated as weeds compete with the crop plants by occupying a space, which would otherwise be available to the crop plant. Anything that reduces this space reduces the plant growth. Weeds reduce wheat yield and profit by competing with the crop for moisture, light and nutrients. Weeds also can interfere with harvest and lowers the quality of grains. Yield loss and harvest problems caused by weed species in wheat will vary depending on the weed species, weed population, time of application, time of weed emergence, growing conditions and status of wheat crop. A healthy stand of wheat that has a head start on weeds is competitive and will suppress weed growth. Studies show that weed and canopy architecture especially plant height, location of branches and maximum leaf area determine the impact of competition for light and thus have a major influence on crop yield (Cudeny *et al.*, 1991). Increased uptake of mineral nutrients in weeds often results in a significant competitive advantage over crop species. About 80% of the global cereal production comes from wheat, maize and rice but their yield is greatly affected by these unwanted plants. Wheat (*Triticum aestivum* L.) is the most important cereal throughout the world. It has been estimated that globally yield reduction in wheat due to weeds is 13.1% (Oerke *et al*., 1994) or even more in some cases which is indeed a great loss towards food self sufficiency.

When solar radiation interacts with matter, it may be reflected, transmitted or absorbed. The spectral reflectance of crop canopies is determined by a) leaf spectral properties b) LAI and canopy geometry c) background (soil or residue) reflectance d) illumination and view angles e) atmospheric transmittance (Bauer, 1985). When vegetation density is low, background reflectance significantly influences the canopy reflectance. When vegetation density is high, leaves are the primary scattering elements and the background contributes little to overall canopy reflectance. Generally an area having very vibrant vegetation will reflect much more NIR radiation than a sparsely vegetated area (Qi *et al.,* 1994). However since human eyes cannot see NIR light, this important physical property of vegetation is unnoticeable to a human by-stander. With the aid of optical remote sensors, the reflectance of electromagnetic radiation from vegetation including that in NIR region can be detected and quantified. Then with further processing, this information can be used to formulate a strategy for site specific crop management.

Plant canopy light reflectance measurements have been used to characterize the spectral characteristics of plant species and aerial photography and video-graphy have proven useful for detecting plant species on rangelands (Everitt *et al.,* 1986). Many rangeland plant species are distinguishable on aerial imagery when in specific phonological stages (Everitt and Deloach, 1990; Everitt and Villarreal, 1987). Leafy spurge produces showy yellow bracts in late May or early June giving the plant a conspicuous appearance so it might be distinguishable on aerial imagery in this phonological stage (Lacey *et al.,* 1985).

(Gibson *et al.,* 2004) support the idea that remote sensing has potential for weed detection in soybean, particularly when weed management systems do not require differentiation among weed species.

(Everitt *et al.,* 1992) reported that Drummond and common golden weed can be separated from other plant species and soil at flowering in the fall. Similarly, (Shepherd and Lee, 2007) supported that in most instances the best opportunity for scrub weed (*Ulex europaeus*) discrimination occurs during flowering periods.

The spectral properties of leaves are determined by the concentration of chlorophyll and other pigments in the visible (400-700nm) wavelength region, by mesophyll structure in the near infrared (700-1200nm) region and by amount of water in the middle infrared (1200-2400nm) region. As leaves expand, mature and senesce, physiological and morphological changes occur that affect their spectral properties. The temporal variation of spectral parameters i.e. infrared: red reflectance ratio or radiance ratio (RR) and normalized difference vegetation index (NDVI) during the life cycle of crop represent the growth and development of the crop.

METHODOLOGY

Field experiments were conducted at the Student's Research Farm of the Department of Agronomy, Punjab Agricultural University, Ludhiana during *rabi* seasons of 2006-07 and 2007-08. Ludhiana is located in Trans-Gangetic agroclimatic zone and represents the Indo-Gangetic alluvial plains. It is located at $30^{o}56'$N latitude, $75^{o}52'$E longitude and at an altitude of 247 m above the mean sea level.

Ludhiana is characterized by sub-tropical semi-arid type of climate with hot summer and very cold winters. The mean maximum and minimum temperatures therefore show considerable fluctuation during summer and winter seasons. The meteorological data recorded during crop growing seasons indicate that almost normal weather conditions prevailed during the two crop seasons except for rainfall, which was highly variable during two years of study. Maximum temperature ranged between 19.5 to 36.8^{o}C during first year and 16.9 to 34.1^{o}C during second year against the normal range of 18.3 to 34.2^{o}C from November to April. Minimum temperature ranged between 4.2 to 19.4^{o}C during first year and 4.5 to 17.7^{o}C during second year against a normal range of 4.2 to 16.9^{o}C. First year received 185 mm rainfall during November to April, whereas the second season received 89 mm of rainfall against a normal value of 111 mm.

