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Allelopathic potential of corn residues to manage weeds in cowpea

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ABSTRACT

Field experiments were carried out at two sites to test the responses of weeds in cowpea crop to soil incorporation and surface mulching of corn residue alone or in combination with 50% rate of trifluralin herbicide. Conventional and zero tillage systems without corn residues, half of label rate and full label rate of trifluralin were included for comparison. Incorporated or mulched corn residues significantly reduced weed density and dry weight compared to conventional tillage treatment (control) at both sites. Residue incorporation and mulching plots in combination with 50% of label rate of trifluralin revealed significantly lower weed numbers and dry weight as compared to their respective controls. Soil incorporation and surface mulching of corn residue in combination with 50% rate of trifluralin achieved similar weed control and cowpea grain yield when compared to the 100% trifluralin treatment. Plots amended with corn residue showed greater levels of phenolics. Also, the periods of maximal suppressive effect against the test weed coincided with periods of maximum phenolic content, indicating the possible involvement of phenolics in weed suppression. Combination of allelopathic residues and a reduced rate of herbicides could reduce herbicide usage in agricultural systems while the weed control is not compromised.

Key words: Allelopathy, corn incorporated and mulch residues, less herbicide, weed management, cowpea

INTRODUCTION

Field crops infested with weeds suffered severe losses in both quantity and quality of output. Herbicides have historically been used in weed management strategies (15). Herbicide usage has become essential to weed control in modern agriculture and a number of herbicide molecules are available for this purpose. Yet, overuse and inappropriate application of herbicides during the past 60 years have harmed ecosystems, raised questions about public health, and created populations of weeds that are resistant to herbicides (16,23). These factors have caused the FAO Expert Consultation Group on "Weed Ecology and Management" to express grave concern over the use of herbicides for weed management and to advocate decreasing or eliminating their usage (24). Nonetheless, because of the rising need for food to feed the expanding global population, pesticide use cannot be completely abolished. Hence, researchers have concentrated on employing integrated weed control techniques in field crops to reduce the input of pesticides (7).

Allelopathy has been touted as one of the most effective methods for weed management in field crops (28,36). Allelopathic plant extract, plant residue integration, cover crops, and residue mulch are some of the several approaches that may be used to include allelopathy into weed management programs (28,32). Unfortunately, these tactics'

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effectiveness was often lower than the full dose of chemical herbicides. As a result, allelopathy and reduced herbicides rates are combined to manage weeds in various field crops. A significant amount of study was done utilizing allelopathic plant extract in conjunction with various herbicides, and effective results in terms of reducing weeds and enhancing various field crops were reported (11,21). Nevertheless, for large-scale operations, this strategy has limitations (4). Allelopathic residues have been used with reduced herbicide rates during the past ten years to suppress weeds and provide crop yields that are comparable to or better than those produced with herbicides used at their recommended rates (4,5,22). There isn't much information available, however allelopathic residue mulches and reduced herbicide rates have been attempted together (38).

In Iraq, corn is a summer crop grown twice a year. It is rotated with other crops, primarily cowpeas which is widely used as nutritional crop. The farmers used trifluralin as a pre-emergence herbicide to control summer weeds that severely infest cowpea. Corn is reported to be allelopathic against weeds by several investigators (18,19), and several allelochemicals mainly phenolics were identified in corn herbage (13,37). Present study explored the effect of corn residues incorporated into field soil or used as a surface mulch in combination with lower rate of trifluralin on weeds of cowpea as a cost effective and safe weed control practice. The possible role of phenolics released from decomposing corn residues in field in modifying weed emergence and biomass has been discussed.

MATERIALS AND METHODS

The intended study was carried out at two sites. The first one was on a research farm at Baghdad University's College of Science, located at 33° 16' 13" N latitude and 44° 22' 44" E longitude and 40 meters above sea level. The farm's soil was calcareous loamy and had a pH of 7.3, an EC of 1.2 dSm^{-1}, and an organic carbon content of 1.2 g Kg^{-1}. The second site was on a Wasit University research farm, located at 32° 29' 49.8" N and 45° 50' 33.5" E longitude, 35 m above sea level. The soil was calcareous sandy loam, and its pH, EC, and organic carbon values were 7.17, 2.3 dSm^{-1}, and 4.87 g kg^{-1}, respectively.

