Quantification of intra- and inter-row weed competition in maize

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Keywords: *Maize, Band spray, competition, economics, integrated weed management*

Abstract

Maize is sown in wider rows (60cm) and has slow initial growth making the crop sensitive to weed competition. The information on contribution of weeds in intra- and inter-row spaces on maize grain yield would help in designing effective weed management strategies. The competitive effect of intra and inter-row weeds on maize grain yield was investigated in a field study conducted at two locations under different agroecological zones in 2018. Four treatments (weedy check, weed free check, weed free in intra-rows (20 cm wide), weed free in inter-rows (40 cm wide) were evaluated in a randomized complete block design. The experimental fields had dominance of grass and sedge weeds. Weedy check plots recorded significantly higher density and dry biomass of weeds than all weed control treatments. Weed free in inter-row had significantly lower total weeds density and biomass than weed free in intra-row. Season long weed competition reduced maize grain yield by 31-40%. Weed free check recorded the highest maize grain yield (6.9-7.3 t ha^{-1}) which was significantly higher than all weed control treatments. Weed competition in intra-row and in inter-row reduced grain yield by 10-14% and 14-15%, respectively, in comparison with weed free check. The study concluded that effective control of weeds in inter-row as well as in intra-row was important and broadcast application of herbicide was desirable. Alternatively, integrated use of band application of herbicide in intra-row and mechanical weeding in inter-row could be adopted for reducing herbicide load in maize.

Abbreviations

MHa - million hectare
d - days after sowing
LSD - Least significant difference
INR - Indian rupees

Introduction

Maize is highly sensitive to weed competition from early stages of growth (Kumar and Sundari, 2002). It is grown on a variety of soils, climates and management practices and, each environment is affected with different types of weed problems. Weeding is critical to remove crop-competitors for nutrients, water, sunlight, etc. for uncompromised yield quantity and quality (Pannacci *et al.*, 2017). If weeds not managed within first 3- 6 weeks of sowing, yield losses up to 76% may be incurred (Ali *et al.*, 2013; Gharde *et al.*, 2018). Even low weed infestations of less than five plants m^{-2} of common weed species such as Chenopdium album may cause yield losses of 15-30% in maize (Kropff and Spitters 1991; Carballido *et al*. 2013; Keller *et al*. 2014). Weed competition is extremely problematic during the critical period of crop establishment which is estimated to occur between 20d and 60d in maize (Keller *et al*. 2014; Knezevic *et al*. 2002). During this period, crops do not tolerate co-existence of weeds without losing yield. At early stages of crop-weed competition, weeds located nearer to or in between crop rows are the most critical (Ullah *et al*., 2008). Effective weed control is very important in maize production, particularly in the early period of growth, due to its initial slow growth rate and wider row spacing (Triveni *et al*. 2017).

Weeds are often controlled by combinations of pre- and post-emergence herbicides or mechanical weed control until closure of crop canopy. Looking into the present scenario of rising labour costs and labour scarcity, the herbicides will continue to play a key role in maize. However, due to restrictions in herbicide use and spread of herbicide resistant weed populations, alternative methods of weed control are becoming more important. Still, the problem of weed competition in the 10-15 cm wide band within crop rows remains. Maqbool *et. al* (2016) showed that weeds present within in intra-row caused more reduction in crop growth rate than inter-row weeds being present close to maize plants. Combinations of inter-row weeding with band spraying were more effective in maize than only mechanical weed control treatments and reduced herbicide input by 50-70% (Mehrtens *et al*. 2005). In addition to inter-row, weeds in intra-row zone could considerably reduce yields in the ranges of 18-76 % (Chandel *et al*., 2015; Gharde *et al*., 2018; Alba *et al*., 2020) and therefore their eradication is also critical. Very little is known about the contribution of weeds in intra- and inter-rows on maize grain yield which would help in designing integrated weed management strategies in this crop. The proposed study investigated the competitive effect of intra- and inter-row weeds on maize grain yield

Material and methods

Experimental trials

A field experiment was carried out in summer 2018 at two locations at Ludhiana (30° 54' N latitude, 75° 48' E longitude) and at Langroya (31° 32' N latitude, 76° 54' E longitude) in India. At Ludhiana, the experimental soil was loamy sand having pH 7.49, electrical conductivity 0.22 dSm^{-1} at 25°C, organic carbon 0.27%, available nitrogen 131 kg ha^{-1}, available phosphorus 19.6 kg ha^{-1}, available potassium 127 kg ha^{-1} and, at Langroya, the soil was clay loam having pH 8.02, electrical conductivity 0.20 dSm^{-1} at 25°C, organic carbon 0.34%, available nitrogen 174 kg ha^{-1}, available phosphorous 15.2 kg ha^{-1}, available potassium 325 kg ha^{-1}.

