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Efficacy of Pre- and Post-Transplant Herbicides in Tobacco (*Nicotiana tabacum* L.) Influenced by Precipitation and Soil Type

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Abstract

Field trials were carried out over two tobacco cropping seasons (2020 and 2021) to assess the effectiveness of soil (PRE-T) and post-transplant (POST-T (OT)) herbicides in a tobacco crop, depending on rainfall and the type of soil. The effectiveness of PRE-T and POST-T (OT) herbicides alternated according to the presence of weeds, treatments, the region, and years. Unpredictable meteorological conditions throughout the two study years likely influenced the control of weeds. An unusually moist May in 2020 with a precipitation of 29 mm in the first WA PRE-T before the emergence of weeds generated the leaching of the PRE-T herbicide from the surface of the soil, which was likely the most probable reason for the reduced effectiveness of PRE-T-applied herbicides (less than 77%) in comparison to the POST-T (OT) application treatment in 2020 in the Prilep region. Conversely, the restricted rainfall after PRE-T and POST-T (OT) application may have caused the unsatisfactory efficacy of both PRE-T and POST-T (OT) herbicide treatments in the Titov Veles region in 2021 (less than 78 and 80%, respectively) in comparison with 2020. Excessive rain immediately after PRE-T and POST-T (OT) application resulted in the injury of tobacco plants in the Prilep region in 2020 and 2021, which was between 8 and 25%, and 7 and 22%, respectively, after seven DAHAs across both treatments. The injuries caused by pendimethalin and metolachlor were more serious. The yields of tobacco after both PRE-T and POST-T treatment in each region typically reflect the overall effectiveness of weed control and the extent of tobacco crop injury.

Keywords: herbicide efficacy; weed control; tobacco; precipitation; soil type

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1. Introduction

Tobacco (*Nicotiana tabacum* L.) is the one of the most extensively cultivated and economically beneficial industrial crops worldwide. It is a significantly profitable crop in respect of the generation of revenue, export income, and employment [1]. At least 14 different types of tobacco are grown around the world [2], and one of them is oriental sun-cured tobacco, which accounts for 94% of the total production in R.N. Macedonia. It is one of the most economically important crops, and more than 80% of its total production is exported [3]. In 2021, 15,457 ha of oriental tobacco were harvested, with an average yield of 1574 kg/ha [4]. Weeds are one of the main constraints to high yield and quality in tobacco production, because tobacco is one of the most susceptible crops to weed interference.

Crop yield reductions are not solely caused by weed competition effects, but also because several weeds, in particular broadleaf ones, serve as hosts for various pests and diseases that are harmful to the crop [2,5]. Weeds obstruct the harvesting of tobacco, as well as the curing process, and also increase the impurity percentage in harvested tobacco [6]. The loss of tobacco yield caused by competition with weeds is the primary factor that leads to a decrease in both yield and quality. Wilson (1995) [7] assessed a 77% reduction in yield and a 10% decline in quality because of tobacco weed competition, which occurred at different unspecified densities of miscellaneous weed species. Niell, cit. by Ian et al. (2013) [8], noted a 12% reduction in yield caused by aggressive weeds during a two-week growth phase, along with a 64% yield loss when weeds were allowed to persist during the critical weed-free period of 2 to 6 weeks. Hauser and Miles (1975) [9] reported that the presence of uncontrolled weeds caused a 26% decrease in flue-cured tobacco yields, diminished the index of price, and resulted in significant alterations in the grade distribution and chemical composition of flue-cured tobacco.

With respect to weed control, due to the timing of the tobacco transplanting period (from the beginning of May to mid-May), this crop is very often characterized by a complex pluri-specific weed flora composed of annual summer grass and broad-leaf weeds [10]. This weed flora has been traditionally controlled through PRE-T (pre-transplantation) and POST-T (OT) (post-transplantation over-the-top) (within 7 days of transplanting) herbicide applications, due to the scarce availability of POST-em herbicides.