Seeds and herbicides

Seeds of cowpea (*Vigna unguiculata* L. (Walp) cv. Ramshorn), corn (*Zea mays* L) Ronaldinio hybrid, and trifluralin herbicide were acquired locally.

Sources of corn residues

Fields at both sites were ploughed with discs in early March 2019 and split into four plots (5 x 2 m) with four replications. Corn was hand sown on March 19 and 24, 2019 in Baghdad and Wasit fields, respectively. Sowing was placing by dibbling seed at 20 cm spacing in 75 cm apart rows, yielding a density of 6.6 plants m^{-2} (29). Urea (46% N) at 240 kg ha^{-1} and phosphorus as triple superphosphate (46 % P_2O_5) at 160 kg ha^{-1} were used as indicated for corn crop. All phosphorous and half of the nitrogen were applied at planting, while the remaining half of the nitrogen was applied at the blooming stage (29). As necessary, pest control and irrigation were handled.

In July 2019, at physiological maturity, the corn cobs were removed and the remaining were cut to ground level, air dried for 2- weeks under shade and chopped into pieces (2-3 cm) by manual fodder cutter. All plots were tilled twice and divided into 3 sub-plots (1.5 × 2 m) at the beginning of August 2019 and used as per following treatments:

Experimental treatments used

#	Til Plots
1	No corn residues (Control 1)
2	Corn residues incorporated
3	Corn residues incorporated + 50 % trifluralin
4	50 % Trifluralin
5	100 % full Trifluralin
	No Til Plots
6	No corn residues (Control 2)
7	Corn residues mulched
8	Corn residues mulched + 50 % trifluralin
9	50 % Trifluralin
10	100 % full Trifluralin Dose

For residue incorporation treatments, corn residues were incorporated into the soil at a rate of 5 t ha^{-1}, which is about 50 % of the corn residues remained after harvest (20). Corn residues were applied to the surface of the plots at a rate of 5 t ha^{-1} for the mulching treatments. Trifluralin was applied as per treatment two days before planting of cowpea using a calibrated spray volume of 300 L ha^{-1} using a hand sprayer equipped with a Tee Jet nozzle at a pressure of 270 kPa, and top soil was mixed in with a rake to avoid volatilization and photolysis of the herbicide.

Fertilizers included triple super phosphate (phosphorus) at 240 kg ha^{-1} and urea (46 % N) at 80 kg ha^{-1}. All phosphorus and half of the nitrogen were applied at sowing, with the remainder N applied one month later. On August 5, 2019, cowpea seeds were manually sown in 40 cm apart rows and 20 cm apart plants attaining plant density of 12.5 plants m^{-1}. All plots received the recommended irrigation.

Both locations had experiments set up in a split plot configuration with four replications using a randomized full block design. Herbicide rates were given to the sub plots whereas corn residue rates were placed in the main plots.

At 30 and 75 days following planting, weed density and dry weight were measured for each experimental unit using two randomly chosen quadrats (50×50 cm). Weeds were counted, clipped, and oven-dried at 70 ºC for 72 h. The dry weight of the weeds was then recorded using a digital scale. Weed biomass and density data were translated to units of area (m^{-2}).

Weed seedling emergence assay

The effects of decaying corn residue in soil on the development of weeds in cowpea fields for the two locations were investigated independently in a lab/pot experiment. Litter-free soil was taken from the mulched and soil-incorporated plots at 0, 2, 4, 6 and 8 weeks after residue treatments. Soil samples from plots with no tillage and conventional tillage were taken for comparison. The soil was placed into plastic pots (200 g/pot) after air drying for three days at room temperature. There were 20 pigweed seeds sown in each pot. Four replications of the pots were put up in a randomized pattern under natural growing conditions. Each pot received irrigation as necessary. Each pot was thinned to three seedlings at 15 days after sowing and the seedlings were allowed to flourish for two more weeks before destructive sampling. Plants were then manually removed from the pots under running water, and the dry weight of the pigweed was calculated after oven drying the plants for three days at 70 °C.

