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Trifluralin and Corn Residues for Weed Management in Mung Bean Fields, Central Iraq

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Abstract

A field experiment was conducted at two sites (Baghdad and Wasit Governorates) to evaluate the effects of allelopathic corn residues applied as soil incorporation or mulch, alone and in combination with reduced (50% of recommended dose) rate of trifluralin herbicide on weeds growth and mung bean yield. Conventional soil tillage and zero soil tillage treatments with corn residues were performed, while 50% dose and full dose of trifluralin only (without residues) treatments were included for comparison. Soil incorporation and mulch of corn residues reduced weed density and dry weight biomass and improved yield and yield components of mung bean in both sites. Mulch application was more effective than soil incorporation for weed control. However, the reduction in weed growth and the increase in mung bean yield were below the levels achieved by the label dose of herbicide. Application of 50% dose of trifluralin in plots incorporated or mulched with corn residues reduced weeds and scored yield similar to that achieved by 100% herbicide dose applied in both conventional and zero tillage plots. Chemical analysis revealed the presence of higher phenolics in plots amended with incorporated and mulched corn residues compared to their control plots. Chemical analysis also revealed that the periods of maximum quantities of phenolics paralleled with the periods of maximum suppressive activity against weed tested under field condition, which explains the phytotoxicity of phenolics on weed suppression. Such approach may help in reducing reliance upon high concentrations of trifluralin herbicide, improving the sustainability of agroecosystem, improving environmental safety, mitigating human health risks, and reducing the ability to tolerate herbicides.

Keywords: low dose; herbicide; allelopathy; weed management; mung bean; maize.

الترفلورالين ومخلفات الذرة الصفراء لإدارة الأدغال في حقل الماش

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الخلاصة

نفذت تجربةحقلية في موقعين مختلفين في محافظتي بغداد و واسط لدراسة تأثير استخدام مخلفات الذرة الصفراء المخلوطة في تربة الحقل او المستخدمة كغطاء لسطح تربة الحقل بصورة منفردة او مع جرعة منخفضة (50% من الجرعة الموصى بها) من مبيد الترفلورالين في نمو الادغال وحاصل الماش. وقد نفذت

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معاملات شملت اضافة مخلفات الذرة الصفراء قبل حراثة التربة ومعاملة اضافة مخلفات بدون حراثة التربة ومعاملتي 50 و 100% من مبيد الترفلورالين لأغراض المقارنة. بينت الدراسة ان خلط المخلفات بتربة الحقل او استخدامها كغطاء قد سببت اختزالا معنويا في كثافة و نمو الادغال مع زيادة في حاصل الماش مقارنة بمعاملتي المقارنة مع تقدم عامل التغطية على عامل الخلط في الحد من نمو الادغال, الا ان هذا الاختزال لا يرتقي الى الاختزال الذي حققته معاملة التركيز الموصى بها من مبيد الترفلورالين. ان معاملة خلط مخلفات الذرة الصفراء بالتربة او تغطيتها للحقل مع استخدام نصف الجرعة الموصى بها من المبيد قد سجلت زيادة في اختزال كثافة ونمو الادغال وزيادة في حاصل الماش ومكوناته بنسبة مساوية احصائيا لما حققته معاملة الجرعة الكاملة من المبيد في كلا الموقعين. وعند اجراء التحاليل الكيميائية لتربة الحقل تبين وجود محتوى عال من المركبات الفينولية في تربة الحقل المضافة اليها مخلفات الذرة الصفراء خلطا او تغطيتا وفي كلا الموقعين مقارنة بمعاملتي المقارنة. وقد لوحظ ان الفترات التي شهدت تراكيز عالية من المركبات الفينولية قد ارتبطت مع فترات تسجيل اعلى معدلات للتثبيط في كثافة ونمو الادغال المدروسة الأمر الذي يشير الى سمية المركبات الفينولية للأدغال في الحقل. ان استخدام هذه الطريقة سيساهم في اختزال تركيز مبيد الترفيورالين المضاف الى التربة ويحسن من استدامة النظام الزراعي وتحسين امن النظام البيئي و صحة الانسان فضلا عن تحقيق حاصل عالي لايختلف عن ما يحققه المبيد بكامل الجرعة.

