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Research Paper

Effect of different densities of *Rumex spinosus* on growth and yield of wheat (*Triticum aestivum*) and spectral characteristics of *Rumex spinosus*

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ABSTRACT

A field experiment was conducted during the winter (*rabi)* seasons of 2012–13 and 2013–14 at Ludhiana, Punjab, to study the spectral characteristics of *Rumex spinosus* L. in wheat (*Triticum aestivum* L.) and to identify the optimum time for distinguishing *R. spinosus* from wheat crop. The treatments consisted of different density levels of *R. spinosus,* viz. 5, 10, 15, 20, 25 and 30 plants/m^2 and a sole population of *R. spinosus* and solid wheat stand. A decreasing trend in growth, yield-contributing characters and grain yield of wheat was observed with the increased population densities of *R. spinosus* from 5 to 30 plants/m^2*.* The highest grain yield (5.4 t/ha) was recorded in sole wheat crop and a weed density 30 plants/m^2 recorded the lowest grain yield (2.9 t/ha). The highest values of radiance ratio and normalized difference vegetation index (NDVI) were recorded in pure wheat crop and the least in sole *R. spinosus.* Solid stand of wheat crop can be distinguished from sole *R. spinosus* 30 days after sowing (DAS) and remain distinguished up to 120 DAS and but different density levels of *R. spinosus* can be discriminated amongst themselves from 60 DAS onwards.

***Key words** :* Grain yield, Growth, Remote sensing, *Rumex spinosus*, Wheat

Rumex spinosus L. (spiny emex, devil's thorn), is a problematic weed of wheat due to its spiny seeds which adversely affect harvest efficiency and crop quality. It is an annual broad-leaf weed of the Polygonaceae family. The weed is about 0.3–1.0 m tall, ascending with smooth ovate to nearly triangular 0.03 m large leaves and woody fruits, tipped with 3 sharp and hard spines which cling to grazing animals and automobile tyres and is, thereby, disseminated (Motooka *et al.* 2002). It also contaminates wheat grain and causes injury to livestock. Its control is difficult due to its fleshy tap-root system by which it completes its life-cycle by absorbing and storing moisture for its development and re-sprouting ability. It starts germinating in winter (November and December) and attains maturity in March or April before harvesting of wheat, barley, gram and lentil crops.

Remote-sensing techniques can serve as a better tool and will help in better management decisions by detection of different types of weed flora. With the help of remote-sensing techniques, fast and cost-effective mapping of weed densities can be done. Farmers usually apply herbicides on the entire field even if the field has some patches of weeds. In this way, unnecessary use of herbicides leads to environmental pollution along with higher cost of cultivation. This technology will help in site-specific detection of weeds and their management. Further site-specific weed management will help in reducing the herbicide use up to 11–90% without affecting crop yield (Gerhards and Christensen, 2003). As the reflectance of crops, weeds and soils differ in their wavelengths, there is potential for using reflection measurements at different wavelengths to distinguish between all of them. Keeping in view the importance of remote sensing in site-specific weed management, this experiment was planned with the objective to apply remote-sensing technology for the detection of *Rumex spinosus* in wheat crop and to study the spectral characteristics of *R. spinosus* in wheat and to find out the optimum time span for distinguishing *R. spinosus* from wheat, based on their relative spectral reflectance characteristics.