Soil phenolic content

With and without corn residues, conventional and zero tillage plots', soil samples were collected at intervals corresponding to the decomposition times (0, 2, 4, 6 and 8 weeks) employed for the bioassay experiment in pots. Each soil sample was completely blended before being left to air dry for three days at ambient temperature. 250 ml of distilled water and 250 g of dry soil samples were each added individually, and the mixture was shaken for 24 hours at 200 rpm (8). Under vacuum, Whatman No. 2 filter paper was used to filter the soil suspensions, and the Folin-Denis technique was used to calculate the phenolic content (22).

Cowpea growth and yield

The seed yield and yield components of cowpea (number of pods per plant, number of seeds per pod, and weight of 100 seeds) of ten randomly selected plants from each plot at physiological maturity (75 DAS) were recorded (23).

The data were subjected to a variance analysis using the GEN STAT program. The least significant difference (LSD) was used to compare treatment means at the 0.05 probability level (25).

RESULTS AND DISCUSSION

Weeds density and dry biomass

Weed flora dominating the cowpea in both sites comprised mainly of *Malva rotundifolia* L., *Corchorus olitorius* L., *Sorghum halepense* L., *Cynodon dactylon* L., *Setaria viridis* (L.) P. Beauv, *Echinochloa colonum* (L.) Link, *Portulaca oleracea* L., *Cyperus rotundus* L. and *Convolvulus arvensis* L.

At the Baghdad and Wasit locations, respectively, the incorporation of 5 t ha^{-1} of corn residue into the field soil at 30 DAS decreased weed density by 33 and 31 % in comparison to conventional tillage (control) (Table 1). When compared to no tillage, corn residue mulch at the Baghdad and Wasit locations reduced weed density by 56 and 35 %, respectively (control). The decrease rose further when a lower (50 %) rate of trifluralin was added to plots amended with corn residues, resulting in similar weed density reduction to that in full rate trifluralin treatments.

The incorporation of maize residues decreased weed populations and dry biomass by 54 and 31% over conventional tillage at the Baghdad site and by 23 and 13 % over conventional tillage at the Wasit site, respectively, at 75 DAS (Table 2). Trifluralin applied at 50 % of the label rate in zero-tillage plots reduced weed density and dry biomass by 36 and 53 % at the Baghdad site and 64 and 72 % at the Wasit site, respectively. Nevertheless, when residue-incorporated or mulched plots were applied with 50 % of the label rate of trifluralin, the decrease increased and resulted in the lowest weed density and dry biomass, which is statistically comparable to that recorded with the recommended rate of trifluralin.

Table 1. The effect of using corn residues as mulch or soil incorporation together with a reduced rate (50 %) of trifluralin on weed density at 30 DAS of cowpea at two experimental sites.

Treatments*	Weed density m^{-2}*	
	Baghdad site	Wasit site
Tilled Plots		
No corn residues (Control 1)	43.0	16.0
Corn residues incorporated	29.0	11.0
Corn residues incorporated + 50 % trifluralin	15.0	6.0
50 % Trifluralin	27.0	10.5
100 % full Trifluralin	16.5	5.0
No-till Plots		
No corn residues (Control 2)	79.0	23.0
Corn residues mulched	35.0	15.0
Corn residues mulched + 50 % trifluralin	17.0	7.0
50 % Trifluralin	31.8	13.0
100 % full Trifluralin Dose	20.0	8.0
L.S.D ($P\leq 0.05$)	13.9	5.6

* Conventional and zero tillage are without residues and trifluralin.

Table 2. The effect of applying corn residues as mulch and soil incorporation together with a reduced rate (50 %) of trifluralin on weed biomass and density at 75 DAS of cowpea at two experimental sites.

