Integration of Corn (*Zea mays* L.) Residues with Reduce Herbicide Dose for Weed Management in Wheat Fields

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Abstract

In the worldwide search for new strategies in sustainable weed management, the use of plant species able to produce and release secondary metabolites into the environment could be an effective alternative to some synthetic herbicides. Reduction in herbicide usage without compromising yields can lead to less environmental harm and lower production costs. Field trials were conducted to appraise the efficacy of reduced doses (60% of the label dose) of a post emergence sulfonyleurea herbicide [Atlantis 3.6 WG (iodo+mesosulfuron)] with corn residues to control weeds in wheat (*Triticum aestivum* L.) field.

Field study was conducted during 2016-2017 in Kirkuk, using the randomized complete block design (RCBD) with 4 replications to test the effect of corn residues at 6 t ha\(^{-1}\) alone or in combination with reduced dose of Atlantis (60% of the label dose) on weed and wheat crop. Weedy check and label rate of Atlantis were also included for comparison. Total phenolic in field soil amended with corn residues at 6 t ha\(^{-1}\) was determined during different periods after sowing. Result showed that incorporation of corn residues at 6 t ha\(^{-1}\) reduced weed density by 68.8 and 46.1% of control after 60 and 120 days after sowing (DAS), respectively. However, the suppression of weed population and dry weight biomass was further improved when the plots were treated with 60% of labeled rate of herbicide and amended with corn residues. The results also revealed that weed suppression was directly translated into yield of wheat. Application of Atlantis herbicide at 60% rate in plots amended with corn residue resulted 59.3% over control in grain yields. Chemical analyses indicated that total phenolics started to increase at 14 and 28 days of decomposition and declined thereafter until vanished 8 weeks of decomposition. Weed suppression was correlated with the higher concentration of phenolics in soil. These results recommended redesigning of crop rotations based on allelopathic phenomenon needs to be considered to achieve sustainability and reduce the pesticide input in agroecosystems and thereby reducing the environmental pollution.

**Keywords:** Allelopathy, phenolics, reduced herbicide dose, Atlantis, weed management, wheat.

Introduction

Among various factors adversely influencing crop productivity, weed infestation in crop lands remains the most devastating one. Weeds are the most important class of pests that interfere with crop plants through competition and allelopathy, resulting in direct loss to quantity and quality of the product (Gupta, 2004), and indirectly increasing production costs. Potential yield reduction caused by uncontrolled weed growth throughout growing season has been estimated to be 45 to 95% depending on crop species and climatic conditions (Ampong and De Datta, 1991). For example, weeds are reported to cause 48% yield loss of wheat in Pakistan (Khan and Haq, 2002).
Weed management strategies like herbicide application and manual weeding are effective for weed control (Kahramanoglu and Uygur, 2010), but in some cases it seems to be uneconomical because of higher costs and excessive use of herbicide may also lead to soil and water pollution. Herbicides for weed control during the past few decades has resulted in serious ecological problems, such as resistance, shifts in weed populations that are more closely related to the crops that they infest, minor weeds becoming dominant (Heap, 2007), and greater environmental and health hazards (Rao, 2000).

Due to these limitations, Weed scientists are very much aware of public concerns regarding the use of herbicides. Many programs were implemented to reduce herbicide use. One of the possible methods for reducing the herbicides may be the use of allelopathy phenomenon (Weston, 1990; Khanh et al., 2005; Khaliq et al., 2010; Bahdoria, 2011).

Several strategies have been developed to use this ecological phenomenon for weed control such as crop rotations, allelopathic mulches or cover crop, spray of allelopathic plant water extracts (Worsham, 1991; Bhowmik and Inderjit, 2003; Khan and Khan, 2012; Alsaadawi, et al. 2013). A practical approach has been developed where the residues of allelopathic crops have been left to dry under field conditions and the promptly incorporated into production sites for weed management (Khaliq, et al. 2011; Alkhateeb, et al., 2013). Low herbicide doses were applied along with residue incorporation. To ensure satisfactory weed control, even under unfavorable regimes of crop production factors, manufactures often recommended higher than necessary doses of an herbicide. However, it's not always necessarily to apply full herbicide dose (Talgre et al., 2008) and there can flexibility regarding herbicide rates depending on important issues such as the weed spectrum, densities, their growth stage and environmental conditions of the site (Buhler et al., 1992; Walker et al., 2002).

