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Assessment of yield and economic losses in agriculture due to weeds in India

Yogita Gharde[a,*], P.K. Singh[a], R.P. Dubey[a], P.K. Gupta[b]

[a] ICAR - Directorate of Weed Research, Jabalpur 482 004, MP, India
[b] JNKVV - KVK Katni, Jabalpur 482 004, MP, India

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ABSTRACT

Weeds are notorious yield reducers that are, in many situations, economically more harmful than insects, fungi or other crop pests. Assessment of crop yield and economic losses due to weeds in agriculture is an important aspect of study which helps in devising appropriate management strategies against weeds. A study was conducted to estimate the yield and economic losses due to weeds using the data from 1581 On-Farm Research trials conducted by All India Coordinated Research Project on Weed Management between 2003 and 14 in major field crops in different districts of 18 states of India. The study revealed that potential yield losses were high in case of soybean (50–76%) and groundnut (45–71%). Greater variability in potential yield losses were observed among the different locations (states) in case of direct-seeded rice (15–66%) and maize (18–65%). Three factors viz. location (state), crop, and soil type significantly ($p < .0001$) explained the variability in actual yield losses due to weeds at farmers' fields. Significant differences were also observed between different locations, crops and soil types. Actual economic losses were high in the case of rice (USD 4420 million) followed by wheat (USD 3376 million) and soybean (USD 1559 million). Thus, total actual economic loss of about USD 11 billion was estimated due to weeds alone in 10 major crops of India viz. groundnut (35.8%), soybean (31.4%), greengram (30.8%), pearlmillet (27.6%), maize (25.3%), sorghum (25.1%), sesame (23.7%), mustard (21.4%), direct-seeded rice (21.4%), wheat (18.6%) and transplanted rice (13.8%).

1. Introduction

Reduction in economic losses in agricultural production due to abiotic and biotic factors is of utmost importance in modern day input-intensive agricultural systems. Sustaining the production levels demands devising newer strategies for mitigating the ill-effects of these adverse factors. As with abiotic causes, especially the lack or excess of moisture in the growth season, extreme temperatures, high or low irradiance and nutrient supply, biotic stresses have the potential to reduce yields substantially (Oerke, 2006). Among the major biotic constraints, weeds are considered as the most harmful to agricultural production besides affecting agrobiodiversity and natural water bodies. They also affect the crop production indirectly, by competing with the crop for resources, sheltering crop pests, interfering with water management, reducing the yield and quality, and subsequently increasing the cost of processing (Zimdahl, 2013). Therefore, weed management is the major and important part of crop production.

In India, reduction in crop yield was estimated as 31.5% (22.7% in winter and 36.5% in summer and rainy seasons) by weeds (Bhan et al., 1999). Whereas, the economic losses due to weeds in India was estimated as INR 20 to 28 billion about two decades ago (Sahoo and Saraswat, 1988; Sachan, 1989). In another study, it was reported that loss in agricultural production due to weeds amounts to INR 1050 billion per annum (NRCWS, 2007; Varshney and PrasadBabu, 2008).

In general, the yield loss due to weeds is almost always caused by a group of different weed species, and these weeds may have substantively different competitive ability (Weaver and Ivany, 1998; Milberg and Hallgren, 2004). Practically, it is very difficult to estimate the yield loss due to single weed species and therefore, it is estimated as the collective efforts by all the weeds. Overall, weeds produced the highest potential loss (34%), with animal pests and pathogens being less important (losses of 18 and 16%) worldwide (Oerke, 2006).

As far as studies on yield loss at global level is concerned, Milberg and Hallgren (2004) explored the large-scale patterns in yield loss in cereals due to weeds in Sweden and mentioned that weed biomass explained 31% of the variation in yield loss due to weeds. Whereas, O'Donovan et al. (2005) developed various regression equations in western Canada to estimate the effects of weeds on yield loss of field crops. Oliveira et al. (2014) also presented that insect, pests cause an average annual production loss of 7.7% in Brazil, which is a reduction of approximately 25 million tonnes of food, fibre and biofuels. They also estimated the total annual economic losses as approximately USD

* Corresponding author.
E-mail addresses: Yogita.Gharde@icar.gov.in, yogita_iasri@rediffmail.com (Y. Gharde).