Treatments*	Baghdad site		Wasit site	
	Weed density (m^{-2})	Dry weight biomass (g m^{-2})	Weed density (m^{-2})	Dry weight biomass (g m^{-2})
Tilled Plots				
No corn residues (Control 1)	62.8	189.5	27.5	124.2
Corn residues incorporated	29.0	130.0	21.3	108.5
Corn residues incorporated + 50 % trifluralin	18.0	79.6	9.5	23.6
50 % Trifluralin	30.8	156.8	16.0	94.5
100 % full Trifluralin	27.0	117.7	11.5	39.0
No-till Plots				
No corn residues (Control 2)	75.2	256.9	48.5	332.2
Corn residues mulched	48.0	121.0	17.3	94.1
Corn residues mulched + 50 % trifluralin	27.8	98.4	11.8	29.0
50 % Trifluralin	60.0	160.1	22.0	99.5
100 % full Trifluralin Dose	30.4	104.8	13.0	44.5
L.S.D ($P\leq 0.05$)	25.9	68.6	5.5	27.7

*Tillage and zero tillage treatments are without corn residues and trifluralin (Control).

Cowpea yield and yield components

At the Baghdad site, the incorporation of corn residues, a decreased (50 %) rate of trifluralin and a full rate of trifluralin treatments enhanced seed production by 50, 50 and 80 % than conventional tillage, respectively. At Wasit site, seed production was unaffected by corn residues at 5 t ha^{-1}, but was increased by 50 and 120 % over conventional tillage treatments, respectively, with decreased 50 % trifluralin dose (Table 3). Trifluralin at 50 % in combination with corn residues produced biological yields statistically comparable to those in the treatments when trifluralin was applied at the full rate at both locations. At the Baghdad site, corn mulch (5 t ha^{-1}), residue mulch + 50 % trifluralin and the full rate of trifluralin enhanced seeds yield by 120, 100 and 183 % compared to conventional tillage treatment.

Table 3. The impact of applying corn residues as mulch and soil incorporation together with a reduced rate (50 %) of trifluralin on grain yield and other yield-related metrics of cowpea grown at two experimental locations.

Treatments	Baghdad site				Wasit site			
	Seeds yield (t ha^{-1})	Yield components			Seeds yield (t ha-1)	Yield components		
		Pods per plant	Seeds per pod	100- seeds weight (g)		Pods per plant	Seeds per pod	100- seeds weight (g)
Til Plots								
No corn residues (Control 1)	1.0	7.7	5.4	19.3	1.0	8.0	3.9	21.0
Corn residues incorporated	1.5	10.7	6.9	19.3	0.8	9.1	3.8	22.0
Corn residues incorporated + 50 % trifluralin	2.1	18.3	10.0	21.1	2.4	20.8	7.9	22.3
50 % Trifluralin	1.5	12.0	6.1	19.5	1.5	9.8	4.4	21.6
100 % full Trifluralin	1.8	14.0	6.9	20.1	2.2	17.5	5.7	21.9
No Til Plots								
No corn residues (Control 2)	0.6	4.9	4.5	19.2	0.8	6.9	3.5	21.4
Corn residues mulched	1.5	11.2	6.7	20.2	1.2	12.5	5.4	21.8
Corn residues mulched + 50 % trifluralin	1.9	14.4	8.3	21.1	2.3	18.7	7.4	22.7
50 % Trifluralin	1.2	9.5	5.4	20.0	1.3	9.5	4.1	21.7
100 % full Trifluralin Dose	1.7	13.0	6.6	20.6	1.9	17.2	6.7	21.8
L.S.D ($P \leq 0.05$)	0.6	3.4	1.1	1.4	0.3	2.6	0.7	0.9

* Tillage and zero tillage treatments are without corn residues and herbicide (Control).

