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# Research Article
# Optimum Herbicide Dose Management in Direct Seeding for Cereals Production: Case of Semi-arid Area of Algeria

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## Abstract

**Background and Objective:** The herbicide application for weed control and yield response achievement in direct seeding is a challenging task in cereal productions. Mostly the direct seeding is linked to the use of glyphosate, the herbicide with many environmental effects have been showed. The present research study experimented during two subsequent years 2014/2015 and 2015/2016 in a semi-arid area of Algeria on cereal plots aimed to study a possible management of weed in direct seeding for a sustainable production. **Materials and Methods:** Considering some characteristics of the studied soil (texture, calcium carbonate, cation exchange capacity, organic matter, C/N ratio and soil moisture), four doses of glyphosate were tested: 1080, 900, 720 and 540 g ha$^{-1}$ with residual concentrations in the soil. The fate of glyphosate in the soil was followed over a period of 140 days and the concentrations were measured by HPLC-UV following derivatization step. The yield was determined depending on doses applied and glyphosate dissipation. For the statistical analysis of the data, one-way ANOVA ($p<0.05$) was performed. **Results:** Seven days after treatment, the concentrations of glyphosate in the soil were important in the first horizon (0- 0.20 m). The measurements showed that the herbicide fractions have dissipated in the deep layers of the soil (0.20 m). The amount of glyphosate remaining in the soil 140 days after application depended on the doses applied. The high herbicide residues and the maximum yield (1.9 t ha$^{-1}$) were obtained in response to the highest dose of herbicide (1080 g ha$^{-1}$) applied. **Conclusion:** If the high dose is reduced to 65% of its content, the yield decreases to 1.4 t ha$^{-1}$, which is reasonable during a transition period from conventional tillage to conservation tillage for soil and environment safety.

Key words: Cereal productions, glyphosate, direct seeding, dissipation, soil and environment safety

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

Intensive farming system requires the use of herbicide to get maximum yield from the available land. This applies equally to tillage based conventional farming as to no till farming[1]. The 1970s marked the introduction of glyphosate, this herbicide transformed grain production in Western Canada as it facilitated the widespread adoption of minimum-till and zero-till farming systems[2]. The falling price of the predominant herbicide, glyphosate, had a significantly positive effect on the adoption of no-till, with 78% of farmers practicing no-till in 2008[3]. No-till or direct seeding as a conservation technology of soils is a sustainable fight against poverty in Europe, even in Asia and Africa[4]. However, the high use of herbicides in direct seeding as "glyphosate" is the active matter and the results of many research suggest toxic effect of glyphosate[5-6], environmental and agricultural sciences focus their attention on the study of this herbicide. Knowing the use of herbicides, is toxic for the environment and for non-target organisms including pollinators and wildlife, contaminates the soil, water and air thereby, affecting ecosystem functioning, favours the selection of resistant pests and causes acute and chronic toxicity to humans[7]. In this context, many firms demonstrated the benefits of the direct seeding through two main axes: A first one is "environmental" which aims to underline the ecological virtue of this technique, while the second one is to contribute to the food challenge by maintaining a high productivity level[8]. Although there is not a specific method to analyze glyphosate in the environment[9], many results worldwide showed the effect and the fate of glyphosate on the agricultural environment (soil, water, sediment) under controlled and field conditions[10-11]. In North Africa, the convergence to direct seeding as a conservation agriculture using glyphosate for chemical weed control aims to improve the food production and to conserve soil quality, especially that a severe weed control is important during the first years of adaptation of direct seeding[12]. The present research interests to a possible management of chemical weed control in direct seeding for a sustainable production. Researchers hypothesis is that the direct seeding machinery combined to a suitable dose of glyphosate can enhance cereal production and preserve soil quality with safety measures in the same time. The HPLC-UV detection method was used with previous derivatization step by 9-Fluorenylmethylchloroformate (FMOC-Cl) to analyze the amount of glyphosate in the soil. Moreover, the time dependent residual amount of the glyphosate in the soil was assessed for four doses of herbicide to analyze the cereal production afterwards.

