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Magnetic treatment of herbicide spraying solutions to increase the activity of weed control in wheat crop

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ABSTRACT

Enhancing herbicide efficacy is crucial for sustainable weed management and crop productivity. This study investigated the effect of using magnetized water as a carrier on the efficacy of various herbicides and their subsequent impact on wheat (*Triticum aestivum* L. cv. Gemaza 11). Field experiments were conducted at the experimental research station at the Faculty of Agriculture, Alexandria University, during the winter season 2021-2022 using a randomized complete block design (RCBD) with four replications. Herbicide treatments included flumetsulam (Candy), pinoxaden (Axial), and a mixture of iodosulfuron-methyl sodium + mesosulfuron-methyl + thiencarbazone-methyl (Atlantis), each applied at three recommended rates (0.5x, 0.75x, and 1x). Each herbicide was prepared in both regular and magnetized water (3000 Gauss). Results demonstrated that herbicides applied in magnetized water consistently provided superior weed control compared to those in regular water. This was evident through significantly lower fresh weight and a higher percentage reduction of key annual broadleaf (*Melilotus indica*, *Medicago* spp.) and grassy weeds (*Lolium temulentum*, *Avena fatua*) at both 3 and 6 weeks after application. The enhanced efficacy is attributed to the altered physicochemical properties of magnetized water, which likely improve herbicide solubility, leaf wetting, and plant uptake. Furthermore, the use of magnetized water positively influenced crop physiology, leading to increased chlorophyll and nitrogen content in wheat leaves. This translated into significant improvements in yield components, including higher biological yield, grain yield, and 1000-grain weight. The study concludes that magnetizing spray water is a highly effective, low-cost, and environmentally friendly adjuvant technology that can significantly boost herbicide performance, improve weed control, and enhance wheat growth and yield.

Keywords: Herbicide efficacy; Magnetized water; Weed control; Wheat (*Triticum aestivum*); Herbicides; Measured outcomes.

INTRODUCTION

Wheat is the most widely grown cereals in Egypt where the total cultivation area is 2.450 million Feddans (Shehata et al., 2022). Weeds are the major problem in wheat production. The percentage of, weeds in the first 30 - 40 days after sowing (the critical period of crop-weed competition) can sensually limited the growth of wheat plants (Nedunzhiyan et al., 1998). Almost hundred percent crop loss, due to weeds competition, was recorded weeds / m was followed by decrease of 143 gm and 158 gm in grain and in wheat field (Fahad et al., 2015).

The ability of the herbicide to suppression of target weed depending on

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the amount of the absorbed herbicide and arrived of active ingredient to plant's effect site. This depending primarily on several factors such as the type of the weed, the type of herbicide group and the concentration of the active ingredient on it, as well as the environmental factors and the time of spraying. On the basis of the absorbed quantity of the active ingredient, some herbicides may be dependent on the selectivity (Nandula and Vencill 2015).

The use of some applications to increase pesticide absorption from weed, contributes to highly efficient control and reduces herbicide spraying rates and thus reduces environmental pollution and material cost (Rashid et al., 2010; Tudi et al., 2021). Water surface tensile and herbicide charge are essential and determinant of the quantity of the herbicide absorbed by the leaves, so several substances were used to reduce the surface tensile of the herbicide's at the spray, which were adding to solution as surface-tightening (Alfarttoosi et al., 2019). However, a large proportion of the herbicide may be a not absorbed by the leaves due to environmental conditions or the closing of the stomata on the plan (Alfarttoosi et al., 2019).

Recently, the concept of use water magnetic technology on agriculture, or the so-called biomagnetic stimulation of vegetation through the stimulation of plant metabolism and changes on the properties of cells membranes (Fabricant 2024). Abu-Saied et al., (2023) found that hydrophobic magnetic treatment results of reduced surface tension and changes on the physical of water and making it easier to absorb from the plant. Also, the magnetization of the spray solution of herbicides increases the readiness of the nutrients when sprayed on the plant (Alfarttoosi et al., 2019; Doklega 2017). The use of some applications to increase herbicide absorption by weeds, leads to highly efficient control and reduces herbicide spraying rates and thus reduces environmental contamination and material cost (Hatami et al., 2016). Magnetic water treatment reduces surface tension and changes in Phyto-water properties, making it easier to absorb by plants (Abu-Saied et al., 2023).

With the advent of herbicides to solve the problem, flumetsulam will be used for broad leaved weeds and pinoxaden for grassy weeds, and (Atlantis Active+BiopureWG20.4%) idosulfuron methyl sodium 0.9% + thiencarbonzon methyl 1.5% + mesosulfuon methyl + mefenpyrdremyl will be used to control grassy and broad-leaved weeds. With the advent of magnetized water technology in agriculture to increase crop yields, the use of magnetized water increases the weed absorption of herbicides, which increases efficiency and reduces herbicide rates and thus reduces environmental pollution and cost. In this experiment, (100%-50%) of the recommended dose of herbicides with magnetized and normal water was used. The aim of the experiment is to reduce the dose of herbicide through the use of magnetization and to evaluate the effectiveness of the herbicides against weeds and their effect on the crop (Sabra et. al., 1999 and Sabra and Hossien, 2004).