The soil of the experimental fields was normal in soil reaction and electrical conductivity, was low in organic carbon and available nitrogen and medium in available phosphorus and potassium.

To establish the critical population levels of primary weed species in wheat i.e. *Phalaris minor* and *Avena ludoviciana* and to establish its optimum time span for distinguishing it from wheat, different plant populations of these two weed species i.e. *Phalaris minor* and *Avena ludoviciana* viz. 0, 10, 15, 25, 50, 75, 100, 125, 150, 200, 250 plants m^{-2} were maintained in wheat crop and solid stand of *Avena ludoviciana* and *Phalaris minor* were also kept (T_{max}).

Radiometric observations

Spectral reflectance in two wave bands i.e. Red (625-689 nm) and Infrared (760-897 nm) was recorded at fortnightly interval with the help of hand held ground truth spectroradiometer and remote sensing parameters were calculated as under:

Radiance ratio (RR) and Normalized difference vegetation index (NDVI)

Radiance ratio (RR) and Normalized difference vegetation index (NDVI) were derived from Red and IR band reflectance by the following formulae:

RR = Infrared Reflectance (IR)/ Red Reflectance(R).

NDVI = (IR-R)/ (IR+R)

RESULTS AND DISCUSSION

Spectral vegetation indices are the most important one and they attempt to measure biomass or vegetative vigour. A vegetation index is a dimensionless, radiometric measure that function as an indicator of relative abundance and activity of green vegetation often including LAI, percentage green cover, chlorophyll content, green biomass and absorbed PAR. A vegetation index should maximize sensitivity to plant biophysical parameters preferably with a linear response in order that sensitivity be available for a wide range of vegetation conditions and to facilitate validation and calibration of the index. A vegetation index should normalize or model external effects such as sun angle, viewing angle and the atmosphere for consistent spatial and temporal comparisons.

Radiance Ratio (RR) of P. minor and Wheat crop

The use of NIR or R spectral bands singly does not account for seasonal sun-angle differences and can be affected by atmospheric attenuation in the case of satellite based (vs. ground based) measurements. To avoid these problems, a number of indices with reflectance near R and NIR wavelengths have been derived and tested for their ability to accurately predict total wet and dry crop biomass, leaf water content and leaf chlorophyll (Tucker, 1979). Among the best was the simple NIR/R ratio, first used by (Rouse *et al.*, 1973), and a weighted difference (NIR-R)/(NIR+R), also termed the normalized difference vegetation index (NDVI).

The data on radiance ratio (RR) presented in figs 1 and 2 shows that RR value increases in the early stages of crop growth with increasing green biomass, reaches a maximum at maximum crop canopy cover and after that decreases as the leaves senesce. The highest RR values were obtained at 95 DAS almost in all the treatments. The pure wheat treatment (T_0) had the higher RR value compared to other treatments at all the observational stages. Treatment T_{max} (Pure *Phalaris minor* plot) showed a lowest RR value among all the treatments. The differences in RR between pure wheat and pure weed are mainly due to dark green colour of wheat and more LAI and biomass of wheat crop compared to T_{max} (pure *Phalaris minor*). The data on radiance ratio showed that population level of 15, 25, 50, 75,100, 125 and 150 plants of *P. minor* cannot be distinguished from each other in their radiance ratio at earlier stage of 34 DAS but higher population levels beyond this including pure *Phalaris minor* (T_{max}) can be discriminated from pure wheat crop at much earlier stage i.e. 34 DAS during 2006-07. At 52 DAS, all the population levels showed different RR from pure wheat crop but, it is difficult to

Fig 1 Radiance ratio (RR) under varying populations of *Phalaris minor* during 2006-07