1. Introduction

Herbicides account for two thirds of the total pesticide usage in the world [1]. Therefore, it is imperative to find out some natural practices or methods to control the weeds. Allelopathy has been found to offer eco-friendly approaches that can be used for controlling weeds effectively with least environmental concerns. Application of allelopathic crop extracts and residues is among the practical strategies for this purpose [2, 3]. However, in most cases, allelopathic extracts or crop residues provide limited weed suppression, and most often suppression of weed growth is not comparable to those achieved with labeled herbicide doses [4]. Therefore, other methods that help increase the efficacy of allelopathic extracts or residues may be critical to enhance weed suppression while reducing our reliance on herbicides. A substantial scope exists to reduce the herbicide rate in which lower rates of herbicides are applied in combination with aqueous extracts. Likewise, allelopathy of sunflower and sorghum residues, combined with lower rates of herbicides, showed similar weed suppression to that achieved by the label rate of herbicides in barley and wheat fields, respectively [5,6]. This study evaluated the influence of allelopathic corn residues applied as soil-incorporated or as mulch, alone and in combination with reduced (50%) rate of trifluralin, on weed growth and mung bean yield.

2. Materials and methods

2.1. Experimental sites

The experiment was conducted at two sites. The first one is the research farm of the College of Science, Baghdad University, Baghdad (33° 16' 13" N latitude and 44° 22 ' 44" E longitude, 40 m above sea level). The soil of the farm was loamy with organic carbon content, pH, and EC values equal to 2.8 g Kg^{-1}, 7.7, and 1.2dSm^{-1}, respectively. The second site is the research farm of Wasit University, (32° 29' 49.8" N latitude and 45° 50 ' 33.5" E longitude, 35 m above sea level). The soil of the farm was silt clay loam with organic carbon content, pH, and EC values equal to 2.2 g Kg^{-1}, 7.5, and 2.3dSm^{-1} respectively.

The fields of the two sites were tilled twice at the beginning of March 2019 by using a disc plough and divide into 4 plots measuring 5 × 2 m with four replications. Seeds of corn cv. Ronaldinio hybrid were sown in March 19th and 24th, 2019, at Baghdad and Wasit fields, respectively, in rows, with a distance of 20 cm between seeds and 75 cm between rows, as recommended for corn crop [7]. Nitrogen fertilizers of urea (46% N) at 240 kg ha^{-1} and phosphorus, as triple superphosphate (46% P_2O_5), at 160 kg ha^{-1} were applied as

recommended for corn crop [8]. Pest control and irrigation were applied whenever necessary. At maturity, the cones were removed and the corn herbage was dried for few days under shade and then chopped into 2-3 cm pieces with the help of fodder cutter.
For implementation of the experiment, all the above mentioned plots were tilled twice and divided into 3 sup-plots measuring 1.5 × 2 m^2 at the beginning of August 2019, which were used to apply the following treatments:
1- Conventional tillage control. 2- Incorporated corn residues. 3- Incorporated corn residues + 50% trifluralin. 4- 50% trifluralin in conventional tillage. 5- 100% trifluralin in conventional tillage. 6- Zero tillage control. 7- Mulch corn residues. 8- Mulch corn residues + 50% trifluralin. 9- 50% trifluralin in zero tillage. 10- 100% trifluralin in zero tillage. For mulching treatments [4-7], corn residues at a rate of 5 t ha^{-1} were spread on the surface of their respective zero tillage plots just after trifluralin spraying. Zero tillage (treatment 1) without corn mulch was included for comparison.
Label rate (2.4 L ha^{-1}) and half label rate (1.2 L ha^{-1}) of trifluralin herbicide were sprayed on their respective zero tillage and conventional plots, two days before planting the mung bean, for comparison. Volume of spray (300 L ha^{-1}) was calibrated using water. The herbicide doses were applied using hand sprayer fitted with T- Jet nozzle at a pressure of 270 k Pa. After the spraying of trifluralin, the field soil was mixed by rake to prevent volatilization and photolysis of trifluralin herbicide. Nitrogen as urea (46% N) at 80 kg ha^{-1} and phosphorus as triple super phosphate (46% P_2O_5) at 240 kg ha^{-1} were applied to all plots as recommended by the Iraqi Ministry of Agriculture for mung bean crop. Seeds of mung bean were manually sown at the beginning of August, 2019, in all plots in 40 cm spaced crop rows, keeping a plant to plant distance of 20 cm. All plots received recommended irrigation during the entire course of study.
The experiment was conducted in a randomized complete block design (RCBD) with four replications.

