Weed Management in Cowpea through Combined Application of Allelopathic Sorghum Residues and Less Herbicide

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***Abstract*—A Field study was conducted to explore the allelopathic potential of sorghum residues alone and in combination with half (1.2 L ha-1) of recommended rate of trifluralin herbicide for controlling weeds in cowpea field. Sorghum residues at 5 and 10 t ha-1 were used either alone or in combination with trifluralin at 1.2 L ha-1. Trifluralin at full label rate (2.4 L ha-1), weedy check and weed free treatments were also included for comparison. Incorporation of sorghum residues at 5 and 10 t ha-1 reduced weed density by 6 and 43 % of control and dry weight biomass by 48 and 66% of control, respectively. However, application of herbicide at 50% rate in plots amended with sorghum residues at 5 and 10 t ha-1 provided weed density and dry weight biomass suppression greater than that of full herbicide rate treatment. Chemical analysis of sorghum residues amended field soil revealed the presence of phenolics in higher concentration. Periodic data revealed that maximum quantities of phenolics were coincided with the period in which maximum suppressive activity against the weeds was noticed. Application of sorghum residue at 10 t ha^{-1} to the plots amended with half rate of trifluralin herbicide provided seed yield significantly higher than that achieved by sole application of label rate of herbicide, which could be used as a feasible and environmentally sound weed management approach in cowpea field.**

***Index Terms*—allelopathy, sorghum residues, herbicide, phenolics, weed, cowpea**

I. Introduction

Weeds are identified as the most omnipresent class of pests interfering with crop plants through competition and allelopathy. Traditionally, weed management practices includes preventative, cultural, mechanical, biological, and chemical tactics [1]. However, with the rapid increase in the number of effective herbicides after 1960's, weed management techniques have become more reliant on herbicides. The overdependence and irrational use of herbicides during the last 40 years has resulted in growing public concern over their impact upon human health, environment pollution and evolution of herbicide weed resistant [2]. Due to these risks, much attention is being focused on the alternative methods of weed control. Allelopathy is suggested to offer a great prospective to manage weeds. Different strategies in which allelopathy is involved have been suggested such as using allelopathy in crop rotations, cover crops, mulches, smother crop, crop mixtures, intercropping and use of allelopathic crop residues or extracts [3]. Allelopathic crop residues as mulch or incorporated into field soil have been found to be the most successful strategy in weed suppression [4]. However, in most cases, the efficacy of allelopathic residues was generally below that of herbicides [5]. Therefore, many researchers have discussed the possibility of integrating allelopathic residues with other managing options for weed control. Bhowmik and Inderjit [6] suggested that a herbicide applied in combination with allelopathic conditions could enjoy a complementary interaction, and may help to minimize herbicide usage for weed management in field crops. The combination of allelopathic crop extract with lower rate of herbicide for weed control was first explored by Cheema group in Pakistan during the last decade [6]-[10]. These scientists postulated that herbicide use can be reduced by 50 – 70 % when herbicides are used in combination with aqueous sorghum extracts for weed control in field crops such as wheat, cotton, mung bean and maize. Although, successful results have been obtained from allelopathic plants extract applied with low herbicide rates. However, to employ this technology, large volumes of sprays are required for field application. Also, additional work in other soil types and appropriate concentrations for each crop should be determined for large scale field operations [11]. Due to these limitations, an alternative practical and feasible approach has been developed by Alsaadawi group where the residues of allelopathic crops including sorghum and sunflower have been left to dry under field conditions and then promptly incorporated into production sites for weed management. By using this approach with faba bean, wheat, barley and mung bean, it was found that application of half the labeled rates of the test herbicide in field soil amended with sorghum or sunflower residues suppress weeds and generated crop yield similar to that of the full rate of herbicides [12], [13]. Although, information regarding the integration effect of allelopathic potential of sorghum

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residues with lower rate of herbicide on weeds of various crops is available. Nonetheless, combined allelopathic potential of sorghum residues with reduced rate of trifluralin herbicide against weeds in cow pea have never been reported. Therefore, the present study was conducted to evaluate the possibility of using of allelopathic sorghum residues in combination with half rate of trifluralin for weed control with the objective of conserving environment and promoting sustainable agricultural production systems.