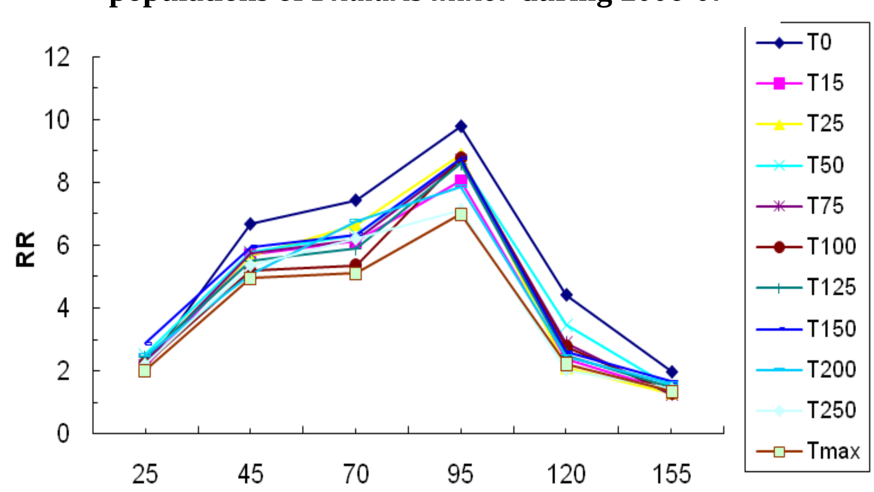
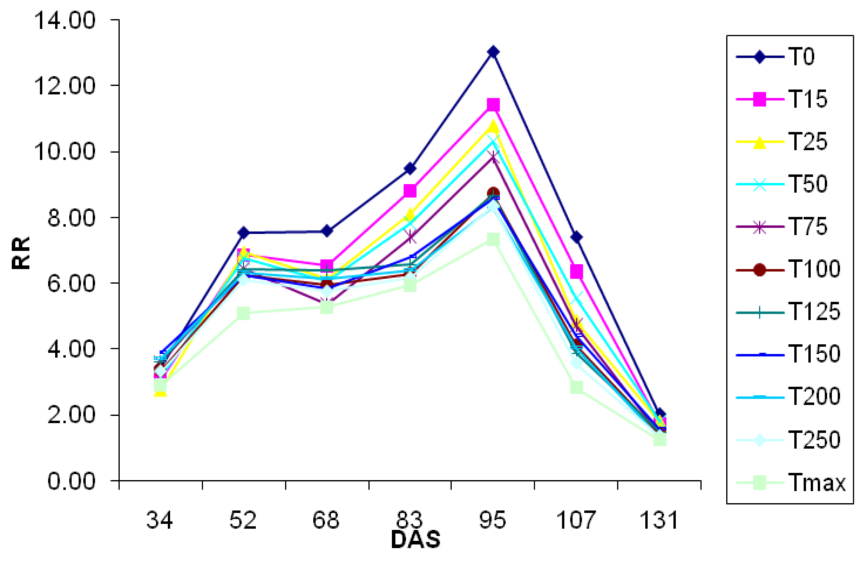


Fig: 2 Radiance ratio (RR) under varying populations of *Phalaris minor* during 2007-08



differentiate amongst various *P. minor* treatments. Almost all the levels of plant population can be discriminated amongst themselves after 68 DAS and remain distinguished up to 107 DAS. The pure wheat plot can be distinguished from different weed population treatments much earlier i.e. 34 DAS and remains different from rest of the treatments up to 107 DAS.

During 2007-08, the highest radiance ratio was recorded in pure wheat plot and it is distinguished from rest of the treatments at 45 DAS and remain different from rest of weed population treatments up to 120 DAS. Pure wheat crop can be distinguished from various *P. minor* populations (15-250 plants/m^2) at all observational stages throughout the growing season except at 25 DAS. Early in the season when soil background is dominant and later in the season when crop is in senescence stage, the *P. minor* weed and wheat crop cannot be distinguished. However, when *P. minor* population is too high i.e. pure *P. minor* plot (T_{max}), it can be distinguished from pure wheat crop much earlier i.e.25 (DAS) till 120 days of crop growth.

(Brown and Noble, 2005) reported that airborne remote sensing has been successful for detection of distinct weed patches when the patches are dense and uniform and have unique spectral characteristics. The use of multispectral imaging sensors such as color digital cameras on a ground-based mobile platform shows more promise for weed identification in field crops. Spectral features plus spatial features such as leaf shape and texture and plant organization may be extracted from these images.

