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Derivation of weed intensity maps in wheat (*Triticum aestivum*) using spatial data with GIS in the central districts of Punjab, India

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ABSTRACT

Remote sensing technologies are playing an increasingly important role in agricultural production. Because of their potential for high spatial and spectral resolution, satellite and aircraft images can contain detailed site specific information about conditions in agricultural fields. It can be used for monitoring crop growth, yield potential, soil conditions, weed intensity etc. For the commercial extension of site-specific herbicide application technology, rapid and cost effective methods for creating accurate weed maps are required. An experiment was conducted to generate weed prescription maps using spatial data with GIS and remote sensing in the central districts of Punjab, India 2007-08 and 2008-2009. The objective of this research was to demonstrate the potential of optical airborne remote sensing in the detection of some specific weeds and their densities in wheat (*Triticum aestivum* L.) crop in the central districts of Punjab, India. The analysis of spectral and ground measurement was done to select wave bands (wavelength regions) suitable for distinguishing weed-infested and weed-free crop areas. The results of this study showed that weed prescription mapping can be used for forecasting the infestations, on the basis of which farmers can be take the preventive control measures for weed control, which ultimately helps them in preventing yield losses and these weed maps can also be used as an input in yield forecasting models in future.

Key words: *Anagallis arvensis, Malwa neglecta, Medicago* sp, *Melilotus alba*, *Polypogen monspeliensis, Rumex dentatus,* Remote sensing and GIS, Weed intensity

Technologies of remote sensing and precision agriculture are, in combination, playing an increasingly important role in agricultural production. Because of their potential for high spatial and spectral resolution, satellite and aircraft images can contain detailed site specific information about conditions in agricultural fields. They can be used for monitoring crop growth, yield potential, soil conditions, weed intensity etc. (Thomasson *et al.* 2003). Vegetation indices (VI's) and derived metrics have been extensively used for monitoring and detecting vegetation and land cover change (De Fries *et al.* 1995). Spectral reflectance from image data has often been used to calculate vegetation indices that have been related to crop growth status. The development of vegetation indices is based on differential absorption, transmittance and reflectance of energy by the vegetation in the red and infra red regions of the electromagnetic spectrum (Jensen 1996). Normalized difference vegetation index (NDVI) is one of the vegetation indices that have been commonly used in remote sensing applications in agriculture. Goel *et al.* (2003) used hyperspectral image classification to detect weed infestations and nitrogen status in corn. They found it difficult to distinguish between the effects of weeds and nitrogen treatments. However, when one factor was considered at a time, maps indicating weed infestation or nitrogen treatment could be generated with a satisfactory level of accuracy. Bajwa and Tian (2001) used an airborne digital color-infrared sensor to acquire remotely sensed images for mapping weed density. Weed densities and species vary field to field and thus uniform application of weed control measures over an entire field is neither economical nor environment friendly. However, such variations within fields have largely been ignored due to technological limitations in the application of herbicides (Medd and Pratley 1998). In precision or site specific crop and weed management, within-field weed variations are considered and patch spraying is used instead of the blanket application of herbicides. This reduces both treatment cost and herbicide loading in the environment (Christensen *et al.* 1998). Precise weed detection is a prerequisite for both the formulation of a better weed management strategy and its timely implementation. Currently, technology to manage fields on the basis of sub-field units is available. However for the commercial extension of site-specific herbicide application technology, rapid and cost effective methods for creating accurate weed maps are required. (Lamb *et al*. 1999). Presently two different

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approaches for weed monitoring and patch spraying are being followed. The first approach involves the development of weed maps and decision making prior to the application of herbicides. The other approach is based on the real-time detection of weeds and on decision making at the time of spraying (Rew and Cousens 1998). The potential of remote sensing has already been established in mapping crop areas and estimating crop yields over extensive areas. These applications could be easily integrated into precision agricultural practices. The objective of this research was to demonstrate the potential of optical airborne remote sensing in the detection of some broad leaved weeds and their densities in wheat crop in the central districts of Punjab (India). The analysis of spectral and ground measurement was done to select wave bands (wavelength regions) suitable for distinguishing weed-infested and weed-free crop areas.