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17.7 billion. Soltani et al. (2016) also estimated average yield loss in corn as 50%, which equates to a loss of 148 million tonnes of corn valued at over USD 26.7 billion annually in the United States and Canada.

Most of the studies conducted in past are more or less based on the experimental data which may not be always representative for field situation. Although, estimation of yield losses from experimental situation is subject to local effects and sometimes it is valid only for some cropping situation, it may be difficult to extrapolate the results for farmers' yield losses (Milberg and Hallgren, 2004). The reason may be the experimental situations that might not be the representative for a field condition (Savary et al., 1998). Further, it is more realistic to establish results from field trials comparing the different treatments in the farmers' field (Walker, 1983; Zanin et al., 1992; Oerke et al., 1994; Oerke and Dehne, 1997; Tamado et al., 2002). Hence, to observe the magnitude and variability of yield losses due to pests, data from farmers' fields are needed (Friesen and Shebeski, 1960; Taylor and Lill, 1986). Therefore, the study has been taken to reassess the yield losses (potential and actual) estimates along with economic losses by weeds affecting major field crops grown in India based on data from farmers' fields.

2. Materials and methods

2.1. Field trials

The study was conducted to estimate the yield losses and economic losses due to weeds using the data from a total of 1581 on-farm research trials conducted by All India Coordinated Research Project on Weed Management (AICRP-WM) during 2003-14 in 10 major field crops in different regions of India (Fig. 1; Table 1). The study centres were located in Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand and West Bengal (Table 2). The information and data of on-farm research trials, conducted during 2003-14, were collected from different centres located in these states. These trials were conducted having plot size of about 1000 m^2 for each treatment. For the study, yield data of three treatment plots *viz.* farmers' practice (1 hand weeding/mechanical weeding), weedy check (no control of weeds) and weed free were used to calculate yield losses. Weed free situation was maintained with the use of herbicide supplemented by hand weeding. Yield data of farmers' practice was used to estimate actual yield losses in different crops whereas; yield data of weedy check plot was used to estimate the potential yield loss *vis a vis* weed free situation.

Table 1
Number of trials considered for the calculation of yield losses due to weeds across the India.

Season	Crop	Number of trials
Rainy	Transplanted rice (*Oryza sativa* L.)	461
	Direct-seeded rice (*Oryza sativa* L.)	195
	Pearl millet (*Pennisetum glaucum* (L.) R. Br.)	72
	Soybean (*Glycine max* (L.) Merr.)	132
	Sorghum (*Sorghum bicolor* (L.) Moench)	39
	Groundnut (*Arachis hypogaea* L.)	24
	Greengram (*Vigna radiata* (L.) R. Wilczek)	10
	Sesame (*Sesamum indicum* L.)	19
Winter	Wheat (*Triticum aestivum* L.)	490
	Maize (*Zea mays* L.)	98
	Mustard (*Brassica* spp.)	41

2.2. Calculation of yield losses due to weeds

Actual and potential yield losses were calculated using following formulas as given in Milberg and Hallgren (2004); Galon and Agostinetto (2009); Soltani et al. (2016):

$$\text{Actual yield loss due to weeds} = \left(\frac{\mathrm{WF}_y - \mathrm{FP}_y}{\mathrm{WF}_y}\right) \times 100 \tag{1}$$

