INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
20–0219/202x/00–0–000–000
DOI: 10.17957/IJAB/15.1547
http://www.fspublishers.org

Full Length Article

Weed Management in Direct-Seeded Fine Rice Using Allelopathic Crop Residue Mulches and Nitrogen for Sustained Yields in Pakistan

Safdar Hussain[1,2], Sardar Alam Cheema[1*], Muhammad Sanaullah[3] and Muhammad Farooq[1,4]
[1]*Department of Agronomy, Faculty of Agriculture, University of Agriculture, Faisalabad-38040, Pakistan*
[2]*Agriculture Extension Department, Punjab-Pakistan*
[3]*Institute of Soil and Environmental Sciences, Faculty of Agriculture, University of Agriculture, Faisalabad-38040, Pakistan*
[4]*Department of Plant Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Al-Khoud 123, Oman*
[*]For correspondence: sardaralam35@gmail.com
Received 10 February 2020; Accepted 06 June 2020; Published ________________

Abstract

Direct seeding of rice is a new method of rice production; however, weeds pose serious threat to its productivity. Using residues of allelopathic crops as mulches on soil surface along with appropriate nitrogen (N) application may become an environmental friendly and sustainable way to manage weeds. This two-year field study was conducted to explore the impact of mulching with residues of three allelopathic crops (wheat, rice and sorghum) and three N sources (urea, calcium ammonium nitrate (CAN) and ammonium sulphate (AMS) on weeds and productivity of direct-seeded fine rice. Treatments with plastic mulch and no mulch were established as controls. Results showed that all mulches significantly ($P \leq 0.05$) influenced the density and dry biomass of broad leaf weeds (BLWs), narrow leaf weeds (NLWs) and sedges. Maximum suppression of density (90.8, 87.9, and 85.5% of BLWs, NLWs and sedges, respectively) and dry biomass (92.2, 88.0, and 90.5% of BLWs, NLWs and sedges, respectively) of weeds was noticed with plastic mulch over control. Amongst allelopathic crop residue mulches, maximum suppression of the density (69.5, 57.7 and 61.3% of BLWs, NLWs and sedges, respectively) and dry biomass (71.6, 55.8 and 53.2% of BLWs, NLWs and sedges, respectively) was observed with wheat mulch over control. Nitrogen application overall increased the growth of weeds in terms of its dry biomass, compared with the control. However, wheat mulch with all N sources substantially reduced the density of BLWs at 75 DAS during the year 2014 and dry biomass of all kind of weeds at 60 and 75 DAS of rice in both the years over control. Significant negative correlation of density and dry biomass of all weeds was observed with water soluble phenolics in the soil indicating strong influence of allelopathic mulches on weeds. Maximum paddy yield improvement (30.2%) was observed with the plastic mulch; however, amongst the crop residue mulches, maximum improvement (25.6%) of paddy yield was observed with wheat mulch over control. Overall, allelopathic crop residue mulches, especially wheat mulch, in association with N fertilizers suppressed weeds and improved paddy yield by improving competitiveness of crop plants against weeds and therefore may be used to manage weeds and sustain productivity of rice.

Keywords: Direct seeded rice; Weed suppression; Allelochemicals; Nitrogen sources; Paddy yield

Introduction

Rice (*Oryza Sativa* L.) is the leading dietary cereal of half of the world's population (IRRI, Africa Rice and CIAT 2010; Chauhan and Johnson 2011; Awika 2011). Likewise, it is also an important cereal crop of Pakistan with the production estimates of 6.85 million tons, covering an area ~2.72 million hectares (GOP 2016–2017). It occupies the vital place in agriculture centred economy of Pakistan and is 2nd leading agricultural trade commodity of the country (GOP 2016–2017). In recent two decades, rice growing farmers of Asia are turning from the traditional transplanting (anaerobic rice culture) system to direct seeding (aerobic rice culture) system of rice cultivation, as this system of aerobic-rice culture has favoured tremendous economic and technological opportunities to the farmers (Chauhan and Johnson 2011). In aerobic rice system, dry seed is directly seeded into a well-prepared pulverized soil after tillage or under zero tillage condition of soil (Rao *et al*. 2007; Farooq *et al*. 2011). Despite of its benefits, high infestation of weeds is a major issue due to simultaneous germination/ emergence of weeds with rice and absence of standing water during early growth stage of crop to subdue weed germination and growth (Chauhan and Johnson 2010; Farooq *et al*. 2013). Almost 85–98% yield reductions are expected to occur due to un-controlled weeds found in

To cite this paper: Hussain S, SA Cheema, M Sanaullah, M Farooq (202x). Weed management in direct-seeded fine rice using allelopathic crop residue mulches and nitrogen for sustained yields in Pakistan. *Intl J Agric Biol* 00:000–000

direct-seeded rice culture (Chauhan and Johnson 2011; Singh *et al*. 2011). However, productivity of direct-seeded rice may be improved on sustained basis by overcoming weed infestation.

Although, herbicides against weeds are available, their widespread application has several negative effects on the surrounding environments and human health. Therefore, investigations are turning to the safe, efficient, cost effective, ecofriendly and practicable alternate approaches. In this respect, exploitation of allelopathic phenomenon of plants is gaining great emphasis for natural weed management in cropping systems (Jabran *et al*. 2015; Nawaz *et al*. 2015). Allelopathic plants release diverse kind of secondary metabolites (allelochemicals) which helps to suppress weeds. In addition, capability of crops to compete weeds may be improved by providing favorable environment to crop plants by adopting different cultural practices for reduction of weed stress (Pester *et al*. 1999; Buhler 2002). Cultural practices which reduce weed stress and favor crops in weed crop competition may include higher seed rates, thin spacing between crop plants, use of higher rates of mineral fertilizers (fertilizer managements) and crop residue managements with in the soil (Buhler and Gunsolus 1996; Buhler 2002). These cultural practices may improve crop competitiveness against weeds and shrink the reproductive capability of weeds (Buhler 2002).

Applying residues/mulches (covering the soil surface) of allelopathic crops is an easy, cost effective and environment friendly practice which has numerous positive impacts on agro-ecosystem and productivity (Galinato *et al.* 2011; Qin *et al.* 2015; Farooq *et al*. 2017). The apparent mechanisms through which crop residues mulches would suppress weeds in rice and other crops may include physical suppression, sunlight blockage, and release of allelochemicals on decomposition (Hong *et al*. 2004; Batish *et al*. 2007). Likewise, employment of crop fertilization especially N may also be a promising approach in integrated weed management to shrink weed infestation and increasing competitiveness of crops against weeds (DiTomaso 1995; Buhler 2002; Blackshaw and Brandt 2008). Nitrogen is a key nutrient which regulates growth and development of plants and plays significant role in the competitive balance between weeds and crops (DiTomaso 1995; Raun and Johnson 1999). Mostly, inorganic, or organic forms of N sources applied to the soil are converted to nitrate by the process of nitrification (McLeod 1998).

Despite of several benefits, application of crop residues as mulch may cause nutrient deficiency during early crop growth stages due to immobilization of nutrients (Gentile *et al.* 2008). However, timely crop fertilization may help overcome this issue (Hejazi *et al*. 2010). Mineral nutrient applications especially N may favor crop plants against weeds during crop-weed competition (DiTomaso 1995; Cathcart *et al*. 2004). Nitrogen application at the time of residue incorporation may improve residue degradation and reduces N immobilization. Nitrogen application has got influential role over weed competition in cultural weed management and may continuously be designed for improved uptake of nutrients by crops compared with the weeds present in field (DiTomaso 1995; Harbur and Owen 2004). Since, the majority of annual weed plants emerge from top of the pulverized soil, mineral nutrients broadcasted on top of the soil surface may offer the weeds equal chances to utilize and uptake the nutrients applied on soil together with the crop plants in field conditions (Melander *et al*. 2005). Weed plants may also become less responsive to N applications at early stages of growth of crops compared with later applications (Blackshaw *et al*. 2004).