MATERIALS AND METHODS

Weed maps were prepared in the GIS environment using Arc GIS 9.1. Following steps were followed to prepare the weed prescription maps: (1) The districts of Ludhiana, Jalandhar, Kapurthala, Tarn Taran, Shaheed Bhagat Singh Nagar (Nawan Shehar) were selected as study area for preparation of weed maps. (2) The data were collected from farmers' fields in the study area for the weed density (different broad leaf weeds (plants/m^2) in wheat plots), X, Y coordinates (latitude-longitude) were noted using Global Positioning System (GPS). (3) The latitude- longitude data was converted to Degree-decimal format. The coverage file (point) was then generated from the location data in Arc GIS. (4) The weed density data was transformed as attribute table and attached to the point file coverage already generated. (5) Then the point file coverage was converted to raster format through Kriging method giving equal distance points. (6) Reclassification was done by applying district boundary as a mask on the generated map. (7) *Generation of Wheat Mask:* (a) Three-dates (November, December and January) digital data acquired through Canadian Satellite SAR was classified using logistic modeling. (b) First of all, the non-agricultural and agricultural land areas were segregated. (c) Within the agricultural area, wheat and non-wheat areas were differentiated. (8) Wheat area was detected and weed density map was overlaid on wheat map and the different broad leaf weed density in the wheat field was mapped.

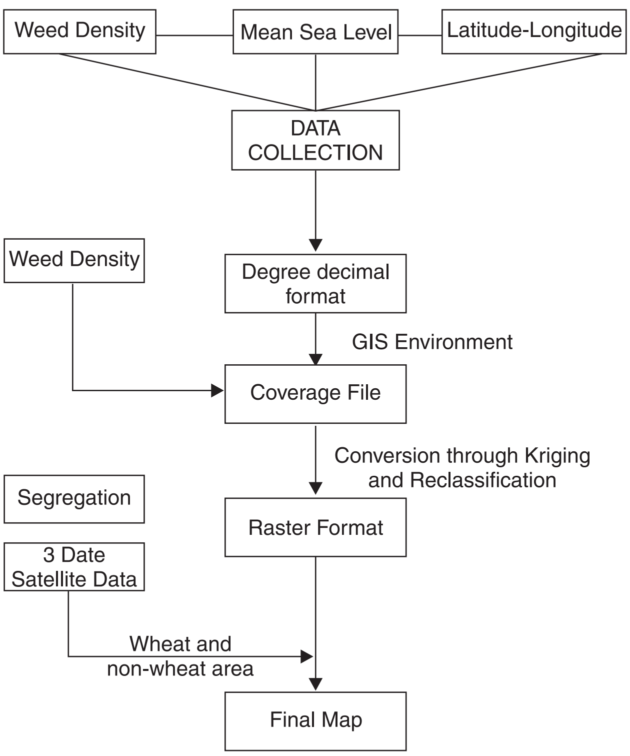

Fig 1 Weed prescription mapping in the GIS

RESULTS AND DISCUSSION

Weed mapping in GIS environment

Weed maps were prepared in the GIS environment using Arc GIS 9.1. Data collected from the farmer's fields in five districts (Jalandhar, Kapurthala, Ludhiana, Shaheed Bhagat Singh Nagar and Tarn Taran) regarding X, Y coordinates and weed density were analyzed in GIS. Descriptions of different weed species along with its densities are presented in Tables 1 to 7.

For studying the infestation levels of different weed species in wheat, five districts were selected as study area (Fig 2). This figure depicts the detailed information (total geographical area and area sown under wheat) of the five central districts of Punjab under study. The % area calculated from the maps showed that out of total geographical area (TGA) of Tarn Taran district, 76.28% area is under wheat (agricultural), while remaining 23.91% is non-wheat (non-agricultural). In Kapurthala district 66.24% of TGA is agricultural and 33.75% is non-agricultural. In Jalandhar 60.52% of total geographical area is agricultural and 39.48% is non-agricultural. Similarly in Shaheed Bhagat Singh Nagar and Ludhiana 50.76 and 70.91% of TGA is agricultural and 49.24 and 29.13% is non-agricultural area respectively.

In study area, infestation by *Polypogen monspeliensis* in wheat was studied and presented in Table 2 and Fig 2. It showed that in Tarn Taran District, this weed was quite common and spread over a large area. 71.58 thousand hectare

Table 1 Distribution of Geographical area between the Agricultural area and the non-agricultural area

District	Total geographical area ('000 ha)	Wheat area ('000 ha)	% of total geographical area (TGA)	Non-wheat* area ('000 ha)	% of TGA
Tarn Taran	241.9	184.53	76.28	57.85	23.91
Kapurthala	163.2	108.11	66.24	55.09	33.75
Jalandhar	263.2	159.29	60.52	103.91	39.48
Nawan Shehar	126.0	63.96	50.76	62.04	49.24
Ludhiana	370.2	263.36	70.91	107.84	29.13

*Non-wheat includes built up, rivers, canals, fallow, forests and other crops etc.

