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Research Article

Bioeconomic evaluation of allelopathic crop leachates integrated with reduced doses of herbicide for horse purslane management in maize under field conditions

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INFORMATION ARTICLE

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

HIGHLIGHTS

- Allelopathic crop leachates mixed with half dose of herbicide are effective to manage horse purslane in maize
- Allelopathic crop leachates+ half dose of herbicide is economical than full dose of herbicide
- Integrated use of allelopathy and reduced rates of herbicides may be an eco-friendly way for weed management

ABSTRACT

Background: Continuous use of commercial herbicides is posing a severe threat to environment and creating herbicide resistant weeds. Allelopathy offers a promising alternative to commercial herbicides for sustainable weed management. The farmers are highly concerned with maximum yield as well as cost of the weed control techniques.
Objective: To investigate economic and weed control efficiency of allelopathic crop water leachates mixed with lower rates of herbicide.
Methods: Rapeseed (*Brassica napus* L.), sunflower (*Helianthus annuus* L.) and sorghum (*Sorghum bicolor* L.) crop leachates (18 L ha^{-1} each) tank mixed with lower doses (25, 33 and 50% of recommended dose) of S-metolachlor+atrazine were sprayed as pre-emergence for horse purslane (*Trianthema portulacastrum* L.) management in maize (*Zea mays* L.). Label dose (1,080 g a.i. ha^{-1}) of herbicide (S-metolachlor+atrazine) and a weedy check treatment were also maintained.
Results: The results showed that rapeseed+sunflower+sorghum allelopathic leachates mixed with half dose (540 g a.i. ha^{-1}) of S-metolachlor+atrazine was effective against horse purslane and increased maize yield (grain) by 45% and 5% as compared with control and label dose of herbicide, respectively. Likewise, economic analysis showed that the same treatment was most economical with 40% and 9% higher net benefits than control and label dose of herbicide, respectively and 2407% marginal rate of return. It also gave an additional benefit of US$ 24.07 for investment of every US$1.
Conclusions: By using this technique, herbicides use can be minimized by 50% for sustainable weed management without compromising maize yield and net benefits.

1 Introduction

Though herbicide use is an effective way for weed management; however, its continuous use has developed weed resistance to several herbicides. At present, 255 weed species have been reported as resistant to 163 herbicides worldwide (Heap, 2018). Moreover, herbicides pollute the water, aerial and soil environments and have enhanced the risk of diseases due to presence of herbicidal residues in the food (Eisler, 2000). Furthermore, increasing costs of the herbicides result in higher cost of production and less net income of the farmers, particularly in developing countries. These problems are pressing the researchers to look for alternative weed control options (Macías et al., 2007; Perveen et al., 2019).

Herbicide use could not be abolished due to high demand of food for masses; nevertheless, their use can be minimized in field crops by using integrated weed management approaches (Anderson, 2007). Crop allelopathy, a natural phenomenon that involves the release of allelochemicals by one plant which inhibits the growth of other plants, may be helpful to minimize the use of herbicides (Weston and Duke, 2003; Mushtaq et al., 2013). Allelopathy has been advocated as alternative to herbicides, particularly in the recent years, for weed management in agronomic crops (Macías et al., 2007; Jamil et al., 2009; Perveen et al., 2019). To reduce herbicide use, a viable option is the integrated use of lower herbicide doses and allelopathic crop leachates. (Cheema et al., 2005; Iqbal et al., 2009).

Rapeseed, sunflower and sorghum are three important allelopathic crops grown worldwide and their inhibitory effects against weeds have been well documented (Weston and Duke, 2003; Macías et al., 2007). Allelopathic crop leachates can be used as foliar sprays like herbicides (Singh et al., 2003). Leachates of sorghum, sunflower and rapeseed have been found effective in managing weeds in field crops (Batish et al., 2002; Weston and Duke, 2003; Norsworthy et al., 2007). Allelopathic leachate mixture of two or more crops may enhance their efficacy for weed control (Duke et al., 2000). Likewise, mixture of allelopathic leachates combined with lower doses of herbicides is as effective as label dose of herbicides for weed control in field crops (Cheema et al., 2005; Iqbal et al., 2009); however, it is not well known whether this technique is economical.