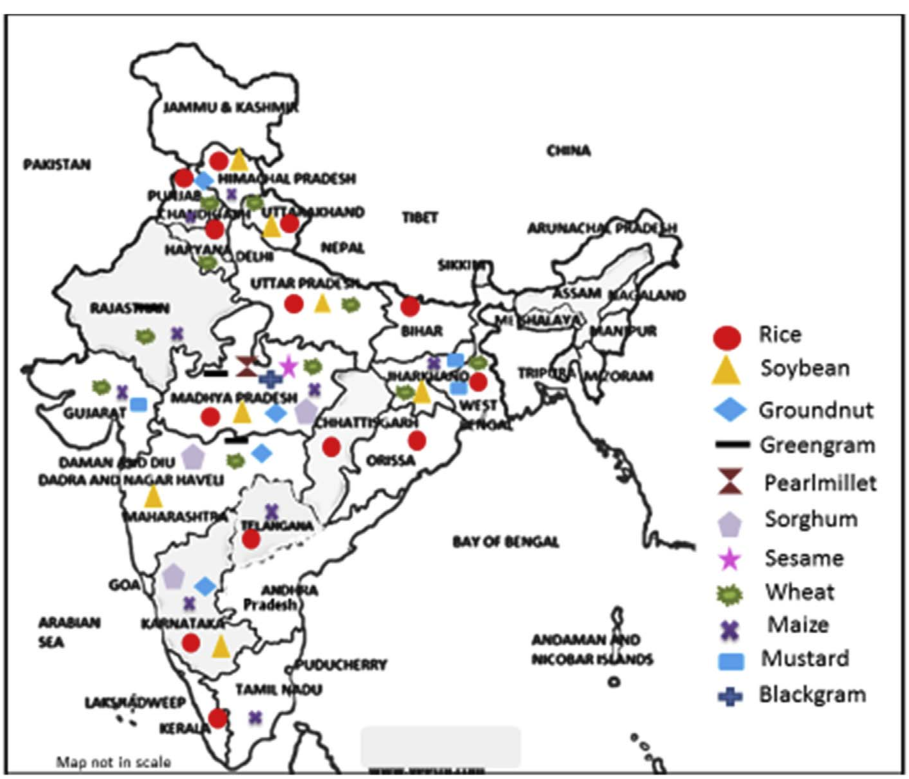


Fig. 1. Map of India depicting the locations (states) of which data were considered for calculation of yield and economic losses due to weeds for different crops given as legends.

Table 2
Geographical location of the centres around which the on-farm research trials were conducted during 2003-14.

S.N.	State	Geographical location of centre (Latitude/longitude/altitude)
1.	Bihar	25.98° N, 85.67° E, 53 m
2.	Chhattisgarh	21.24° N, 81.70° E, 290 m
3.	Gujarat	22.53° N, 72.97° E, 45 m
4.	Haryana	29.15° N, 75.71° E, 216 m
5.	Himachal Pradesh	32.10° N, 76.55° E, 1291 m
6.	Jharkhand	23.44° N, 85.32° E, 625 m
7.	Karnataka	13.08° N, 77.58° E, 920 m; 15.49° N, 74.98° E, 751 m
8.	Kerala	10.55° N, 76.28° E, 3 m
9.	Madhya Pradesh	26.22° N, 78.19° E, 412 m
10.	Maharashtra	17.75° N, 73.18° E, 240 m; 19.25° N, 76.80° E, 9 m
11.	Odisha	20.26° N, 85.81° E, 26 m
12.	Punjab	30.90° N, 75.81° E, 247 m
13.	Rajasthan	28.09° N, 73.35° E, 235 m
14.	Tamil Nadu	11.02° N, 76.93° E, 426 m
15.	Telangana	17.33° N, 78.42° E, 543 m
16.	Uttar Pradesh	26.53° N, 81.84° E, 112 m; 26.49° N, 80.31° E, 126 m
17.	Uttarakhand	30.31° N, 78.41° E, 244 m
18.	West Bengal	23.68° N, 87.69° E, 49 m

$$\text{Potential yield loss due to weeds} = \left(\frac{\mathrm{WF}_y - \mathrm{WC}_y}{\mathrm{WF}_y}\right) \times 100 \qquad (2)$$

where, WF_y – crop yield in weed free situation, FP_y – crop yield in farmers' practice and WC_y – crop yield in weedy check plot. On the other hand, average yield loss data was obtained by calculating average of those locations (states) from where information was collected for a particular crop.