II. Materials and Methods

A. Site Selection

Study proposed was conducted at Research field of Biology Department, College of Science, Baghdad University, Baghdad, Iraq (33 ° 16' 13" N latitude and 44 ° 22 ' 44" E longitude, 40 m above sea level). The soil of the field was loamy with organic carbon, EC and pH were 1,2%, 1.23 dS/m and 7.3, respectively.

B. Seeds and Herbicides Sources

Seeds of *Sorghum bicolor* (L.) Moench *cv* Enqath were brought from State Board for Agricultural Researches, Ministry of Agriculture, Iraq. Seeds of cowpea *Vigna unguiculata* L. (Walp) *cv.* California ram shorn, (USA) were purchased from a local market. The local name of the cultivar is *Biader*. Treflan (trifluralin) herbicide was brought from the national committee for pesticides registration and approval, Ministry of Agriculture, Iraq.

C. Field Experiment Preparation of Sorghum Residues

The field was tilled twice using a disc plough and divided in plots measuring 3.5×4 m^2. Seeds of sorghum *cv.* Enkath were sown in the plots on March 18, 2015 in rows with a distance of 10 cm between seeds and 75 cm between rows [14]. Plots without sorghum crop were left and used as a control. Nitrogen fertilizers as urea (46% N) at 240 kg ha^{-1} and phosphorus as triple superphosphate (46% P_2O5) at 160 kg ha^{-1} were applied as recommended for this crop, all phosphorous and half of the nitrogen were applied at planting while the remaining half of the nitrogen (120 kg ha^{-1}) was applied at flowering stage [15]. Pest control and irrigation were applied as recommended for this crop. At physiological maturity, the heads were removed, mature sorghum plants were harvested at the beginning of July, air dried for several days under sun , chopped into pieces to about 2-3 cm and kept until use. Based on previous results [14], [16], It was found that 13.3 mature plants of sorghum which occupied 1 m^2 area added about 10 ton (t) of air - dried tops per hectare (ha) of soil to a depth of 30 cm; therefore residue rates at 5 and 10 t ha^{-1} were used in this experiment to test their effects on yield and yield components of cowpea crop and companion weeds.

D. Implementation of Experiment

All plots were tilled twice and divided into 4 sup-plots measuring 1.5×1.5 m^2 at the beginning of August. Residues of sorghum cultivar were incorporated into the soil of field plots at rates of 5 and 10 t ha^{-1} alone or in combination with half dose of trifluralin herbicide. Weedy checks (without sorghum residues), weed free and label rate (2.4 L ha^{-1}) of trifluralin herbicide were included in the experiment for comparison. Trifluralin herbicide was sprayed on plots two days before planting of cowpea field. Volume of spray was calibrated using water (300 L ha^{-l}) using hand sprayer fitted with T- Jet nozzle at a pressure of 270 k Pa. After that the field soil was mixed by comb to prevent volatilization and photolysis of the herbicide. Nitrogen as urea (46% N) at 80 kg ha^{-1} and phosphorus as triple super phosphate (46% P_2O5) at 240 kg ha^{-1} were applied to these plots as recommended by Ministry of Agriculture for cowpea crop. All phosphorus and half of the nitrogen were applied during seed bed preparation, while remaining nitrogen was applied after one month of sowing. Uniform seeds of cowpea crop were manually sown on August 9, 2015 in all plots in 40 cm spaced crop rows keeping plant to plant distance of 20 cm (8.8 plant m^{-1}) [17]. All plots received recommended irrigation during the entire course of study. Weeds from weed free plots were removed every week by hand pulling throughout the crop's life span. The experiment was conducted in Randomized Complete Block Design (RCBD) with four replications. The experiment consists of the following treatments:

a. Control (without sorghum residues and trifluralin).
b. Sorghum residues at 5 t ha^{-1}.
c. Sorghum residues at 5 t ha^{-1} + half of label rate of trifluralin.
d. Sorghum residues at 10 t ha^{-1}.
e. Sorghum residues at 10 t ha^{-1} + half of label rate of trifluralin.
f. Label rate of trifluralin.
g. Half of label rate of trifluralin
h. Weed free

E. Weeds Measurements

At the physiological maturity of cowpea crop (75 days after sowing), weed density were recorded from tow randomly selected quadrates (25×25 cm^2) in each experimental unit (plot). Number of weeds was recorded from the selected quadrate and weed density was determined. For dry weight biomass determination, the weeds in the selected quadrate were clipped at the soil surface, stored in polyethylene bag and brought to laboratory for recording their biomass. The biomass was determined after air-drying the plant materials in oven at 70 °C for three days using digital balance. Data on weed density and biomass were determined as per m^2.