The farmers are highly concerned with maximum yield and cost of the weed control methods. Therefore, besides biological efficiency, any weed management technique may also be evaluated under field conditions for its economic suitability before recommendation to farmers (CIMMYT, 1988). The present study was carried out to investigate a mixture of rapeseed+sunflower+sorghum leachates combined with lower doses (25, 33 and 50% of recommended dose) of S-metolachlor+atrazine for management of horse purslane in maize field and to analyze its economic fitness through calculating net benefits, marginal rate of return and net benefit-cost curve. Horse purslane, a noxious weed of maize and other arable crops, is distributed worldwide in tropical, subtropical and semiarid regions (Balyan and Bhan, 1986). It is highly competitive with crops and its infestation reduces crop yields, on an average, by 32%. The yield losses may be higher if the weed is not timely controlled (Balyan and Bhan, 1989).

2 Materials and Methods

2.1 Crop husbandry and site

The experiment was carried out in the field. Seedbed was prepared after application of soaking irrigation. Hybrid maize (Monsanto-919) was sown in autumn on 18th of August with row to row spacing of 70 cm and seed rate of 30 kg ha^{-1} (Figure 1). Thinning was done 25 days after sowing (DAS) to keep plant to plant distance of 15 cm. Nitrogen (150 kg ha^{-1}) was applied in 3 splits (at sowing, 35 DAS and tasseling stage), while both potash (K_2O) and phosphorus (P_2O_5) at 100 kg ha^{-1} were used at the time of sowing. The irrigations were applied according to the need of the crop. Insect-pests were controlled with the application of standard insecticide(s).

2.2 Preparation of leachates and application of treatments

For preparation of crop leachates, mature biomass (above-ground) of rapeseed, sunflower and sorghum was collected from respective fields. The grains were separated, and herbage was used to prepare crop leachates. The shade-dried crop material was chopped (2-3 cm) and soaked in water (100 g L^{-1}, w/v). After 24 h, it was filtered with sieve to obtain the allelopathic crop leachates. The leachates were boiled (100 °C) to avoid any fungal contamination and to decrease the volume of leachates. There is no adverse effect of boiling on efficacy of crop leachates (Jamil et al., 2009).

Calibration was done to calculate spray volume (330 L ha^{-1}) using knapsack sprayer (Jamil et al., 2009). Crop leachates as rapeseed, sunflower and

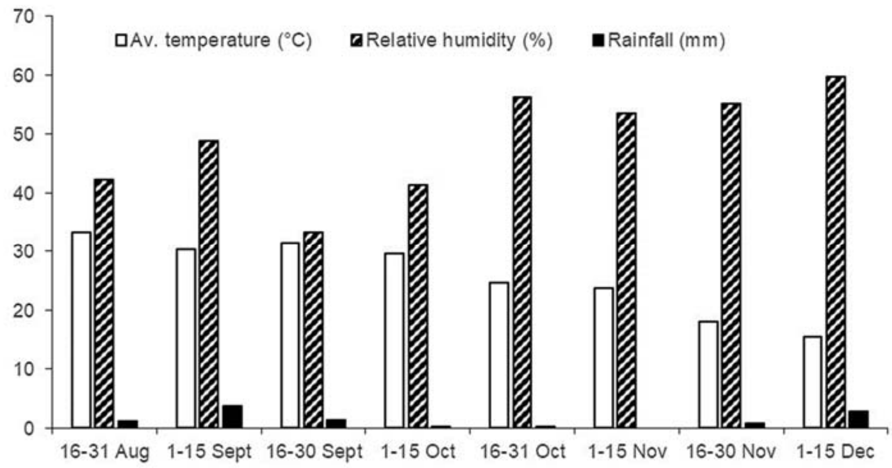


Figure 1 - Weather parameters during growing season of the maize crop.

sorghum each at 18 L ha^{-1} were tank mixed with 25% (270 g a.i. ha^{-1}), 33% (360 g a.i. ha^{-1}) and 50% (540 g a.i. ha^{-1}) of label rate (1,080 g a.i. h^{-1}) of S-metolachlor+atrazine (Primextra Gold® 720-SC). The leachates+herbicide mixture was sprayed on the soil next day to sowing of the crop as pre-emergence to weeds. A label dose of herbicide, S-metolachlor+atrazine and a weedy check as control were also used.