PRE-T and POST-T (OT) herbicides are designed for application to the soil, and certain quantities of water by precipitation or irrigation are needed for their activation [11,12]. For these herbicides, rainfall is necessary in a period of 1–2 weeks following application for the herbicide to dissolve in the soil–water solution, allowing it to be absorbed by the emerging weeds after their germination [13,14]. It is widely known that PRE-T and POST-T (OT) herbicides, such as dimethenamid-P and *S*-metolachlor, need rainfall for 7–10 days following application to ensure proper infiltration into the active zone for weed seed germination [15,16]. Inadequate or postponed rainfall can diminish the efficacy of herbicides and can consequently lead to a reduction in the control of weeds [17,18]. Depending on the type of soil, high amounts of rainfall (i.e., exceeding 25 mm) immediately after application may lead to the leaching of herbicides, thereby diminishing their effectiveness [19,20]. Pendimethalin and clomazone are examples of herbicides that exhibit greater persistence in the soil when conditions are dry, potentially impacting rotational crops, but are easily transported by leaching in wet soil conditions [21,22]. Additionally, their ability to control weeds is limited, particularly regarding the control of annual grasses, when the soil is dry for as long as three weeks following application [23]. Considering the importance of tobacco production in North Macedonia, this is the first multi-site, two-season study conducted in this country with the aim of (I) assessing the efficacy of the PRE-T and POST-T (OT) application of herbicides specific to the tobacco crop, (II) assessing the level of efficacy in weed control, (III) assessing the occurrence of phytotoxic symptoms on tobacco depending on rainfall and soil quality, and (IV) assessing the effect on tobacco yield.

2. Materials and Methods

The field experiments were executed throughout two seasons of tobacco cultivation in 2020 and 2021 on commercial tobacco fields in the Prilep and Titov Veles tobacco growing regions in south-western and central Macedonia on fluvisol sandy loam and vertisol, respectively ([24], Table 1).

Table 1. Experimental field characteristics and treatments.

Tobacco Type	**"Prilep" cv. P-23**			
Region	**Prilep**		**Titov Veles**	
Soil characteristics	fluvisol sandy loam		vertisol	
Coarse (%)	18.50		3.50	
Fine sand (%)	55.10		34.20	
Clay + silt (%)	26.40		60.30	
Organic matter (%)	1.56		2.40	
pH-water (%)	6.90		7.20	
Year	2020	2021	2020	2021
Data of transplantation	26.05.2020.	19.05.2021.	18.05.2020.	11.05.2021.
Inter-row/in-row plant spacing	40 × 15 cm			
Herbicide (name, a.m., HRAC classification)			doses	
Stomp Aqua (pendimethalin 455 g/L, HRAC-3)			3.0 L/ha	
Proman (metobromuron 500 g/L, HRAC-5)			2.5 L/ha	
Gamit 4F (clomazone 320 g/L, HRAC-13)			1.0 L/ha	
Challenge 600 EC (aclonifen 600 g/L, HRAC-34)			2.5 L/ha	
Dual Gold 960 (S-metolachlor 960 g/L, HRAC-15)			1.5 L/ha	
Frontier 900 EC (dimethenamid 900 g/L, HRAC-15)			1.7 L/ha	

The tobacco was produced through standard tillage techniques. Preparation of the soil was achieved through moldboard plowing in the autumn and two passes with a field cultivator, which were performed in the spring. Prior to the spring transplanting, fertilizer was applied according to the rates determined by soil testing. The field experiment characteristics are shown in Table 1. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer, which was adjusted to deliver 300 L/ha of aqueous solution at a pressure of 220 kPa. Herbicides were applied two days PRE-T and five days POST-T (OT). Weeds at the time of treatment were at dry seed–beginning of seed imbibition growing stage (BBCH 00-01). The experimental design was a randomized complete block system with four replicates and a plot size of 20 m^2. The studies included both untreated control and weed-free treatments. The plots designated for the weedy control remained untreated throughout the entire duration of the experiment. The maintenance of weed-free control was ensured by hand weeding. Hand weeding was initiated when weeds emerged and continued as necessary to ensure the plots remained weed-free. The experimental plots were inherently populated with a high density of *Amarathus retroflexus* L. (AMARE), *Portulaca olearacea* L. (POROL), *Chenopodium album* L. (CHEAL), *Polygonum aviculare* L. (POLAV), and *Digitaria sanguinalis* (L.) Scop. (DIGSA). Except for DIGSA, grass weed infestations were light throughout both experimental years. Weed density in non-treated control plots was 305 and 267 plants/m^2 in 2020 and 2021, respectively, in the Prilep region, and 209 and 87 plants/m^2 in 2020 and 2021, respectively, in the Titov Veles region.