MATERIALS AND METHODS

The field experiment was conducted in the Department

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of Agronomy, Punjab Agricultural University, Ludhiana, which is situated in trans-gangetic agro-climatic zone, representing the Indo-Gangetic alluvial plains at 30° 56' N latitude, 75° 52' E longitude and an altitude of 247 m above mean sea-level. This tract has 4 distinct seasons, namely spring, summer, autumn and winter. The climate of this region is characterized as sub-tropical semi-arid with hot summer (18.9 to 33.8°C) and very cold winters (5.3 to 17.6°C). The mean maximum and minimum temperatures show considerable fluctuation during the summer and winter. The average annual rainfall is 705 mm, approximately 80% of which is received during July – September. The experiment was conducted during the winter (*rabi*) seasons of 2012–13 and 2013–14. The soil of the experimental field was loamy sand, normal in reaction (*p*H 7.3) and electrical conductivity (0.15 dS/m), low in organic carbon (0.39%) and available N (225.2 kg/ha) and very high in available P (17.1 kg/ha) and K (202.48 kg/ha). The experiment was laid out in randomized complete block design with 6 population levels of *Rumex spinosus,* viz. 5, 10, 15, 20, 25 and 30 plants/m^2, and 2 pure stands each of *R. spinosus* and wheat, replicated 4 times. The wheat variety 'PBW 550' was sown on 12 November, 2012 and 11 November 2013 using seed rate of 112.5 kg/ha. The recommended doses of fertilizers were applied (125 kg N/ha, 50 kg P_2O_5/ha and 30 kg K_2O/ha). The sources of NPK used was urea, diammonium phosphate and muriate of potash respectively. Half of the recommended dose of N and whole of P and K were applied at the time of sowing and remaining N was applied as top-dressing at the time of first irrigation. The field was charged/seeded with *R. spinosus* seeds as per the requirement of different weed density levels at the time of wheat sowing. The weed density was maintained with respect to the requirement of treatment on m^2 basis. The plot with sole *Rumex* sp., wheat sowing was not done, instead *Rumex* seed was sown. Solid wheat stand was kept weed-free throughout the season. Gap-filling of the weed plants was done to maintain proper weed density/m^2. No herbicide was used in the crop for weed-control purpose. The required weed density in respective treatments was maintained manually by thinning and gap-filling.

Spectral reflectance was recorded in 2 wave bands, i.e. red (625-689 nm) and infrared (760–897 nm), at monthly intervals till harvesting with the help of hand-held ground truth spectro-radiometer. Pure white films are good reflectors of light, so values of reflectance from a white plane were also recorded. Per cent reflectance by crop in the red band (625–689 nm) of spectrum was calculated at different growth stages of the crop using following vegetation indices:

Different spectral indices using per cent canopy reflectance

Sr No.	Vegetation indices	Abbreviations	Formula	References
1	Normalized difference vegetation index	NDVI	IR-R/IR+R	Rouse *et al.* (1974)
2	Radiance Ratio	RR	IR/R	Jordan (1969)

The data were statistically analyzed using F-test as per the procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at P=0.05 were used to determine the significant of difference between treatment means.

RESULTS AND DISCUSSION

Remote-sensing parameters

From 30 to 90 days after sowing (DAS), a decrease in red reflectance was recorded in all treatments, thereafter, a sharp increase was observed in all treatments (Fig. 1), this might be because of increased chlorophyll index from 30 DAS up to 90 DAS. Least reflectance was observed in sole *R. spinosus* compared to rest of the treatments. On the other hand, reverse trend was noticed in IR reflectance values (Fig. 2), as it decreased sharply 90 DAS. As the crop growth advanced, IR value increased in all the treatments. The infra red light (IR) has a positive relation with the plant vigour and chlorophyll content. The IR reflectance of wheat ranged between 20 and 60% in *R. spinosus* from 30 to 90 DAS. Due to more scattering of infra-red light in the leaves, there was a sharp decrease in IR reflectance values at 90 DAS. Results are in line with Chang *et al.* (2005), in which they reported the decreased reflectance in IR due to wilting. As radiation of NIR wavelengths enters the mesophyll layer of leaf, multiple reflections and refractions occur inside the hydrated plant cells and the air pockets that separate them. Chang *et al*. (2004) reported that the lowest reflectance was recorded in soil followed by weed-free and the highest reflectance in