By applying this technique, it was found that application of sunflower or sorghum residues in combination with lower rate of herbicides provide weed suppression and crops yield similar to that achieved by the label rate of the tested herbicides (Al-Bedairy, et al., 2011; Alsaadawi, et al. 2013).

In Iraq, wheat crop is an important crop and cultivated for large scale following corn in crop rotation. Uncontrolled weeds may reduce wheat yield up to 45% compared with weed free conditions. Information concerning the effect of combination of corn residues and lower rate of herbicide has not been explored for weed management in wheat field. The present study was, therefore, conducted to evaluate the possibility of using allelopathic corn residues in combination with reduced (60% of label dose) Atlantis 3.6 WG for weed control with the benefits of low cost and safe weed control in wheat.

Materials and Methods
1. Field preparations

1.1. Site selection

The proposed study was conducted at Center agriculture section, county / Koopat Hasak 63, south-west Kirkuk, Iraq. The field was characterized by loam silt clay soil with pH 7.4, EC 1.5 dS/m and 0.40 % organic matter.

1.2. Seeds and herbicide sources

Seeds of wheat cv. Sham 6 were obtained from Department of field crop, Agriculture Research Directorate, Abu-Ghraib. Atlantis 3.6 WG herbicide (post-emergence plant) which
belongs to a group of (Mesosulfuron- methyl 30g/kg+ Iodosulfuron – sodium 6g/kg + Mefenpyr-diethyl (Safener) 90 g/kg) is a product of Bayer Company-Germany.

1.3. Field trial
To test and evaluate the effects of incorporation of corn residues with Atlantis 3.6 WG herbicide, applied at reduced rate (60% label dose) on weeds of wheat crop and on wheat crop yield, plots that received corn residues incorporated in soil at two rates: 0, 6 t ha\(^{-1}\) of previous experiments were divided into plots measuring 7×8 m\(^2\) at the middle of November 2016. Fertilizers Nitrogen as urea (46% N) and phosphorus as triple super phosphate (46% P\(_2\)O\(_5\)) were applied to these plots as recommended for wheat crop (Cheema and Khaliq, 2000). Grains of wheat cv. Sham 6 were sown at first of December 2016, all plots in 20 cm a part crop rows at seeding rate of 140 kg ha\(^{-1}\). All plots received equal irrigation water during the entire course of study. The experiment consists of the following treatments:

b. Atlantis (Label dose 320g/ha).
c. Residues at 6 t ha\(^{-1}\) + 60% of the label dose Atlantis 3.6 WG

d. Residues at 6 t ha\(^{-1}\)

e. Atlantis (60% of the label dose 192g/ha)
f. Weed free.

The experiment was conducted in a randomized complete block design with four replications. The post-emergence foliar application was done with a Knapsack hand sprayer fitted with a T-Jet nozzle and at a pressure of 207 k Pa at 45 d after sowing (DAS). Spray volume (300 L ha\(^{-1}\)) was determined by calibration using water.

Weeds from weed free plots were manually removed every week by hand pulling throughout the crop life span. A weedy control was maintained for comparison.

2. Data collection for weeds and wheat.
Weed density m\(^2\) (60 + 120 DAS): Data on weed density were recorded at 60 and 120 DAS from two randomly selected quadrants (1m\(^2\)) from each experimental unit. Data on weed density was converted and expressed as per plot.

Weed dry biomass g/m\(^2\) (120 DAS): Weeds were clipped at ground level to record their biomass. Weed dry weight was recorded after drying in an oven at 70 °C for 72 h.

Data on wheat yield and wheat dry biomass were recorded from randomly selected samples after harvested and sun dried of wheat. The total biomass and yield per m\(^2\) was converted to tones per hectare (t ha\(^{-1}\)).