2.1. Data Collection

Weed control efficacy was estimated 28 days after herbicide application (DAHA), following weed emergence (6–8 tobacco leaves, BBCH 16-18), by counting weed plants within a 1 m^2 area in each plot. Herbicide efficacy was calculated using the following equation [25]:

$$W_{CE} = WK - WT/WK \times 100$$

where

W_{CE}—weed control efficiency;

WK—number of weeds in the untreated plots;

WT—number of weeds in the treated plots.

Tobacco injury was visually evaluated using a 0–100% rating scale, where 0 indicates no injury to tobacco plants and 100 represents complete plant death [26]. Visual estimates of percent tobacco injury were estimated at 7 and 21 DAHA, based on the average percentage of deformation, plant stunting, chlorosis, or necrosis (or combination of all) observed in treated tobacco plants compared to untreated plants at both localities during the two-year experimental period. Yields were obtained by mechanically harvesting every plot. Each plot was harvested a total of six times per year as the plants matured and ripened, in order to achieve optimum leaf quality and grade. Harvesting started on 9 July 2020 and 1 July 2021 in the Prilep region, and on 2 July 2020 and 26 June 2021 in the Titov Veles region, respectively. Subsequent harvests occurred every 13 to 15 days, depending on the year.

2.2. Meteorological Conditions During and After the Herbicide Application

Total weekly precipitation and weekly average temperatures one week before and four weeks after PRE-T and POST-T (OT) applications were recorded, respectively (Table 2). The amount of precipitation during the 1st WB PRE-T A and 2nd WA PRE-T A in 2020 corresponded to the average observed in the Prilep region, but the 1st WAA was exceptionally rainy, especially on the 3rd, 4th, and 5th day of the week, as well as the 1st day of the 2nd WA PRE-T A. The 1st WB POST-T (OT) A was unusually wet, particularly on the 3rd, 4th, and 5th day of the week, together with the 1st day of the 1st WA POST-T (OT) A. Precipitation during other weeks was extremely scarce (3, 1, and 3 mm). In the Titov Veles region, the amount of precipitation that fell during the 1st WB PRE-T A, and the 1st and 2nd WA PRE-T A of the same year (2020) was 35% above the 30-year average for this region. Slightly above the 30-year average for this region (18%) were the precipitation levels recorded during the 1st WB POST-T (OT) A and the 1st WA POST-T (OT) A. In 2021, precipitation during the 1st WB PRE-T A was scarce in the Prilep region, while the rainfall during the 1st and 2nd WA PRE-T A was in line with the average for this region. The 1st WB POST-T (OT) A was dryer than the 1st and 2nd WA POST-T (OT) A, which were above the 30-year average for this region (22%). In the Titov Veles region, during the same year, the period covering the 1st WB PRE-T A and the 1st and 2nd WA PRE-T A was very dry (4, 7, and 8 mm). Rainfall occurred over 3- to 4-day intervals during the 3rd and 4th W PRE-T A. Similarly, the 1st WB POST-T (OT) A and the 1st WA POST-T (OT) A were also dry. Rainfall was recorded over three to four days during the 2nd and 3rd W POST-T (OT) A. (Table 2). One week before and four weeks after the PRE-T and POST-T (OT) applications, temperatures—especially in 2021 for both regions—were marginally above the average, a phenomenon attributed to the favorable environmental conditions associated with frost-free night-time periods during the assessed 1st week before PRE-T and the four-week period after POST-T (OT) applications, respectively. PRE-T and POST-T (OT) treatments in both years were applied at times that corresponded with the standard timing for herbicide applications in the tobacco production sector of North Macedonia (Table 2), thus serving as a representation of producer practices and label recommendations.

Table 2. Average weekly temperatures and cumulative weekly precipitation 1 week before and 4 weeks after PRE-T and POST-T (OT) A at Prilep (fluvisol) and Titov Veles (vertisol) region in 2020 and 2021.