(Richardson *et al.*, 1985 and Menges *et al.*, 1985) used remote sensing to distinguish among experimental plots of *Cucumis melo* L., *Gossypium hirsutum* L., *Sorghum helepense* (L.), *Amaranthus palmeri* and *sorghum bicolor* (L.). They were relatively successful in distinguishing crops from weeds during late-season stages of crop growth; but had difficulty in distinguishing between bare soil and crops during early-season growth stages. Their increased accuracy during late-season growth stages was due to increased ground cover. Similarly, (Medline *et al.*, 2000) it was reported that the relatively low classification accuracy (83%) of *I. Lacunose* was due to *S. obtusifolia* and *S. carolinense* population variability, contributing to variability in reflectance properties from areas with similar *I. lacunosa* infestations.

Radiance ratio (RR) of Avena ludoviciana and wheat crop

Perhaps the most widely accepted method for describing vegetative growth using reflectance spectra is through the calculation of band ratios or vegetation indices. Vegetation indices are spectrally based values generated through the mathematical manipulation of reflectance measurements from two or more spectral wavelengths. Theoretically, the calculation of vegetation indices should provide values that are more highly correlated to LAI, biomass, or vegetative cover than the raw reflectance measurements (Wanjura and Hatfield, 1987). (Thenkabail *et al.,* 2000) found that LAI and biomass were highly correlated with vegetation indices than crop height and canopy cover. Lack of consistency in vegetation index performance can be attributed to the fact that the measured spectral response of a given environment depends uniquely on the atmosphere, sensor calibration, ambient lighting conditions, soil background and the homogeneity of the scene (Bannari *et al*, 1995).

The data on radiance ratio (RR) presented in figs. 3 and 4 showed that it increased with the advancement of crop growth, reaches maximum at maximum crop canopy cover and then decreases till maturity. The highest RR value was reached at 95-100 DAS in almost all the treatments and decreased thereafter. The pure wheat (T_0) had highest RR value compared to other treatments at all

Fig 3 Radiance ratio (RR) under varying populations of *Avena ludoviciana* during 2006-07

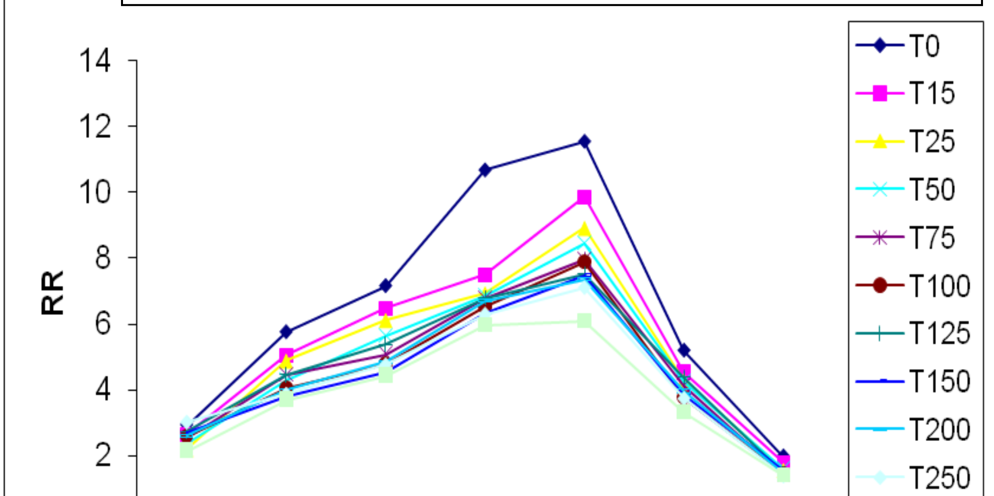
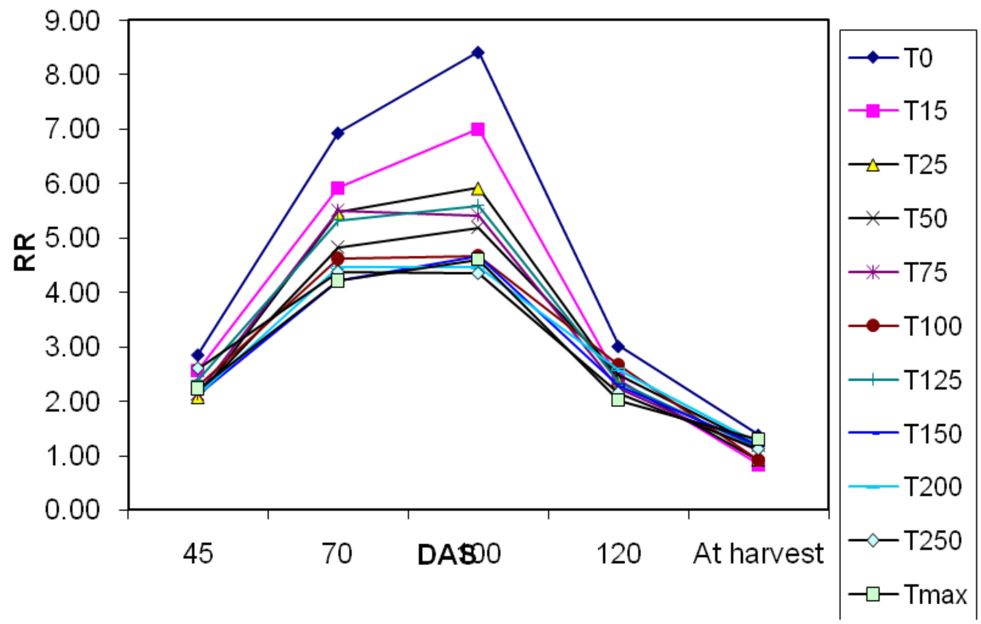