Research information accessible on the combined use of N fertilizers and crop residues used as mulches for management of weeds in direct seeded rice is limited. We assumed that cultural weed management in aerobic rice can increase and sustain the yield of direct seeded rice using N fertilizers in combination with the allelopathic crop residue mulches. Thus, objective of the study was to explore the impact of mulching with residues of allelopathic crops and N fertilization on weed management and productivity of direct-seeded fine rice.

Materials and Methods

Site and climate

This two-year field trial was conducted at Agronomic Experimental and Research Farm, Department of Agronomy, University of Agriculture, Faisalabad-Pakistan (Longitude 73.8°E, Latitude 31.8°N, and Altitude 184.4 m above sea level). Location of the experimental farm comes under climatic conditions of sub-tropics, having average temperature variables of 26°C to 40°C in summer season, and 6°C to 21°C in winter season. The average annual rainfall is around 300 mm and most of the rains (Monsoon) occur during the months of July and August. The climatic variables like temperature, rainfall, relative humidity, and sunshine hours during the whole experimental period are given in Table 1.

Planting material and crop residues for mulching

Seed of rice cultivar "Super Basmati" was obtained from the Punjab Seed Corporation, Faisalabad, Pakistan. Residues three allelopathic crops *i.e*., wheat, sorghum and rice were obtained from the experimental farm. Dry crop residues were chopped into pieces of 2–3 cm by a fodder cutter and were used as mulching material at the rate of 4 tons ha^{-1}.

Experimental design and treatments

Experiment was conducted under randomized complete block design (RCBD) with factorial arrangement of treatments having 3 replications. The net plot size was 6 m

Table 1: Weather data at the experimental site during the experimental period

	Rainfall (mm)	Relative humidity (%)	Temperature (ºC)			
			Monthly maximum	Monthly minimum	Monthly Mean	Sunshine (h)
Year 2014						
June	07.1	33.5	40.9	28.1	34.5	09.38
July	57.5	53.9	37.0	28.0	32.5	09.00
August	4.8	52.7	37.1	27.3	32.2	09.10
September	140.2	61.2	33.9	24.5	29.2	07.70
October	03.6	54.6	31.3	19.1	25.2	07.80
November	10.0	61.7	26.3	11.5	18.9	07.60
Year 2015						
June	11.6	39.0	38.0	25.6	31.8	09.38
July	128.0	61.1	34.9	27.0	31.0	05.10
August	48.4	60.4	35.9	26.7	31.3	07.00
September	75.2	51.6	35.4	24.4	29.9	08.20
October	14.5	52.9	32.2	19.1	25.4	07.50
November	08.8	61.5	27.1	12.1	19.6	06.60

*Values of rainfall are the total rainfall received during that month; Values of mean relative humidity, temperature, and sunshine are the monthly averages; Monthly maximum and monthly minimum are the highest and lowest temperature values observed during that month at any day

× 3 m. Three sources of N [urea, ammonium sulphate (AMS) and calcium ammonium nitrate (CAN)] were applied at the rate of 125 kg ha^{-1} alone or in combination with different crop residue mulches (sorghum, rice and wheat residues) applied at the rate of 4 tons ha^{-1} as experimental treatments. Black polyethylene sheet was spread in between rows as a control treatment for mulches. Another control treatment (no N and no mulch) was also maintained to compare the treatment means.

Land preparation, crop husbandry and harvesting

Rice seeds were directly drilled with a hand drill in 22.5 cm apart rows using seed rate of 50 kg ha^{-1} in a well pulverized fine seedbed. Field was irrigated as per requirements without maintaining the flooded water conditions in field. About 15 irrigations were applied from seeding to crop maturity in each of the experimental year. Mineral fertilizers were used at the rate of 125:90:0 kg N: P: K ha^{-1} using urea (46% N), CAN (26% N), AMS (21% N), and single super phosphate (SSP) (18% P_2O_5). The entire amount of phosphorous was applied at sowing of crop; however, N was applied in two splits i.e. one split at 20 days after sowing and 2nd split at panicle initiation stage of crop. Carbufuran (Furadan 3G) and chlorpyriphos were used at the rate of 25 kg ha^{-1} and 2.5 L ha^{-1}, respectively, after 50 days of direct seeding of the crop to manage rice borer and leaf folder. Crop was harvested on November 10 and 8 during 2014 and 2015, respectively. Crop was harvested manually, sundried and threshed for recording the yield data following Jabran *et al*. (2015).

Total water/soil soluble phenolics

Soil samples were taken from three different places of each treatment plot using an auger and were composited for analysis of water soluble phenolics. For analysis, chemical reagents like Na_2CO_3 (solution) 20% (w/v), vanillic acid (100 μg mL^{-1}) and a folin-ciocalteaue reagent were used. Soil was extracted using distilled water to have an extract having the water soluble phenolics. The reagents were mixed in extract using procedure prescribed by the Box (1983) and absorbance of samples was recorded at 760 nm using a spectrophotometer. Working solutions (0, 2, 4, 6, 8 and 10 ppm) of vanillic acid were prepared as standard and concentration of phenolics were determined as equivalents of vanillic acid (μg vanillic acid equivalents g^{-1} soil).

Weed parameters

Data on weed density and dry biomass was recorded at 45, 60 and 75 days after sowing (DAS) of rice from four quadrants (0.5 m × 0.5 m) in each treatment plot. Density of each kind of weeds was counted and then weeds were cut from the surface of soil to record the dry biomass (g m^{-2}) of the individual weeds after drying weeds in oven at 105°C.

Data analysis

Data collected was statistically analysed following two-way ANOVA using the software (computer Statistics 8.1) (Statistics; Analytical software; Tallahaassee, F.L., U.S.A., 1985–2003). Treatment means were compared using least significance difference (LSD) test at probability level of 5.0% (Steel *et al*. 1997).

Results

Weed dynamics

The predominant population of weeds at the experimental site consisted mainly of *Trianthema portulacastrum* (horse purslane; a broad leaf weed), *Dactyloctenium aegyptium* (Crow foot grass; a narrow leaf weed), *Echinochloa crusgalli* (barnyard grass; a narrow leaf weed) and *Cyperus rotundus* (purple nutsedge; a sedge).