Materials and treatments

The experimental field at Ludhiana was sown with maize-wheat, and, at Langroya, the field was sown with paddy-*Egyptian clover* (forage) during previous three years. All residues were removed at ground level at the time of crop harvest. A pre-sowing irrigation was applied to ensure adequate moisture in the soil for sowing of maize. When the field attained workable soil moisture, the plots were prepared for maize sowing with three ploughing (one disc harrowing, two tyne cultivations). Maize hybrid PMH-1 was sown manually on flat beds using 20 kg seed ha^{-1}, in 60 cm spaced rows and plants spaced at 20 cm, on 05 June 2018 at Ludhiana, and on 12 June 2018 at Langroya. Recommended doses of fertilizers viz. 125 kg N, 60 kg P_2O_5 and 30 kg K_2O ha^{-1} and were applied to raise the crop. Full dose of P_2O_5 and K_2O and one-third dose of N were broadcast at sowing, before the last ploughing. Rest of N fertilizer was applied by top dressing in two equal splits, at knee high stage and pre-tasseling stages, at workable field moisture. The experiment consisted of four treatments (unweeded check, weed-free check, weed free in intra-row area, weed free in inter-row area) laid out in randomized complete block design with four replications. Four hand weeding were given in weed free treatment at 15d, 30d, 45d and 60d of maize. In inter-row weed free treatment, the weeds present beyond 10 cm distance from each side of crop row were allowed to compete with crop and those from remaining areas were removed manually at 15d, 30d, 45d and 60d. In intra-row weed free treatment, the weeds present within 10cm distances from each side of the row were removed manually at 15d, 30d, 45d, 60d and those present in remaining areas were allowed to compete with crop.

Harvesting, sampling and data recording

Weed density was recorded at 45d and 60d from two representative spots each measuring 60 cm x 60 cm from each plot. The above ground portion of weeds from the same area then harvested at ground level and dried in oven 65± 5°C and dry biomass was recorded. Data on maize plant height and biomass was recorded from five randomly selected plants from each plot at 45d and 60d. Maize grain yield and stover yield were recorded from 14.4 m^2 area (four crop rows each of six metre length) from each plot. The crop was manually harvested on September 12th, 2018 at Ludhiana and on October 8th, 2018 at Langroya.

Statistical analysis

The data were statistically analysed using the PROC MIXED procedure in SAS version 9.3 (SAS 2011). Weed density and weed dry biomass data were square-root transformed prior to analysis and back-transformed means are presented with mean separation based on transformed values. The means were separated with Fisher's protected LSD test at P≤0.05 where analysis of variance indicated significant treatment effects. The economics of all treatments were worked out by taking into account all the prevailing variables costs.

Results and discussion

Weed flora

Major weed species in the experimental field consisted of *Cyperus rotundus* and *Dactyloctenum aegyptium* at both locations, *Acrachne racemosa* at Ludhiana and *Echinochloa colona* at Langroya only. Other weed species included *Eleusine indica* and *Trianthema portulacastrum* at both locations; *Digitaria ciliaris* and *Commelina benghalensis* at Ludhiana only. At 45 days after sowing (d), under weedy check, sedge weeds had the highest relative density (> 60%) followed by grass weeds (> 35%) at both locations.

Table 1 - Weed density under different weed control treatments in maize in 2018 (Ludhiana and Langroya).

Treatment	Weed density*(plants m^{-2})											
	Ludhiana						Langroya					
	Sedges		Grasses		Total		Sedges		Grasses		Total	
	45d	60d	45d	60d	45d	60d	45d	60d	45d	60d	45d	60d
Weedy check	4.54 (20)	1.86 (3)	3.67 (13)	1.99 (6)	5.66 (35)	2.74 (9)	4.31(16)	2.90 (8)	3.59 (11)	2.58 (6)	5.36 (28)	3.81 (14)
Weed free check	1.00 (0)	1.00 (0)	1(0)	1 (0)	1.00 (0)	1.00 (0)	1.00(0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free in intra-row	2.58 (6)	1.41 (1)	1.31 (3)	1.31 (2)	3.39 (10)	1.89 (3)	3.87(9)	2.85 (8)	2.68 (6)	1.49 (2)	4.16 (16)	2.85 (8)
Weed free in inter-row	2.33 (5)	1.39 (1)	1.10 (2)	1.10 (1)	2.17 (7)	1.51 (2)	3.05(8)	1.86 (3)	1.83 (3)	1.00 (0)	3.51 (12)	2.40 (6)
LSD(p=0.05)	0.24	0.24	0.22	0.21	0.61	0.37	0.33	1.07	0.66	1.52	0.46	1.27

* Data were square root transformed before analysis; parentheses are original means.