2.2. Weed measurements

At the physiological maturity of the mung bean crop (60 DAS), weed density was recorded from two randomly selected quadrates (50×50 cm) in each experimental unit (plot), then the weeds were clipped at the soil surface, placed in perforated paper bags, oven dried at 70 ˚C for three days, and recorded for their weight by digital balance [8,9]. Data of weed density and biomass were converted and expressed in square meter.

2.3. Determination of biological activity and total phenolics in soil of plots amended with corn residues

This experiment was conducted to test if the decomposed corn residues in soil were responsible for the poor growth of weeds observed in mung bean fields and to test if the phenolics are released from corn residues into the field soil and correlated with the inhibition of the test weed. Soil samples from corn mulch residues and corn residues-incorporated plots were taken at biweekly interval starting from the sowing time and continued for 8 weeks. Soil samples from plots of zero and conventional tillage were also included for comparison. The soil samples of each treatment were mixed thoroughly, allowed to dry at room temperature for 3 days, and divided into two parts. The first part was packed in plastic pots of 200 g capacity. Twenty seeds of jungle rice were sown in each pot. The pots were placed under natural growing conditions and arranged in a complete randomized design with 4 replications. All pots were irrigated with appropriate amount of water whenever needed. Seed germination was recorded at 15 days after sowing, after which the seedlings were thinned to 3 per pot and allowed to grow for additional two weeks. The total dry weight was determined after oven drying the plants at 70˚C for 3 days using an electrical sensitive balance. The second part of soil samples was used for phenolics determination following the procedure of Ben-Hammouda *et al.* [10]. Soil samples free of plant debris of each treatment were separately mixed and allowed to dry at room temperature for 3 days. 250 grams of dry soil was extracted separately in 250 ml of distilled water by shaking for 24 h at 200 rpm. The soil suspensions were filtered through Whatman No. 2 filter paper under vacuum by rotary evaporator and their content of phenolics was determined by applying the Folin-Denis method [11].

2.4. Mung bean measurements

At harvesting time, ten plants were selected randomly from each plot and seeds yield and yield components (number of pods per plant, number of seeds per pod, and weight of 100 seeds) were recorded following standard procedures [8,9]. Data were statistically analyzed by analysis of variance (ANOVA) with the GENSTAT software. Treatment averages were compared through the use of the Least Significant Difference (LSD) at the ≤ 0.05 probability level [12].

3.Results and Discussion

3.1. Weed measurements

Plots incorporated with corn residues significantly reduced weed density by 20 and 43% over conventional tillage control at Baghdad and Wasit sites, respectively (Table 1), while plots mulched with corn residues suppressed weed density by 31 and 60 % over zero tillage control at Baghdad and Wasit sites, respectively. Furthermore, the use of corn residues as soil incorporation or as mulch in combination with trifluralin provided reduction in weed density that is statistically similar to that of the recommended dose of the herbicide treatments.

Residues incorporation significantly reduced weed dry weight by 53 and 51% of conventional tillage control at Baghdad and Wasit sites, respectively. while corn residues applied as mulch depressed weed dry weight by 61 and 32% of zero tillage control at Baghdad and Wasit sites, respectively. The suppression achieved by combination of soil incorporation and mulch of corn residues was increased and became statistically similar to that achieved by the full dose of herbicide treatments.

Table 1- Effects of corn residues applied as soil incorporation and mulch with the reduced (50%) rate of trifluralin herbicide on weed density and dry weight biomass at 60 DAS of mung bean grown at two experimental sites.

Treatments*	Baghdad site		Wasit site	
	Weed density (Plants $m^{-2)}$	Dry weight biomass (g/m^2)	Weed density (Plants $m^{-2)}$	Dry weight biomass (g/m^2)
Conventional tillage control	36.2	93.6	27.0	116.2
Incorporated corn residues	29.0	44.0	15.3	57.3
Incorporated corn residues + 50% trifluralin	15.0	25.3	9.5	11.5
50% trifluralin in conventional tillage	29.0	45.6	16.3	46.2
100% trifluralin in conventional tillage	18.0	32.6	9.8	12.5
Zero tillage control	52.0	138.2	31.7	115.8
Mulch corn residues	36.0	54.5	12.6	78.3
Mulch corn residues + 50% trifluralin	18.0	29.5	9.8	12.4
50% trifluralin in zero tillage	35.2	80.4	18.8	33.8
100% trifluralin in zero tillage	27.0	47.8	11.3	15.8
L.S.D (P≤ 0.05)	15.2	42.7	4.7	4.7

* Conventional and zero tillage treatments are without residues and herbicide. The amount of corn residues applied as soil incorporated or mulch was 5 t ha^{-1}.