2.3. Factors affecting the yield loss

Data on different factors (year, location, season, crop, crop situation, and soil type) from 844 on-farm research trials were analysed using analysis of variance (ANOVA) to find out the factors which significantly explained the variability in the yield loss (data on all the factors were available only for 844 trials). ANOVA model (general linear model) was fitted to the data which is given as follows:

$$y_{ijklmn} = \alpha + Year_i + Location_j + Season_k + Crop_l + Situation_m + Soil\ Type_n + e_{ijklmn}$$

where, y_{ijklmn} is the observation pertaining to ith year, jth location, kth season, lth crop, mth crop situation and nth soil type. e_{ijklmn} is an error term assumed to be normally and independently distributed with mean zero and a constant variance σ^2. Assumptions (normality, randomness and homogeneity of the error variance) were confirmed with studentized residuals and Shapiro-Wilk normality test (Onofri et al., 2010) before fitting the model. Analysis was performed using SAS 9.3 (SAS Institute, Cary NC) software.

2.4. Calculation of economic loss

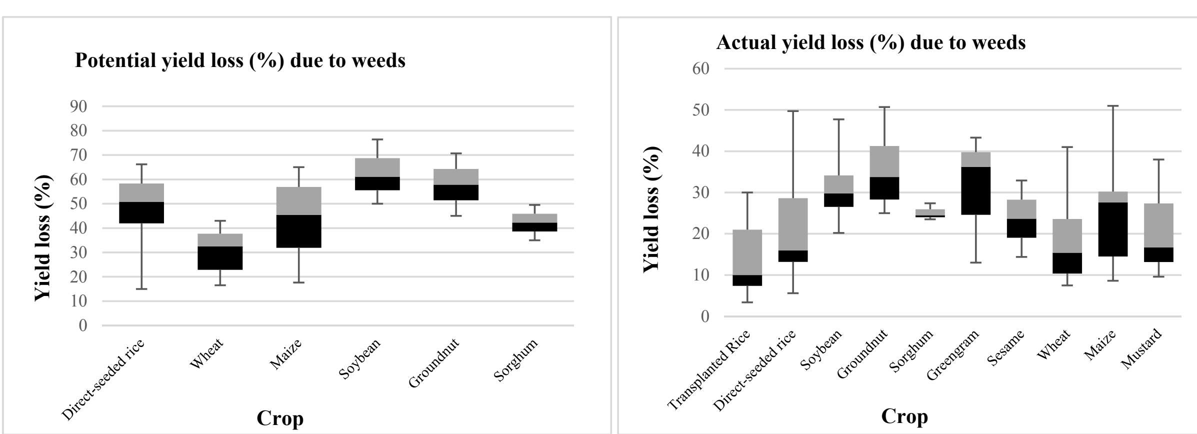
In order to calculate the economic losses caused by weeds, normal estimates of the production of different crops (average of 2008-09 to 2013-14) in different locations and Minimum Support Price (MSP) of the crops for the crop year 2014-15 were considered. MSP for the year 2014-15 was considered to base the estimates on present value. It was calculated using average yield loss data of a crop for each location (state) and formula (3) given by Oliveira et al. (2014) for each state. Altogether, cumulative figure for economic loss was generated by summing the data of all the states.

$$\text{Economic loss due to weeds} = \text{Normal estimate of production} \times \left(\frac{\%\ \text{yield loss due to weeds}}{100}\right) \times \text{MSP} \qquad (3)$$

3. Results and discussion

3.1. Potential yield losses due to weeds

Potential yield losses due to weeds were calculated with the help of yield data from weedy check *vis a vis* weed free situation and is presented through box plot diagram (suitable data was available only for 6 major crops) (Fig. 2(a)). It showed that potential yield loss was very high in case of soybean which experienced about 50–76% yield reduction followed by groundnut where 45–71% yield loss was recorded due to weeds. High variation in the yield losses were observed among the different states in the case of direct-seeded rice (15–66%) and maize (18–65%).