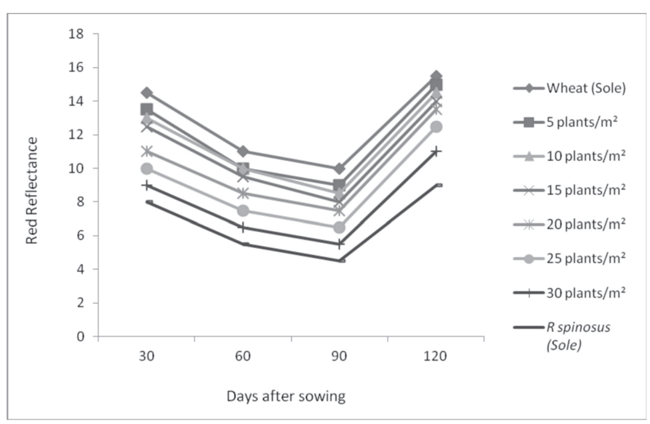

Fig. 1. Red reflectance of wheat crop under different population levels of *Rumex spinosus*

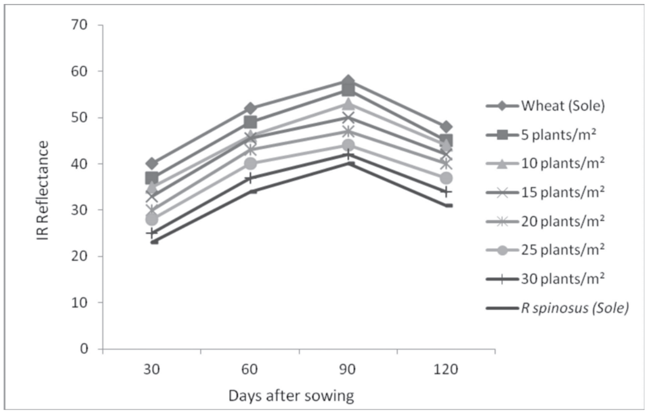

Fig. 2. Infra red light (IR) reflectance of wheat under different population levels of *Rumex spinosus*

weed-infested areas. Increased reflectance from weed-infested areas was most likely due to increased biomass and canopy cover. The different values of radiance ratio between wheat and sole *R. spinosus* were mainly due to difference in colour of leaves, more leaf-area index (LAI) and dry matter of wheat as compared to sole *R. spinosus*. Decrease in red reflectance with increasing population of *R. spinosus* might be due to chlorophyll absorption and increased chlorophyll index was due to less absorption of red light by the crop leaves as the crop advanced towards maturity.

Pure weed population recorded the minimum red reflectance compared to the pure wheat and other weed population levels. The spectral reflectance of a vegetation canopy will differ from the reflectance of individual plant leaves due to variations in the leaf area and orientation, illumination angle, shadows, background surfaces such as soil and the presence of multiple leaf layers (Colwell, 1974). With the dense crop canopy from 60 DAS till 90 DAS, there was increase in radiance ratio (Fig. 3) and later on its value decreased as the leaves senescence. The RR values obtained were the highest at 90 DAS in all the treatments followed by sharp decline. Higher radiance ratio was recorded in sole wheat treatment than the other treatments at all the growth stages due to better crop vigour, and the least radiance ratio was recorded in sole *R. spinosus*. The different values of RR between wheat and sole *R. spinosus* were mainly due to difference in colour of leaves, more LAI and dry matter of wheat crop compared to sole *R. spinosus*. The data on RR showed that in case of *R. spinosus,* it cannot be distinguished at 30 DAS, but later on as the age advanced, different densities of *R. spinosus* can be discriminated amongst themselves from 60 days onwards. Kaur *et al.* (2015 and 2016), who reported that correlation between different plant parameters and vegetation indices were best at 75–105 days after sowing in wheat and rice.