3.2. Mung bean yield and yield components

All treatments significantly increased seed yield in both sites when compared to the respective control treatments (Table 2). However, combination of reduced (50%) dose of herbicide and corn residues, applied as soil incorporation or as mulch, produced maximum seed yield and was statistically similar to that achieved by using the recommended dose of trifluralin herbicide in both sites of study.

Number of pods per plant and number of seeds per pod were significantly increased in plots incorporated or mulcted with corn residues in both sites, but it did not match with the increase obtained by the full dose of herbicide. However, plots treated with reduced herbicide in combination with incorporated or mulch corn residues produced a number of pods per plant and a number of seeds per pods that were similar or even higher than those recorded by the full dose of herbicide. All treatments did not affect the weight of 100-seed compared to their controls, with the exception of treatments of a combination of corn residues as a mulch or as soil incorporated with reduced (50%) rate of herbicide, which produced weight of 100- seed similar to that scored by the label rate of herbicide.

3.3. Biological activity and total phenolics profile of soil in plots amended with corn residues

Total phenolics in all test treatments were significantly increased with the increase of most of decomposition periods tested at both sites (Table 3). However, total phenolics were found to be drastically higher in soil incorporated and mulched with corn residues than in conventional and zero tillage soils without corn residues at all decomposition periods at both sites. Seedling emergence of jungle rice in all treatments was reduced by most of decomposition periods (Table 4). However, reduction of seedling emergence was found to be higher in mulched and incorporated soil with corn residues than in conventional and zero tillage soil at almost all decomposition periods at both sites.

Table 2- Effects of corn residues applied as soil incorporated and mulch with the reduced (50%) rate of trifluralin herbicide on seeds yield and yield components of mung bean grown at two experimental sites.

Treatments*	Baghdad site				Wasit site			
		Yield components				Yield components		
	Seeds yield (t ha^{-1})	Number of pods per plant	Number of seeds per Pod	weight of 100 seeds (g)	Seeds yield (t ha^{-1})	Number of pods per plant	Number of seeds per pod	weight of 100 seeds (g)
Conventional tillage control	0.9	21.9	7.0	3.3	0.8	12.0	7.9	3.3
Incorporated corn residues	1.3	36.6	7.5	3.5	1.3	21.7	8.7	3.4
Incorporated corn residues +50% trifluralin	3.1	63.1	11.0	3.8	2.1	33.1	10.9	3.9
50% trifluralin in conventional tillage	2.1	35.6	7.9	3.4	1.2	20.7	8.0	3.7
100% trifluralin in conventional tillage	2.9	45.4	8.7	3.8	1.4	28.2	9.1	3.7
Zero tillage control	0.8	19.3	6.9	3.5	0.7	14.2	7.2	3.6
Mulch corn residues	1.6	37.0	7.4	3.5	1.2	20.0	8.6	3.7
Mulch corn residues + 50% trifluralin	2.8	48.0	10.3	3.6	2.0	32.0	9.7	3.9
50% trifluralin in zero tillage	1.4	23.1	7.7	3.6	1.2	20.7	7.8	3.6
100% trifluralin in zero tillage	2.0	43.4	9.2	3.6	1.8	29.8	8.9	3.7
L.S.D (P≤ 0.05)	0.4	10.4	1.0	0.3	0.4	3.4	0.7	0.3

* Conventional and zero tillage treatments are without residues and herbicide. The amount of corn residues applied as soil incorporated or mulch was 5 t ha^{-1}.

Table 3- Phenolics content of soil incorporated and mulch with corn residues at different periods of decomposition in two experimental sites.