F. Cowpea Measurements

At harvest, ten plants were randomly selected from each plot and number of pods, number of seeds per pod, weight of 100-seed and seeds yield were recorded using standard procedure.

G. Determination of Total Phenolics in Sorghum Residues Amended Soil

This experiment was conducted to determine the quantity of phenolics released from decomposed sorghum residues in soil over different decomposition periods using Folin-Denis method [18]. Soil samples were taken from plots amended with 5 t ha^{-1}, 10 t ha^{-1} residue and from plots without residue (control) at a depth of 30 cm at 1, 14, 28, 42 and 56 days after sowing (DAS). The soils were mixed thoroughly and allowed to dry at room temperature for 3 days. Samples of 250 g dry soil were extracted separately in 250 ml of distilled water by shaking for 24 h at 200 rpm [19]. Soil suspensions were filtered through Whatman No. 2 filter paper under vacuum. Folin-Denis reagent (0.5 ml) and Na_2CO_3 (one ml) were added to one ml of soil water extract and left to stand for 30 minutes. Absorbance was determined at 750 nm on a spectrophotometer [20]. The phenolics content was obtained by standard curve using different concentrations of ferulic acid.

H. Bioassay of Soil Amended with Sorghum Residues and Trifluralin against Weeds

This experiment was conducted to test if the phenolics released from decomposed sorghum residues in soil were responsible for the poor growth of weeds observed in cowpea field. Soil samples were taken from the following plots:

a. Plots amended with sorghum residues at 10 t ha^{-1}
b. Plots treated with 100 % trifluralin.
c. Plots amended with sorghum residues at 10 t ha^{-1} + 50 % trifluralin.
d. Plots without sorghum residues and trifluralin (control)

The soil samples were taken to a depth of 30 cm at 1, 14, 28, 42 and 56 days after sowing. The soils were mixed thoroughly and allowed to dry at room temperature for 3 days. The soil was packed in plastic pots of 200 g capacity and twenty seeds of *Portulaca oleracea* L. The pots were arranged in randomized complete block design and were irrigated with appropriate amount of water whenever needed. Seed germination was recorded at 15 days after sowing, after that, the seedling were thinned to 3 per pot and allowed to grow for additional two weeks. The plants were pulled from the pots using running water. Total dry weight of pigweed was determined after oven drying the plants at 70 $^{\circ}$C for 3 days.

I. Statistical Analyses

The data were subjected to statistical analysis using analysis of variance (ANOVA) by GENSTAT computer software package. Differences among treatment averages were compared using Least Significant Difference (LSD) at 0.05 probability level [21].

III. Results

A. Weed Density and Biomass

Weed flora dominated the cowpea field during the study comprised mainly of *Sorghum halepense* L., *Cynodon dactylon* L., *Portulaca oleracea* L., *Convolvulus arvensis* L., *Echinochloa colonum* (L.) *Link, Cyperus rotundus* L., *Cynodon dactylon L., Corchorus olitorius* L., *Malva rotundifolia* L. Both trifluralin rates and sorghum residues posed significant reduction in weed density and dry biomass over control (Table I), with the exception of weeds density at lower rate of residues (5 t ha^{-1}) which recorded non significant reduction over control. Incorporation of sorghum residues at 5 and 10 t ha^{-1} reduced weed density by 6 and 43% over control, respectively. The corresponding inhibition in weed dry biomass was 48 and 66 % of control, respectively for these rates of sorghum residues. Reduced (50%) rate of trifluralin furnished 34 and 59% reduction in weed density and dry biomass as against 75 and 97% reduction realized with the label rate of this herbicide. However, higher suppression was recorded by combination of sorghum residues with lower rate of herbicide than by sorghum residue rates and lower rate of herbicide when applied alone. The combination of sorghum residues and half rate of trifluralin herbicide were also provided weed suppression similar to that of the label rate of herbicide.