Table 2 Extent of infestation by *Polypogen monspeliensis* in wheat in different districts of Punjab (‘000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jallandhar	Nawan Shehar	Ludhiana
<2		17.58	7.21	27.27	2.48
2-4		1.32	9.02	7.21	76.53
4-6	6.53	34.47	13.55	7.24	66.3
6-8	49.96	50.9	5.12	6.88	63.24
8-10	71.58	3.65	0.01	9.19	26.33
10-12	22.78			2.52	17.85
12-14	14.84				7.33
14-16	18.28				2.04
16-18	0.05				
Total area (‘000 ha)	241.9	163.2	263.2	126.0	370.2

Table 3 Extent of infestation by *Anagalis arvensis* in wheat across different districts of Punjab (‘000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jallandhar	Nawan Shehar	Ludhiana
<2	181.13	41.06	2.94	35.21	65.92
2-4	2.89	25.27	17.08	14.88	154.65
4-6		25.22	7.82	13.33	41.5
6-8		16.36	5.72	0.51	0.02
8-10		0.01	1.37		0.01
10-12					
Total area (‘000 ha)	241.9	163.2	263.2	126.0	370.2

Larger area (74.9%) of Tarn Taran district was found to be having lower plant density of *Anagalis arvensis* (Table 3), i.e. <2 plants/m^2.

area was found to be infested with 8-10 plants/m^2 followed by 49.96 thousand hectare area, with plant density of 6-8 plants/m^2. So almost 50% of the total geographical area of the district was infested with plant density ranging between 6 to 10 and about 23% area was infested with density of 10-16 plants/m^2. In Kapurthala district, almost 52.31% area was found to be infested with weed density of 4-8 plants/m^{2}and 10.77 area was infested by <2 plants of *Polypogen monspeliensis* m^2. Very less area i.e. 3.65 thousand hectare was infested by 8-10 plants/m^2. Very less area i.e. 13.26% of TGA was found to be infested with this weed in Jalandhar district with plant density of 2 to 8 plants/m^2 with largest area infested by 4-6 plants/m^2. In Shaheed Bhagat Singh Nagar, larger area, i.e. 27.27 thousand hectare was found to be infested by less density, i.e. <2 plants/m^2 and 26.22% area was having weed density of 2 to 12 plants/m^2.

55.7% area of Ludhiana district was infested by density of 2 to 8 plants/m^2, 7.1% with 8-10 plants/m^{2}and 6.80% with 10-14 plants/m^2. So about 70-80% of TGA in Ludhiana district was infested with *Polypogen* with different plant densities.

In Kapurthala district, 25% of TGA was having infestation of <2 plants/m^2 and about 41% area was found to be infested with 2 to 8 plants/m^2. 13.33% area of Jalandhar district was found to be infested with this weed with density of 2 to 10 plants/m^2 with larger area having 2-4 plants/m^2.

In Shaheed Bhagat Singh Nagar, 50% of TGA was infested with this weed having density ranging from 2-6 plants/m^2. In Ludhiana a larger part of wheat area, i.e. 154.65 thousand hectare (41.8%) was infested with weed density of 2-4 plants/m^2, 17.8% with <2 plants/m^2 and 11.2% with weed density of 4-6 plants/m^2 .

Almost 22.19% of TGA in Tarn Taran district was infested with *Lepidum sativa* with density of 10-20 plants/m^{2}and 12.8% with density of <10 plants/m^2. So a major proportion of Tarn Taran district have densities of *Lepidium* sp. ranging from 10-20 plants/m^2. 62.56% of TGA in Kapurthala and 69.77% in Ludhiana district, 13.10% in Jalandhar, 50.63% in Nawan Shehar was infested with 10-20 plants/m^2.

A major portion of central zone was observed to be infested with *Lepidium sativa* density of 10-20 plants/m^2.