Results showed that all mulches affected the density and dry biomass of BLWs, NLWs, Sedges and TWs in

Table 2: Influence of mulches and nitrogen sources on density and dry weight of broad leaf weeds in rice

Treatments	Density of broad leaf weeds (m^{-2})						Dry weight of broad leaf weeds (g m^{-2})					
	45 DAS		60 DAS		75 DAS		45 DAS		60 DAS		75 DAS	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Mulches (M)												
Control	26.3A (-)	29.0A (-)	26.1A (-)	37.6A (-)	24.3A (-)	30.7A (-)	14.1A (-)	17.2A (-)	16.0A (-)	18.9A (-)	18.3A (-)	26.9A (-)
Plastic Mulch (PM)	2.3 D (90.1)	2.5E (91.4)	3.5E (86.6)	4.8E (87.2)	3.3E (86.4)	4.2E (86.3)	0.7D (95.0)	1.5E (91.3)	2.2E (86.3)	2.0E (89.4)	2.6E (85.8)	3.8E (85.9)
Sorghum Mulch (SM)	10.4B (60.5)	8.8C (70.0)	13.2C (49.4)	12.3C (67.3)	12.2C (50.0)	13.4B (56.3)	3.9B (72.3)	7.0C (59.3)	8.9C (44.4)	9.3C (50.8)	9.7C (47.0)	14.2B (47.2)
Rice Mulch (RM)	10.4B (60.5)	10.3B (64.5)	15.2B (41.7)	15.3B (59.3)	13.8B (43.2)	11.3C (63.2)	3.6C (74.4)	8.3B (51.7)	10.5B (34.4)	11.9B (37.0)	10.8B (41.0)	13.6C (49.4)
Wheat Mulch (WM)	8.9C (66.2)	7.9D (72.8)	9.8D (62.5)	10.7D (71.5)	8.2D (66.2)	8.4D (72.6)	3.5C (75.2)	5.5D (68.0)	6.8D (57.5)	7.5D (60.3)	7.2D (60.6)	8.5D (68.4)
LSD ($P \leq 0.05$)	*0.91*	*0.69*	*0.91*	*1.23*	*0.69*	*0.69*	*0.23*	*0.42*	*0.33*	*0.36*	*0.26*	*0.50*
N Sources (NS)												
Control	11.8	11.8	13.6	15.3	11.4B	12.5B	5.0C	7.1B	8.0B	8.8B	8.4C	11.8C
Urea	11.7	11.7	13.5	16.5	12.5A	13.8A	5.4A	8.2A	9.2A	10.4A	10.0B	13.7B
AMS	11.7	11.5	13.5	16.5	12.6A	14.3A	5.2AB	8.1A	9.1A	10.2A	10.1B	14.2A
CAN	11.5	11.7	13.6	16.3	12.9A	13.7A	5.1BC	8.2A	9.2A	10.3A	10.3A	13.8A
LSD ($P \leq 0.05$)	*Ns*	*ns*	*Ns*	*ns*	*0.61*	*0.62*	*0.21*	*0.38*	*0.29*	*0.33*	*0.23*	*0.44*
Interaction (M×NS)												
Control	26.3	29.0	26.7	37.0	21.7b	29.0	13.5	15.8	14.7	16.4b	15.5d	24.0b
M0 × Urea	25.7	29.0	25.3	37.7	24.7a	31.0	14.6	17.7	16.4	20.0a	19.5b	27.4a
M0 × AMS	26.7	28.7	25.7	38.0	25.3a	31.7	14.1	17.4	16.4	19.6a	18.0c	28.3a
M0 × CAN	26.7	29.3	26.7	37.7	25.7a	31.0	14.3	17.8	16.3	19.6a	20.1a	27.8a
PM × NS0	2.0	2.3	3.3	4.3	2.7g	3.3	0.6	1.4	1.9	1.8i	2.0n	3.4i
PM × Urea	2.7	2.7	4.0	4.7	3.3g	4.3	0.8	1.6	2.1	2.1i	2.6m	3.9i
PM × AMS	2.7	2.7	3.7	5.0	3.7g	4.7	0.8	1.5	2.2	2.1i	2.8m	3.9i
PM × CAN	2.0	2.3	3.0	5.0	3.7g	4.3	0.5	1.5	2.4	2.1i	2.9m	3.9i
SM × NS0	10.7	8.7	14.0	12.0	12.3de	12.7	3.8	6.1	7.8	7.9fg	9.6hi	12.4ef
SM × Urea	10.7	9.0	12.7	13.0	12.0e	13.7	4.1	7.5	9.1	9.8e	9.0i	15.0c
SM × AMS	10.3	8.7	12.3	12.0	12.0e	14.0	3.9	7.3	9.2	10.0e	9.9gh	14.9c
SM × CAN	10.0	8.7	13.7	12.3	12.3de	13.3	3.8	7.3	9.4	9.6e	10.4g	14.4c
RM × NS0	11.0	10.7	14.7	14.0	13.0cde	10.3	3.4	7.2	9.7	11.2d	9.4hi	12.0f
RM × Urea	10.7	10.3	15.7	15.3	14.3c	11.3	3.8	8.4	11.2	12.7c	10.9f	13.3de
RM × AMS	10.0	10.0	15.3	16.3	13.7cd	11.7	3.5	8.7	10.4	11.3d	11.7e	14.7c
RM × CAN	10.0	10.3	15.0	15.7	14.0c	11.7	3.6	8.8	10.6	12.4c	11.2f	14.2cd
WM × NS0	9.0	8.3	9.3	9.0	7.3f	7.3	3.5	5.0	5.8	6.7h	5.9l	7.3h
WM × Urea	9.0	7.7	10.0	11.7	8.3f	8.7	3.6	5.9	7.1	7.4gh	7.9j	8.9g
WM × AMS	9.0	7.7	10.3	11.3	8.3f	9.3	3.6	5.4	7.0	8.2f	8.0j	9.5g
WM × CAN	9.0	8.0	9.7	10.7	8.7f	8.3	3.5	5.6	7.2	7.6fg	7.1k	8.5g
LSD ($P \leq 0.05$)	*ns*	*ns*	*ns*	*ns*	*1.38*	*ns*	*ns*	*ns*	*ns*	*0.73*	*0.52*	*0.99*

Values of main effects and interaction sharing the same letter for a parameter during an experimental year, do not differ significantly ($P \leq 0.05$)
Control = plots with no mulch and no N application; NS= N sources; AMS= ammonium sulphate; CAN= calcium ammonium nitrate; NS0= no N; M0= no mulch; M= mulch type; PM= plastic mulch; SM= sorghum mulch; RM= rice mulch; WM= wheat mulch; DAS= days after sowing

direct seeded fine rice during both growing seasons. Maximum suppression of the density (90.8, 87.9, and 85.5%) and dry biomass (92.2, 88.0, and 90.5%) of all kind of weeds was noticed with plastic mulch over control (no mulch) (Table 2, 3, 4 and 5). Amongst the different allelopathic crop residue mulches, maximum suppression of density (average of two years) (69.5, 57.7 and 61.3%) and dry biomass (71.6, 55.8 and 53.2%) of BLWs, NLWs and sedges was observed with the wheat mulch over control; however, rice and sorghum mulch also caused substantial reductions of density and dry biomass of all kind of weeds during both growing seasons (Table 2, 3, 4 and 5). It was also observed that mulches suppressed weeds till last harvest of weeds at 75 DAS during both the years of experimentation.

Nitrogen sources appeared to have considerable effect on density and dry biomass of all kind of weeds (Table 2–5); however, interaction of N sources and mulches was found noteworthy only for dry biomass of TWs in both seasons of experimentation (Table 5). The density and dry biomass was found lesser with no N (control) compared with N application. Among the N sources, reduction of the dry biomass of total weeds was seen with the applications of CAN and urea during the year 2014 and 2015, respectively (Table 5).

Correlations between water soluble phenolics in soil and weeds

There was found a significant negative correlation between the water soluble phenolics in soil, density as well as dry biomass of weeds at critical period of competition during both the years of experimentation (Table 6). This strong and negative correlation suggests that the phenolics released in soil from the crop residue mulches have strong suppressive effects on the germination and growth of weeds in rice.