## MATERIALS AND METHODS

**Field experiments:** Field experiments were conducted in the high plains of Setif Eastern Algeria over an area of 1080 $m^2$ for $S_1$ (2014/2015) and $S_2$ (2015/2016) season. The direct seeding was the main technique used in the last 8 years. The experimental site divided into five plots for the different glyphosate treatments of weed (four treatments and one control plot) with three repetitions. In $S_1$, weed treated by one dose of glyphosate (1080 g $ha^{-1}$). The climate is semi- arid with a cold rainy winter and a hot dry summer. The amount of rainfall and temperature during the $S_1$ and $S_2$ agricultural seasons were presented in the Fig. 1. Temperatures were relatively high during the two seasons compared to 17.96°C average temperature of the last 10 years[13]. The soil is moderately deep (40-70 cm) with a slight slope (0-3%) and solid calcareous crust at a depth of 60 cm. The soil characteristics which are presented in the Table 1, were determined using the method of Mathieu and Pieltain[14]: Organic matter (OM) content was calculated from the measurement of organic carbon (OC) using the ANNE method, the total nitrogen ($Na^+$) by Kjeldahl method, the pH of the soil ($pH_{water}$) measured with a pH meter, cations exchange capacity (CEC) using the Metson method and total calcium carbonate ($CaCO_3$) measured with a calcimeter. In this study, two soil horizons considered (Horizon1 $H_1$: 0-0.2 m and Horizon 2 $H_2$:0.2-0.6 m).

**Glyphosate management and soils sampling:** The glyphosate formulation known as 'Ridazate' (Aoko BV manufacturer, 360 g $L^{-1}$) was used. In $S_1$, the dose of 1080 g $ha^{-1}$ was applied while in $S_2$, four doses selected based on surveys of farmer's conducted in $S_1$: $D_1$ (1080 g $ha^{-1}$), $D_2$ (900 g $ha^{-1}$), $D_3$ (720 g $ha^{-1}$) and $D_4$ (540 g $ha^{-1}$). The control plot (T) which not receives treatment was reserved. The barley (*Hordium vulgare*) was the cereal sown in $S_2$. Soil

Table 1: General characteristics of the soil

| Parameters | First horizon 0-20 cm ($H_1$) | Second horizon >20 cm ($H_2$) |
|---|---|---|
| **Particle size distribution** | | |
| <0.002 mm (clay) (%) | 35.720 | 35.720 |
| 0.002-0.05 mm (silt) (%) | 37.820 | 37.820 |
| >0.05 mm (sand) (%) | 26.450 | 26.450 |
| Organic matter (OM) (%) | 3.950 | 3.800 |
| Organic carbon (OC) (%) | 2.296 | 2.209 |
| Nitrogen (N) (%) | 0.220 | 0.198 |
| C/N ratio | 10.436 | 11.156 |
| pH water | 7.440 | 7.450 |
| CEC (mEq/100 g) | 24.583 | 24.418 |
| $CaCO_3$ (%) | 21.560 | 26.990 |

samples were collected at dates that depended on the barley growing stages to determine the variation of glyphosate concentrations in the soil (Table 2). The soil moisture was measured for all sampling dates and for both horizons. For each dose, 30 soil samples were collected. Cereal yields were estimated after harvesting.

**Glyphosate laboratory analysis:** Derivatization was carried out as follows: 0.25 mL of borate buffer 5% and 0.30 mL of FMOC-Cl 2 mM in $CHCl_3$ were added to 1 mL of sample. Glyphosate concentrations were determined by HPLC-UV. The methodology closely followed that described by Peruzzo *et al.*[15]. The concentration of herbicide was measured after extracting 15 g of soil sample with $KH_2PO_4$ 0.1 M, agitated for 15 min, centrifuged for 10 min at 3500 rpm and filtered through Whatman filter paper (No. 1). The extraction was repeated on solid residue to obtain a 25 mL extract from each sample. Extracts were then filtered through 0.45 mm cellulose acetate membrane. The reaction was stopped after 24 h at 40°C in the dark (water bath). The reaction was stopped, 0.30 mL of $H_3PO_4$ (2%) were added and the sample was stored at 4°C until analysis. The derived product (Gly- FMOC) was analysed using HPLC (YL9100 HPLC System,