B. Yield and Yield Components of Cowpea

All treatments posed positive influence on yield and yield components and biological yield of cowpea (Table II and Table III). Plots amended with sorghum residues at 5 and 10 t ha^{-1} significantly increased seed yield by 106 and 98 % over control, respectively. The corresponding increase in biological yield was 62 and 84 % over control, respectively for these rates of sorghum residues. Application of half rate of trifluralin provided 74 and 55% increase in seed and biological yield as against 170 and 105 % increase realized with the label rate of this herbicide. However, higher seed and biological yields were recorded by combination of sorghum residues and reduced rate of trifluralin than by sorghum residue rates and lower dose of trifluralin when applied alone. The combination of sorghum residues at 10 t ha^{-1} and half rate of trifluralin provided seed and biological yield higher than that of the label rate of herbicide.

Application of sorghum residues and reduced rate of trifluralin alone or in combination showed a significant increase over control in all yield component parameters (Table III). However, maximum values of yield components were recorded in plots amended with sorghum residue at 10 t ha^{-1} and treated with reduced rate of trifluralin which were significantly greater than the label trifluralin rate treatment.

C. Phenolics Dynamic in Field Soil Amended with Sorghum Residues

Total phenolics in field soil significantly increased after incorporation of sorghum residues and reached its peak at 4th week of residues decomposition and continued with higher level at 6th, then decreased significantly at 8th week (Fig. 1).

D. Biological Activity of Field Soil Amended with Sorghum Residues and Trifluralin against Weed

Seedling emergence of *Portulaca oleracea* L was significantly suppressed by all treatments at all decomposition periods with the exception of sorghum residues where the suppression started at 2-week decomposition period (Table IV).

TABLE I. EFFECT OF DIFFERENTN RATES OF SORGHUM RESIDUES ALONE AND IN COMBINATION WITH THE REDUCED RATE OF TRIFLURALINE HERBICIDE ON DENSITY AND BIOMASS OF WEEDS IN COWPEA FIELD

Treatments	Total number of weeds/m^2	Reduction % of control	Dry weight (g/m^2)	Reduction (% of control)
Weedy check (control)	73.0	-------	524.0	-------
Residues at 5 t ha-1	68.5	6	271.0	48
Residues at 5 t ha-1 + half label rate of trifluralin	16.5	77	18.0	97
Residues at 10 t ha-1	41.5	43	179.0	66
Residues at 10 t ha-1 + half Label rate of trifluralin	14.0	81	6.0	99
Half label rate of trifluralin (1.2 L ha-1)	48.0	34	215.0	59
Label rate of trifluralin (2.4 L ha-1)	18.0	75	17.0	97
L.S.D. ≤ 0.05	18.7	------	152.4	------

*Each number is an average of four replicates.

TABLE II. EFFECT OF DIFFERENTN RATES OF SORGHUM RESIDUES ALONE AND IN COMBINATION WITH THE REDUCED RATE OF TRIFLURALINE HERBICIDE ON SEED AND BIOLOGICAL YIELDS OF COWPEA

Treatments	Seeds yield (t/ha)*	Biological Yield (t/ha)*
Weedy check (control)	0.62	2.45
Residues at 5 t ha-1	1.28	3.97
Residues at 5 t ha-1 + half of label rate of trifluralin	1.80	5.92
Residues at 10 t ha-1	1.23	4.52
Residues at 10 t ha-1 + half of label rate of trifluralin	2.70	7.65
Label rate of trifluralin 2.4 L ha-1	1.67	5.03
Half of label rate of trifluralin 1.2 L ha-1	1.08	3.80
Weed free (without Residues)	1.41	4.85
L.S.D. ≤ 0.05	0.33	1.51

*Each number is an average of four replicates (Plots).

TABLE III. EFFECT OF DIFFERENTN RATES OF SORGHUM RESIDUES ALONE AND IN COMBINATION WITH THE REDUCED RATE OF TRIFLURALINE HERBICIDE ON YIELD COMPONENTS OF COWPEA

Treatments	Number of pods /plant	Number of seeds /pod	Weight of 100 seeds (g)
Weedy check (control)	6.4	4.87	18.66
Residues at 5 t ha-1	13.2	5.80	22.84
Residues at 5 t ha-1 + half of label rate of trifluralin	17.4	5.60	22.18
Residues at 10 t ha-1	11.5	5.73	22.49
Residues at 10 t ha-1 + half of label rate of trifluralin	22.1	6.91	23.53
Label rate of trifluralin (2.4 L ha-1)	14.2	5.35	22.98
Half Label rate of trifluralin (1.2 L ha-1)	11.8	5.15	19.55
Weed free (without residues)	14.7	5.50	19.67
L.S.D. ≤ 0.05	4.18	0.76	0.51