Table 3: Influence of mulches and nitrogen sources on density and dry weight of narrow leaf weeds in rice

Treatments	Density of narrow leaf weeds (m^{-2})						Dry weight of narrow leaf weeds (g m^{-2})					
	45 DAS		60 DAS		75 DAS		45 DAS		60 DAS		75 DAS	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Mulches (M)												
Control	24.5A (-)	16.7A (-)	24.3A (-)	27.9A (-)	22.4A (-)	27.9A (-)	7.7A (-)	7.1A (-)	10.8A (-)	10.4A (-)	18.1A (-)	15.3A (-)
Plastic Mulch (PM)	2.6E (89.4)	3.3E (80.2)	3.3D (86.4)	4.8E (82.8)	3.7D (83.4)	4.6E (83.5)	0.7D (90.9)	1.7E (76.1)	1.6E (85.2)	2.8D (73.1)	2.3E (87.3)	3.5E (77.1)
Sorghum Mulch (SM)	9.4C (61.6)	9.3C (44.3)	13.2C (45.6)	11.0D (60.6)	11.3B (49.6)	9.8C (65.9)	3.2C (58.4)	4.3C (39.4)	5.8D (46.3)	5.2C (50.0)	8.5C (53.0)	5.3D (65.4)
Rice Mulch (RM)	14.6B (40.4)	13.8B (17.4)	14.3B (41.2)	12.0C (56.9)	11.6B (48.2)	14.2B (49.1)	4.4B (42.8)	5.6B (21.1)	7.6B (29.6)	6.5B (37.5)	12.6B (30.4)	9.7B (36.6)
Wheat Mulch (WM)	8.4D (65.7)	8.4D (49.7)	15.2B (37.4)	13.8B (50.5)	8.8C (60.7)	7.6D (72.8)	2.9C (62.3)	3.6D (49.3)	6.9C (36.1)	6.9B (33.6)	7.0D (61.3)	5.8C (62.1)
LSD ($P \leq 0.05$)	*0.93*	*0.87*	*1.12*	*0.85*	*0.85*	*0.74*	*0.29*	*0.51*	*0.29*	*0.38*	*0.28*	*0.35*
N Sources (NS)												
Control	11.7	10.1	13.7	12.3B	11.7	12.0B	3.3B	3.8B	5.8B	5.5B	8.3C	6.7B
Urea	11.9	10.1	14.2	14.1A	11.7	13.1A	3.9A	4.6A	6.9A	6.8A	10.3A	8.3A
AMS	11.9	10.4	13.7	14.5A	11.1	13.2A	3.9A	4.7A	6.7A	6.6A	10.2AB	8.2A
CAN	12.1	10.6	14.5	14.6A	11.5	12.9A	3.9A	4.7A	6.8A	6.6A	9.9B	8.4A
LSD ($P \leq 0.05$)	*ns*	*ns*	*ns*	*0.76*	*ns*	*0.66*	*0.26*	*0.45*	*0.26*	*0.34*	*0.25*	*0.31*
Interaction (M × NS)												
Control	24.7	17.0	23.7	25.7	23.7	26.3	7.3	6.1	9.7c	9.4b	15.5c	13.1b
M0 × Urea	24.0	16.0	23.3	27.7	22.7	28.3	7.8	7.1	10.6b	11.2a	19.7a	15.6a
M0 × AMS	24.0	16.7	24.0	29.3	22.0	28.7	7.8	7.5	10.9b	10.6a	18.5b	16.1a
M0 × CAN	25.3	17.0	26.0	29.0	21.3	28.3	8.1	7.7	11.7a	10.6a	18.6b	16.2a
PM × NS0	2.7	3.3	3.3	3.7	4.0	4.0	0.6	1.4	1.4i	2.8h	2.0k	2.9i
PM × Urea	2.3	3.0	3.3	4.3	3.7	4.7	0.7	1.8	1.7i	2.9h	2.4k	3.5hi
PM × AMS	2.7	3.3	3.0	5.3	3.0	4.7	0.7	1.7	1.7i	2.8h	2.4k	3.5hi
PM × CAN	2.7	3.3	3.7	5.7	4.0	5.0	0.7	1.8	1.8i	2.8h	2.4k	3.9h
SM × NS0	9.3	9.0	13.0	9.3	10.7	9.3	2.7	3.7	4.9h	4.5g	7.4hi	4.1h
SM × Urea	9.7	9.0	14.3	11.3	11.0	10.0	3.5	4.5	6.3fg	5.7ef	8.7g	6.0ef
SM × AMS	9.3	9.3	12.3	11.3	11.0	10.0	3.3	4.4	6.0g	5.2fg	9.0g	5.5fg
SM × CAN	9.3	10.0	13.0	12.0	12.3	10.0	3.2	4.6	5.8g	5.5f	8.9g	5.7ef
RM × NS0	13.3	13.0	13.3	10.7	10.7	13.0	3.7	4.7	6.9ef	5.7f	10.9f	8.4d
RM × Urea	15.3	14.0	14.7	12.7	12.7	15.0	4.5	5.8	8.0d	6.9cd	13.1e	10.4c
RM × AMS	15.3	13.7	15.3	12.3	11.0	14.7	4.9	6.2	7.9d	7.0cd	13.9d	9.7c
RM × CAN	14.3	14.3	14.0	12.3	12.0	14.0	4.5	5.8	7.8d	6.5de	12.5e	10.4c
WM × NS0	8.3	8.0	15.3	12.3	9.7	7.3	2.3	3.0	6.0g	5.3fg	5.9j	4.9g
WM × Urea	8.0	8.3	15.3	14.7	8.7	7.7	3.2	3.8	7.8d	7.2cd	7.7h	6.0ef
WM × AMS	8.3	9.0	14.0	14.3	8.7	8.0	3.0	3.8	6.8ef	7.6c	7.1i	6.3e
WM × CAN	9.0	8.3	16.0	14.0	8.0	7.3	3.1	3.8	7.0e	7.5c	7.3hi	5.7ef
LSD ($P \leq 0.05$)	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*0.59*	*0.77*	*0.56*	*0.70*

Values of main effects and interaction sharing the same letter for a parameter during an experimental year, do not differ significantly ($P \leq 0.05$)
Control = plots with no mulch and no N application; NS= N sources; AMS= ammonium sulphate; CAN= calcium ammonium nitrate; NS0= no N; M0= no mulch; M= mulch type; PM= plastic mulch; SM= sorghum mulch; RM= rice mulch; WM= wheat mulch; DAS= days after sowing

Rice productivity

Results showed that yield of rice was improved by all the crop residue mulches and N sources over control (no mulch with no N); however, interaction of mulches and N sources was found insignificant during both years (Table 7). Plastic mulch resulted ~30.2% higher paddy yield compared with control in both growing seasons (Table 7). Allelopathic crop residue mulches also improved paddy yield over control. Amongst the allelopathic crop residue mulches, wheat mulch showed highest improvements of paddy yield (25.5%) followed by sorghum mulch which caused 23.5% improvement compared with control (Table 7). Application of N significantly improved the yield over control (no N). Amongst different N sources, AMS was found better in yield improvements (35.5%) during both the years followed by urea which exhibited about 32.8% yield improvement (Table 7).