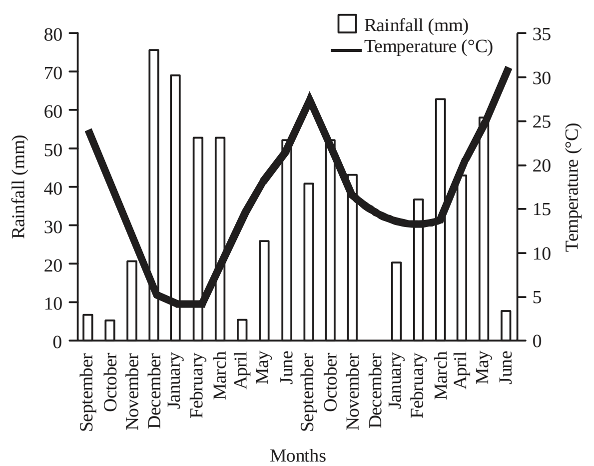


Fig. 1: Cumulative precipitations and average temperatures of studied region (Setif), during 2014/2015-2015/2016 seasons

YL Clarity software). The chromatographic conditions were a 50 mm $C_{18}$ column, mobile phase: 65% $H_3PO_4$ 0.05 M pH = 6.1, 35% acetonitrile at 0.8 mL $min^{-1}$, UV detection took place at 206 nm at a temperature of 25°C and a pressure of 65 bars.

**Statistical analysis:** Analysis of variance (one-way ANOVA) was performed of variations in the concentrations of glyphosate over time and the effect of the doses on yield using the Statgraphics v. 5.0 software package. The ANOVA was based on the HSD criterion (honestly significant difference) with a significance level of $p<0.05$ throughout the study.

## RESULTS AND DISCUSSION

The present research work result to obtain an optimum glyphosate dose management in semi-arid environment for cereals production. The experimental observations and results obtained during research activities such as dissipation and yield responses of glyphosate were discussed as follows.

**Follow up of glyphosate in the soil:** The detection of glyphosate in the soil under field conditions using the HPLC method in the present research work shows positive results where the molecule was detected in the soil during $S_1$ and $S_2$. The concentration of herbicide applied in December, 2014 (1080 g $ha^{-1}$) was not totally dissipated over a period of 319 days. In fact, 0.380 µg $kg^{-1}$ measured in the first 20 cm of soil ($H_1$). The follow-up of control soil during $S_2$ indicated some fractions remaining in the first horizon of the soil from the previous application (1080 g $ha^{-1}$) at different times sampling (Fig. 2).

In the deeper soil layers (>20 cm), the glyphosate concentration was under the limit of quantification (LQ = 0.264 µg $kg^{-1}$) between 319 and 506 days after a first application. The small concentrations detected in the first horizon were not transferred to the deep under rainfall event occurred during $S_2$. In $S_2$ and to follow the fate of

Table 2: Glyphosate treatment and soil sampling schedule

| $S_1$ (2014/2015) | | $S_2$ (2015/2016) | |
|---|---|---|---|
| Treatment ($D_1$) | December 1st, 2014 | Treatment ($D_1$, $D_2$, $D_3$, $D_4$) | December 2th, 2015 |
| Seeding | December 8th, 2014 | Seeding | December 7th, 2015 |
| First sampling | October 15th, 2015 | First sampling | December 8th, 2015 |
| Second sampling | February 9th, 2016 | Second sampling | February 9th, 2016 |
| Third sampling | March 20th, 2016 | Third sampling | March 20th, 2016 |
| Fourth sampling | April 24th, 2016 | Fourth sampling | April 24th, 2016 |
| | | Harvesting | June, 2016 |

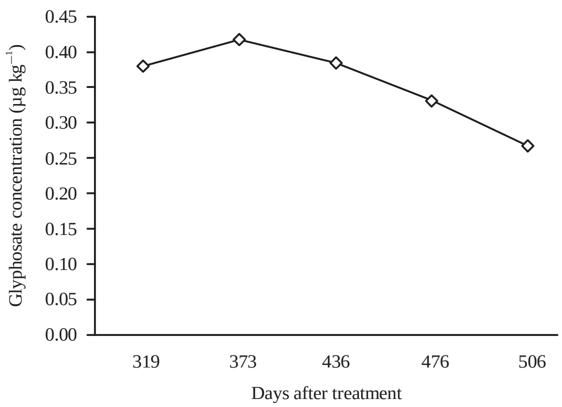


Fig. 2: Glyphosate distribution from the first application (from 2014 to 2016)