A total of 76.07% of TGA in Tarn Taran district was infested with *Rumex mextimis* and out of this major portion of this area was infested with plant density of 8-24 plants/m^2. In Kapurthala, 30.6% area was infested with *Rumex* with density of 8-12 plants/m^2 followed by 14.33% with 4-8 plants/m^2 and 12.54% with 12-16 plants/m^2. 34.92% of TGA in Jalandhar was infested with *Rumex* sp. density ranging from <4 to 16 plants/m^2 and 50.74% area in Shaheed

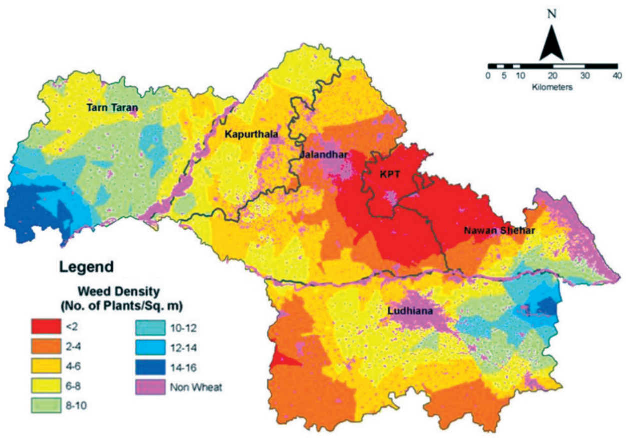

Fig 2 Spatial variability of *Polypogen monspeliensis* in Central zone of Punjab

Table 4 Extent of infestation by *Lepidium sativa* in wheat in different districts of Punjab (‘000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jalandhar	Nawan Shehar	Ludhiana
<10	30.87	36.4	17.96	58.21	205.77
10-20	153.49	65.69	16.52	5.59	52.51
20-30		3.9	0.3	0.12	2.94
30-40		1.59	0.1		
40-50		0.33	0.04		
50-60		0.02	0.01		
Total area (‘000 ha)	241.9	163.2	263.2	126.0	370.2

Table 5 Extent of infestation by *Rumex mextimis* in wheat across different districts of Punjab ('000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jalandhar	Nawan Shehar	Ludhiana
<4		0.04	8.93	46.86	112.48
4-8	2.18	23.4	11.78	17.07	123.19
8-12	55.49	49.98	12.85		26.43
12-16	59.85	20.48	1.36		
16-20	40.51	14.03			
20-24	25.41				
24-28	0.57				
Total area ('000 ha)	241.9	163.2	263.2	126.0	370.2

Bhagat Singh Nagar was infested with plant density of 4-8/m^2. In Ludhiana, a larger proportion of the TGA, i.e. 70.8% was found to be infested with this weed having density of 4 to 12 plants/m^2. So Tarn Taran and Ludhiana districts have largest infestation by *Rumex mexitimus* weed as compared to other districts.

62.32% of TGA in Tarn Taran district was found to be infested with 6-8 plants/m^2 and 64.69% of TGA in Kapurthala was observed to be infested with 2-6 plants of *Medicago denticulata*/m^2. In Jalandhar comparatively less area (13.27% of TGA) was infested with this weed as compared to other four districts (Fig 3).

Table 6 Extent of infestation by *Medicago denticulata* in wheat in different districts of Punjab ('000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jallandhar	Nawan Shehar	Ludhiana
<2		0.97	0.8	2.7	
2-4	5.07	53.09	12.62	60.52	49.21
4-6	28.21	52.48	17.6	0.7	100.97
6-8	150.74	1.39	3.91		70.67
8-10					36.72
10-12					4.52
Total area ('000 ha)	241.9	163.2	263.2	126.0	370.2

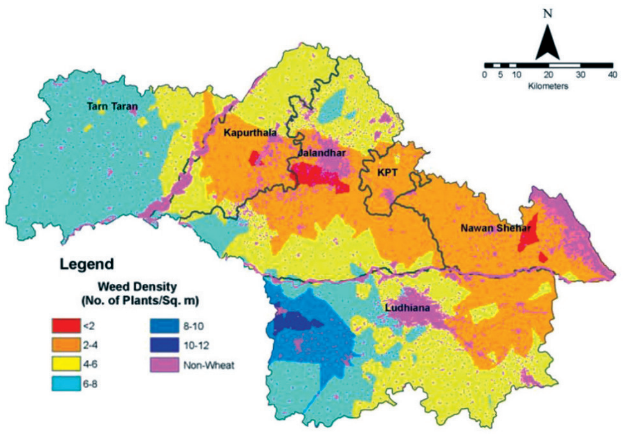

Fig 3 Spatial variability of *Medicago denticulata* in Central zone of Punjab

Table 7 Extent of infestation by *Malwa neglecta* in wheat across different districts of Punjab ('000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jallandhar	Nawan Shehar	Ludhiana
<2	55.78			1.12	34.03
2-4	118.02	19.03	7.04	46.01	80.87
4-6	9.87	58.86	10.47	16.79	70.98
6-8	0.35	29.3	11.47		76.2
8-10		0.99	5.78		0.03
10-12			0.17		
Total area ('000 ha)	241.9	163.2	263.2	126.0	370.2