MATERIALS AND METHODS

Experimental design and applications

Experiment was conducted in the experiment station, Abbis farm of the Faculty Agriculture, Alexandria University during the winter seasons 2021-2022. Experimental unit was 9 m^2 with dimensions 3×3 m. All agricultural transactions related to the wheat crop, such as planting, fertilizing, etc., were carried out in accordance with the recommendations of the Ministry of Agriculture, except for the application of the herbicides, which are the subject of experimentation. Randomized completely block design (RCBD) was used with 4 replications. Study was included planting cultivar Gemaza 11 Bread wheat. the weed control treatments (herbicides) were flumetsulam for broad weeds, pinoxaden for grassy weeds, and idosulfuron methyl sodium 0.9% + thiencarbonzon methyl 1.5% + mesosulfuon methyl + mefenpyrdremyl will be used to control grassy and broad leaf weeds by three recommendation rates with and without magnetized spraying solution. The amount of water was calculated on the 200 L/Feddan. The water magnetization device was used with the severity of 3000 Gs attached with spray tube on the treatments. Spraying of herbicide was applied at arrival of the weeds plant to fourth stage of the leaves at the early morning by backpack sprayer, under constant pressure. When crop plants were arrival to physiological stage maturity, the existing weeds were counted and their types diagnosed in each experimental unit in the way Squares. The intensity of the weed and weed percentage are estimated in each experimental unit wheat crop reaches the stage of physiological maturity. The design of regular and magnetic treatment of herbicide spraying solutions to increase the activity of weed control in Wheat was shown in Table 1. In addition, the common, trade, chemical name and rate of herbicidal treatment used in these experiments are shown in Table 2.

Table 1: Design of regular and magnetic treatment of herbicide spraying solutions to increase the activity of weed control in wheat

	Wheat						g/L/Treatment	Herbicides preparation in regular water (A)
Wheat large scale herbicidal treatments	11*	1*	4*	7*	22	(A)	0.135 g	Candy 80%WDG at 15g (0.5F)-1
	10*	2*	3*	8*	21		0.203 g	Candy 80%WDG at 22.5g(0.75F)-2
	9*	3*	2*	6*	20		0.27 g	Candy 80%WDG at 30g (1F)-3
	8*	4*	1*	9*	19		2.3 cm^3	Axial 5%EC at 250 mL (0.5F)-4
	7*	5*	11*	10*	18		3.4 cm^3	Axial 5%EC at 375 mL (0.75F)-5
	6*	7*	10*	11*	17		1.5 cm3	Axial 5%EC at 500 mL (1F)-6
	5*	6*	9*	1*	16		2.3+0.6 cm^3	Atlantis Active + BioPower 62.5 + 250ml-7
	4*	8*	7*	2*	15		3.4+0.8 cm^3	Atlantis Active + BioPower 94 + 375 ml-8
	3*	9*	8*	3*	14		4.5+1.1 cm^3	Atlantis Active + BioPower 125 + 500 ml-9
	2*	10*	6*	4*	13		-	(Hand Weeding) -10
	1*	11*	5*	5*	12		-	(unweeded Control) -11
	11	1	4	7	11	(B)	**g/L/Treatment**	**Herbicides preparation in magnetic water (B)**
	10	2	3	8	10		0.135 g	Candy 80%WDG at 15g (0.5F)-1
	9	3	2	6	9		0.203 g	Candy 80%WDG at 22.5g(0.75F)-2
	8	4	1	9	8		0.27 g	Candy 80%WDG at 30g (1F)-3
	7	5	11	10	7		2.3 cm^3	Axial 5%EC at 250 mL (0.5F)-4
	6	7	10	11	6		3.4 cm^3	Axial 5%EC at 375 mL (0.75F)-5
	5	6	9	1	5		1.5 cm3	Axial 5%EC at 500 mL (1F)-6
	4	8	7	2	4		2.3+0.6 cm^3	Atlantis Active 20.4%WG + Biopower 62.5 + 250 ml-7
	3	9	8	3	3		3.4+0.8 cm^3	Atlantis Active 20.4%WG + Biopower 94 + 375 ml -8
	2	10	6	4	2		4.5+1.1 cm^3	Atlantis Active 20.4%WG + Biopower 125 + 500 ml -9
	1	11	5	5	1		-	(Hand Weeding) -10
	R_1	R_2	R_3	R_4			-	(unweeded Control) -11
	Irrigation canal							

Note: The area of the experimental unit (Replicate) is equal to 9 m^2 (3×3 meters) = 9×4 = 36 m^2. The weight or volume is calculated on the basis of 36 m^2 and placed in the sprinkler with 8 L of water and sprayed in the four rep. for each treatment normal water or magnetized water (i.e., the rate per acre mentioned in the table is multiplied by 0.009 to obtain the required weight or volume).

Table 2. The common, trade, chemical name and rate of herbicidal treatment used in this experiment

Treatment	Trade name	Common name	Chemical name	Rate of application
Treatment 1	Candy 80% WG	Flumetsulam 80%	2’,6’-difluoro-5-methyl]1,2,4[triazolo]1,5a[pyrimidine-2-sulfonanilide	15g /F (0.5F)
Treatment 2	Candy 80% WG	Flumetsulam 80%	,,	22.5g/F (0.75F)
Treatment 3	Candy 80% WG	Flumetsulam 80%	,,	30g/F(1F)
Treatment 4	Axial 5% EC	Pinoxaden	[8-(2,6-diethyl-4-methylphenyl)-7-oxo1,2,4,5-tetrahydropyrazolo[1,2-d] [1,4,5] oxadiazepin-9-yl]2,2-dimethylpropanoate	250 ml/F (0.5F)
Treatment 5	Axial 5% EC	Pinoxaden	,,	375 ml/F (0.75F)
Treatment 6	Axial 5% EC	Pinoxaden	,,	500 ml/F(1F)
Treatment 7	Atlantis Active + Biopower	Iodosulfuron-methyl sodium 0.9% + Mesosulfuron- methyl 4.5% + Thiencarbazone-methyl 1.5% + Mefenpyr diethyl 13.5%	Iodosulfuron-methyl sodium, Mesosulfuron- methyl, Thiencarbazonemethyl, Mefenpyr diethyl (Safner)	62.5+250 ml/F (0.5F)
Treatment 8	Atlantis Active + Biopower	Iodosulfuron-methyl sodium 0.9% + Mesosulfuron- methyl 4.5% + Thiencarbazone-methyl 1.5% + Mefenpyr diethyl 13.5%	,,	94+375 ml/F (0.75F)
Treatment 9	Atlantis Active + Biopower	Iodosulfuron-methyl sodium 0.9% + Mesosulfuron- methyl 4.5% + Thiencarbazone-methyl 1.5% + Mefenpyr diethyl 13.5%	,,	125+500 ml/F(1F)