Discussion

All mulches reduced the density and dry biomass of BLWs, NLWs, sedges and TWs in direct seeded fine rice (Table 2–5). Highest suppression of weeds was observed by the black plastic mulch (Table 2–5). The suppression of weeds by the black plastic mulch might be due to the restrictions in germination and development of weed seedlings due to the lack of light (shading effect) and increased soil temperature below the black plastic mulch (Diaz-Perez *et al*. 2012). Allelopathic mulches also suppressed weeds significantly (Jabran *et al*. 2016; Farooq *et al*. 2017). The suppressive effect of allelopathic mulches is either owing to the physical or chemical effects. Physical effects may include shade effects which can inhibit weed seed germination (Khaliq *et al*. 2011; Chauhan and Mahajan 2014). However, there seems more like a chemical effect of mulches, as they release

Table 4: Influence of mulches and nitrogen sources on density and dry weight of sedges in rice

Treatments	Density of Purple nutsedge (m^{-2})						Dry weight of Purple nutsedge (g m^{-2})					
	45 DAS		60 DAS		75 DAS		45 DAS		60 DAS		75 DAS	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
						Mulches (M)						
Control	-	-	9.1A (-)	6.8A (-)	10.6A (-)	11.3A (-)	-	-	3.9A (-)	3.8A (-)	9.7A (-)	6.5A (-)
Plastic Mulch (PM)	-	-	1.6D (82.4)	1.3E (80.9)	2.1E (80.1)	1.3E (88.5)	-	-	0.2D (94.8)	0.6E (84.2)	1.7E (82.4)	0.9E (86.2)
Sorghum Mulch (SM)	-	-	4.8B (47.2)	4.2C (38.2)	4.9C (53.8)	3.3D (70.8)	-	-	1.8B (53.8)	2.5C (34.2)	5.2C (46.4)	3.2C (50.7)
Rice Mulch (RM)	-	-	4.8B (47.2)	5.2B (23.5)	5.8B (45.2)	6.3B (44.2)	-	-	1.8B (53.8)	3.2B (15.8)	6.5B (33.0)	4.3B (33.8)
Wheat Mulch (WM)	-	-	3.3C (63.7)	2.8D (58.8)	3.5D (67.0)	4.4C (61.1)	-	-	1.6C (59.0)	2.0D (47.3)	4.2D (56.7)	2.4D (63.1)
LSD ($P \leq 0.05$)	-	-	*0.55*	*0.52*	*0.36*	*0.60*	-	-	*0.11*	*0.14*	*0.27*	*0.21*
						N Sources (NS)						
Control	-	-	4.9	4.1	5.1B	4.7B	-	-	1.6C	2.1B	4.8C	2.9C
Urea	-	-	4.8	4.1	5.6A	5.3A	-	-	2.0A	2.6A	5.6B	3.5B
AMS	-	-	4.7	3.9	5.4A	5.3A	-	-	1.9AB	2.5A	5.5B	3.7A
CAN	-	-	4.7	4.1	5.5A	5.8A	-	-	1.8B	2.5A	6.0A	3.8A
LSD ($P \leq 0.05$)	-	-	*ns*	*ns*	*0.32*	*0.54*	-	-	*0.10*	*0.13*	*0.24*	*0.18*
						Interaction (M × NS)						
Control			9.0	6.7	10.0	10.3	-	-	3.1b	3.3b	8.5c	5.4c
M0 × Urea	-	-	9.7	7.0	11.0	11.3	-	-	4.3a	4.0a	9.9b	6.3b
M0 × AMS	-	-	8.7	6.3	10.3	11.7	-	-	4.1a	4.2a	9.8b	7.3a
M0 × CAN	-	-	9.0	7.0	11.0	12.0	-	-	4.1a	3.9a	10.7a	7.0a
PM × NS0	-	-	1.7	1.3	2.0	1.0	-	-	0.1g	0.5h	1.7k	0.8i
PM × Urea	-	-	1.3	1.0	2.0	1.3	-	-	0.2g	0.5h	1.8k	1.0i
PM × AMS	-	-	1.7	1.3	2.3	1.3	-	-	0.2g	0.6h	1.8k	0.9i
PM × CAN	-	-	1.7	1.3	2.0	1.7	-	-	0.2g	0.6h	1.7k	1.1i
SM × NS0	-	-	5.0	4.0	4.7	2.7	-	-	1.7de	2.0f	4.4i	2.5g
SM × Urea	-	-	5.3	4.3	5.3	3.3	-	-	2.3c	2.9cd	5.3h	3.0f
SM × AMS	-	-	4.3	4.0	5.0	3.7	-	-	1.7de	2.2ef	5.2h	3.5e
SM × CAN	-	-	4.3	4.3	4.7	3.7	-	-	1.7de	2.8d	5.7gh	3.7e
RM × NS0	-	-	5.3	5.3	5.7	5.7	-	-	1.6de	3.1bc	5.9fg	3.8e
RM × Urea	-	-	4.7	5.3	6.0	6.3	-	-	1.7de	3.4b	6.6de	4.6d
RM × AMS	-	-	5.0	5.0	5.7	6.3	-	-	1.8d	3.3b	6.4ef	4.3d
RM × CAN	-	-	4.3	5.0	6.0	6.7	-	-	1.7de	3.1bc	7.1d	4.5d
WM × NS0	-	-	3.3	3.0	3.0	3.7	-	-	1.4f	1.7g	3.5j	1.9h
WM × Urea	-	-	3.0	2.7	3.7	4.3	-	-	1.5ef	2.1ef	4.4i	2.5g
WM × AMS	-	-	3.7	3.0	3.7	4.7	-	-	1.7de	2.1ef	4.2i	2.6g
WM × CAN	-	-	3.0	2.7	3.7	5.0	-	-	1.6de	2.3e	4.5i	2.7fg
LSD ($P \leq 0.05$)	-	-	*ns*	*ns*	*ns*	*Ns*	-	-	*0.23*	*0.29*	*0.55*	*0.42*

Values of main effects and interaction sharing the same letter for a parameter during an experimental year, do not differ significantly ($P \leq 0.05$)
Control = plots with no mulch and no N application; NS= N sources; AMS= ammonium sulphate; CAN= calcium ammonium nitrate; NS0= no N; M0= no mulch; M= mulch type; PM= plastic mulch; SM= sorghum mulch; RM= rice mulch; WM= wheat mulch; DAS= days after sowing

certain biochemicals (allelochemicals) on leaching with water during irrigation or on decomposition of the residues (Clark 2007; Liebman and Davis 2009; Ghahray *et al.* 2009). Released allelochemicals can inhibit the germination, growth and photosynthetic capacity of other plants and weeds (Alsadaawi *et al.* 2012; Chauhan and Mahajan 2014). This assumption is strengthened by significant negative correlations found between water soluble phenolics (a large group of allelochemicals) concentration present in soil samples and growth of weeds in this study (Table 6). A lot of field crops with allelopathic nature may enrich the root zone of the soil with allelochemicals, which can suppress the germinating weeds in field crops (Dmitrovic *et al.* 2014). Tabaglio *et al.* (2008) also documented that using the allelopathic plant residues both as mulch or incorporated suppress weeds in crop production systems. This kind of response of soil applied mulches of many plants like wheat, sorghum, rice and rye against weeds of rice has also been documented in several other studies (Ercoli *et al.* 2005; Gavazzi *et al.* 2010; Kato-Noguchi *et al.* 2010; Dmitrovic *et al.* 2014; Jabran *et al.* 2015).

Use of N as a management technique for weeds suppressions seems to have positive effect on rice crop enhancing the rice crop ability compared with the weeds and it may be attributed to the better uptake of N and other nutrients by the rice crop during the early growth stages of the direct seeded rice (Ditomaso 1995; Buhler 2002). However, increase of dry biomass of weeds with the application of N fertilizers was also observed and this may be ascribed to the increase in general competitiveness of weed plants in response to the better soil nutrients prominence especially N, where some of weeds present in crops might have become more active in exploiting the existing excessive soil N and other mineral nutrients (Buhler 2002; Blackshaw 2005).