2.3 Statistical design and data collection

A randomized complete block design (RCBD) was used with 4 replications and gross plot size of 7 m×2.8 m. At 40 and 60 DAS, horse purslane dry biomass and density were obtained from two places of respective plot measuring 0.5 m×0.5 m. The data of two samples were averaged and presented as m^2. Maize was harvested at 110 DAS. Biological and grain yield was obtained by harvesting all plants of each plot and presented as Mg ha^{-1}. Grain production efficiency was calculated by ratio of the total grains to cob weight.

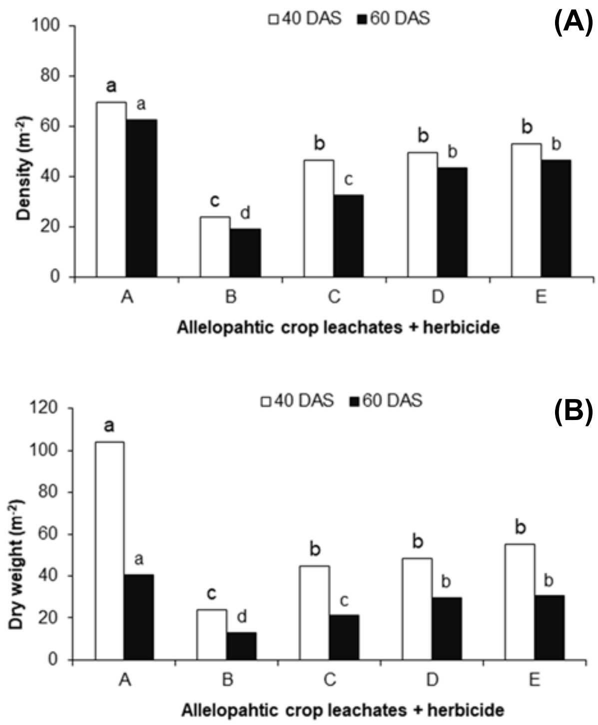
2.4 Statistical and economic analyses

ANOVA was used to statistically compare treatment means at P<0.05 (Steel et al., 1997). Economic analysis (partial budget, total cost that vary, net benefits, marginal rate of return and net benefit-cost curve) was performed following CIMMYT (1988).

3 Results and Discussion

3.1 Effect of allelopathic crop leachates and lower doses of herbicide on horse purslane

All treatments significantly reduced the density and dry matter production of horse purslane over control (Figure 2). Mixture of rapeseed, sunflower and sorghum leachates each at 18 L ha^{-1} integrated with half dose (540 g a.i. ha^{-1}) of S-metalochlor+atrazine reduced the density of horse purslane by 33-48% and dry matter production by 48-57% at 40 and 60 DAS, respectively. Label dose of S-metolachlor+atrazine at 1,080 g a.i. ha^{-1} suppressed horse purslane density by 65-70% and dry matter production by 68-77% at 40 and 60 DAS, respectively.



(A) Control; (B) S-metolachlor+atrazine at 1,080 g a.i. ha^{-1}; (C) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 540 g a.i. ha^{-1}; (D) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 360 g a.i. ha^{-1}; (E) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 270 g a.i. ha^{-1}. Bars of same color having different letters are statistically different at p<0.05.

Figure 2 - Effect of allelopathic crop leachates combined with reduced doses of S-metolacholar+atrazine on (a) density and (b) dry matter production of horse purslane.