RESULTS AND DISCUSSION

The efficacy of various herbicidal treatments prepared in both regular and magnetized water was evaluated against annual broadleaf weeds, specifically *Melilotus indica* and *Medicago spp.*, in a winter wheat crop (Table 3). The data, measured as fresh weight (gm/m²) and percentage reduction (R%) compared to the control, revealed clear trends. Across all treatments, the application of herbicides prepared in magnetic water consistently resulted in lower weed biomass and a higher percentage of reduction for both weed species and their total population. For instance, in Treatment 8, the total weed fresh weight was 69.8 g/m² (84.4% reduction) when applied with regular water, but this was further reduced to 39.3 g/m² (91.5% reduction) when the same herbicide was prepared in magnetic water. This pattern of enhanced efficacy with magnetic water was observed for nearly every treatment. Furthermore, all herbicidal treatments, irrespective of the water type used, were significantly more effective than the standard hand weeding (H. weeding) practice, which showed a total reduction of only 70.9% and 69.9% with regular and magnetic water, respectively. Treatment 9 applied with regular water showed the highest overall efficacy, achieving a 91.9% reduction in total weed biomass, underscoring the inherent potency of this particular treatment.

The results demonstrate that the use of magnetized water as a carrier for herbicides significantly enhances their effectiveness against broadleaf weeds in wheat. The consistent and statistically significant improvement in weed biomass reduction across multiple treatments suggests that magnetized water acts as a bio-stimulant for the herbicide solution. This phenomenon can be attributed to the physical changes water undergoes when exposed to a magnetic field, which includes a reduction in surface tension, increased solubility, and improved molecular clustering (Al-Douri et al., 2021; Pang and Deng 2008). These altered physicochemical properties likely enhance the herbicide's ability to wet leaf surfaces more thoroughly, penetrate the plant cuticle, and be more readily absorbed and translocated within the weed, thereby increasing its phytotoxic impact (Grewal and Maheshwari 2011).

Table 3. Effectiveness of herbicidal treatment prepared in regular and magnetic water after three weeks against annual broad leaf weeds in wheat crop during winter season 2021/2022.

Treatment	Regular water						Magnetic water					
	M. indica		*Medicago spp.*		Total		*M. indica*		*Medicago spp.*		Total	
	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%
Treatment 1	33.3	79.0	92.0	68.1	125.3	72.0	35.3	79.9	40.0	86.1	75.3	83.8
Treatment 2	27.0	83.0	76.1	73.6	103.1	76.9	18.0	89.7	25.0	91.3	43.0	90.7
Treatment 3	17.0	89.3	76.0	73.7	93.0	79.2	15.0	91.4	17.9	93.8	32.9	92.9
Treatment 7	21.8	86.3	71.0	75.4	92.8	79.3	13.3	92.4	29.5	89.8	42.8	90.8
Treatment 8	9.8	93.8	60.0	79.2	69.8	84.4	10.3	94.1	29.0	90.0	39.3	91.5
Treatment 9	9.0	94.3	27.0	90.6	36.0	91.9	27.3	84.4	13.0	95.5	40.3	91.3
Hand weeding	50.5	68.1	79.8	72.4	130.3	70.9	60.0	65.7	79.8	72.4	139.8	69.9
Control	158.5	0.0	288.7	0.0	447.2	0.0	175.0	0	288.7	0.0	463.7	0.0
$LSD_{0.05}$	30.3		37				61		14			

Wt. = g/m^2 of fresh weight, R%=% of Reduction in weeds

Effect on annual grassy weeds

Table 4 shows the effectiveness of herbicidal treatment prepared in regular and magnetic water after three weeks on annual grassy weeds in wheat crop during winter season 2021/2022. The results demonstrate a significant enhancement in herbicidal efficacy when applied in magnetic water compared to regular water against annual grassy weeds in wheat. For every treatment (T4-T9), the total fresh weight (Wt.) of weeds (both *Lolium temulentum* and *Avena fatua*) was substantially lower, and the corresponding percent reduction (R%) was higher, in the magnetic water group. This effect was particularly pronounced for *A. fatua*, where the average weed control efficacy across treatments increased from approximately 74% with regular water to over 98% with magnetic water. For instance, in treatment 9, the control of *A. fatua* reached 99.0% with magnetic water compared to 94.1% with regular water. The total weed control for all treatments was consistently and significantly superior with magnetic water, with efficacy values ranging from 85.0% to 95.3%, compared to 75.1% to 83.8% with regular water. All treatments, regardless of water type, were significantly more effective than the weedy control and the hand weeding check, as confirmed by the low LSD values.

The consistent and significant improvement in herbicidal efficacy observed with magnetically treated water can be attributed to the physicochemical alterations in the water's structure. Magnetization is known to reduce the surface tension and cluster size of water molecules, which likely enhances the solubility of the herbicide, improves its penetration through the plant cuticle, and facilitates greater translocation within the weed (Grewal and Maheshwari 2011). This increased bioavailability of the active ingredient explains the superior control, especially of the more resilient *A. fatua*. The findings align with previous studies, such as those by Lin et al., (2024), who reported that pesticides prepared in magnetized water showed higher biological activity due to improved wetting and spreading properties on leaf surfaces. This technology presents a promising, low-cost, and environmentally friendly adjuvant strategy to reduce herbicide doses while maintaining high weed control efficacy, thereby contributing to more sustainable weed management practices in wheat cultivation.