In Shaheed Bhagat Singh Nagar 48.03% area was infested with 2-4 plants of *Medicago* sp./m^2 and in Ludhiana, 70.8% area was infested with 2 to 12 plants/m^2 with larger area (27.27%) having weed density of 4-6 plants/m^2 followed by 19.09% by 6-8 plants/m^2.

Malwa neglecta is becoming a problematic weed these days and in central zone of Punjab, it has spread every where. 71.85% of TGA was found to be infested with 2 to 4 plants of *Malwa neglecta*/m^2 in Tarn Taran district and 65.68% area in Kapurthala was observed having infestation of 2-8 plants of this weed m^2.

In Jalandhar, only 13.3% area was infested and in Shaheed Bhagat Singh Nagar 36.51% area was found to be infested with 2-4 plants/m^2. In Ludhiana this weed has spread over a larger area, i.e. 70.8% with plant density of 2 to 8 plants/m^2. Largest area (21.85%) of Ludhiana have 2-4 plants/m^2 followed by (20.58%) 6-8 plants/m^2.

76.08%, 66.13%, 13.27%, 50.73% and 70.8% area was found infested with *Melilotus alba* densities ranging from 2 to 12 plants/m^2 in Tarn Taran, Kapurthala, Jalandhar, Shaheed Bhagat Singh Nagar and Ludhiana, districts respectively. Largest area was infested with this weed in Tarn Taran district and Ludhiana district have larger area (60.39 thousand hectare) and highest density of 6-8 plants/m^2.

Site specific applications of herbicides offer a lot of potential for reducing the use of synthetic pesticides in agriculture. For corn, it has been estimated that pesticide

Table 8 Extent of infestation by *Melilotus alba* in wheat across different districts of Punjab ('000 ha)

Density (Plants/m^2)	Tarn Taran	Kapur-thala	Jallandhar	Nawan Shehar	Ludhiana
<2	63.48	18.06	14.37	44.68	79.86
2-4	120.4	88.59	11.9	19.24	92.45
4-6	0.15	1.22	8.26		28.53
6-8		0.05	0.39		60.39
8-10					0.77
10-12					0.08
>12					0.03
Total area ('000 ha)	241.9	163.2	263.2	126.0	370.2

savings in the order of 50% could be feasible. One of the main limitations for the adoption of precision herbicide application is the availability of quick and economical means of identifying weed patches. Fluorescence spectroscopy could be investigated as an efficient tool for weed-crop discrimination (Panneton *et al*. 2006).

Mapping techniques from the remote sensing domain are superior to conventional ground based methods of vegetation mapping (DeFries and Townshed 1994, Townshed *et al*. 1991). Information on temporal and spatial variation in weed seedling populations within agricultural fields is very important for weed population assessment and management. Primarily, spatial information allows a potential reduction in herbicide use, when post emergent herbicides are only applied to field sections with high weed infestation levels. In a two year study, herbicide use with map-based approach was reduced in winter cereals by 6-81% for herbicides against broad leaved weeds and 20-79% for grass weed herbicides. The efficacy of weed control varied from 85 to 98%, indicating that site specific weed management will not result in higher infestation levels in the crops under study (Gerhards and Oebel 2006). The results of Rodriguez-Moreno (2014) showed that if leaf analyses are complemented with a few additional measures, instantaneous and with a minimal cost, it is possible to deduce the diagnosis using statistical and spatial analysis in maize crop. It was observed that both weeds between rows and crop canopy had significant relationships with remotely sensed images. Weed stress should be taken into consideration when remotely sensed reflectance data from a field are used to predict crop growth and development. This weed mapping system had provided useful tool for the remote-sensing research project in collecting ground truth data, and it also has a potential to be used for precision agriculture (Sui *et al.* 2007).

From the above study it is concluded that weed prescription mapping study can be used for forecasting the weed infestations, on the basis of which farmers can be advised to take the preventive control measures which can help in preventing yield losses due to weeds. These weed maps can be used as an input in yield forecasting models.

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