At the Baghdad location, incorporated corn residue significantly enhanced the number of pods per plant and the number of seeds per pod by 39 and 28 % over the conventional tillage treatment, however at the Wasit site, there were no discernible changes between these treatments (Table 3). At the Baghdad and Wasit locations, respectively, Corn residues incorporated along with 50 % of trifluralin considerably enhanced the quantity of pods per plant (56 and 23 %) compared to the conventional tillage control. The reduced (50 %) rate of herbicide when coupled with corn residue produced yield components significantly higher than those recorded by the sole application of the full label rate of trifluralin at both sites.

Corn residue mulch significantly increased number of pods per plant and number of seeds per pod by 129 and 49 % over zero tillage treatment, respectively at Baghdad site, and by 81 and 55 % over the zero tillage treatment, respectively at Wasit site (Table 3). The residue mulch + reduced (50 %) rate and the full rate of trifluralin treatments significantly increased the number of pods per plant by 94 and 165 % and the number of seeds per pod by 20 and 47 % over the zero tillage treatment, respectively. However, combination of 50 % dose of trifluralin and mulch of corn residue resulted in similar seed and biological yields advantage as compared to the full rate of trifluralin treatment.

Incorporated and mulched corn residues at 5 t ha^{-1} and the application of 50 % of full dose and full dose of trifluralin herbicide in conventional tillage plots did not significantly affect 100-seeds weight (Table 3) at both sites. However, combination of incorporated or mulched corn residue and the reduced rate of trifluralin (50 %) resulted in a heavier 100-seed than that of the respective full rate of trifluralin control.

Total phenolics in field soil

Total phenolics increased progressively as the decomposition proceeded (Figure 1). Peak values in tilled plots with residue incorporation were achieved at 4th (Baghdad) and 8th (Wasit) week after treatments. Nonetheless, the corresponding peaks for no-till mulching were reached at 6th week at both the sites (Figure 1) and declined thereafter. Throughout all stages of decomposition, phenolics were higher in the residue mulched plots than in the conventional and zero tillage soils without corn residues.

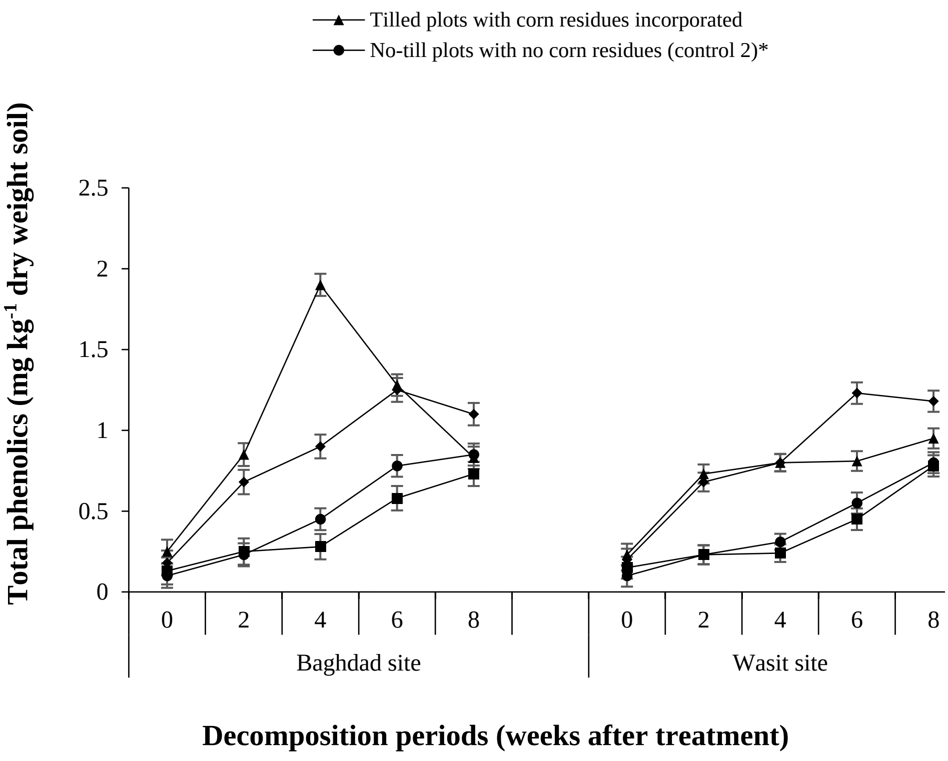

Figure 1. Phenolic content of soil incorporated or mulched with corn residues at two sites at different periods of decomposition. Vertical bars above means indicate standard error of three replications.