3. Determination of total phenolics in corn residue–amended soil.
Folin-Denis method was used for total phenol analysis (A.O.A.C., 1990) and ferulic acid was used as standard since it is an allelopathic agent present in corn plant (Haslam, 1988). Soil samples were taken from soil of plots amended with corn residues (6 t ha\(^{-1}\)) at a depth of 30 cm at 1, 14, 28, 45 and 60 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 hrs at 200 rpm (Ben- Hammouda et al., 1995). Soil suspensions were filtered through Whatman No. 2 filter paper under vacuum. Folin-Denis (0.5
ml) and Na₂CO₃ 40% (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 (Blum et al., 1991). The total phenolic content was obtained by standard curve using different concentrations of pure standard of ferulic acid.

4. Statistical analysis

The collected data were statistically analyzed using analysis of variance (ANOVA) by GENSTAT computer software package. Differences among treatment averages were compared using Least Significant Difference (LSD) ≤ 0.05 probability level, (Steel et al., 1997).

Results

1. Weed parameters

1.1. Effect of different rates of Atlantis herbicide and corn residues on total weed density in wheat field

Field observations showed that 70% of weeds species grown in the wheat field were broad leaf viz. *Malva rotundifolia* L., *Amaranthus retroflexus* L., *Chenopodium album* L., *Polygonum aviculare* L. and *Convolvulus arvensis* L. and the remain was grass weeds, namely *Avena fatua* L., *Lolium rigidum* L., and *Hordeum spontaneum* L. (Table1).

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>(White goosefoot)</td>
<td><em>Chenopodium album</em> L.</td>
<td>Chenopodiaceae</td>
</tr>
<tr>
<td>(Cheese weed)</td>
<td><em>Malva rotundifolia</em> L.</td>
<td>Malvaceae</td>
</tr>
<tr>
<td>(Field Bindweed)</td>
<td><em>Amaranthus retroflexus</em> L.</td>
<td>Amaranthaceae</td>
</tr>
<tr>
<td>(Knotgrass)</td>
<td><em>Convolvulus arvensis</em> L.</td>
<td>Convolvulaceae</td>
</tr>
<tr>
<td>(Wild oats)</td>
<td><em>Avena fatua</em> L.</td>
<td>Poaceae</td>
</tr>
<tr>
<td>(Rye grass)</td>
<td><em>Lolium rigidum</em> L.</td>
<td>Poaceae</td>
</tr>
<tr>
<td>(Wild barley)</td>
<td><em>Hordeum spontaneum</em> L.</td>
<td>Poaceae</td>
</tr>
</tbody>
</table>

The result presented in table 2 revealed that soil incorporation of corn residues at 6 t ha⁻¹ significantly reduced total weed density by 68.8 and 46.1% of control after 60 and 120 days after sowing (DAS), respectively. However, the inhibition of weed population by the residues rates was significantly increased when the residues combined with the herbicide. Foliar application of 60% of label rate of Atlantis to plots amended with corn residue at 6 t ha⁻¹ significantly suppressed weed density more than the respective residue rates when applied alone (91.5 and 78.8 % of control respectively), and recorded the highest reduction in weed density compared to all treatments. However, Application of 60 % of the label dose Atlantis recorded minimum reduction (37.1 and 42% of control respectively) in weed density.
Table 2. Effect of different rates of Atlantis herbicide and corn residues on total weeds density in wheat field.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Weed density (Plants per plot) at 60 DAS*</th>
<th>% of control</th>
<th>Weed density (Plants per plot) at 120 DAS</th>
<th>% of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Control (Weedy check)</td>
<td>226.8</td>
<td>0</td>
<td>317.5</td>
<td>0</td>
</tr>
<tr>
<td>2- Atlantis (Label rate)</td>
<td>23</td>
<td>89.8</td>
<td>46.5</td>
<td>85.3</td>
</tr>
<tr>
<td>3- Atlantis 60% of label rate</td>
<td>142.5</td>
<td>37.1</td>
<td>184</td>
<td>42</td>
</tr>
<tr>
<td>4- Residues at 6 t ha⁻¹</td>
<td>70.8</td>
<td>68.8</td>
<td>171</td>
<td>46.1</td>
</tr>
<tr>
<td>5- Residues + 60% of label rate of Atlantis</td>
<td>19.2</td>
<td>91.5</td>
<td>65.5</td>
<td>79.3</td>
</tr>
<tr>
<td>LSD ≤ 0.05</td>
<td>29.25</td>
<td>17.62</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*DAS= day after sowing