The NDVI values calculated for the different treatments having variable population of *R. spinosus* are presented in Fig 4. The NDVI increased as the crop advanced in age and reached the maximum at 90 DAS and later on sharp decline was recorded. This reduction in NDVI was because of decrease in absorption of light in the red region owing to cell degeneration and decrease in LAI. Higher values of NDVI significantly described the good crop growth and development (Sultana *et al.,* 2014). The highest NDVI values were observed in pure wheat and the different levels of *R. spinosus* population can be easily distinguished from pure wheat crop at 30 DAS (Fig. 4). It was observed that by using RR and NDVI, pure wheat can be distinguished from pure *R spinosus* population levels at 30 DAS and different weed population levels of *R. spinosus* can be discriminated amongst themselves from 60 DAS. Similar results were reported by Kaur *et al.* (2014) for *Rumex spinosus*. Dark green colour and better growth of wheat as compared to *R. spinosus* contributed towards higher value of RR and NDVI under sole wheat and lowest under sole *R. spinosus*.

Effect on growth attributes

The plant height was at par with *R. spinosus* having 5

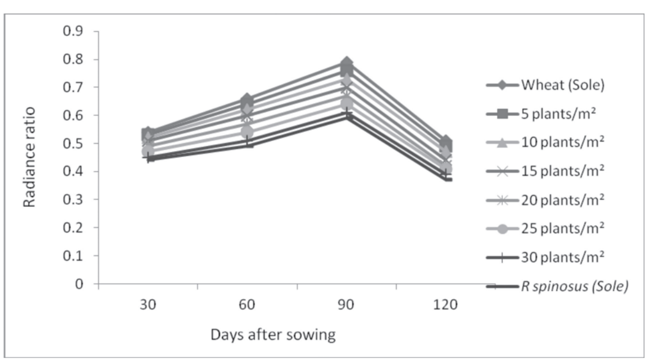

Fig. 3. Radiance ratio of wheat crop under different densities of *Rumex spinosus*

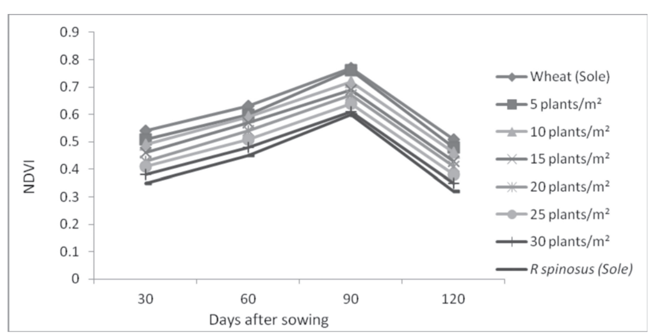

Fig. 4. Normalized difference vegetation index (NDVI) of wheat crop under different population densities of *Rumex spinosus*

plants/m^2 with sole wheat (Table 1). Significantly higher dry-matter accumulation was recorded in solid wheat stand compared to all *R. spinosus* density levels. With the increase in population density of *R. spinosus* beyond 10 plants/m^2, significant reduction in plant height and LAI was observed. The PAR interception increased significantly with the increase in *Rumex* population compared to sole wheat crop. This might be due to broad leafy nature of the *Rumex* sp. Data recorded on PAR interception showed that higher the density of *R. spinosus*/m^2, more was the PAR interception. However, reverse trend was observed in chlorophyll index (Table 1). There was a significant reduction in chlorophyll content with the increased population densities of *R. spinosus* from 10 to 30 plants/m^2. Significant reduction in tillers/m^2 was recorded with the increase in density of *R. spinosus.* Similarly, effective tillers population was significantly reduced due to presence of weeds which compete with the crop for almost all the growth factors. A reduction of 12.94% in effective tillers population was noticed between solid wheat stand and *Rumex* population of 30 plants/m^2.