(a) (b)

Fig. 2. (a) Potential and (b) actual yield losses due to weeds in major field crops of India.
Box plot depicts the 'Minimum value', 1st Quartile 'Q1', 'Median', 3rd Quartile 'Q3' and 'Maximum value' of the yield loss data (bottom to up). End point of the minus error bar is the minimum value, black area showed the difference between median and Q1, Grey area showed the difference between Q3 and median and upper most point of the plus error bar is maximum value of the data.

Table 3
Actual yield losses (%) due to weeds in different crops.

Season	Crop	Actual yield loss (%)
Rainy	Transplanted rice	13.8
	Direct-seeded rice	21.4
	Soybean	31.4
	Groundnut	35.8
	Sorghum	25.1
	Pearl millet	27.6
	Greengram	30.8
	Sesame	23.7
Winter	Wheat	18.6
	Maize	25.3
	Mustard	21.4

3.2. Actual yield losses due to weeds

It is evident from Table 3 that average actual yield loss (%) is high (> 30%) in case of groundnut, soybean, and greengram. Actual yield losses vary greatly among locations (states) depending upon the growth condition of crops and intensity of weeds, (Fig. 2(b)). Variation among locations is high in the case of direct-seeded rice (6–50%) followed by maize (9–51%). Actual yield loss was less in transplanted rice as compared to direct-seeded rice. Yield losses due to weed competition in direct-seeded rice may go up to 100%, where weeds are left uncontrolled throughout the season (Singh et al., 2015).

3.3. Factors contributing variability in actual yield losses

ANOVA was used to find out the significant contributors among all factors (year, location (state), season, crop, crop situation, and soil type) which explained the variability in actual yield losses due to weeds. Results of the ANOVA revealed that three factors *viz*. location (state), crop, and soil type significantly affected the actual yield losses at farmers' field (Table 4). Significant differences were also observed between different locations (states), crops and soil types.

Actual yield loss data of 10 years for 10 major field crops were considered for the analysis (where data were available for all the factors) and ANOVA results revealed that year factor was unable to explain significant variation in yield losses. Some extreme values of yield losses were also observed in different years. On the other hand, location (state) factor significantly affected the yield losses as it was found significant at 1% level of significance. It can be seen in Fig. 3(a) that data exhibited great variation between the actual yield losses of different locations (states). Very high values of yield losses were observed in the Jharkhand state whereas, Uttar Pradesh observed great variation in yield loss data within itself. Yield loss data of all the states were significantly different from each other and thus contributed significantly in explaining the variability in yield loss data. Among all other factors, season (rainy/winter) and crop situation (irrigated/rainfed) did not explain the significant amount of variation in yield losses whereas, effect of crop and soil type was observed significant in explaining the yield losses (Fig. 3(b) and (c)).

Table 4
Results of ANOVA after fitting the general linear model to the actual yield loss data.

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	9	1284.19	142.69	3.45	0.06
Location	14	9309.03	664.93	16.09	< .0001
Season	1	24.32	24.32	0.59	0.44
Crop	10	3364.28	336.43	8.14	< .0001
Situation	1	0.42	0.42	0.01	0.92
Soil Type	5	1665.02	333.00	8.06	< .0001

3.4. Yield losses due to weeds in different crops

3.4.1. Rice

The present study revealed that in direct-seeded condition, weeds caused 15–66% potential yield losses in weedy situation (Fig. 2 (a)) whereas, it was up to 46 and 90% in other studies (Johnson et al., 2004; Andres et al., 2007; respectively). The study conducted here also revealed that in direct-seeded condition, actual yield losses ranged from 6 to 50% (Fig. 2(b)). This high variation in yield losses may be due to the intensity and duration of the crop-weed competition which determines the magnitude of crop yield losses (Swanton et al., 2015; Jha et al., 2017). On the other hand, in transplanted condition, weeds caused 3–30% yield losses in farmers' fields (Fig. 2(b)).