1.2. Effect of different rates of Atlantis herbicide and corn residues on total weed biomass in wheat field

The results presented in table 3 revealed that average weed biomass was significantly reduced by the residues of corn incorporated in field soil after 120 DAS (59.47 % of control). The interaction of herbicides and corn residues showed significant effect on weed biomass. The reduction in weed biomass was increased when Atlantis applied at reduced 60% of label rate to plots amended with corn residues at 6 t ha⁻¹, scored weed biomass reduced (85.3 % of control) than the residue rate when applied alone. However, Atlantis application (60 % of the label rate) recorded minimum reduction (41.3 % of control) in weed biomass. Reduced herbicide doses with corn residues were more effective against weeds in terms of both density and dry weight.

Table 3. Effect of different rates of Atlantis herbicide and corn residues on dry weight of weeds grown in wheat field after 120 DAS.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry weight (g per m²)</th>
<th>% of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Control (Weedy check)</td>
<td>198.9</td>
<td>0</td>
</tr>
<tr>
<td>2- Atlantis (Label rate)</td>
<td>41.6</td>
<td>79</td>
</tr>
<tr>
<td>3- Atlantis 60% of label rate</td>
<td>116.7</td>
<td>41.3</td>
</tr>
<tr>
<td>4- Residues at 6 t ha⁻¹</td>
<td>80.2</td>
<td>59.67</td>
</tr>
<tr>
<td>5- Residues + 60% of label rate of Atlantis</td>
<td>29.2</td>
<td>85.3</td>
</tr>
<tr>
<td>LSD ≤ 0.05</td>
<td>13.12</td>
<td></td>
</tr>
</tbody>
</table>

2. Crop parameters
2.1. Effect of different rates of Atlantis herbicide and corn residues on dry weight biomass of wheat crop.

The results in table 4 revealed that the biomass was significantly affected by herbicide and corn residues treatments compared to control. The biomass was increased by 16 % of the control...
when corn residues were incorporated in to the field soil at 6 t ha\(^{-1}\). However, these increments were significantly improved when the reduced dose of herbicide was applied to plots amended with corn residue at 6 t ha\(^{-1}\). Plots treated with 60% of label rate of Atlantis herbicide and amended with corn residue at 6 t ha\(^{-1}\) increased dry weight by 49% of the control. Application of label rate of Atlantis recorded 47% of the control. Plots treated with 60% of label rate of Atlantis herbicide was recorded 8.7% of control.

Table 4. Effect of different rates of Atlantis herbicide and corn residues on dry weight biomass of wheat crop.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry weight (t ha(^{-1}))</th>
<th>% of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Control (weedy check)</td>
<td>7.45</td>
<td>------</td>
</tr>
<tr>
<td>2- Atlantis (label rate)</td>
<td>9.55</td>
<td>128.1</td>
</tr>
<tr>
<td>3- Atlantis 60% of label rate</td>
<td>8.10</td>
<td>108.7</td>
</tr>
<tr>
<td>4- Residues at 6 t ha(^{-1})</td>
<td>8.64</td>
<td>116</td>
</tr>
<tr>
<td>5- Residues + 60% of the label rate.</td>
<td>11.10</td>
<td>149</td>
</tr>
<tr>
<td>LSD ≤ 0.05</td>
<td>0.44</td>
<td></td>
</tr>
</tbody>
</table>

2.2. Effect of different rates of Atlantis herbicide and corn residues on yield of wheat crop.

The result in table 5 revealed that the grain yield appeared to be significantly affected by herbicide and corn residue treatments. The grain yield was increased by 34.2 and 59.3% of the control when corn residues were incorporated into the field soil alone or with reduced herbicide dose, respectively. Wheat grain yield was increased in the range of 16.7-55% with different doses of Atlantis as compared to control. However, weed free plots (weeding) recorded higher yield (163.7%) than the other treatments.