TABLE IV. EFFECT OF DECOMPOSING *SORGHUM BICOLOR* RESIDUES IN SOIL AMENDED WITH HALF LABEL RATE OF TRIFLURALIN AT DIFFERENT DECOMPOSTION PERIODS ON SEEDLING EMERGENCE OF *PORTULACA OLERACEA* L

Treatments	% seedling emergence			
	Decomposition periods (Week)*			
	2	4	6	8
Weedy check (Control)	77.5	66.2	66.2	61.2
Residues at 10 t ha-1	65.2	40.0	43.8	36.2
Residues at 10 t ha-1 + half of label rate of trifluralin	42.5	30.0	32.5	27.5
Label rate of trifluralin (2.4 L ha-1)	16.2	18.8	21.2	12.5
L.S.D. ≤ 0.05	15.4	10.8	8.5	13.9

*Each number is an average of four replicates.

TABLE V. EFFECT OF DECOMPOSING *SORGHUM BICOLOR* RESIDUES IN SOIL AMENDED WITH HALF LABEL RATE OF TRIFLURALIN AT DIFFERENT DECOMPOSTION PERIODS ON DRY WEIGHT BIOMASS OF *PORTULACA OLERACEA* L

Treatments	Seedling dry weight biomass (mg)			
	Decomposition Periods (Week)*			
	2	4	6	8
Weedy check (Control)	11.1	9.4	8.5	6. 7
Residues at 10 t ha-1	8.9	6.3	5.7	5.5
Residues at 10 t ha-1 + half of label rate of trifluralin	7.2	6.0	5.3	5.5
Label rate of trifluralin (2.4 L ha-1)	6.1	5.9	4.9	4.0
L.S.D. ≤ 0.05	2.0	2.1	1.4	1.2

*Each number is an average of four replicates.

TABLE VI. CORRELATON COEFFICIENT BETWEEN TOTAL SOIL PHENOLICS AND SEEDLING EMERGENCE AND GROWTH OF *PORTULACA OLERACEA* L. GROWN IN SOIL AMENDED WITH 10 T HA-1 OF SORGHUM RESIDUES AT DIFFERENT DECOMPOSTION PERIODS

Decomposition period (week)	% of seedling emergence	Seedling dry weight (mg)
2	0.61*	0.66*
4	0.63*	0.78*
6	0.62*	0.73*
8	0.62*	0.65*

* Significant at 0.05 level according to student t test.

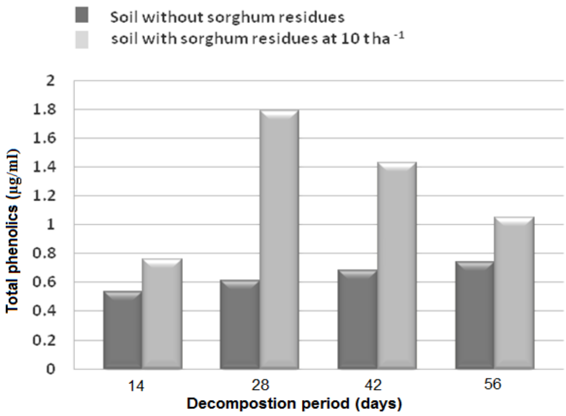

Figure 1. Total phenolics release in field soil amended with sorghum residues at 10 t ha-1 during different decomposition periods. Differences between treatments at each decomposition period are significant at 0.05 level according to LSD test.

The highest suppression of seedling emergence was recorded by the label rate of trifluralin, followed by the combination of sorghum residues and lower rate of herbicide. In most treatments, the suppression of seedling emergence seedling started at 2-week and remained higher even at 8-week of decomposition period.

Dry weight biomass of pigweed was significantly suppressed by all treatments and at all decomposition periods (Table V). The highest weed suppression was recorded by the combination of sorghum residue with lower rate of herbicide, followed by the label rate of trifluralin herbicide. Statistical analyses indicated that a highly significant negative correlation between seedling emergence and dry weight biomass of *Portulaca oleracea* L and concentration of total phenolics in field soil amended with sorghum residues at 10 t ha^{-1} and reduced rate of trifluralin decomposed at different times (Table VI).