Weed density and biomass

At 45d, weedy check had significantly higher density of sedge and grass weeds and total weed density than weed free, weed free in inter-row and weed free in intra-row, at both locations (Table 1). The broadleaf weed density did not vary among weed control treatments. Weed free in inter-row had similar density of sedge and grass weeds, however, total weed density was significantly lower when compared to weed free in intra-row. Lesser area under weedy conditions in inter-row weed free treatments than weed free in intra-row was reflected in lower weed density. At 60d, there was significant reduction in weed density as compared to that recorded at 45d. Here also, weed-free in inter-row had lower density of sedges than weed-free in intra-row, at Langroya. At 60d, many weed species had completed their life cycle and dried up hence weed density was lower as compared to at 45d. Maize plants grew taller at 60d (> 225cm) than at 45d (< 140cm) stage and shading by crop plants did not allow new weed seedlings to emerge while existing weed plants had completed their life cycle. Hence weed density was reduced at 60d. Maize plant height and dry biomass production increased significantly from 45 to 60 d (*e.g.* 109 to 311 g m^{-2} at Ludhiana) which exerted shading and suppressing effect on emergence of new weeds seedlings as well as growth of existing weed plants.

At 45d, weedy check had significantly higher biomass of grass, sedge and broadleaf weeds as compared to all weed control treatments (Table 2). The contribution of grass weeds to total weed biomass was the highest at both locations (70% at Ludhiana and 82% at Langroya). As recorded in case of weed density, weed free in inter-row had significantly lower biomass of all type of weeds and total weed biomass as compared to weed-free in intra-row which may be attributed to more space available for weed growth in weed free in intra-row which increased weed biomass. At 60d, weed biomass either remained same or there was little increase as compared to that recorded at 45d, under weedy check and weed free in inter-/intra-row treatments. As maize plants made significant increase in plant height and biomass accumulation, shading by crop plants did not allow existing weeds to add more biomass and prevented new weeds to emerge hence there was not much change in weed biomass rather it decreased when data was recorded at 60d as compared to at 45d.

Maize grain yield and yield attributes

At 45d, weed free check had significantly taller plants than weedy check and weed free in intra-/inter-row, at both locations (Table 3). Weed free in intra-/inter-row had similar crop plant height. Maize plants had significantly less height under weedy check than all weed control treatments. In case of weed free treatments, crop was free of weed competition and produced taller plants while under weedy check the weeds offered competition to maize plants which suppressed plant growth and height. There was significant increase in maize plant height from 45 to 60d under all weed

Table 2 - Weed dry biomass under different weed control treatments in maize in 2018 (Ludhiana and Langroya).

Treatment	Weed dry biomass* (g m^{-2})											
	Ludhiana						Langroya					
	Sedges		Grasses		Total		Sedges		Grasses		Total	
	45d	60d	45d	60d	45d	60d	45d	60d	45d	60d	45d	60d
Weedy check	2.93 (8)	1.73 (2)	4.71 (21)	3.26 (10)	5.53 (30)	5.06 (26)	2.05 (3)	1.67 (2)	4.45 (19)	4.00 (15)	5.89 (23)	4.91 (23)
Weed free check	1.00 (0)	1.00 (0)	1 (0)	1 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free in intra-row	2.08 (3)	1.17 (0)	3.14 (9)	1.96 (3)	3.58 (12)	2.23 (4)	1.75 (2)	1.32 (1)	2.82 (7)	2.56 (5)	3.54 (12)	2.96 (8)
Weed free in inter-row	1.79 (2)	1.22 (0)	2.65 (6)	1.32 (1)	3.15 (9)	1.22 (1)	1.63 (2)	1.36 (1)	2.07 (3)	2.26 (4)	2.58 (6)	2.40 (5)
LSD (p=0.05)	0.25	NS	0.15	0.42	0.19	0.90	0.18	0.29	0.52	0.44	0.48	0.43

* Data were square root transformed before analysis; parentheses are original means

Table 3 - Effect of different weed control treatments on maize plant height and biomass in 2018 (Ludhiana and Langroya).