Table 5. Effect of different rates of Atlantis herbicide and corn residues on grain yield of wheat crop.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Grain yield (t ha(^{-1}))</th>
<th>% of control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Weedy check (Control)</td>
<td>2.98</td>
<td>------</td>
</tr>
<tr>
<td>2-Atlantis (label rate)</td>
<td>4.62</td>
<td>155.0</td>
</tr>
<tr>
<td>3- Atlantis 60% of label rate</td>
<td>3.48</td>
<td>116.7</td>
</tr>
<tr>
<td>4-Weed free (weeding)</td>
<td>4.88</td>
<td>163.7</td>
</tr>
<tr>
<td>5-Residues at 6 t ha(^{-1})</td>
<td>4.00</td>
<td>134.2</td>
</tr>
<tr>
<td>6-Residues + Atlantis 60% of label rate.</td>
<td>4.75</td>
<td>159.3</td>
</tr>
<tr>
<td>LSD ≤ 0.05</td>
<td>0.4</td>
<td>------</td>
</tr>
</tbody>
</table>

3. Determination of Total phenolics in field soil

Total phenolics in field soil significantly increased after incorporation of corn residues and reached their peak at 4 weeks of residues decomposition, then decreased significantly at 6 weeks and vanished at 8 weeks (Fig. 1).
Discussion

Allelopathy has been reported to offer a significant role in weed control (Sodaeizadeh and Hosseini, 2012). Several non herbicidal weed control strategies in which Allelopathy is involved has been explored such as rotational crop, cover crop, smother crop, intercropping, crop mixtures, plant water extract and use of allelopathic crop residues as mulch or incorporated in field soil (Mohammadi, 2013). Of the all of these strategies, use of allelopathic plant residues is the most successful, effective and readily available (Kelton et al., 2012). Nevertheless, the efficacy of crop residues is not comparing with the efficacy of the herbicides. Hence the present study was focused to test if we can improve the efficacy of corn residues by integrated it with the lower doses of Atlantis herbicide.

In present study, the inhibitory effect of corn residues incorporated into the field soil suggests that the residues contain phytotoxic compounds released into the rhizosphere by dissolving in irrigation water and/or by the action of soil microorganisms and affect the receiver plants. Several researchers indicated that the residues of allelopathic plants are the main source of allelopathic compounds in natural and agricultural ecosystems (Singh et al., 2003; Batish et al., 2001; Alsaadawi and Dayan, 2009). The increase in phytotoxicity against weed density and biomass due to increase in concentration of allelopathic compounds released from the residues into the field soil. However, several studies indicate that small seeded crops and weeds are more susceptible to allelochemicals under field conditions than the large seeded plants. This is attributed to greater surface to volume ratio, resulting in more exposure of such seeds to allelochemicals. Furthermore, allelochemicals released by crop residues remain in the upper surface of soil where small seeds are present compared with larger seeds that are sown deeply. Similar results were reported in other plant species by several researchers (Alsaadawi et al., 1998; Sarbout, 2010; Alkateeb et al., 2013).

The presence and release of allelochemicals from the residues incorporated into soil is further confirmed by the experiment of phenolics determination in soil. Since phenolics are the major category of water-soluble allelochemicals responsible for most allelopathic activity, Phenolics appeared to be released from corn residues after incorporation in soil, reached
maximum peak at 4th week of decomposition and then declined until vanished at the end of 8th week (Figure 1).