3.4.2. Soybean

The estimates obtained showed 50–76% potential yield losses and 20–48% actual yield losses due to weeds in soybean. Other researchers obtained the yield losses due to weed infestation in soybean to the tune of 20–77% (Kurchania et al., 2001; Channappagoudar and Biradar, 2007). Whereas, Datta et al. (2017) reported that the presence of weeds up to critical stage of soybean may cause 8–55% reduction in yield.

3.4.3. Groundnut

High potential yield losses in groundnut were observed as 45–70%, whereas, actual yield losses were 24–51%. In general, yield loss in groundnut due to weeds was reported to be 17–84% (Singh et al., 1992). The extent of yield losses was also reported up to 62% during the rainy season and up to 47% during the summer season. Reason for high losses could be the slow growth of the crop at the initial stages, and high weed competition at later stages (Jat et al., 2011). Similarly, weeds occupy the space that is not covered by the crop which ultimately resulted in decrease in yield.

3.4.4. Sorghum

Weeds can cause 15–97% losses in sorghum yield under different climatic conditions (Peerzada et al., 2016). In the present study, 23.5–27.4% actual yield losses were observed in the farmers' fields whereas, 35–50% potential yield losses were recorded in weedy condition. In another study, 40–80% yield loss was observed due to weed competition in sorghum during the growth of the crop (Ishaya et al., 2007).

3.4.5. Greengram

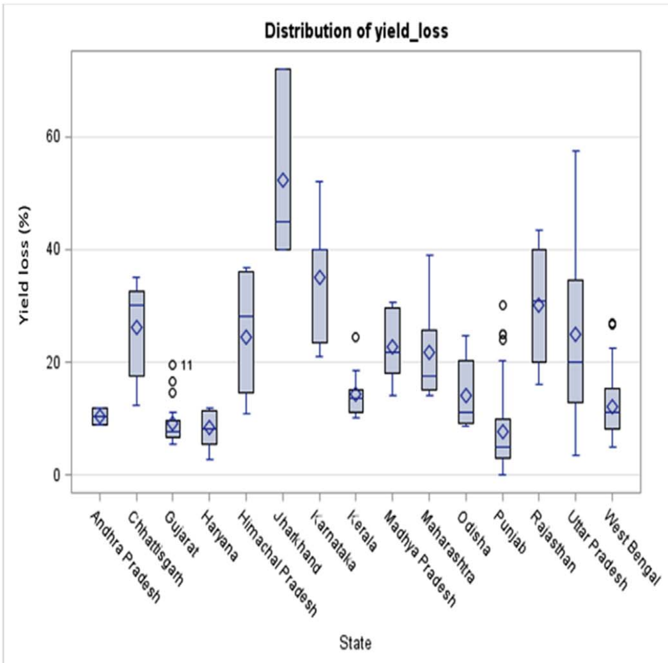
Actual yield losses due to weeds were assessed to be 13–43% in greengram in rainy season, whereas, Mirjha et al. (2013) found it as ranging from 30 to 85%. The magnitude of yield losses in greengram caused by weeds depends upon weed species, their densities and crop-weed competition period (Singh et al., 2015).