Fig 4 Radiance ratio (RR) under varying populations of *Avena ludoviciana* during 2007-08



the observational stages. Treatment T_{max} (Pure wild oat plot) recorded lowest RR value compared to all other treatments. The differences in RR between pure wheat and pure weed treatments is mainly due to dark green colour of wheat, more LAI and biomass of wheat crop compared to wild oats. During early period of growth and at later stages of crop growth, it is difficult to discriminate between various weed population treatments, but pure wheat crop (T_0) can be easily distinguishable from rest of the treatments at earlier stages and remain separable throughout the crop growth period during both the years. The treatments having lower wild oats densities cannot be distinguished among themselves during earlier stages i.e. at 34 DAS (2006-07) and 45 DAS (2007-08), but treatments with higher weed populations (125 plants of *Avena ludoviciana* to 250 plants) can be distinguished at earlier stages too during both the years. Almost all population levels can be discriminated from 68-70 DAS and remain distinguished from each other up to 100 DAS for both the years of study.

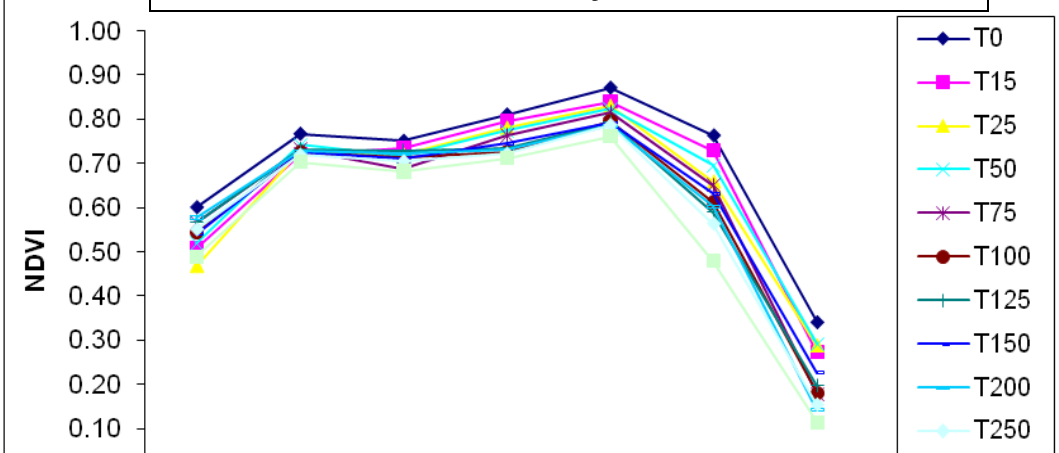
Normalized Difference Vegetation Index (NDVI) of P. minor and wheat