Results also showed that application of mulches improved the yield of rice. Increase in yield with the use of plastic mulch may be attributed to better weed control with black plastic mulch, higher nutrients uptake and use efficiency (especially N) of plants and improved photosynthetic capability of crop plants during early growth stages of the crop (Diaz-Perez *et al.* 2012; Liang *et al.*

Table 5: Influence of mulches and nitrogen sources on density and dry weight of total weeds in rice

Treatments	Density of Total weeds (m^{-2})						Dry weight of Total weeds (g m^{-2})					
	45 DAS		60 DAS		75 DAS		45 DAS		60 DAS		75 DAS	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
						Mulches (M)						
Control	50.8A (-)	45.7A (-)	59.4A (-)	73.0A (-)	57.3A (-)	69.8A (-)	21.8A (-)	24.3A (-)	30.6A (-)	33.2A (-)	46.1A (-)	48.6A (-)
Plastic Mulch	4.9E	5.8E	8.4E	10.8D	9.1E	10.2E	1.3E	3.2E	3.9E	5.5E	6.6E	8.2E
(PM)	(90.4)	(87.3)	(85.8)	(85.2)	(84.1)	(85.4)	(94.0)	(86.8)	(87.2)	(83.4)	(85.6)	(83.1)
Sorghum Mulch	19.8C	18.1C	31.1C	27.5C	28.3C	26.6C	7.1C	11.3C	16.5C	17.1C	23.4C	22.7C
(SM)	(61.0)	(60.4)	(47.6)	(62.3)	(50.6)	(61.9)	(67.4)	(53.5)	(46.1)	(48.5)	(49.2)	(53.3)
Rice Mulch (RM)	25.0B	24.1B	34.4B	32.5B	31.2B	33.0B	8.0B	13.9B	19.9B	21.6B	29.9B	27.6B
	(50.7)	(47.2)	(42.1)	(55.5)	(45.5)	(52.7)	(63.3)	(42.8)	(34.9)	(34.9)	(35.1)	(43.2)
Wheat Mulch	17.3D	16.3D	28.0D	27.3C	20.4D	20.3D	6.4D	9.1D	15.2D	16.4D	18.4D	16.7D
(WM)	(65.9)	(64.3)	(52.8)	(62.6)	(64.4)	(70.9)	(70.6)	(62.5)	(50.3)	(50.6)	(60.0)	(65.6)
LSD ($P \leq 0.05$)	*1.24*	*0.96*	*1.48*	*1.41*	*1.20*	*1.47*	*0.33*	*0.66*	*0.43*	*0.61*	*0.47*	*0.58*
						N Sources (NS)						
Control	23.5	21.9	32.5	31.7B	28.2B	29.7B	8.3B	10.9B	15.4C	16.5B	21.6C	21.4C
Urea	23.5	21.8	32.4	34.7A	29.9A	32.4A	9.3A	12.8A	18.1A	19.8A	25.9A	25.5B
AMS	23.7	21.9	31.7	35.0A	29.1AB	33.1A	9.1A	12.8A	17.6B	19.3A	25.8A	26.2A
CAN	23.7	22.3	32.5	34.9A	29.9A	32.7A	9.0A	12.9A	17.8AB	19.4A	25.2B	25.9A
LSD ($P \leq 0.05$)	*ns*	*ns*	*ns*	*1.26*	*1.08*	*1.31*	*0.29*	*0.59*	*0.39*	*0.54*	*0.42*	*0.52*
						Interaction (M × NS)						
Control	51.0	46.0	59.3	69.3	55.3	66.3	20.8	21.9	27.6b	29.1b	39.5c	42.5c
M0 × Urea	49.7	45.0	58.3	72.3	58.3	70.3	22.4	24.9	31.3a	35.2a	49.1a	49.3b
M0 × AMS	50.7	45.3	58.3	73.7	57.7	71.7	21.9	24.9	31.4a	34.4a	46.3b	51.7a
M0 × CAN	52.0	46.3	61.7	73.7	58.0	71.0	22.3	25.4	32.2a	34.1a	49.4a	50.9a
PM × NS0	4.7	5.7	8.3	9.3	8.7	8.7	1.3	2.7	3.4 l	5.1i	5.7n	7.1k
PM × Urea	5.0	5.7	8.7	10.0	9.0	10.3	1.4	3.4	3.9kl	5.5i	6.8m	8.4j
PM × AMS	5.3	6.0	8.3	11.7	9.0	10.7	1.5	3.2	4.1kl	5.4i	7.0m	8.4j
PM × CAN	4.7	5.7	8.3	12.0	9.7	11.0	1.2	3.3	4.4kl	5.5i	7.0m	8.9j
SM × NS0	20.0	17.7	32.0	25.3	27.7	24.7	6.5	9.8	14.4i	14.4h	21.3i	19.1f
SM × Urea	20.3	18.0	32.3	28.7	28.3	27.0	7.6	12.0	17.7de	18.5f	23.0h	24.0e
SM × AMS	19.7	18.0	29.0	27.3	28.0	27.7	7.2	11.7	16.9ef	17.4fg	24.1g	23.9e
SM × CAN	19.3	18.7	31.0	28.7	29.3	27.0	7.0	11.9	16.8f	17.9f	25.0g	23.8e
RM × NS0	24.3	23.7	34.0	30.0	29.3	30.3	7.1	11.8	18.3d	21.27d	26.2f	24.2e
RM × Urea	26.0	24.3	35.0	33.3	33.0	33.7	8.3	14.3	21.0c	22.9c	30.5e	28.3d
RM × AMS	25.3	23.7	35.7	33.7	30.3	34.3	8.5	14.9	20.1c	21.5d	32.0d	28.7d
RM × CAN	24.3	24.7	33.0	33.0	32.0	33.7	8.1	14.7	20.1c	22.0cd	30.8e	29.1d
WM × NS0	17.3	16.3	28.7	24.3	20.0	18.3	5.7	8.0	13.3j	20.0e	15.3 l	14.2i
WM × Urea	16.7	16.0	27.7	29.0	20.7	20.7	6.8	9.7	16.4fg	16.6g	20.0j	17.4gh
WM × AMS	17.3	16.7	27.3	28.7	20.7	21.3	6.6	9.2	15.5h	17.9f	19.3jk	18.4fg
WM × CAN	18.0	16.3	28.3	27.3	20.3	20.7	6.6	9.4	15.7gh	17.4fg	18.9ik	16.9h
LSD ($P \leq 0.05$)	*ns*	*ns*	*ns*	*ns*	*ns*	*Ns*	*ns*	*ns*	*0.87*	*1.22*	*0.94*	*1.16*

Values of main effects and interaction sharing the same letter for a parameter during an experimental year, do not differ significantly ($P \leq 0.05$)
Control = plots with no mulch and no N application; NS= N sources; AMS= ammonium sulphate; CAN= calcium ammonium nitrate; NS0= no N; M0= no mulch; M= mulch type; PM= plastic mulch; SM= sorghum mulch; RM= rice mulch; WM= wheat mulch; DAS= days after sowing

Table 6: Correlation coefficients (*r*) between water soluble phenolics (in soil), density and dry weight of weeds in rice