Treatments*	Total phenolics					
	Decomposition periods (Week)*					
	0	2	4	6	8	LSD ≤ 0.05
	Baghdad site					
Conventional tillage soil (Control)	0.13	0.25	0.28	0.58	0.73	0.08
Incorporated corn residues soil	0.25	0.85	1.90	1.28	0.83	0.02
Zero tillage soil	0.10	0.23	0.45	0.78	0.85	0.09
Mulch corn residues soil	0.18	0.68	0.90	1.25	1.10	0.20
LSD ≤ 0.05	0.08	0.15	0.14	0.30	0.15	
Wasit site						LSD ≤ 0.05
Conventional tillage soil	0.15	0.23	0.24	0.45	0.78	0.08
Incorporated corn residues soil	0.23	0.73	0. 80	0.81	0.95	0.15
Zero tillage soil (Control)	0.10	0.23	0.31	0.55	0.80	0.10
Corn residues Mulch soil	0.20	0.68	0.80	1.23	1.18	0.09
LSD ≤ 0.05	0. 06	0.09	0.09	0.15	0.19	

*Each value is an average of four replicates.

Table 4-Biological activity of soil incorporated and mulch with corn residues at different periods of decomposition against seedling emergence of Jungle rice in two experimental sites.

Treatments	% of Seedling emergence					
	Decomposition Periods (Week)*					
	0	2	4	6	8	LSD ≤ 0.05
	Baghdad site					
Conventional tillage soil	63.8	57.5	48.8	36.3	33.8	4.9
Incorporated corn residues soil	50.0	38.8	15.0	26.3	31.0	6.8
Zero tillage soil	63.8	56.3	50.0	43.8	38.8	5.5
Mulch corn residues soil	56.2	48.8	38.8	38.8	37.5	6.0
LSD ≤ 0.05	7.6	5.0	4.8	4.6	8.0	
	Wasit site					LSD ≤ 0.05
Conventional tillage soil	47.5	45.5	42.5	38.3	32.5	5.9
Incorporated corn residues soil	42.5	35.0	11.2	18.8	21.5	9.2
Weedy check in zero tillage soil	47.5	44.0	41.2	40.8	39.0	7.1
Mulch corn residues soil	46.2	45.0	32.5	30.0	32.5	7.5
LSD ≤ 0.05	6.0	6.7	5.5	5.4	6.4	

*Each number is an average of four replicates.

Dry weight biomass of jungle rice was reduced by soil incorporated and mulched with corn residues in most of decomposition periods in both sites (Table 5). Total phenolics content released from corn residues into the field soil showed highly negative correlation with the seedling emergence and dry weight biomass of jungle rice weed at all decomposition periods at both sites of study (Table 6).

Table 5-Biological activity of soil incorporated and mulch with corn residues at different periods of decomposition against seedling dry weight of Jungle rice in two experimental sites.

Treatments*	Plant dry weight biomass (mg)					
	Decomposition Periods (Week) *					
	0	2	4	6	8	
	Baghdad site					LSD ≤ 0.05
Conventional tillage soil	86.3	82.1	78.0	78.2	77.6	0.7
Incorporated corn residues soil	82.0	78.1	68.6	70.9	70.9	0.7
Zero tillage soil	82.1	80.1	77.8	73.6	74.5	0.8
Mulch corn residues soil	80.5	77.7	73.5	74.6	74.0	1.7
LSD ≤ 0.05	1.0	0.9	1.2	0.9	1.6	
	Wasit site					LSD ≤ 0.05
Conventional tillage soil	72.9	71.7	69.6	70.4	70.3	2.7
Incorporated corn residues soil	72.7	69.7	63.6	65.8	68.5	1.6
Zero tillage soil	70.5	70.5	69.5	68.8	70.0	1.2
Mulch corn residues soil	70.3	68.6	64.0	65.5	68.0	6.6
LSD ≤ 0.05	1.0	2.7	2.3	5.7	5.0	

*Each number is an average of 4 replicates. The amount of corn residues applied as soil incorporated or mulch was 5 t ha^{-1}.

Table 6-Correlation between total phenolics in the test treatments and percent of seedling emergence and dry weight biomass of Jungle rice grown in the field soil amended with corn residues at Baghdad and Wasit sites.