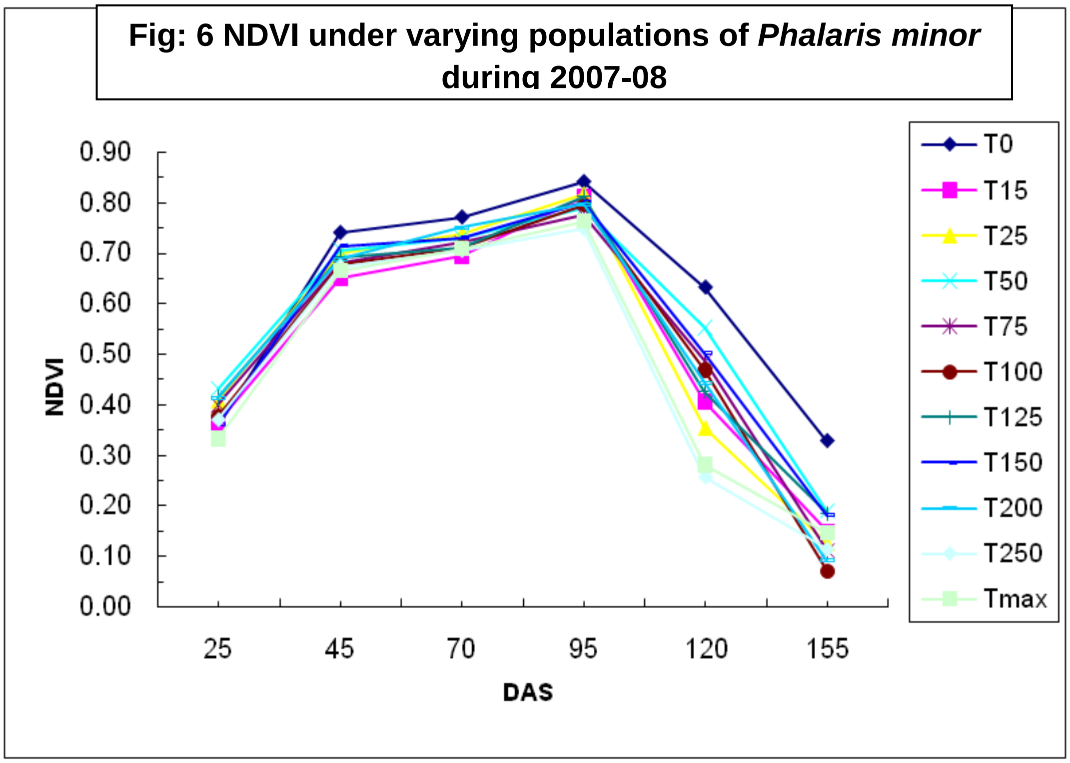
The normalized difference vegetation index (NDVI) is used to highlight the vegetation component in a soil background and due to normalization also minimizes the effects of illumination and other measurement conditions. This allows a comparison of the same crop across space and over time. Because of the tendency for healthy vegetation to absorb red light and reflect energy in the NIR, vigorous plants will have a high NDVI value. Conversely, as plant health declines, so does the ability to absorb red light and reflect NIR; this scenario results in low NDVI values signifying a decrease in plant vigor (Henry *et al.*, 2004).

Similar trend was also observed in case of NDVI Fig 5 and 6. The figure showed that NDVI goes on increasing with advancement in crop age, reaching the maximum at 95 DAS and then decreases after 95 DAS mainly due to senescence of leaves in all the treatments during both the years i.e. 2006-07 and 2007-08. This is because the absorption of energy in the red region begins to decrease and the reflected energy in the infra-red region decrease due to cell degeneration and a decrease in LAI. The values of NDVI in pure wheat (T_0) treatment ranged from 0.34-0.87 (2006-07) and from 0.33-0.84 (2007-08) and in pure weed plot (T_{max}) from 0.11 to 0.76 and 0.15 to 0.76 during 2006-07 and 2007-08, respectively. Among all the treatments, pure wheat crop (T_0) treatment showed the highest NDVI values (0.87 and 0.84). The separation of weed free crop from different levels of weed is clearly visible in NDVI. Various population levels of *P.* minor can be distinguished from pure wheat crop at 34DAS during 2006-07 and at 45DAS during 2007-08. Early in the season when soil background is dominant and later in the season when crop is in senescence stage, the *Phalaris minor* and wheat crop cannot be distinguished. However, pure wheat crop recorded the highest NDVI throughout the crop growth during both the years. The perusal of the RR (Fig. 1 & 2) and NDVI (Fig. 5 & 6)) data revealed that both RR spectral index and NDVI spectral index are good in distinguishing *P. minor* and wheat crop.