Weeds parameters	Water soluble phenolics in soil	
	Year 2014	Year 2015
Density of BLW	-0.4262**	-0.6049**
Density of NLW	-0.2637*	-0.4408**
Density of sedges	-0.4646**	-0.4271**
Density of TW	-0.3800**	-0.5412**
Dry weight of BLW	-0.3305**	-0.4520**
Dry weight of NLW	-0.2121	-0.2876*
Dry weight of sedges	-0.3896**	-0.2842*
Dry weight of TW	-0.3038*	-0.3953**

Where BLW= broad leaf weeds; NLW= narrow leaf weeds, TW; total weeds; * significant at $P \leq 0.05$; ** highly significant at $P \leq 0.01$

2013). Improvement in paddy yield as a result of allelopathic mulches would possibly be due to better weed control and improved soil conditions by residue mulch application during early stages of crop growth (Cheema *et al.* 2000; Alsadaawi *et al.* 2012). Roldan *et al.* (2003) and Jordan *et al.* (2010) also highlighted the benefits of retention of crop residues in soil which may improve soil organic matter contents, use efficiency of essential nutrients and soil biological properties. Indeed, crop residue mulches conserve soil moisture, add organic matter in soil and supplies N on decomposition and enhance crop productivity (Bakht *et al.* 2009; Gopal *et al.* 2010; Ali *et al.* 2012). Likewise, crop competitiveness may be enhanced by synchronized additions of crop residue mulches and N fertilizers thereby improving growth and yield of crops (Pester *et al.* 1999; Buhler 2002).

Positive response of grain yields to N application may be attributed to increased growth of crop plants and better translocation of photosynthates towards grains (Lopez-Bellido and Lopez-Bellido 2001; Hejazi *et al.* 2010). Nitrogen application in combination with crop residues may also improve competitiveness of crops against weeds, improve nutrient release and uptake by plants by boosting

Table 7: Influence of mulches and nitrogen sources on paddy yield (Mg ha^{-1}) of rice

Treatments	2013–2014					2014–2015				
	Control	Urea	AMS	CAN	Mean (M)	Control	Urea	AMS	CAN	Mean (M)
	Paddy yield (Mg ha^{-1})									
No Mulch	1.9	3.0	3.1	3.1	2.8C (-)	1.8	3.1	3.2	3.0	2.7D (-)
Plastic Mulch	2.7	4.1	4.4	4.0	3.8A (26.3)	2.8	4.5	4.7	4.3	4.1A (34.1)
Sorghum Mulch	2.6	3.8	4.0	3.8	3.5B (20.0)	2.9	4.0	4.1	3.9	3.7BC (27.0)
Rice Mulch	2.6	3.7	3.9	3.6	3.4B (17.6)	2.7	3.9	4.0	3.8	3.6C (25.0)
Wheat Mulch	2.8	3.8	4.0	3.7	3.6A (22.2)	2.9	4.1	4.2	3.9	3.8B (28.9)
Mean (NS)	2.5C (-)	3.7B (32.4)	3.9A (35.9)	3.6B (30.5)		2.6C (-)	3.9AB (33.3)	4.0A (35.0)	3.8B (31.6)	
LSD ($P \leq 0.05$)	*M= 0.13, NS=0.12*					*M=0.17, NS=0.15,*				

Values of main effects and interaction sharing the same letter for a parameter during an experimental year, do not differ significantly ($P \leq 0.05$)
Control = plots with no mulch and no N application; NS= N sources; AMS= ammonium sulphate; CAN= calcium ammonium nitrate; M= mulch type

microbial activity within the root zone and eventually may improve the productivity and sustainability of cropping systems (Batish *et al*. 2001; Ali *et al*. 2012).

Conclusion

Use of mulches (plastic and allelopathic crop residue) in combination with N fertilizer resulted reductions of weed infestation in terms of density and dry biomass, enhanced the competitive ability of rice crop against weeds and improved the paddy yield. Overall, plastic mulch was better in terms of weed suppression and yield improvement. Amongst allelopathic crop residue mulches, wheat mulch stands superior in suppression of the density and dry biomass of BLWs, NLWs and sedges and paddy yield improvements compared with other allelopathic mulches.

Author Contribution

S. Hussain carried out experiment and prepared the first draft. S.A. Cheema, M. Sanaullah and M. Farooq conceived the idea, planned the experiment and provided critical feedback in analysis and preparing the manuscript. S.A. Cheema SA supervised the whole work.

References

Ali RI, TH Awan, M Ahmad, MU Saleem, M Akhtar (2012). Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. *J Anim Plant Sci* 22:108–112

Alsadaawi IS, KA Sarbout, Al-Shamma, M Laith (2012). Differential allelopathic potential of sunflower (*Helianthus annuus* (L.) genotypes on weeds and wheat (*Triticum aestivum* (L.) crop. *Arch Agron Soil Sci* 58:1139–1148

Awika JM (2011). Major cereal grains production and use around the world. *In*: *Advances in Cereal Science: Implications to Food Processing and Health Promotion*, pp: 1–13. Awika JM, V Piironen, S Bean (Eds.). ACS Symposium Series; American Chemical Society: Washington DC, USA

Bakht J, M Shafi, JM Tariq, Z Shah (2009). Influence of crop residue management, cropping system and N fertilizer on soil N and C dynamics, and sustainable wheat (*Triticum aestivum* (L.). *Soil Till Res* 104:233–240

Batish DR, K Lavanya, HP Singh, RK Kohli (2007). Phenolic allelochemicals released by *Chenopodium murale* affect the growth, nodulation and macromolecule content in chickpea and pea. *Plant Growth Regul* 51:119–128

Batish DR, HP Singh, RK Kohli, S Kaur (2001). Crop allelopathy and its role in ecological agriculture. *J Crop Prod* 4:121–162

Blackshaw RE (2005). Nitrogen fertilizer, manure and compost effects on weed growth and competition with spring wheat. *Agron J* 97:1612–1621

Blackshaw RE, RN Brandt (2008). Nitrogen fertilization rate effects on weed competitiveness is species dependent. *Weed Sci* 56:743–747

Blackshaw RE, LJ Molnar, HH Janzen (2004). Nitrogen application timing and application method affect weed growth and competition with spring wheat. *Weed Sci* 52:614–622

Box JD (1983). Investigation of the Folin-Ciocalteau phenol reagent for the determination of the polyphenolic substances in natural waters. *Water Res* 17:249–261

Buhler DD (2002). Challenges and opportunities for integrated weed management. *Weed Sci* 50:273–280

Buhler DD, JL Gunsolus (1996). Effect of date of pre-plant tillage and planting on weed populations and mechanical weed control in soybean (*Glycine max* (L.). *Weed Sci* 44:373–379

Cathcart RT, K Chandler, CJ Swanton (2004). Fertilizer nitrogen rate and response of weeds to herbicides. *Weed Sci* 52:406–412

Chauhan BS, DE Johnson (2011). Growth response of direct seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. *Weed Sci* 59:119–122

Chauhan BS, DE Johnson (2010). The role of seed ecology in improving weed management strategies in the tropics. *Adv Agron* 105:221–262

Chauhan BS, G Mahajan (2014). *Recent advances in weed management*, p: 414. Springer-Verlag New York, USA

Cheema ZA, A Rakha, A Khaliq (2000). Use of sorghab and sorghum mulches for weed control in mungbean. *Pak J Agric Sci* 37:140–144

Clark A (2007). *Managing cover crops profitably*, 3rd edn. Sustainable Agriculture Network, Handbook Series Book 9. Beltsville, Maryland, USA