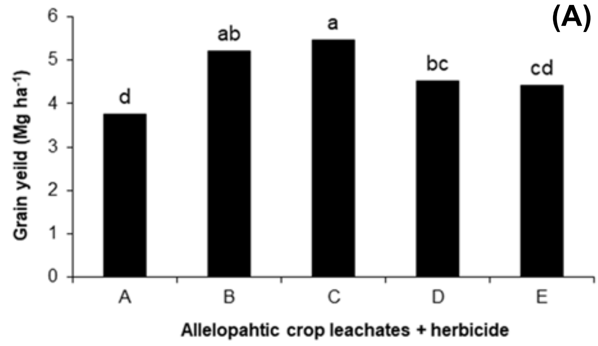
3.2 Effect of allelopathic crop leachates and lower doses of herbicide on yield of maize

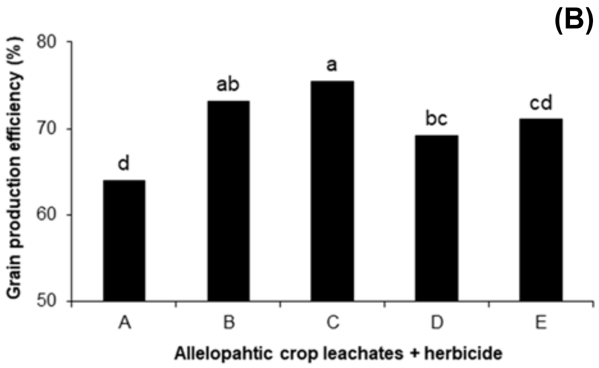
All treatments significantly improved grain yield and grain production efficiency of maize as compared with control (Figure 3). Maximum grain production efficiency (76%) was obtained from the mixture of rapeseed+sunflower+sorghum each at 18 L ha^{-1} combinedwith S-metolachlor+atrazine at 540 g a.i. ha^{-1}. This treatment also increased maize grain yield by 45% and 5% over control and label dose of herbicide, respectively.

3.3 Economic analysis of the study

Partial budget calculation revealed that all the treatments produced significantly higher net benefits as compared with control (Table 1). Rapeseed+ sunflower+sorghum leachates combined with half dose (540 g a.i. ha^{-1}) of S-metolachlor produced 40% higher net benefits than control and 9% higher net benefits than full dose (1,080 g a.i. ha^{-1}) of S-metolachlor+atrazine (Table 1 and Figure 4). Application of label dose of herbicide (1,080 g a.i. h^{-1}) resulted in the highest total cost that varied. Marginal rate of return was maximum (2407%) in rapeseed+ sunflower+sorghum leachates mixed with half dose (540 g a.i. ha^{-1}) of S-metolachlor+atrazine, while label dose of herbicide (S-metolachlor+atrazine) at 1,080 g a.i. ha^{-1} was uneconomical with negative marginal net benefits (-24) and was dominated by preceding treatment due to higher cost that varies and lower net benefits than preceding treatment (Table 2). Likewise, marginal rate of return revealed that for every US$1 invested on weed control using rapeseed+sunflower+sorghum leachates combined with half dose (540 g a.i. ha^{-1}) of S-metolachlor+ atrazine recovered the US$1 (cost) and an additional benefit of US$24.07 (Table 2). In case of the label dose (1,080 g a.i. ha^{-1}) of S-metolachlor+atrazine, even the invested amount (US$1) was not recovered (Table 2 and Figure 4).

Rapeseed, sunflower and sorghum leachates combined with half dose (50% of label dose) of S-metolachlor+atrazine suppressed horse purslane