IV. DISCUSSION

Analysis of the data of the present study revealed that sorghum residues incorporated into the field soil inhibited population density and dry biomass of weeds and the suppression magnitude achieved was proportional to the rate of incorporated sorghum residues (Table I). This reduction in weed suppression seems an outcome of inhibitory effects exerted by sorghum residues incorporated in to the field soil. Such a reduction is believed to originate by the release of phytotoxic allelochemicals from sorghum residues in the immediate vicinity during their decomposition. Subsequent work showed the presence of sizeable amount of phenolics in field soil early after planting.

No attempt was made to identify the allelochemicals in the phenolics residue; however sorghum residues contain several putative allelochemicals responsible for biological activity *viz*, p-coumaric acid, syringic acid, vanillic acid, p-hydroxybenzoic acid and ferulic acid [7], [14]. These phytotoxins are reported to have inhibitory effects on several processes such as inhibition of chlorophyll biosynthesis, respiration, photosynthesis, ions uptake, hormones biosynthesis and cell division, inhibition of the activity of some enzymes involved in essential metabolic processes [22]-[24].

Also, most of these allelochemicals are water soluble and when imbibed by germinating weed seeds, hampered their germination and subsequent seedling growth. Thus contributing to overall decline in the density, vigor and stand establishment of the weed community [25]. Although sorghum residues showed significant reduction in weed population density and dry weight biomass, their efficacy could not comparable with that of the label rate of trifluralin herbicide. However, when herbicide application at 50% of label rate was applied to plots amended with test rates of sorghum residues, a greater weed suppression was recorded than sole application of trifluralin herbicide (Table I). These results confirmed hypothesis proposed by Bohwmik and Inderjit [6] that lower dose of herbicide applied in combination with allelopathic conditions could enjoy a complementary interaction and may help to minimize herbicide usage for weed management in field crops. Also, these results are in line with those obtained by Alsaadawi *et al*. [26] who reported similar suppression of weed population and biomass in faba bean with sorghum residues when applied in combination with reduced rate of trifluralin. Further, Al-Eqaili *et al*. [27] found that combined sunflower residues and reduced rate (50% of full dose) of chevalier herbicide were effective as the label rate of herbicide in suppression of weed density and dry weight in wheat field. Chemical analysis of sorghum residues amended field soil revealed the presence of phenolics in higher concentration. Additional test proved a significant negative correlation between the total phenolics and seedling emergence and dry biomass suppression of *Portulaca oleracea* L. (one of the weeds dominated the cowpea field). This suggests that phenolics are involved in the suppression of weeds and may explain the poor growth of weeds noticed early after planting time.

The increase of cowpea biological and seed yield (Table II) by application of sorghum residues alone or in combination with reduced herbicide rate of trifluralin over weedy check treatment seems an outcome of reduced weed-crop competition for any of the growth factors which might have contributed to higher yield and biomass. By minimizing competition due to better weed control, cowpea plants uptake more water and nutrients that resulted in vigorous growth and seed yield. Furthermore, incorporation of sorghum residues into the field soil improved physical, chemical and biological properties of soil [28], [29] and this could explain why the higher rate (10 t ha^{-1}) of sorghum residues along with reduced (50% of full dose) rate of trifluralin herbicide showed better yield and dry biomass of cowpea than sole application of label rate of trifluralin. There are many earlier reports available that signify the role of reduced doses of commercial herbicides in combination with allelopathic plant residues to enhance grain and biological yield [12], [13], [26]. Apparently, the higher grain yield by all the test treatments was attributed to improve all the three factors of yield components (Table III). 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 mung bean, broad bean, wheat and barley was due to increase one or two of the three yield components factors [3], [30], [31]. Many researchers have stressed the need for decreasing the use of herbicides in crop production. Residues of the allelopathic plants can serve as the means of using allelopathy for practical weed management. Use of allelopathic crop residues and reduced rates of herbicides have been effective for weed management in field crops such as mung bean, barley and wheat [30], [31], [27].

V. Conclusion

The present study revealed that sorghum residues used with 50% of full rate of trifluralin herbicide is highly effective approach in controlling weeds in cowpea field, improving seeds yield of cowpea crop and increasing environmental safety by reducing reliance on synthetic herbicides. Besides that, the allelopathic residues have a great advantage for improving chemical, physical and nutritional status of the soil, and can be applied on large scale.

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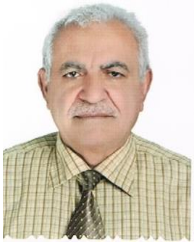

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