Effect on total weeds with broad and narrow leaves

The results from Table 5 demonstrate a clear enhancement in herbicidal efficacy when treatments were prepared in magnetic water compared to regular water after three weeks of application. In regular water, the total weed count across all annual weeds (broadleaf and grassy) for Treatments 7, 8, and 9 were 264.8, 249.6, and 174.6 WT (weed count) respectively, with corresponding percent control values of 79.7%, 80.8%, and 86.6%. When the same herbicides were prepared in magnetic water, the total weed counts were significantly lower at 119.2, 94.8, and 80.3 WT, with percent control values rising to 91.0%, 92.8%, and 93.9%, respectively. This pattern was consistent across individual weed species, including *Melilotus indica*, *Medicago*, and *Lolium temulentum*, where magnetic water preparations consistently resulted in lower weed counts and higher percent control.

The significant increase in herbicidal efficacy observed when herbicides were prepared in magnetically treated water suggests a potential role for water structuring in enhancing bioactivity. The consistent improvement across all tested herbicide formulations (treatments 7, 8, and 9) and against diverse weed species indicates a fundamental mechanism rather than a compound-specific interaction. Magnetized water is reported to have altered physical properties, including reduced surface tension and increased solubility and permeability, which may improve herbicide dissolution, foliar adsorption, and translocation within the plant (Amiri and Dadkhah 2006). This enhanced penetration could lead to a more effective delivery of the active ingredient to target sites, resulting in the superior weed control observed. These findings align with studies in other agronomic contexts where magnetized water improved the efficiency of agrochemicals (Surendran et al., 2016). The use of magnetic water as an adjuvant could therefore be a promising, low-cost, and environmentally benign strategy to reduce herbicide application rates while maintaining or even improving weed management efficacy in wheat cropping systems, contributing to more sustainable agricultural practices.

Table 4. Effectiveness of herbicidal treatment prepared in regular and magnetic water after three weeks against annual grassy weeds in wheat crop during winter season 2021/2022.

Treatment	regular water						Megnetic water					
	L. temulentum		***A. fatua***		**total**		***L. temulentum***		***A. fatua***		**Total**	
	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%	Wt.	R%
Treatment 4	121.0	78.7	92.0	68.1	213.0	75.1	123.0	78.3	5.0	98.3	128.0	85.0
Treatment 5	95.0	83.2	76.1	73.6	171.1	80.0	81.3	85.7	3.0	99.0	84.3	90.2
Treatment 6	79.3	86.0	76.0	73.7	155.3	81.9	58.7	89.7	2.4	99.2	61.1	92.9
Treatment 7	101.0	82.2	71.0	75.4	172.0	79.9	69.3	87.8	7.1	97.5	76.4	91.1
Treatment 8	119.8	78.9	60.0	79.2	179.8	79.0	49.0	91.4	6.5	97.7	55.5	93.5
Treatment 9	121.6	78.5	17.0	94.1	138.6	83.8	37.0	93.5	3.0	99.0	40.0	95.3
Hand weeding	156.5	72.4	79.8	72.4	236.3	72.4	215.8	61.9	79.8	72.4	295.5	65.5
Control	567.0	0.0	288.7	0.0	855.7	0.0	567.0	0	288.7	0.0	855.7	0.0
$LSD_{0.05}$	36		42				31		2.2			

Wt.=gm/m^2 of fresh weight, R%=% of Reduction in weeds.

Effect on annual broad leaf weeds

The efficacy of herbicidal treatments was significantly influenced by the use of magnetic water as a carrier (Table 6). Across all treatments, the application of herbicides prepared in magnetic water consistently resulted in lower weed weights (WT) and higher percent reductions (R%) for both *Melilotus indica* and *Medicago spp.*, as well as for the total weed biomass, compared to their regular water counterparts. For instance, Treatment 3 applied in magnetic water recorded a total weed weight of 57.5 g with an 89.1% reduction, which was substantially more effective than the same treatment in regular water (91.1 g, 80.0% reduction). The most effective treatments overall (treatments 8 and 9) achieved total weed reductions of approximately 89-90%, with magnetic water formulations showing a slight but consistent advantage. The hand weeding control was less effective than most herbicidal treatments, particularly against *Medicago spp.* when using magnetic water. All treatments were significantly different from the control at the 5% significance level, as indicated by the provided LSD values.

Table 5. Effectiveness of herbicidal treatment prepared in regular and magnetic water after three weeks against total annual weeds (broadleaf and grassy weeds) in wheat crop during winter season 2021/2022.

Treatment	Regular water										Magnetic water									
	M. indica		Medicago		*L. temulentum*		*A. fatua*		Total		*M. indica*		Medicago		*L. temulentum*		*A. fatua*		Total	
	WT		WT		WT		WT		WT		WT		WT				WT		WT	
Treatment 7	21.8	86.3	71.0	75.4	101.0	82.2	71.0	75.4	264.8	79.7	13,3	92.4	29.5	89.8	69.3	87.8	7.1	97.5	119.2	91.0
Treatment 8	9.8	93.8	60.0	79.2	119.8	78.9	60.0	79.2	249.6	80.8	10.3	94.1	29.0	90.0	49.0	91.4	6.5	97.7	94.8	92.8
Treatment 9	9.0	94.3	27.0	90.6	121.6	78.5	17.0	94.1	174.6	86.6	27.3	84.4	13.0	95.5	37.0	93.5	3.0	99.0	80.3	93.9
Hand weeding	50.5	68.1	79.8	72.4	156.5	72.4	79.8	72.4	366.6	71.9	60.0	65.7	79.8	72.4	215.8	61.9	79.8	72.4	43	67.0
Control	158.5	0.0	288.7	0.0	567.0	0.0	288.7	0.0	1302.9	0.0	175.0	5.7 o	288.7	0.0	567.0	0	288.7	0.0	1319.4	0.0
$LSD_{0.05}$	30.3		37		36		42				61		14		31		2.2			

WT: g/m^2 of fresh weight, R% of Reduction m weeds.