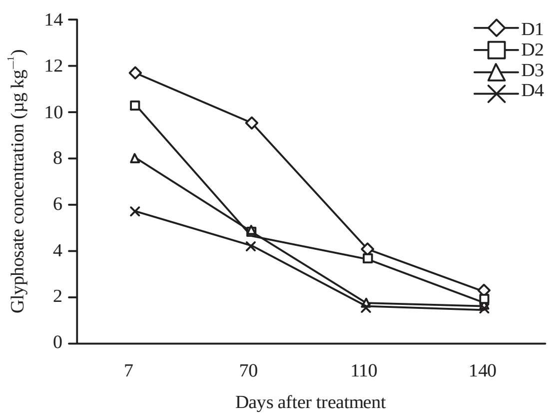


Fig. 3: Glyphosate distribution in the time for first horizon (2015/2016 season), varied between 0-20 cm

different glyphosate concentrations in the soil, the analysis period was determined by 140 days. After application of the four doses, the concentrations of glyphosate in the soil were 11.702 µg kg$^{-1}$ with $D_1$, 10.36 µg kg$^{-1}$ with $D_2$, 8.033 µg kg$^{-1}$ with $D_3$ and 5.72 µg kg$^{-1}$ with $D_4$ at 7 days after treatment, in the first horizon. These results confirmed that some fractions of glyphosate have reached the soil at the time of weeds treatment[16]. The dissipation of glyphosate on first 20 cm of soil was lent during the analysis period. The fractions remaining in the soil, 140 days after second treatment, were approximately 18% with $D_1$ and $D_2$ and 23% with $D_3$ and $D_4$ (Fig. 3).

The glyphosate dissipation that described by SFO kinetics, gives variable half-life values depending on the doses applied (Table 3). The applied low dose concentration (540 g ha$^{-1}$) corresponds to the high value of $DT_{50}$. The dissipation half-live values of glyphosate found under field conditions were high compared to the results of literature[17]. Giesy *et al.*[18] found that

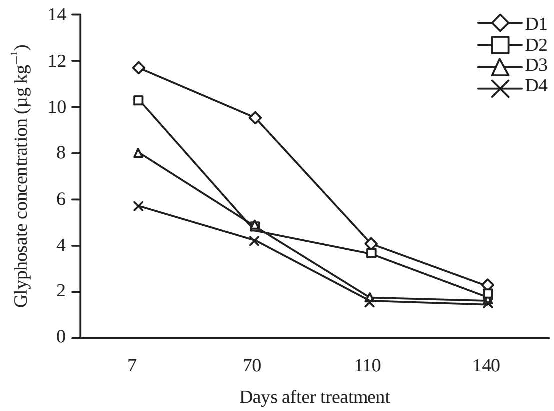


Fig. 4: Glyphosate distribution in the time for second horizon (2015/2016 season), varied between 20-60 cm

the dissipation of glyphosate is essentially due to the microbial degradation but it is limited by its adsorption[19]. The evaluation of the biological potentiality of the soil through the C/N ratio shows that the studied soil could be very active biologically where the temperature and soil moisture "the most important factors regulating microbial activity"[20], were high thus affecting glyphosate dissipation[21,22] (Table 3).

The high half-life value found under low glyphosate concentration ($D_4$) could be explained by the fact that high concentration of glyphosate in the soil stimulates microbial activity[23,24] and may use it for phosphorus source[25], so degradation phenomena should be accelerate. It is known that the high half-live value of herbicides in the field could cause its transfer in the soil. This finding was observed in the second horizon, where no clear trend of glyphosate concentrations was found for all the doses (Fig. 4). The glyphosate dissipation under field conditions was due to dispersion or transfer phenomena related to rainfall event. Seven days after application, the values measured were: 1.281, 1.048, 0.929 and 0.758 µg kg$^{-1}$, respectively from the first dose (1080 g ha$^{-1}$) to the last one (540 g ha$^{-1}$). Seventy days later, the amount of glyphosate increased at a rate of 34.5% with $D_1$, $D_2$ and $D_3$ and 18.63% with $D_4$. These observations suggested that glyphosate has been dispersed significantly in the deep soil layer after 24.8 mm of rainfall recorded in the second sampling ($p<0.05$). These results confirmed the significant effect of rainfall on glyphosate dissipation in the soil[15].

From the third sampling date one, the glyphosate content in the soil decreased significantly ($p<0.05$) until the last sample (140 days after application). The analyses of the second horizon showed the mobility of glyphosate in the soil[26].