Yield attributes and grain yield

Solid wheat recorded the highest ear length (11.3 cm) which was significantly more than rest of the treatments due to no crop-weed competition. Minimum ear length of 7.1cm was recorded in population of 30 plants/m^2 of *R. spinosus*. This might be due to more competition by the weeds for different growth factors. Significantly higher number of grains/ear was recorded in sole wheat (43.1) than rest of the treatments. Least number of grains/ear was recorded in *R. spinosus* having 30 plants/m^2. The reduction in number of grains/ear was in the range of 5.0 to 18.6% under different weed population densities (Table 2). This might be due to shading effect of *R. spinosus* as well as severe competition posed by weed to the crop for light, space, nutrients, water etc. A decrease in 1,000-grain weight of the crop was recorded, as weed density increased from 5 to 30 plants/m^2. This might be due to severe crop-weed competition. Maximum 1,000-grain weight was recorded in sole wheat (40.9 g) and it was significantly higher than rest of weed densities. Higher grain weight observed in solid wheat stand might be due to

Table 1. Growth parameters of wheat under different *Rumex spinosus* densities (pooled data of 2 years)

Treatment	Plant height (cm)	LAI	Dry-matter accumulation (g/m^2)	PAR interception (%)	Chlorophyll index	Effective tillers/ m^2
		At harvest		90 DAS		
Wheat (solid stand)	95.9	3.65	1190.2	77.2	47.5	559.6
5 plants/m^2 of *Rumex spinosus*	94.1	3.37	1097.9	77.4	46.1	543.3
10 plants/m^2 of *Rumex spinosus*	93.1	3.21	995.5	77.6	45.2	536.5
15 plants/m^2 of *Rumex spinosus*	92.4	3.09	938.6	78.0	44.2	529.3
20 plants/m^2 of *Rumex spinosus*	91.8	2.92	888.2	78.2	43.3	519.3
25 plants/m^2 of *Rumex spinosus*	90.1	2.78	842.9	78.6	41.6	507.8
30 plants/m^2 of *Rumex spinosus*	87.9	2.65	794.9	78.9	40.9	487.2
Rumex spinosus (sole)	0	0	0	0	0	0
SEm±	0.5	0.08	19.1	0.1	0.5	5.5
CD (P=0.05)	1.7	0.25	56.3	0.2	1.3	16.0

Table 2. Effect of different densities of *Rumex spinosus* on yield-contributing characters, grain and straw yield of wheat (pooled data of 2 years)

Treatment	Ear-length (cm)	Grains/ear (No.)	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Wheat (solid stand)	11.3	43.1	40.9	5.4	7.3
5 plants/m^2 of *Rumex spinosus*	10.7	40.9	39.3	5.1	6.8
10 plants/m^2 of *Rumex spinosus*	9.9	39.8	39.3	4.8	6.5
15 plants/m^2 of *Rumex spinosus*	9.2	38.8	38.0	4.2	5.8
20 plants/m^2 of *Rumex spinosus*	8.4	37.9	36.6	3.8	5.3
25 plants/m^2 of *Rumex spinosus*	7.7	36.6	35.4	3.2	4.9
30 plants/m^2 of *Rumex spinosus*	7.1	35.0	34.1	2.9	4.4
Rumex spinosus (sole)	0	0	0	0	0
SEm±	0.3	0.6	0.3	0.1	0.1
CD (P=0.05)	0.8	2.1	0.9	0.3	0.3

Table 3. Growth parameters of *Rumex spinosus* under its varying population densities (pooled data of 2 years)