Comparison of the linear and quadratic regressions showed that the regressions of RR and NDVI on plant height, fresh biomass and total dry biomass were improved when the quadratic model was used, but that LAI was linearly correlated with the spectral indices (Mahey *et* al., 1991).A number of studies have reported a linear relationship between the reflectance of various major field crops to leaf area index viz. barley (Penuelas *et al.*, 1997), cotton (Weigand and Richardson, 1990),

Fig: 5 NDVI under varying populations of *Phalaris minor* during 2006-07





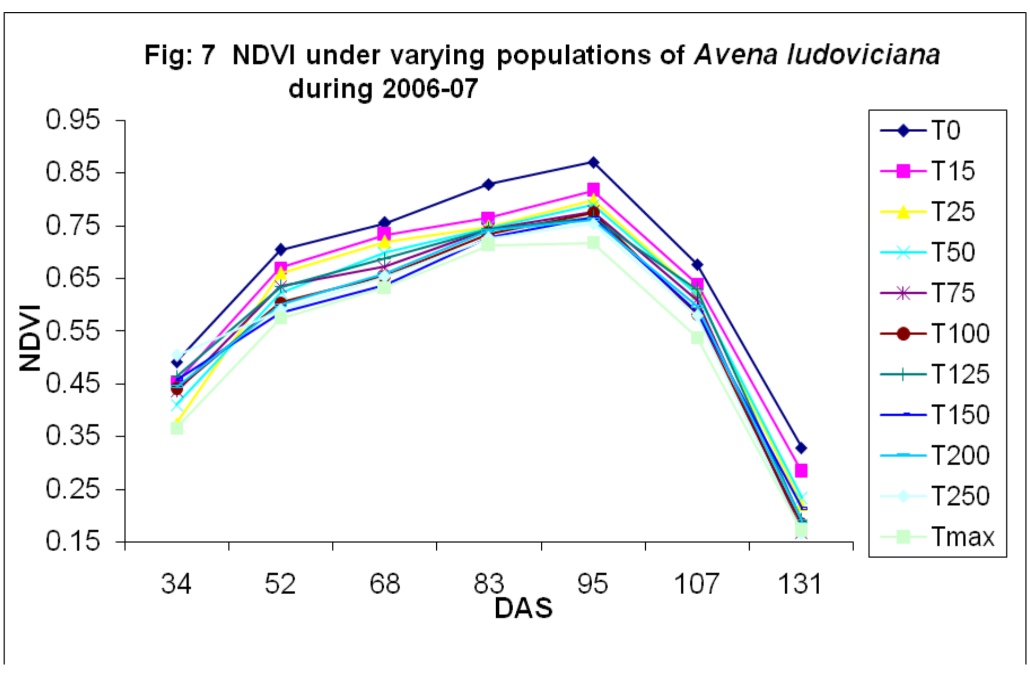
Maize (Ma *et al.*,1996), potato (Bouman *et al.*, 1992), soybean (Holben *et al.*, 1980) and wheat (Mahey *et al* 1991). Similar relationships have been developed for leaf chlorophyll concentration (Penuelas *et al.*, 1994, Filella *et al.*, 1995).

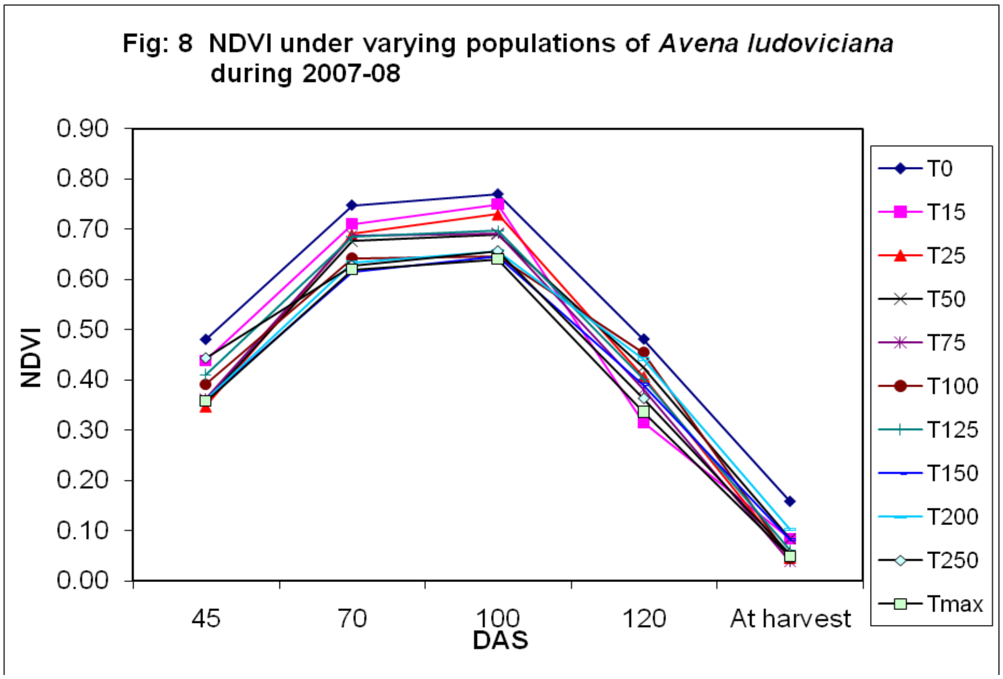
Despite the different problems encountered thus far in detecting weeds, some researchers argue that the spectral characteristics of plants are sufficient without introducing geometric complexities (Price, 1987; Gutman, 1991).