Table 6. Effectiveness of herbicidal treatment prepared in regular and magnetic water after six weeks against annual broad leaf weeds in wheat crop during winter season 2021/2022

Treatment	regular water						magnetic water					
	M. indica		*Medicago spp.*		Total		*M. indica*		*Medicago spp.*		Total	
	WT	R%	WT	R%	WT	R%	WT	R%	WT	R%	WT	R%
Treatment 1	71.3	55.1	61.0	79.5	132.3	71.0	89.0	68.6	45.5	81.5	134.5	74.6
Treatment 2	58.7	63.1	39.5	86.7	98.2	78.5	50.0	82.3	25.0	89.9	75.0	85.8
Treatment 3	56.1	64.7	35.0	88.2	91.1	80.0	31.0	89.0	26.5	89.2	57.5	89.1
Treatment 7	50.5	68.3	37.0	87.6	87.5	80.9	37.0	86.9	47.0	80.9	84.0	84.1
Treatment 8	23.8	85.1	27.0	90.9	50.8	88.9	27.5	90.3	26.0	89.5	53.5	89.9
Treatment 9	23.1	85.5	30.3	89.8	53.3	88.3	29.5	89.6	33.0	86.6	62.5	88.2
Hand weeding	60.0	62.3	71.5	76.0	131.5	71.2	53.0	81.3	97.0	60.6	150.0	71.7
Control	159.0	0.0	297.8	0.0	456.8	0.0	283.0	0.0	246.5	0.0	529.5	0.0
$LSD_{0.05}$	15		14				22		20			

Wt.=gm/m^2 of fresh weight, R%=% of Reduction in weeds

The superior performance of herbicides prepared in magnetic water can be attributed to the enhanced physicochemical properties of the water, which likely improved herbicide solubility, penetration, and overall bioavailability. Magnetic treatment is known to reduce the surface tension and cluster size of water molecules, facilitating better leaf wetting and stomatal absorption of the active ingredients (Amiri and Dadkhah 2006). This increased bioavailability would explain the consistently lower weed biomass and higher percent control observed across all treatments using magnetic water. The findings align with studies by Zlotopolski (2017), who reported that the use of magnetized water as a carrier can enhance the efficacy of agrochemicals, leading to more effective weed control with potential reductions in application rates. This study confirms that using magnetic water as a carrier is a viable strategy to optimize the performance of post-emergence herbicides in wheat, offering a simple and non-invasive method to improve integrated weed management programs.

Effect on annual grassy weeds

The results demonstrate that the carrier water type significantly influenced the effectiveness of herbicidal treatments against annual grassy weeds in wheat (Table 7). Across all herbicidal treatments (treatments 4-9), the application in magnetic water consistently resulted in a higher reduction (%) of weed biomass for both *Lolium temulentum* and *Avena fatua* compared to applications in regular water. For instance, Treatment 8 prepared in magnetic water achieved the highest overall weed control (83.7% reduction), which was statistically superior to its performance in regular water (85.2% reduction in total biomass, but with lower individual species reductions). The hand weeding treatment was significantly less effective than most chemical treatments, highlighting the superior efficacy of the herbicides. All treatments were significantly more effective than the control, as confirmed by the LSD values.

The enhanced efficacy of herbicides prepared in magnetic water can be attributed to the physicochemical alterations in water structure induced by magnetic treatment. Magnetized water is reported to have reduced surface tension and improved solubility, which likely facilitates better herbicide absorption and translocation within the weed plants (Aladjadjiyan 2007). This increased bioavailability of the active ingredient could explain the consistently higher percent reduction in weed biomass observed across all herbicide formulations. These findings align with previous studies showing that magnetized water can enhance the performance of agrochemicals, leading to more efficient weed control (Selim and El-Nady 2011). The superior results of chemical treatments over manual weeding further emphasize the critical role of optimized herbicide application for sustainable weed management. Utilizing magnetic water as a carrier presents a promising, low-cost technology to maximize herbicide efficiency, potentially allowing for reduced herbicide doses while maintaining effective control, thereby supporting more environmentally conscious agricultural practices (Zlotopolski 2017).

Table 7. Effectiveness of herbicidal treatment prepared in regular and magnetic water after six weeks against annual grassy weeds in wheat crop during winter season 2021/2022.

Treatment	Regular water						Magnetic water					
	L. temulentum		*A. fatua*		Total		*L. temulentum*		*A. fatua*		Total	
	WT	R%	WT	R%	WT	R%	WT	R%	WT	R%	WT	R%
Treatment 4	78.5	71.5	61.0	79.5	139.5	75.7	79.0	66.1	60.0	72.9	139.0	69.4
Treatment 5	67.0	75.7	39.5	86.7	106.5	81.4	57.4	75.4	25.0	88.7	82.4	81.9
Treatment 6	63.0	77.1	35.0	88.2	98.0	82.9	64.3	72.4	14.0	93.7	78.3	82.8
Treatment 7	79.0	71.3	37.0	87.6	116.0	79.8	50.7	78.3	47.0	78.8	97.7	78.5
Treatment 8	50.2	81.8	34.5	88.4	84.7	85.2	38.0	83.7	36.0	83.7	74.0	83.7
Treatment 9	46.0	83.3	48.0	83.9	94.0	83.6	36.9	84.2	33.0	85.1	69.9	84.6
Hand weeding	171.0	37.9	71.5	76.0	242.5	57.7	113.0	51.5	97.0	56.2	210.0	53.8
Control	275.3	0.0	297.8	0.0	573.0	0.0	233.0	0.0	221.5	0.0	454.5	0.0
$LSD_{0.05}$	18.0		12.0				9.0		5.0			

Wt.=gm/m^2 of fresh weight, R%=% of Reduction in weeds

Effect on annual broadleaf and grassy weeds

Table 8 presents the effectiveness of herbicidal treatment prepared in regular and magnetic water after six weeks against annual weeds (broadleaf and grassy weeds) in wheat crop during winter season 2021/2022. All herbicidal treatments (treatments 7, 8, and 9) prepared in magnetic water demonstrated a lower total weed count and a higher percentage (%) of weed control compared to the same herbicides prepared in regular water after six weeks. For instance, Treatment 7 in magnetic water resulted in a total weed count of 181.7 with 81.5% control, whereas in regular water, the count was 203.5 with 80.2% control. This trend of enhanced performance with magnetic water was consistent across all herbicide formulations. As expected, the hand weeding treatment provided moderate control (63.4-63.7%), while the control plots exhibited the highest weed density, confirming significant weed pressure (Ashrafi et al., 2009).