Treatments	Plant height (cm)				Crop dry biomass (g m^{-2})			
	Ludhiana		Langroya		Ludhiana		Langroya	
	45d	60d	45d	60d	45d	60d	45d	60d
Weedy check	121	202	70	191	74	184	57	155
Weed free check	142	238	86	223	110	312	86	206
Weed free in intra-row	139	223	79	207	102	291	82	183
Weed free in inter-row	135	225	81	215	103	293	84	189
LSD (p=0.05)	11	22	7	6	6	28	13	16

control treatments, including weedy check; treatment differences however remained non-significant at 45d. Crop dry biomass accumulation showed a trend similar to that recorded in case of plant height as plant biomass increased significantly (2.4 to 2.8 times) from 45 to 60d, at both locations. The weed free check recorded the highest maize grain yield which was significantly higher than weedy check, weed free in inter-/intra-row, at both locations. Weed free in inter-row and weed free in intra-row treatments recorded similar maize grain yield. Maize grain yield under weedy check was significantly lower than all weed control treatments. Season long weed competition reduced grain yield by 31-40%. The stover yield recorded similar trend as recorded in case of grain yield. Weed free check provided the highest economic returns which were INR 6000/ha higher compared to weed free in intra-/inter-row and INR 23000/ha higher than under weedy check.

In case of weedy check, the competition offered by weed plants were reflected in reduced height and biomass of maize plants which reduced maize grain yield. In contrast, under weed free check, maize plants grew in absence of weeds and hence produced taller maize plants with highest accumulation of biomass and highest grain yield. In case of weed free in intra-row there was less area (one-third) which was free from weeds as compared to weed free in inter-row which had more area under weed free (two-third), however, both treatments recorded similar grain yield, at both locations. The similar grain yield among weed free in intra- and inter-row treatments indicated that weed-free conditions in immediate vicinity of maize plants are more important. Maqbool *et. al* (2016) showed that weeds present within in intra-row ,being present close to maize plants, caused more reduction in crop growth rate than inter-row weeds. Weed competition in inter-row and in intra-row reduced grain yield by 10 -14% and 14-15%, respectively, in comparison with weed-free check. It indicated that for getting best yield from maize the weed control in both inter- and intra-row was important. Mehrtens *et al.* (2005) reported that combination of inter-row hoeing with band spraying was more effective than only mechanical weed control treatments. The economic returns were higher under weed free check as compared to weed free in inter-row and in intra-row. These results indicated that for getting best profitability weeds need to be controlled using broadcast application of herbicides. Alternatively, if mechanical weeding is to be practiced, which in general, covers inter-row spaces only, it must be integrated with band application (intra-row) of an herbicide. The latter, band spray of herbicide and mechanical combination seems to be the best strategy for effective control of weeds and for reducing herbicide load in maize.

Table 4 - Maize grain yield and economics under different weed control treatments in 2018. (Ludhiana and Langroya)

	Grain yield (t ha^{-1})		Stover yield (t ha^{-1})		Economics (Mean of 2 locations) (000 INR ha^{-1})		
	Ludhiana	Langroya	Ludhiana	Langroya	Variable costs	Gross returns	Net returns
Weedy check	4.33	4.71	10.4	10.5	43.3	87.8	44.5
Weed free check	7.29	6.86	15.3	12.9	67.3	135.1	67.8
Weed free in intra-row	6.20	5.90	14.1	12.5	55.4	116.6	61.2
Weed free in inter-row	6.56	5.91	15.0	12.7	60.4	120.7	60.3
LSD (p=0.05)	0.59	0.88	3.4	NS	-	-	-

Conclusions

Weed competition in intra-row and in inter-rows reduced maize grain yield by 10-14% and 14-15%, respectively, in comparison with weed free check. For achieving highest grain yield, broadcast application of herbicide is desirable. Alternatively, integration band application of herbicide in intra-row and mechanical weeding in inter-row could be adopted for reducing herbicide load in maize.

Authors' contribution

Conceptualization and designing of the research work (MSB); Execution of field experiments and data collection (NK; MJ); Analysis of data and interpretation (NK, MSB); Preparation of manuscript (NK, MSB; MJ).

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