Normalized Difference Vegetation Index (NDVI) of Avena ludoviciana and wheat crop

Theoretically, the calculation of vegetation indices should provide values that are highly correlated to LAI, biomass, or vegetative cover than the raw reflectance measurements (Wanjura and Hatfield, 1987). A plethora of these indices have been developed for use in remote sensing research over the past 30 years (Rondeaux *et al.*, 1996), but the normalized difference vegetation index (NDVI) has become the most popular. By contrasting a plant's characteristically low red reflectance with its high IR reflectance, vegetation indices such as the NDVI, can accurately distinguish pure vegetation spectra from that of other pure spectra such as soil, water and rock. In a simulation study, (Bouman *et al.*, 1992) concluded that NDVI could estimate LAI with relatively small errors. (Thenkabail *et al.*, 2000) found that LAI and biomass were highly correlated with vegetation indices than crop height and canopy cover. Lack of consistency in vegetation index performance can be attributed to the fact that the measured spectral response of a given environment depends uniquely on the atmosphere, sensor calibration, ambient lighting conditions, soil background and the homogeneity of the scene (Bannari *et al.*, 1995).

The calculated NDVI values for different wild oat populations are reported in Figs 7 and 8. The figure showed that NDVI goes on increasing with advancement in crop age, reaching the maximum at 95 DAS (2006-07) and 100 DAS (2007-08) and then decreases mainly due to senescence of leaves in all the treatments during both the years. This is because the absorption of energy in the red region begins to decrease and the reflected energy in the infra-red region decreases due to cell degeneration and a decrease in LAI. Among all the treatments pure wheat crop (T_0) treatment showed the highest NDVI values. The separation of weed free crop from different levels of weed is clearly visible in NDVI. The various population levels of *Avena ludoviciana* can be distinguished from pure wheat crop at 34 DAS during 2006-07 and at 45 DAS during 2007-08. Early in the season when soil background is dominant and later in the season when crop is in senescence stage, *Avena ludoviciana* weed and wheat crop cannot be distinguished. However, pure wheat crop recorded the highest NDVI throughout the crop growth during both the years. The different weed population treatments can be distinguished from pure wheat crop as well as amongst themselves at earlier stage in case of NDVI i.e. 34 DAS during 2006-07 and 45 DAS during 2007-08 and remain distinguished up to 107 DAS and about 120 DAS during 2006-07 and 2007-08, respectively.





750nm it is possible to discriminate wheat stubble, sunflower, one group of weed species including *E. elaterium* and field bindweed, and two other groups of weeds including scarlet pimpernel and catchweed; and white clover and knotweed, respectively.

(Aparicio *et al.*, 2000) reported that LAI was the crop growth trait that most closely correlated with the spectral reflectance indices. They further studied that when all genotypes, growth stages and environments measured were considered together, a positive linear relationship between simple ratio (SR) and LAI was observed. In contrast the relationship between NDVI and LAI was exponential, with NDVI increasing rapidly, reaching LAI values of about 3. At this stage NDVI tended to reach an asymptote at values between 0.8 and 0.9.

A significant relationship between NDVI and soil water potential was reported by (Yang and Su, 2000) that the increasing of soil water stress with decreasing value of NDVI.

CONCLUSION

The highest RR and NDVI values were recorded under solid stand of wheat and lowest under pure weed plots. This may be due to dark green colour and better vigour of the wheat as compared to *Avena ludoviciana* and *Phalaris minor*. It was observed that by using RR and NDVI, pure wheat can be distinguished from pure populations of *Avena ludoviciana* and *Phalaris minor* after 35 DAS and different levels of weed populations can be discriminated amongst themselves from 68 DAS upto 107 DAS during both the years of investigation.

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