Magnetic treatment is known to reduce water's surface tension and enhance solubility, potentially leading to better herbicide dissolution, improved leaf wetting, and increased cellular uptake (Grewal and Maheshwari 2011). This enhanced penetration and translocation of the active ingredients within the weed plants would result in the observed higher mortality for both broadleaf and grassy weeds. These findings align with previous studies reporting improved agrochemical efficiency when using magnetized water (Hachicha et al., 2018). The consistent performance gain across different herbicide types suggests that magnetic water technology could be a viable, low-cost method to optimize weed control efficacy in wheat crops, potentially allowing for reduced herbicide doses while maintaining desired control levels, an important consideration for sustainable crop management.

Table 8. Effectiveness of herbicidal treatment prepared in regular and magnetic water after six weeks against annual weeds (broadleaf and grassy weeds) in wheat crop during winter season 2021/2022.

Treatment	regular water										Magnetic water									
	M. indica		***Medicago spp.***		***L. temulentum***		***A. atua***		**Total**		***M. indica***		***Medicago spp.***		***L. temulentum***		***A. atua***		**Total**	
		0				0				0		0				0		0		
Treatment 7	50.5	68.3	37.0	87.6	79.0	71.3	37.0	87.6	203.5	80.2	37.0	86.9	47.0	80.9	50.7	78.3	47.0	78.8	181.7	81.5
Treatment 8	23.8	85.1	27.0	90.9	50.2	81.8	34.5	88.4	135.5	86.8	27.5	90.3	26.0	89.5	38.0	83.7	36.0	83.7	127.5	87.0
Treatment 9	23.1	85.5	30.3	89.8	46.0	83.3	48.0	83.9		85.7	29.5	89.6	33.0	86.6	36.9	84.2	33.0	85.1	132.4	86.5
Hand weeding	60.0	62.3	71.5	76.0	171.0	37.9	71.5	76.0	374.0	63.7	53.0	81.3	97.0	60.6	113.0	51.5	97.0	56.2	360.0	63.4
Control	159.0	0.0	297.8	0.0	275.3	0.0	297.8	0.0	1029.9	0.0	283.0	0.0	246.5	0.0	233.0	0.0	221.5	0.0	984.0	0.0
$LSD_{0.05}$	15		14		18		12				22		20		9		5			

Wt.=gm/m^2 olf fresh weight, RYO=% of Reduction in weeds

Effect on chlorophyll and nitrogen contents in wheat crop

The application of herbicides prepared in regular and magnetized water significantly influenced the chlorophyll and nitrogen content in wheat, with the effects varying considerably between treatments and water types (Table 9). For chlorophyll content in regular water, treatment 1 resulted in the highest value (39.549%), which was significantly greater than the control (19.0225%). In contrast, when the same herbicides were prepared in magnetic water, treatment 9 produced the highest chlorophyll content (40.5975%), outperforming both its regular water counterpart (25.23%) and the magnetic water control (20.73%). A similar pattern of differential response was observed for nitrogen content. In regular water, treatment 4 yielded the highest nitrogen percentage (22.11%), whereas in magnetic water, treatment 3 was most effective (22.915%). The hand-weeding control showed lower nitrogen levels, particularly in regular water (9.415%), compared to most herbicidal treatments. The calculated $LSD_{0.05}$ values confirm that the observed differences for both chlorophyll and nitrogen in each water type were statistically significant.

The results indicate that magnetizing the water used for herbicide preparation alters the physiological impact of the treatments on the wheat crop, as reflected in chlorophyll and nitrogen content. The superior performance of certain treatments, such as Treatment 9 for chlorophyll in magnetic water, suggests that magnetic field exposure can enhance the compatibility of specific herbicides with crop physiology, potentially by mitigating phytotoxic stress and preserving photosynthetic capacity. This is consistent with the findings of Grewal and Maheshwari (2011), who reported that magnetic water treatment can improve plant growth and stress tolerance. The variation in response, where no single treatment was superior across all parameters, highlights a complex herbicidal-specific interaction with magnetized water. The low nitrogen content in the hand-weeded plot with regular water is particularly noteworthy and may indicate that without chemical intervention, nutrient competition from weeds was more intense, reducing nitrogen uptake by the crop (Zimdahl 2018). Overall, the data suggest that using magnetic water as a carrier could be a viable strategy to modulate the side-effects of herbicides, potentially leading to improved crop health and yield; however, the effect is highly dependent on the specific herbicide formulation used.