Treatments	Correlation coefficient *	
	Dry weight biomass	% seedling emergence
	Baghdad site	
Weedy check in conventional tillage	- 0.771	- 0.807
Incorporated corn residues	- 0.911*	- 0.963*
Weedy check in zero tillage	- 0.904*	- 0.942*
Mulch corn residues	- 0.894*	- 0.946*
	Wasit site	
Weedy check in conventional tillage	- 0.771	- 0.807
Incorporated corn residues	- 0.911*	- 0.963*
Weedy check in zero tillage	- 0.904*	- 0.942*
Mulch corn residues	- 0.894*	- 0.946*

*Correlation is significant at the 0.05 level.

The data revealed that soil incorporation and surface mulch of corn residue suppressed weed density and growth at both sites, as compared with the respective control (Table 1). Such suppression could be attributed to the release of phytotoxic allelochemicals from the decomposing corn residue into the soil. A look into data of the decomposition period of corn residue indicated that a high negative correlation existed between phenolic content of soil taken from corn residue field and seedling emergence and dry weight of the dominant weed (jungle rice weed). Such a decline was not that apparent and significant for soil taken from fields with conventional and zero tillage. This suggests that increasing phenolic content in soil amended with corn residue is somehow involved in the inhibition of germination and seedling growth of the tested weed. This study did not attempt to identify the individual allelochemicals in corn-residue amended soil. Several investigators demonstrated that corn residues contain potential allelochemicals, including p-coumaric acid, syringic acid, vanillic acid, p-hydroxybenzoic acid, gallic acid, p-coumaric, ferulic acid, p-hydroxy benzoic acid, catechin, rutin, qurcetine, luteolin, and kaemferol [13-15], with inhibitory activity against weeds. Several authors reported the negative impacts of these compounds on various physiological and biochemical processes, including chlorophyll biosynthesis, respiration, photosynthesis, ions uptake, hormones biosynthesis, cell division, and activity of some enzymes involved in essential metabolic processes [16-23]. Allelochemicals are mostly water soluble compounds and, on imbibition by weed seeds, they hamper their germination and subsequent seedling growth, resulting in overall decline in the density, vigor, and stand spread of the weed community [24]. Although weed population and dry weight was reduced by the allelopathic mechanism of corn residues, it does not match with that caused by the full dose of herbicide, which is in line with the results observed by other studies [4,6]. The present study reveals a significant correlation between the pattern of weed suppression and the total phenolic content of soil amended with corn residue as soil incorporation and surface mulching [Table 6]. Under appropriate conditions, allelochemicals may be released in quantities suppressive to the development of the weed seedlings, through the action of mulches that interfere with the growth of surrounding weeds [25]. Such weed suppression may selectively be executed through the physical presence of cover crops on the soil surface and by the release of allelochemicals or microbially altered allelochemicals [25]. Trifluralin is often used as pre-emergence herbicide to control weeds in various leguminous crops, including mung bean. The suppression effects are more obvious at the recommended dose than at the reduced (50%) rate. However, when herbicide at the reduced rate was applied to plots incorporated or mulched with corn residues, the suppressions became statistically equal or even higher than that realized with the label rate of trifluralin atbothsites. This result supports the hypothesis of our study and confirmed the previous hypothesis proposed by Bhowmik and Inderjit [26], that a herbicide applied along with allelopathic interaction could render a complementary effect that helps to minimize herbicide usage for weed management in field crops. Several investigators indicated that the inhibitory effect of mulch on weeds was not only confined to allelopathy mechanism but also to other additional factors, such as reduced light interception, altered soil temperature, and physical hindrance in seedling emergence [27, 28]. Crops are more sensitive to allelopathy under less optimal environments. For example, additive inhibition was shown to result from the joint action of ferulic acid with low levels of trifluralin [29].

The improvement of yield and yield components of mung bean by full dose of herbicide and combination of reduced dose of herbicide and corn residues, applied as surface mulchor soil incorporation, may be attributed to better weed control. Better weed suppression enables crop plants to use the available environmental resources in a better way, along with solar radiation interception, without any hindrance [30-32], resulting in improving crop yield and yield components. In addition to weed suppression, allelochemicals enhance mineralization of nutrients in soil and improve their uptake [33,34], which results in better plant yields.

4. Conclusions

Application of allelopathic corn residues as mulch or as soil incorporation may help in reducing reliance upon trifluralin herbicide and improving the sustainability of agroecosystem, with mulch application appeared to be more effective than soil application approach against weed growth. Furthermore, this achievement leads to environmental safety and minimizes the expansion of herbicide-tolerant weed.

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