Weed seedling emergence and dry biomass

Pigweed seedling emergence was higher in soil of all treatments in both sites during the first 4 weeks except no tillage at Wasit site soil, where the emergence declined after second week of decomposition period with highest decline in 4th and 6th weeks and a mild increase in subsequent weeks of decomposition (Figure 2).

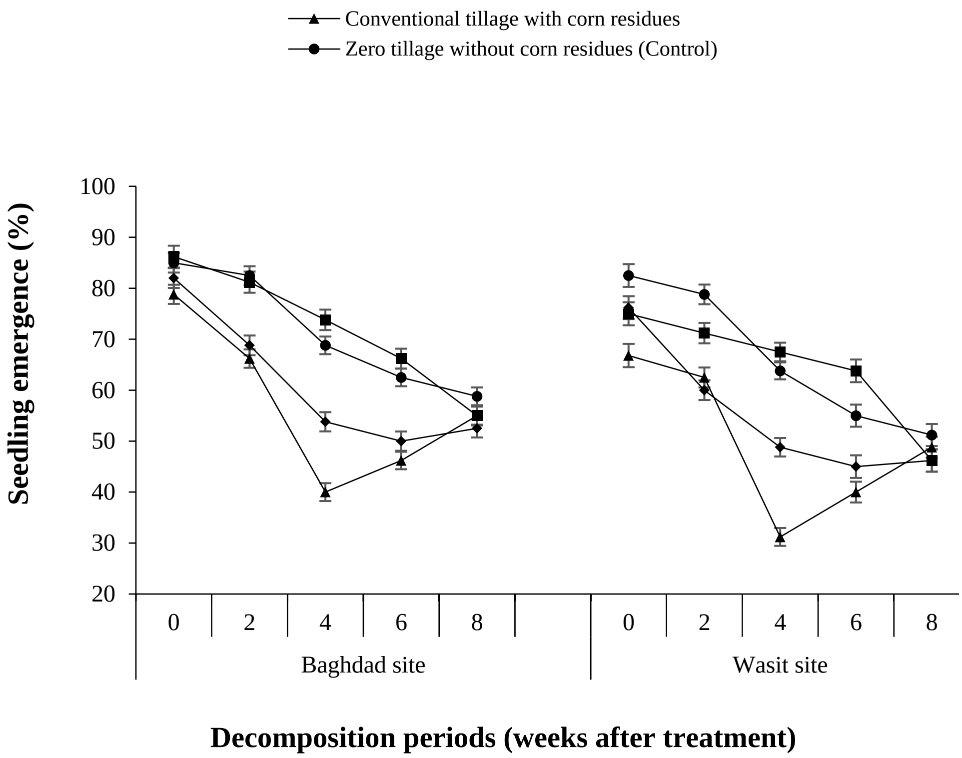

Figure 2. Biological activity of plot mixed and mulched with corn residues at two sites at different periods of decomposition against pigweed seedling emergence. Vertical bars above means indicate standard error of three replications.

Throughout the course of all decomposition periods at both sites, all treatments' dry weight biomass steadily declined with statistically non-significant differences at the 6th to 8th weeks after treatment at both Baghdad and Wasit sites (Figure 3). Incorporating or mulching corn residues into soil resulted in significantly lower dry biomass than the conventional and zero tillage soils without corn residues and such differences were non-significant at all decomposition periods. In both research locations, total phenolic content released from corn residues into the field soil revealed a strongly inverse relationship with pigweed seedling emergence and dry weight biomass throughout all periods of decomposition (Table 4).