Table 9. Effect of herbicidal treatment prepared in regular and magnetic water against chlorophyll % and nitrogen % in wheat crop during winter season 2021/2022

Treatment	Regular water		Magnetic water	
	Chlorophyll	Nitrogen	Chlorophyll	Nitrogen
Treatment 1	39.549	12.665	30.7125	10.915
Treatment 2	38.4975	12.485	23.955	15.515
Treatment 3	36.5475	11.8325	22.0825	22.915
Treatment 4	25.6725	22.11	21.93	21
Treatment 5	21.3925	18.65	31.31	20.33
Treatment 6	21.34	13.915	34.655	15.58
Treatment 7	34.32	14.415	28.8375	11.165
Treatment 8	30.14	18.665	34.17	16.25
Treatment 9	25.23	15.915	40.5975	18.665
Hand weeding	35.48	9.415	26.3725	16.25
Control	19.0225	18.0825	20.73	14.5
$LSD_{0.05}$	12.5	8	10.3	9

Effect on yield components of wheat crop

The results demonstrate a clear and consistent positive effect of using magnetic water (MW) in herbicidal treatments on the yield and yield components of wheat (Table 10). For nearly all treatments, the application of herbicides prepared in magnetic water resulted in higher biological yield and grain yield compared to the same herbicides prepared in regular water (RW). For instance, in treatment 1, biological yield increased from 4777 kg/F to 5250 kg/F, and grain yield increased from 1575 kg/F to 1837 kg/F when using MW. This trend was observed across most treatments, with the control and hand-weeding plots showing no difference, as expected. Furthermore, key yield components such as 1000-grain weight and plant height were generally enhanced in the MW treatments, suggesting improved plant growth and grain filling.

The enhancement in crop performance with magnetic water can be attributed to improved physiological efficiency in plants. Magnetized water is reported to have improved solubility and infiltration properties, which can enhance herbicide efficacy and nutrient uptake (Surendran et al., 2016). This leads to better weed control and reduced crop stress, allowing for more resources to be allocated towards growth and yield formation. The significant increases in 1000-grain weight, a direct determinant of yield, under MW treatments align with findings by Hachicha et al., (2018), who noted that magnetic field-treated water can improve photosynthetic efficiency and assimilate partitioning. While some components like spike length showed a mixed response, the overall improvement in the primary yield parameters confirms that preparing herbicides in magnetic water is a viable strategy to maximize wheat productivity by improving the crop's agronomic performance.

Table 10. Effect of herbicidal treatment prepared in regular and magnetic water on yield and yield components of wheat crop during winter season 2021/2022

Treatment	Regular water							magnetic water						
	Biological Yield Kg/F	Grain Yield Kg/F	Harvest index	1000 grain weight	plant height (cm)	spike length (cm)	No. of tillers	Biological Yield	Grain Yield	Harvest index	1000 grain weight	plant height (cm)	spike length (cm)	No. of tillers
Treatment 1	4777	1575	32.9	48.7	71.7	14.2	3	5250	1837	35.0	56	75.5	11	3
Treatment 2	5040	1575	31.2	47.5	69.7	13.2	2	5670	1890	33.3	55	74.5	10.5	4
Treatment 3	4935	1680	34.0	43.2	65.2	14	3	5512	1890	34.3	50	68.5	10.25	4
Treatment 4	4935	1601	32.4	47.5	74.7	13.7	3	5197	1680	32.3	40	74	11.25	3
Treatment 5	4620	1627	35.2	55.5	70.5	14.5	3	5197	1732	33.3	43.2	71.3	11.25	4
Treatment 6	4620	1601	34.6	53.2	69.5	14.7	3	5092	1732	34.0	45.2	71	10.75	3
Treatment 7	6117	2126	34.6	44.7	69.7	15.7	2	6457	2073	32.1	49.2	84	13.25	3
Treatment 8	6142	2336	38.0	45	67.9	14.7	4	6195	2126	34.3	54.2	78	13	4
Treatment 9	6537	2310	35.3	47.5	65.7	13.5	3	6247	2152	34.4	55.5	76.4	11.5	4
H. weeding	4252	1390	32.6	42	73.7	13	3	4252	1390	32.6	50.7	78	11.5	3
control	3364	1031	30.6	41.2	64.5	12.2	3	3364	1031	30.6	39.2	65.5	10.5	4
$LSD_{0.05}$	1794	769.9	-	6.5	8.9	2.3	1.2	1706.6	610.5	-	9.4	7	1.9	0.86

Figure 1 illustrates the efficacy of herbicide treatments on weed control after three weeks, measured as percentages of broadleaf (%R) and grassy (%R) weeds, alongside their impact on wheat grain yield (kg/ha) under regular water and magnetic water conditions. In the weed control panels, herbicide treatments (T1–T3) significantly reduced broadleaf weeds compared to the control, with T3 achieving the highest suppression (~85% for broadleaf and ~75% for grassy weeds under regular water), while the control showed negligible reduction (<20%). Under magnetic water, T3 maintained strong control (~80% broadleaf, ~70% grassy). Correspondingly, grain yield panels reveal substantial yield increases with herbicide application; T3 under regular water yielded ~2500 kg/ha (versus ~500 kg/ha in control), and under magnetic water, yields peaked at ~2800 kg/ha for T3, indicating synergistic effects of herbicides and magnetic water.

The results demonstrate that herbicide treatments, particularly T3, effectively suppressed both broadleaf and grassy weeds, leading to marked improvements in wheat grain yield, consistent with prior studies showing herbicide-mediated weed reduction enhances resource availability for crops (Oerke 2006). The superior performance under magnetic water suggests potential benefits of magnetic treatment in enhancing herbicide efficacy or plant physiology, aligning with reports on magnetic water improving nutrient uptake and yield in cereals (Maheshwari and Grewal 2009). However, controls highlight the persistent challenge of weed competition without intervention. Future research should quantify economic thresholds and long-term soil health impacts.