3.4.6. Sesame

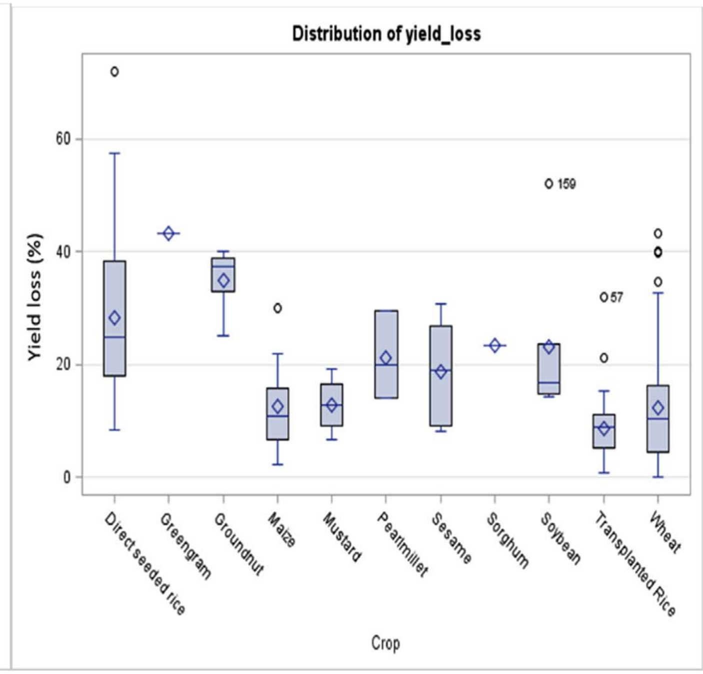
The study revealed that yield losses in farmers' fields were 14–33% due to weeds despite using weed control measures. In another study, yield losses were estimated as 50–75% due to crop-weed competition in sesame (Mruthul et al., 2015). Among all weeds, Nutsedges (*Cyperus rotundus* and *C. esculenthus*), considered the world's worst weeds (Ray, 1975), caused severe loss in yields; around 45% in sesame (Sen, 1976).

3.4.7. Wheat

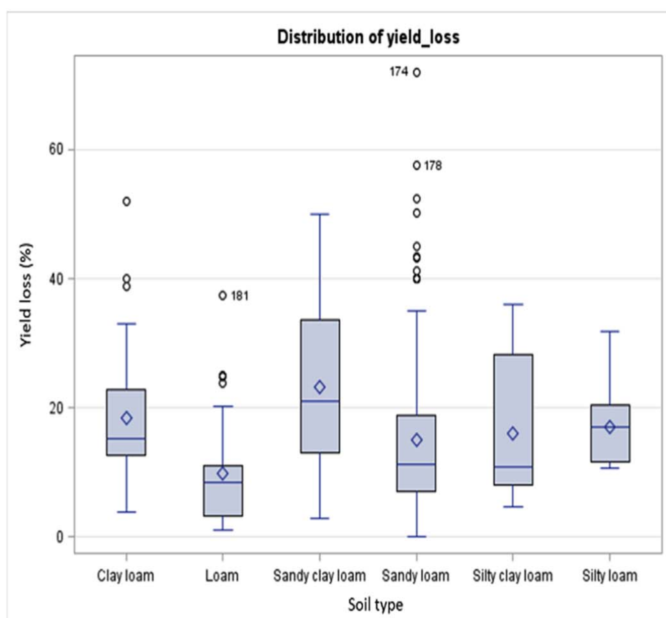
Due to weed infestation, potential yield loss of 16.5–43.0% and actual yield loss to the tune of 7.5–41.0% were observed in the farmers' fields. On the other hand, past studies indicated that crop losses due to weeds throughout the world as a whole is 10–65% in wheat (Gezu and Soboka, 2001). The yield losses due to weed competition may go up to 10–60% sometimes (Rao et al., 2014). Further, weeds accounts for more than 48% loss of potential wheat yield (Khan and Haq, 2002; Fahad et al., 2015).



(a)



(b)



(c)

Fig. 3. Distribution of actual yield losses (%) due to weeds with significant contributors (a) location/state (b) crop (c) soil type.

3.4.8. Maize

Weed infestation being the major constraint in maize production is severe in the rainy season due to its wider spacing. Farmers adopt different location-specific practices to alleviate this biotic stress for improving productivity. However, the results of this study indicated very low to high range of actual yield losses (8.6–51%) due to weeds. Wide range of yield losses indicated the high variation among the data reported by different locations. Previously, Mani et al. (1968) reported 29–70% yield loss due to weeds.

3.4.9. Mustard

Actual yield losses between 9.6 and 38.0% in mustard in different regions of India were observed. Sometimes, it can go up to 65% depending on the crop stage, degree of weed infestation, weed species, and management practices (Yaduraju et al., 2006). Besides this, severe yield reductions, ranging from 35 to 70%, have been reported due to weed infestation, besides reduction in oil content and quality under both rainfed and irrigated conditions (Shekhawat et al., 2017).