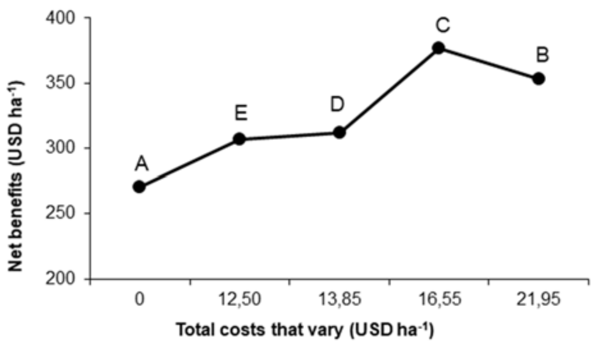
(A) Control; (B) S-metolachlor+atrazine at 1,080 g a.i. ha^{-1}; (C) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 540 g a.i. ha^{-1}; (D) Rapeseed+ sunflower+sorghum leachates each at 18 L ha^{-1}+ S-metolachlor+ atrazine at 360 g a.i. ha^{-1}; (E) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1}+ S-metolachlor+atrazine at 270 g a.i. ha^{-1}. Bars having different letters are statistically different at $p<0.05$.

Figure 3 - Effect of allelopathic crop leachates combined with reduced doses of S-metolacholar+ atrazine on (a) grain yield and (b) grain production efficiency of maize.

Table 1 - Partial budget of horse purslane management in maize

Budget parameter	Weed control treatment					Remark
	A	B	C	D	E	
Grain yield	3.76	5.21	5.46	4.52	4.43	Mg ha^{-1}
Adjusted grain yield (less by 10%)	3.38	4.69	4.92	4.07	3.99	10% reduction in grain yield to bring it at farmers' level
Gross field benefits	270	375	394	326	319	US$ 80 Mg^{-1}
Cost of S-metolachlor+Atrazine	0	16.20	8.10	5.40	4.05	US$ 15/1000 g a.i.
Cost of leachates	0	0	2.70	2.70	2.70	US$ 0.90 per 18 L
Sprayer rent	0	1.00	1.00	1.00	1.00	US$ 1 per spray ha^{-1}
Spray application charges	0	4.75	4.75	4.75	4.75	US$ 4.75 per man-day (one-man-day ha^{-1})
Total cost that vary	0	21.95	16.55	13.85	12.50	US$ ha^{-1}
Net benefits	270	353	377	312	307	US$ ha^{-1}
Increase in net benefits as compared with control (%)	-	31	40	16	14	-

(A) Control; (B) S-metolachlor+atrazine at 1,080 g a.i. ha^{-1}; (C) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1}+ S-metolachlor+atrazine at 540 g a.i. ha^{-1}; (D) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 360 g a.i. ha^{-1}; (E) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 270 g a.i. ha^{-1}



(A) Control; (B) S-metolachlor+atrazine at 1,080 g a.i. ha^{-1}; (C) Rapeseed+sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 540 g a.i. ha^{-1}; (D) Rapeseed+ sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 360 g a.i. ha^{-1}; (E) Rapeseed+ sunflower+sorghum leachates each at 18 L ha^{-1} + S-metolachlor+atrazine at 270 g a.i. ha^{-1}.

Figure 4 - Net benefit curve of horse purslane management in maize by allelopathic crop leachates combined with reduced doses of S-metolacholar+ atrazine.

dry matter production by 57% (Figure 2). Allelopathic effects of sorghum, sunflower and rapeseed leachates against weeds have been reported in several studies and phytotoxins present in these crops have also been identified. Sorghum is a well-studied allelopathic crop and has allelochemicals such as syringic acid, gallic acid, sorgoleone, p-hydroxybenzoic acid, protocateuic acid, vanillic acid, dhurrin, p-coumaric acid, ferulic acid, benzoic acid, m-coumaric acid, p-hydroxybenzaldehyde and caffeic acids; which have phytotoxic effects against weeds (Netzly and Butler, 1986; Alsaadawi et al., 2007; Cheema et al., 2009). In sunflower, isochlorogenic acid, chlorogenic acid, α-naphthol, annuionones and scopolin allelochemicals have been identified, which showed inhibitory effects against weeds (Macías et al., 1998; Macías et al., 2002). Likewise, many species of genus brassica have allelopathic potential against weeds (Bell and Muller, 1973). Glucosinolate hydrolysis products as isothayanates and volatile compounds like benzenoid and isoprenoid are promising allelochemicals released from rapeseed that suppress weed growth (Norsworthy et al., 2006, 2007). The inhibition of horse purslane by combination of sorghum, sunflower and rapeseed leachates may be due to the presence of variety of water soluble allelochemicals. Sorghum, sunflower and rapeseed allelopathic leachates suppressed growth of broad leaf weeds (Batish et al., 2002; Cheema et al., 2005; Norsworthy et al., 2007). The combination of leachates with lower doses of herbicides increases their efficacy for control of weeds. Furthermore, herbicides use could be reduced through its integrative use with allelopathic crop leachates (Cheema et al., 2005; Iqbal et al., 2009).