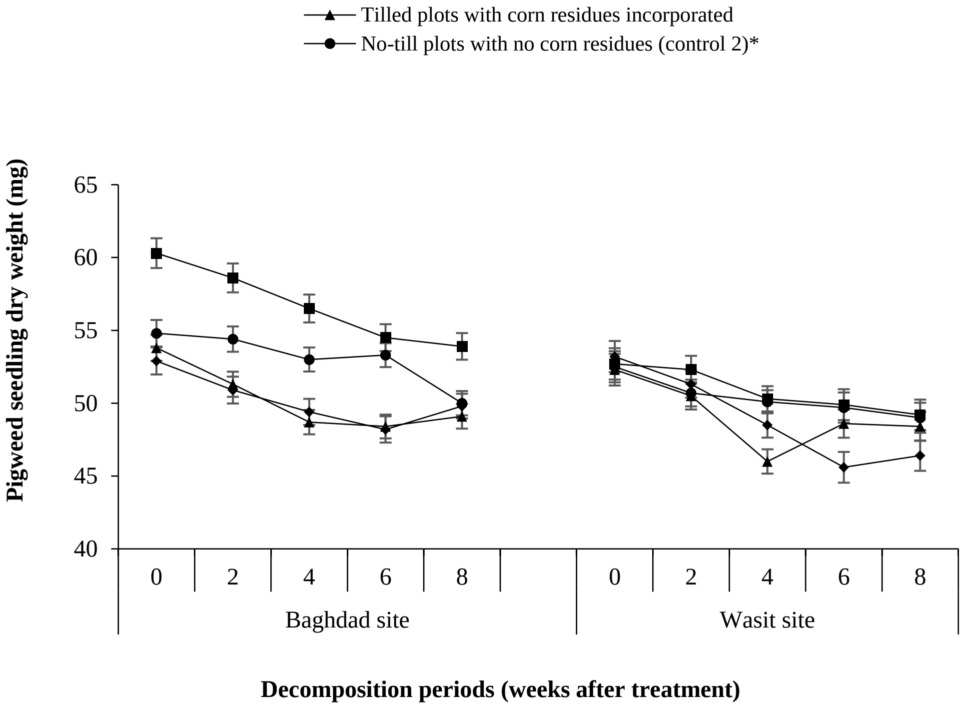

Figure 3. The biological activity of plot mixed and mulched with corn residues at two sites during different decomposition periods against pigweed seedling dry weight. Vertical bars above means indicate standard error of three replications.

Table 4. Correlation between total phenolics in test treatments, emergence rate and dry biomass of pigweed grown in soil incorporated with or mulched with corn residues at Baghdad and Wasit locations.

Treatments	Correlation coefficient	
	Dry weight biomass	% seedling emergence
	Baghdad site	
Tilled plots with no corn residues (control 1)	- 0.940*	- 0.937*
Tilled plots with corn residues incorporated	- 0.970*	- 0.974*
No-till plots with no corn residues (control 2)*	- 0.830*	- 0.890*
No-till plots mulched with corn residues	- 0.966*	- 0.973*
	Wasit site	
Tilled plots with no corn residues (control 1)*	- 0.826	- 0.983*
Tilled plots with corn residues incorporated	- 0.978*	- 0.957*
No-till plots with no corn residues (control 2)*	- 0.617	- 0.637
No-till plots mulched with corn residues	- 0.971*	- 0.953*

*Significant at the 0.05 level, respectively.

Data analysis demonstrated that incorporating corn residues into field soil or residue mulch reduced weed density and dry biomass in the cowpea field (Tables 1 and 2). The release of phytotoxic allelochemicals from decaying corn residues in the rhizosphere may contribute to this decrease. No attempt was made to isolate and identify the allelochemical; however, several investigators have shown that decaying corn residues release a variety of putative allelochemicals including p-coumaric acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, ferulic acid, benzoxazolinones, and others (2,4,37). The inhibitory effect of these allelochemicals on several physiological processes such as chlorophyll biosynthesis, respiration, photosynthesis, ions uptake, hormone biosynthesis, cell division and activity of some enzymes involved in essential metabolic processes have been reported and well documented by many researchers (17,20,26,30,31,34). The majority of these allelochemicals are water soluble, and when ingested by the germinating seeds, they hindered seed germination and subsequent seedling growth, resulting in reduction in density, vigor, and stand establishment of the weed population (14).