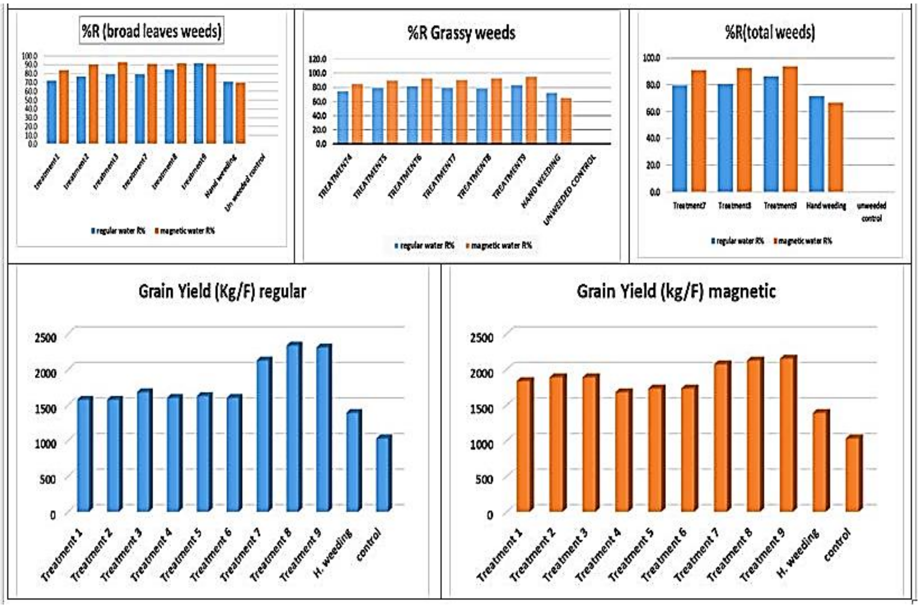

Figure 1. Percentages of weed control (%R) after three weeks treated by herbicide and their effect on wheat grain yield.

Figure 2 presents the average effectiveness of herbicidal treatments (Candy and Axial at 0.5 L/ha and 1 L/ha) on weed control (%R) for broadleaf, grassy, and combined narrow and broadleaf weeds. For broadleaf weeds, Candy at 1 L/ha achieved the highest control at 85.3%, outperforming Axial at 1 L/ha (72.6%), while lower doses yielded 71.5–77.7%. Grassy weed control was most effective with Axial at 1 L/ha (88.6%), followed by Candy at 1 L/ha (77.2%), with 0.5 L/ha rates at 75.4–82.4%. Combined narrow and broadleaf control peaked at 90.2% for Axial at 1 L/ha and 89.3% for Candy at 1 L/ha, indicating dose-dependent efficacy and herbicide-specific weed spectrum targeting.

These findings highlight the superior performance of higher herbicide doses (1 L/ha) across weed types, with Axial excelling on grassy weeds and Candy on broadleaf, supporting selective herbicide use for optimized control (Heap 2014). The averaged effectiveness underscores the importance of application rates in achieving >85% suppression, aligning with field trials showing dose escalation enhances weed mortality and crop competitiveness (Buhler et al., 1998). Variations between herbicides reflect differing modes of action, suggesting integrated strategies for diverse weed flora. Further studies could explore antagonism or synergies in mixtures under varying environmental conditions.

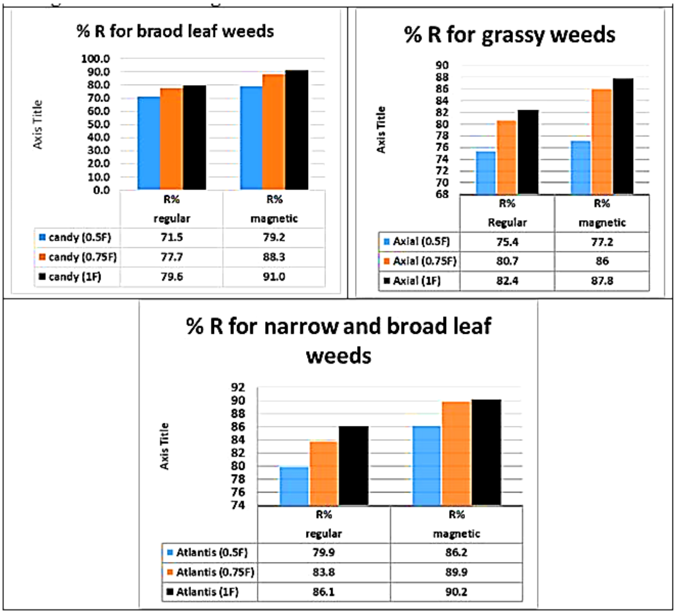

Figure 2. The average of the effectiveness of herbicidal treatments.

CONCLUSION

This study conclusively demonstrates that the use of magnetized water as a carrier for post-emergence herbicides significantly enhances their efficacy in controlling both broadleaf and grassy weeds in winter wheat. The results, consistent across multiple assessment intervals (three and six weeks after application), revealed a clear and statistically superior trend: herbicides prepared in magnetized water consistently resulted in lower weed biomass and a higher percentage of reduction for all major weed species, including *M. indica*, *Medicago spp.*, *L. temulentum*, and *A. fatua*. The enhanced herbicidal performance is attributed to the fundamental physicochemical alterations in magnetized water, such as reduced surface tension and smaller molecular clusters. These changes improve the spray solution's wetting ability, leaf coverage, and penetration through the plant cuticle, thereby increasing the bioavailability and translocation of the active ingredients within the target weeds. This "bio-stimulant" effect of magnetized water was observed across all tested herbicide formulations, indicating a universal adjuvant potential rather than a compound-specific interaction. Beyond superior weed control, the application of herbicides via magnetized water also conferred significant agronomic benefits to the wheat crop. Key physiological parameters, including chlorophyll and nitrogen content, were positively influenced, and critical yield components such as 1000-grain weight and biological yield were consistently improved. This translated into higher final grain yields for most treatments using magnetized water compared to their regular water counterparts, underscoring a dual benefit of reduced weed competition and enhanced crop health. In summary, the magnetization of spray water emerges as a simple, cost-effective, and environmentally benign technology to optimize integrated weed management. By significantly boosting herbicide performance, this approach holds the potential to reduce application rates without compromising control efficacy, thereby supporting more sustainable and productive wheat cultivation systems. The adoption of this technology could offer farmers a practical tool to maximize yield while minimizing the environmental footprint of herbicide use.

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