Diaz-Perez JC, SC Phatak, J Roberson, R Morse (2012). Mulches increase yield and improve weed control in no-till broccoli (*Brassica oleracea* var. *botrytis*). *In: XXVIII International Horticultural Congress on Science and Horticulture for people (IHC2010): International symposium on Organic Horticulture: Productivity and Sustainability*, Vol. 933, pp:337–342. Lisbon, Portugal

Ditomaso JM (1995). Approaches for improving crop competitiveness through the manipulation of fertilizer strategies. *Weed Sci* 43:491–497

Dmitrovic S, A Simonovic, N Mitic, J Savic, A Cingel, B Filipovic, S Ninkovic (2014). Hairy root exudates of allelopathic weed *Chenopodium murale* (L.) induce oxidative stress and down-regulate core cell cycle genes in *Arabidopsis* and wheat seedlings. *Plant Growth Regul* 75:365–382

Ercoli L, A Masoni, S Pampana (2005). Weed suppression by winter cover crops. *Allelop J* 16:273–278

Farooq M, A Nawaz, E Ahmad, F Nadeem, M Hussain, KHM Siddique (2017). Using sorghum to suppress weeds in dry seeded aerobic and puddled transplanted rice. *Field Crops Res* 214:211–218

Farooq M, AA Bajwa, SA Cheema, A Wahid, KH Siddique (2013). The roll of allelopathy in crop production. *Intl J Agric Biol* 15:1367–1378

Farooq M, KHM Siddique, H Rehman, T Aziz, DJ Lee, A Wahid (2011). Rice direct seeding: experiences, challenges and opportunities. *Soil Till Res* 111:87–98

Galinato S, J Yoder, D Granatstein (2011). The economic value of biochar in crop production and carbon sequestration. *Ener Pol* 39:6344–6350

Gavazzi C, M Schulz, A Marocco, V Tabaglio (2010). Sustainable weed control by allelochemicals from rye cover crops: from the greenhouse to field evidence. *Allelop J* 25:259–274

Gentile R, B Vanlauwe, P Chivenge, J Six (2008). Interactive effects from combining fertilizer and organic residue inputs on nitrogen transformations. *Soil Biol Biochem* 40:2375–2384

Ghahray S, SAM Modarres-Sanavy, SHR Hashemi-Petrodi (2009). Study the auto-allelopathic potential of seed hull of ten Iranian rice cultivars (*Oryza sativa* L.) on germination and rice seedling growth. *J Plant Prod* 16:113–128

Gopal R, RK Jat, RK Malik, V Kumar, MM Alam, ML Jat, MA Mazid, YS Saharawat, A McDonald, R Gupta (2010). *Direct dry seeded rice production technology and weed management in rice-based systems*, p: 28. Technical Bulletin. International Maize and Wheat Improvement Center, New Delhi, India

GOP (2016–2017). *Economic survey of Pakistan 2016–2017*, pp: 23–24. Ministry of food, agriculture and livestock, Pakistan Bureau of Statistics, Islamabad, Pakistan

Harbur MM, MDK Owen (2004). Response of three annual weeds to corn population density and nitrogen fertilization timing. *J Weed Sci* 52:845–853

Hejazi A, MJ Bahrani, SA Kazemeini (2010). Yield and yield components of irrigated rapeseed-wheat rotation as influenced by crop residues and nitrogen levels in reduced tillage method. *Amer-Eur J Agric Environ Sci* 8:502–507

Hong NH, TD Xuan, E Tsuzuki, TD Khanh (2004). Paddy weed control by higher plants from South East Asia. *Crop Prot* 23:255–261

IRRI, Africa Rice CIAT (2010). *Global Rice Science Partnership (GRiSP.)* November, 2010

Jabran K, M Hussain, S Fahad, M Farooq, AA Bajwa, H Alharrby, W Nasim (2016). Economic assessment of different mulches in conventional and water-saving rice production systems. *Environ Sci Pollut Res* 23:9156–9163

Jabran K, E Ullah, M Hussain, M Farooq, U Zaman, M Yaseen, BS Chauhan (2015). Mulching improves water productivity, yield, and quality of fine rice under water-saving rice production systems. *J Agron Crop Sci* 201:389–400

Jordan A, LM Zavala, J Gil (2010). Effects of mulching on soil physical properties and run-off under semi-arid conditions in southern Spain. *Catena* 81:77–85

Kato-Noguchi H, T Ino, H Kujime (2010). The relation between growth inhibition and secretion level of momilactone B from rice root. *J Plant Interact* 5:87–90

Khaliq A, A Matloob, HM Shafiq, ZA Cheema, A Wahid (2011). Evaluating sequential application of pre and post emergence herbicides in dry seeded fine rice. *Pak J Weed Sci Res* 17:111–123

Liang XQ, YX Chen, ZY Nie, YS Ye, J Liu, GM Tian, GH Wang (2013). Mitigation of nutrient losses via surface runoff from rice cropping system with alternate wetting and drying irrigation and site-specific nutrient management practices. *Environ Sci Pollut Res* 20:6980–6991

Liebman M, A Davis (2009). Managing weeds in organic farming systems: an Ecological approach, *In: Organic Farming: the Ecological System*, pp: 173–196. Francis CA (Ed.). Agronomy monograph 54. American Society of Agronomy, Madison, Wisconsin, USA

Lopez-Bellido RJ, L Lopez-Bellido (2001). Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crop Res* 71:31–64

McLeod J (1998). The nitrogen cycles. *In: Proceedings of the Workshop on Nitrate-Agricultural Sources and Fate in the Enviornment-Perspectives and Direction*, pp:1–64. Farm Centre, Charlottetowen, PEI, February 26. Soil and Water Conservation Centre, Saint Andre New Brunswick, Eastern Canada

Melander B, IA Rasmussen, P Barberi (2005). Integrating physical and cultural methods of weed control-examples from European research. *Weed Sci* 53:369–381

Nawaz A, M Farooq, SA Cheema, ZA Cheema (2015). Role of Allelopathy in Weed Management. *In: Recent Advances in Weed Management*, pp:39–61. Chauhan BS, G Mahajan (Eds.). Springer International, Cham, Switzerland

Pester TA, OC Burnside, JH Orf (1999). Increasing crop competitiveness to weeds through crop breeding. *J Crop Prod* 2:31–58

Qin WC, C Hu, O Oenema (2015). Soil mulching significantly enhances yields and water and nitrogen use efficiencies of maize and wheat: A meta-analysis. *Sci Rep* 5; Article 16210

Rao AN, DE Johnsun, B Sivaprasad, JK Ladha, AM Mortimer (2007). Weed management in direct seeded rice. *Adv Agron* 93:153–155

Raun WR and GV Johnson (1999). Improving nitrogen use efficiency for cereal production. *Agron J* 91:357–363

Roldan A, F Caravac, MT Hernández, C García, C Sánchez-Brito, M Velásquez, M Tiscareño (2003). No-tillage, crop residue additions and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil Till Res* 72:65–73

Singh Y, VP Singh, G Singh, DS Yadav, RKP Sinha, DE Johnson, AM Mortimer (2011). The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice-wheat system in the Indo-Gangetic plains. *Field Crops Res* 121:64–74

Steel RGD, JH Torrie, DA Dickey (1997). *Principles and procedures of statistics: A biometrical approach*, 3rd edition, pp: 400–428. McGraw Hill Book Co., Inc. New York, USA

Tabaglio V, A Marocco, M Shulze (2008). Alternative weed control using the allelopathic effect of natural benzoxazinoids from rye mulch. *Agron Sustain Dev* 28:397–401