The effect of mulch residue on weeds corresponded with the release of phytotoxins into the soil, and it has been documented that phytotoxins suppress weeds in a variety of ways, including lower light interception, changing soil temperature, and physically impeding seedling emergence (33). It is worth noting that weed population and growth were higher in zero tillage plots than in conventional tillage plots, presumably because weed seeds in zero tillage remained near the surface, whereas most weed seeds in conventional tillage went below the surface, or even deeper, delaying/hindering their germination. Thus, weed population control is more efficient by corn mulch than by corn residues incorporation (Tables 1 and 2).

Corn residues incorporated or mulched, together with the application of a lower (50 %) rate of trifluralin prior to sowing achieved comparable results to the full label rate of trifluralin alone (Tables 1 and 2). These results confirmed the findings of Alsaadawi *et al.* (6) and Bohwmik and Inderjit (9), who reported that a lower dose of herbicide applied in conjunction with allelopathic activities could benefit from a complementary interaction and may help reduce herbicide input for weed management in field crops.

When used in combination with a lower amount of trifluralin, Alsaadawi *et al.* (4) also showed that sorghum residues decreased weed biomass and population in faba bean. Moreover, Al-Eqaili *et al.* (1) found that the combination of sunflower residues with a reduced (50 %) rate of chevalier (30 g/l of each metsufuron-methyl and iodosufuron-methyl sodium) was just as effective as the label rate of herbicide in lowering weed density and dry weight in wheat. The toxicity of corn residue began to develop during the early stages of corn decomposition after incorporation or mulching and typically persisted through the sixth week of decomposition. When corn residue was incorporated to field soil, a chemical examination found that it contained more phenolics than the corresponding control (soil without corn residues). Over the whole decomposition period, there was a highly significant negative correlation between the total phenolics and pigweed seedling emergence as well as with dry weight biomass. This indicated that phenolics are undoubtedly involved in the suppression of weeds and may explain the poor growth of weeds noticed early after planting.

Improved cowpea yield at both sites under the influence of corn residue incorporation and/or mulching might be attributed to lower weed pressure under these treatments as compared with plots without corn residue (Table 1, 2). Surface applied mulches were helpful in suppressing weed pressure and improving maize growth and yield performance (38).

The increase in seeds yield of cowpea (Table 3) in both sites by incorporation or mulching of corn alone might result from a decrease in weed-crop competition. Moreover, adding corn residues to field soil enhanced the soil's physical, chemical, and biological qualities properties of soil (26).

The higher seed yield in all test treatments was attributed to the improved number of pods per plant and number of seeds per pod (Table 3). The increase in yield components by combination of allelopathic residues and lower rate of herbicide was reported to be crop dependent. Several investigators showed that the increase in yield of crops such as cowpea, mung bean, broad bean, wheat and barley was due to increase one or two of the three yield components (4,5,22).

CONCLUSIONS

Our findings showed that using soil-incorporated or mulched maize residue along with a lower dose of trifluralin effectively controlled weeds and increased cowpea seed production. Such an approach is likely to reduce the herbicide application by 50%, and ensure environmental safety, minimize human health risks and curb the expansion of herbicide-resistant weeds.

DECLARATION

We declare that all authors of this Ms have made substantial contributions. We have not excluded any author that substantially contributed to this Ms. We have followed our ethical norms established by our respective institutions.

CONFLICT OF INTEREST

The authors announce that they have no conflict interest.

ETHICAL APPROVAL

Animal models were not used in the experiments conducted for this manuscript.

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