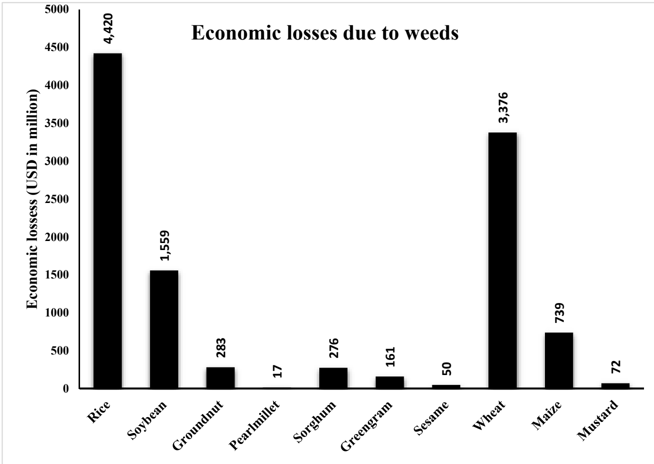


Fig. 4. Economic losses (USD in million) due to weeds in 10 major field crops of India.

3.5. Economic losses due to weeds

Estimates of actual economic losses were the highest in case of rice (USD 4420 million) followed by wheat (USD 3376 million) and soybean (USD 1559 million), respectively (Fig. 4). Rice experienced only 14% actual average yield loss in transplanted and 21% in direct-seeded condition but due to high production in India, it is considered as the most economically affected crop than others considered here. Overall, total economic loss in 10 major crops in 18 states of India was estimated approximately USD 11 billion due to weeds alone. Yaduraju (2012) also estimated the economic losses as approximately USD 13 billion when losses due to weeds were taken as 10% which would amount to a loss of about 25 mt of total food grains in India.

It was reported that globally, weeds are responsible for decreasing the production of the world's eight most important food and cash crops by 13.2% (Oerke, 2006). In economic terms, weeds not only caused annual crop loss amounting to more than USD 100 billion worldwide, and use of herbicides for weed control incurred additional expenditure of about USD 25 billion (Agrow, 2003).

4. Conclusion

Yield losses due to weeds are very important figures for assessment of effectiveness of current plant protection measures (Oerke and Dehne, 2004). These data provide a basis for making decisions on the relative importance of weeds with respect to agriculture and the environment (Walker, 1983). Economic losses due to weeds are also very important statistics for policy makers and others including researchers to understand the impact of weeds as far as economic loss is concerned. Total economic loss of about USD 11 billion was estimated due to weeds alone in 10 major field crops in 18 states of India. In economic terms, the greatest loss of approximately USD 347/ha was observed in groundnut with average loss of about 36% followed by maize (USD 136/ha) and soybean (USD 117/ha). Further losses in wheat and rice were calculated as USD 116 and 89/ha, respectively.

Study conducted includes the direct losses in crop yield due to weed competition. However, there are some other indirect losses including the weed control measures that contribute to increased cost of production and also contribute in increasing economic loss due to weeds (Oliveira et al., 2014). Use of herbicides has been escalated during past decades and is still going up (Choudhury et al., 2016) for controlling weeds at farmers' fields due to shortage of labourers and high cost involved in the manual weeding. At the same time, herbicides are able to control the weeds up to certain time but further flushes of weeds pose new challenges to the farmers during cropping season. Further, high cost of herbicides, their timely unavailability and lack of technical know-how also make weed control difficult for marginal farmers despite its harmful effects on environment. So, there is need to integrate several methods including cultural, mechanical and chemical under integrated weed management (IWM) strategy.

The present study included data of 10 crops from 18 states for the assessment of yield and economic losses due to weeds. However, if more number of crops and locations are included, the losses may be much greater than what is actually estimated from the available data. Also, under changing climate scenario, weeds may get favourable environment against crops and may inflict higher loss in crop production (Peters et al., 2014; Ramesh et al., 2017).

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cropro.2018.01.007.

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