Fig. 5: Observed cereal production under different doses in field conditions

Table 3: Half-life values of glyphosate under field conditions

| Samples | Soil moisture (%) | Samples | Average temperature (°C) | $DT_{50}$ | Days |
|---|---|---|---|---|---|
| 1 | 32 | 1 | 7.66 | $D_1$ | 59 |
| 2 | 45 | 2 | 7.35 | $D_2$ | 55 |
| 3 | 37 | 3 | 7.35 | $D_3$ | 61 |
| 4 | 25 | 4 | 15.16 | $D_4$ | 75 |

Table 4: Cereal yields in response to herbicide doses and residues in the soil

| Treatments | Yield (t $ha^{-1}$) | Herbicide residues in $H_1$ (µg $kg^{-1}$) | Herbicide residues in $H_2$ (µg $kg^{-1}$) |
|---|---|---|---|
| $D_1$ | 19.419 | 2.227 | 1.554 |
| $D_2$ | 14.518 | 1.780 | 1.592 |
| $D_3$ | 13.960 | 1.625 | 1.330 |
| $D_4$ | 12.893 | 1.466 | 1.185 |
| T | 5.019 | 0.267 | L.Q. |

L.Q: Limit of quantification = 0.264 (µg $kg^{-1}$)

**Assessing yields responses to glyphosate doses:** In direct seeding, the use of herbicides involves weed control, especially before crops seeding and at the beginning of its cycle[27].

The yield was found to vary depending on the dose of glyphosate applied ($D_1$, $D_2$, $D_3$, $D_4$), which confirm that the use of herbicides increase grain yield and reduce competition with weed[28,29]. The highest yield obtained (1.9 t $ha^{-1}$) was found in response to the highest dose of glyphosate applied (1080 g $ha^{-1}$). A reduction of applied dose was related to the yield loss due to the weed development, while low yield was obtained in the control soil plot (Fig. 5). Brabham *et al.*[30] and Ama-Abina *et al.*[31] found that a better yield was obtained with treated soil compared to control soil, where the pressure of the weed was, therefore, higher in the control soil plot and displayed rapid and early season growth. Based on these results, the yield variation was significant using $D_1$ and $D_4$ ($p<0.05$), in the contrary, the variation of yield using $D_2$ and $D_3$ is not significant. These results were similar with that observed by Rouane[32] when a significant difference of yield using a half-dose certified of herbicide linked to weed development was found.

However, the increase in yield corresponds to the highest dose linked to the low value of $DT_{50}$ and high residues compared to the other doses (Table 4). Herbicides are likely useful tool for weeds management particularly in the first years after shifting from conventional tillage to conservation tillage[1]. To equilibrate the balance between environment and production, the substituting of $D_1$ by $D_3$ implying 65% fewer herbicide and 30% loss of grain yield is proposed. This alternative should be a reasonable option during transition period from conventional tillage to conservation tillage where the amount of plant infestation and the emergence of annual grasses tend to increase[12]. In fact, "less pesticides and reduced yields" should be acceptable in terms of decreased soil contamination and also better human health, derived from the use of smaller amounts of pesticides, leading, thus to an increased sustainability of various ecosystems[33].

## CONCLUSION

In semi-arid area where the cereal production depends on rainfall conditions, the shift to no-till farming should be necessarily. The present research reflects a real effect of the direct seeding in semi-arid area where the old technique has reached their limits. It provides environmental indicators to manage cereal production systems in the least harmful way possible. The use of a total herbicide is an indispensable tool to preserve production level but a safe threshold concentration including a lowering of the doses must exist. Consequently, the suitable doses should be applied in relation with the soil characteristics. Based on study results, it was observed that use of glyphosate to manage weed control in direct seeding could be an indispensable tool for cereal production under field conditions, without irrigation. Some fractions of glyphosate achieved the soil at the time of weed treatment and, the dissipation of glyphosate in the soil under field conditions depends on the dose applied, the soil characteristics and climatic conditions.

## SIGNIFICANCE STATEMENT

This field study explores the ways to strength the cereal production after the introduction of the direct seeding practice. It particularly highlights about the impacts of a diversity of glyphosate herbicide doses and occurrences applications on both the grain yield and the soil quality and discusses the possibility to obtain a reasonable production with a minimum adverse effects on the soils. This study will help the researchers to uncover the critical area of the large crop production facing new environmental challenges. Thus, a new approach of the conservation agriculture that ensures an efficient weed treatment and sustainable production may be arrived at.

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