Treatment	Plant	Leaf-area index				Dry-matter accumulation (g/m^2)				
	height (cm)	30 DAS	60 DAS	90 DAS	At Maturity	30 DAS	60 DAS	90 DAS	120 DAS	At Maturity
Wheat (solid stand)	0	0	0	0	0	0	0	0	0	0
5 plants/m^2 of *Rumex spinosus*	42.0	0.85	1.84	2.24	2.72	34.2	72.8	77.3	84.8	88.6
10 plants/m^2 of *Rumex spinosus*	43.2	0.87	1.91	2.35	2.83	38.7	81.4	83.9	88.3	91.8
15 plants/m^2 of *Rumex spinosus*	45.3	0.92	1.99	2.55	3.02	43.6	84.2	90.7	95.3	99.4
20 plants/m^2 of *Rumex spinosus*	46.7	0.99	2.09	2.69	3.10	55.4	92.9	97.1	102.8	106.3
25 plants/m^2 of *Rumex spinosus*	50.4	1.06	2.19	2.82	3.26	63.6	100.1	105.9	114.5	116.6
30 plants/m^2 of *Rumex spinosus*	53.1	1.13	2.28	2.84	3.37	76.8	110.2	117.9	123.4	127.3
R spinosus (sole)	57.2	1.27	2.42	3.02	3.48	86.8	122.7	128.9	137.0	138.8
SEm±	1.3	0.024	0.09	0.13	0.07	1.1	1.9	1.8	2.5	1.7
CD (P=0.05)	3.9	0.07	0.24	0.35	0.22	3.0	5.4	4.9	6.9	

higher translocation of photosynthates, as there was no weed competition imposed. The presence of 30 plants of *R. spinosus*/m^2 resulted in 16.5% reduction in 1000-grain weight, compared to sole wheat (Table 2).

With the increase in infestation of *R. spinosus* from 0 to 30 plants/m^2, a significant decrease in grain yield of wheat was observed at each population level of *R. spinosus* (Table 2). Significantly higher grain yield (5.4 t/ha) was observed in solid wheat, which was significantly higher than rest of the treatments. The presence of 5, 10, 15, 20, 25 and 30 plants of *R. spinosus*/m^2 recorded a reduction of 6.8, 12.0, 21.7, 30.3, 41.3 and 46.6% in grain yield, respectively, as compared to solid wheat crop (Table 2). Walia *et al.* (2001) also reported reduction of grain yield to an extent of 30 to 40% under different weed infestations as compared to weed-free treatment.

As the population of *R. spinosus* increased from 10 plants/m^2 onwards, there was significant reduction in plant height and LAI, chlorophyll content, tillers/m^2, effective tillers due to presence of weeds which compete with the crop for almost all the growth factors. Significant reduction in yield and yield attributes might be due to reduction in growth attributes due to presence of *R. spinosus*.

Correlation and regression

Regression analysis indicated that there was significant negative linear relationship between grain yield and weed biomass at harvesting. In regression analysis, the equations $Y = -0.6429x+6.5679$ (Fig. 5) were found to be fit for the wheat grain yield and dry-matter accumulation by *R. spinosus* where Y is grain yield and X is weed dry matter. Correlation between grain yield and weed dry matter at harvest was $R^2 = 0.8307$ (Fig. 5).

It can be concluded that it is possible to discriminate pure wheat stand from the area infested with *R. spinosus* just 30 days after sowing (DAS). But lower population level of *R. spinosus*, like 5 plants/m^2 cannot be distinguished from pure wheat stand even after 60 DAS. The NDVI and radiance ratio (RR) proved the most reliable remote sensing indices to distinguish higher population levels of *R. spinosus* in wheat.

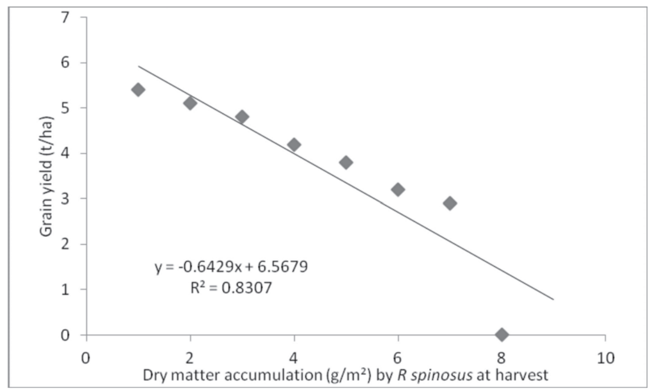

Fig. 5. Effect of dry matter accumulation of *Rumex spinosus* on wheat grain yield at harvesting

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