In the present study, though full dose of herbicide provided more weed inhibition than leachates+ reduced doses of herbicide; nonetheless, the increase in maize yield was higher in rapeseed+sunflower+ sorghum leachates+half dose of S-metolachor+ atrazine than full dose of herbicide (Figure 4). The higher yield by this treatment may be attributed to plant growth promotive effect of allelochemicals on crop (Mallik and Williams, 2005). Integrated use of sorghum leachate with half dose of pendimethalin gave 14% higher yield of cotton than recommended dose of pendimethalin, although weed control was 19% higher in label dose of pendimethalin (Cheema et al., 2005).

Economics of every technology plays important role for its adoption by farmers. Before recommendation to famers, any weed management technique may be carefully evaluated for its cost-effectiveness (CIMMYT, 1988). To investigate the economic fitness of the present study, partial budget, total cost that varied, total net benefits and marginal rate of return were calculated. The economic analysis revealed (Tables 1 and 2; Figure 4) that combination of allelopathic leachates with reduced dose (half) of herbicide is economically viable technique for management of horse purslane. Sorghum, sunflower

Table 2 - Marginal rate of return and dominance analysis

Treatment		Rate ha^{-1}	Total cost that vary (US$)	Net benefits (US$)	Marginal cost	Marginal net benefits	Marginal rate of return	Marginal rate of return (%)
A	Control (weedy check)	-	0.00	270	-	-	-	-
E	Rapeseed+sunflower+sorghum+ S-metolachlor+atrazine	18 L each + 270 g a.i.	12.50	307	12.50	37	2.96	296
D	Rapeseed+sunflower+sorghum+ S-metolachlor+atrazine	18 L each+ 360 g a.i.	13.85	312	1.35	05	3.70	370
C	Rapeseed+sunflower+sorghum+ S-metolachlor+atrazine	18 L each+ 540 g a.i.	16.55	377	2.70	65	24.07	2407
B	S-metolachlor+atrazine	1080 g a.i.	21.95	353	5.40	-24	D*	D*

D* = Dominated by preceding treatment due to higher total cost that vary and less net benefits than the proceeding treatment.

and rapeseed leachates combined with half dose of S-metolachlor+atrazine resulted in higher net benefits than full dose of herbicide. It gave 2407% marginal rate of return which means that investment in this treatment is profitable as compared with label dose of herbicide. The label dose of herbicide was uneconomical due to higher total costs that varied. This proves that use of allelopathic leachates combined with 50% dose of S-metolachlor+atrazine is eco-friendly and economically viable option for management of horse purslane in maize fields.

Sorghum, sunflower and rapeseed are widely grown crops all over the world. Farmers can easily prepare allelopathic leachates at their own farms. After harvesting and threshing, economic portion of the crop is separated, and the remaining herbage may be used for preparation of crop leachates.

4 Conclusions

Combination of sorghum, sunflower and rapeseed leachates with half dose of herbicide is not only effective in managing horse purslane but also cost-effective and increase the maize yield; hence, use of herbicide could be reduced by 50% without comprising the yield and net benefit from the crop. This technique is not only economical but may also be helpful to reduce consumption of commercial herbicides for sustainable weed management especially in the growing need of sustainable agriculture world over.

5 Contributions

MMN, and CZA: planned the experiment; MMN: performed the experiment, collected, and analyzed data and wrote manuscript; HMI, and TT: assisted in data analysis; MA, and HS: assisted in improving write up of the manuscript.

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