Field observations indicated that low percentage of weeds emerged at the beginning of sowing time and continued for about 6 weeks after emergence then started to increase rapidly. Chemical analysis revealed that phenolic acids were highly increased until reached maximum at 4 weeks from sowing time then started to decline until vanished at 8 weeks from sowing time. The decline in phenolic content of residue amended soil is due to the variety of physic-chemical and biological transformations when entering into the soil phase as proposed by Blum et al. (1999). Thus, it appeared that the increase in concentration of total phenolic acids in soil was parallel with high suppressive activity of weeds in the field. These results suggested that phenolics are the main cause of the suppressive activity of weeds. After 2nd month from sowing, weeds started to emerge and grow rapidly; however at that time, the wheat plants became large and highly competitive to weeds. These observations were also reported when the residues of *Sorghum bicolor* were added in broad bean and mung bean field (Al-bedairy et al., 2011; Alkhateeb et al., 2013).

The potential inhibition of incorporated corn residues against weeds population suggested that corn residues provide a significant inhibitory effect. Maximum inhibition (68.8% of control) was achieved at 60 DAS by incorporated corn residues at 6 t ha\(^{-1}\) and this inhibition did not match with the efficacy of the test herbicide 89.8% of control). However, when this amount of residues integrated with reduced dose of Atlantis herbicide, a great reduction of weed population (91.5%) and weed biomass (85.3%) was achieved and this reduction can be comparable with efficacy of standard herbicides. These phytotoxins are reported to have inhibitory effects on several metabolic processes such as inhibition of chlorophyll biosynthesis (Alsaadawi et al., 1986a; Weir et al., 2004), ions uptake (Lehman and Blum, 1999), photosynthesis (Hejl et al., 1993), inhibition of activity of plasma H\(^{+}\)-ATPase which leads to decreased ions and water absorption by guard cells of leaves and causing close of stomata (Hejl and Koster, 2004), Inhibition of stomata opening (Rai et al., 2003). Also phenolic acids are reported to reduce the number of mitochondria and disrupt the membranes surrounding nuclei, mitochondria and dictyosomes (Lorber and Muller, 1976).

This result confirmed the previous hypothesis proposed by Bhowmik and Inderjit (2003) that herbicides applied in combination with allelopathic conditions could have a complementary interaction, and may help to minimize herbicide usage for weed management in field crops. It seems that a reduced level of herbicide may be feasible for providing satisfactory weed control when it works simultaneously with allelopathic conditions. The combination of allelopathy and herbicides has been suggested by several scientists for a long time and very interesting results have been obtained (Cheema et al., 2003a; Cheema et al., 2003b and Barros et al., 2007). However, it is not always necessarily to apply full herbicide dose (Talgre et al., 2008) and there can flexibility regarding herbicide rates depending on the weed spectrum, densities, their growth stage and environmental conditions of the site. Moreover, modern weed science also emphasizes following an ecological approach based on keeping weed populations below threshold levels rather than eradicating them (Barroso et al., 2009).

The improvement in grains and dry weight biomass by corn residues alone or in combination with reduced dose of Atlantis herbicide seems an outcome of reduced weed-crop competition for any of the growth factors which might have contributed to higher yields. It appeared that weed suppression was directly translocated into yield so that significant yield improvement over weedy check was realized by all treatments and their various combinations. Improvement in crop yield by integrating allelopathy with reduced herbicide dose is in line with the previous findings
of Alsaadawi et al. 2011 and Khaliq et al. (2012a, 2012b). The increase in the yield of wheat due to corn residue and herbicide treatments is parallel to significant reduction in weeds population and biomass. The corn residue alone or in combination with reduced dose of herbicide increased yield of wheat over control (34.2 and 59.3 % respectively).

Conclusions

Corn residue showed allelopathic inhibition on weeds grown in wheat field. However the efficacy of the residue is not comparable with the herbicide. The results showed that combination of corn residues and reduced rate (60% of the labeled rate) of Atlantis herbicides appeared to be more effective in controlling weeds population and growth than sole application of residues. Acceptable level of weed suppression in wheat fields was achieved with lower doses (60%) of Atlantis in combination with corn residues a comparable to results with its label dose. This can be used as a cost effective, economical and environmentally friendly approach to minimize weed pressure. Similar studies need to be carried out under varying soil and environmental conditions in various field crops, and for herbicides with different modes of action.

References


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