	Prilep Region (Fluvisol Site)								Titov Veles Region (Vertisol Site)							
	2020				2021				2020				2021			
	PT		PTOT		PT		PTOT		PT		PTOT		PT		PTOT	
Weeks	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**	**P mm**	**T °C**
1st WBA	11	16	29	12	5	18	10	16	10	17	19	14	4	19	7	18
1st WAA	29	12	11	18	10	16	19	16	19	14	14	19	7	18	8	22
2nd WAA	11	18	3	20	19	16	15	19	14	19	3	22	8	22	7	21
3rd WAA	3	20	1	22	15	19	7	21	3	22	0	23	7	21	12	23
4th WAA	1	22	3	23	7	21	5	23	0	23	2	25	12	23	8	25

WBA—week before application; WAA—week after application; P—precipitations; T—temperature; PRE-T—(PT pre transplantation), POST-T (OT) A (PTOT)—post transplantation over-the-top.

2.3. Statistical Analysis

The data underwent testing for variance homogeneity and distribution normality [27] and were log-transformed as necessary to achieve approximately equal variances and improve symmetry prior to conducting ANOVA. An analysis of the efficacy of PRE-T and POST-T (OT) herbicides, tobacco injury, and yield data was performed through a linear mixed model (LMM) utilizing the lmer function from the LME4 package version 1.1-23 [28], in conjunction with ANOVA at a significance level of 5%. The weedy control and weed-free controls were included for injury analysis and tobacco yield. For the tobacco growing seasons of 2020 and 2021, location, herbicide treatment, year, and the interaction between PRE-T and POST-T (OT) treatment and year were treated as fixed effects, while replications within each year were regarded as random effects. The interaction of treatment-by-year was examined for each response variable to evaluate variability over the years. Finally, the data were converted back to their original scale for presentation. Means were separated using the LSD test at a probability of 5%. Statistical analysis was conducted using R statistical software version 4.2.2 [29] with the glmmTMB package (function: *glmmTMB*) [30].

3. Results

Weed Control. The performance of PRE-T and POST-T (OT) herbicides showed variation among different weed species, applied treatments, regions considered, and years observed. The overall performance of the PRE-T and POST-T (OT) herbicides was correlated with climatic and soil conditions. The variations in weather conditions over the two-year study period influenced the outcomes of weed control. An unusually rainy May in 2020 (Table 2), especially during the 1st WA PRE-T A (29 mm) prior to weed emergence, resulted in the leaching of PRE-T herbicides from the soil surface. This occurrence was probably the main reason for the lower effectiveness of PRE-T herbicides when compared to their use as POST-T (OT) treatments in 2020 in the Prilep region (fluvisol site) (Table 3). In 2020, the Titov Velas region (vertisol site) recorded precipitation levels above the 30-year average. However, due to their consistent occurrence, especially during the 1st WA PRE-T A and 1st WA POST-T (OT) A, and the characteristics of the soil (with higher clay and organic matter content), leaching was not observed. Therefore, the efficacy was rated as satisfactory for PRE-T herbicides and outstanding for POST-T (OT) herbicides. Precipitation in 2021 during the 1st and 2nd WA PRE-T A was in line with the average for the Prilep region (fluvisol site). However, rainfall during the 1st and 2nd WA POST-T (OT) A was above the 30-year average for this region (22%), which caused significant herbicide leaching and reduced efficacy of POST-T (OT) herbicide treatment. Conversely, the restricted rainfall following the PRE-T application (4, 7, and 8 mm during the 1st WBA, 1st, and 2nd WAA) and POST-T (OT) application (7, 8, and 7 mm during the 1st WBA, 1st, and 2nd WAA) could have contributed to the unsatisfactory performance of both PRE-T and POST-T (OT) herbicide treatments in the Titov Velas region (vertisol site) in 2021 compared with 2020 (Table 4). The differences in efficacy were not only due to inconsistent weather conditions between the two years of this study, but also to the operating mechanism of the tobacco seedling transplanting machine, as indicated by Fi and YaMin [31]. During seedling transplantation after PRE-T application, the furrow plough of the machine pulled up a non-treated soil layer rich in weed seeds from the surface, covering the treated one. As a result, new weed emergence occurred in the tobacco rows in the PRE-T treatment, which was not the case for the POST-T (OT) herbicide treatment.

Pendimethalin. The application of pendimethalin before and after (OT) application showed different efficacy depending on the growing season in both regions, where statistically significant differences between treatments were also observed (except in the Titov Veles region (the vertisol site) in 2021) (Tables 3 and 4).

In the Prilep region (fluvisol site), in 2020, pendimethalin applied at PRE-T controlled weeds between 68% (POROL) and 77% (DIGSA). A significant increase in weed control was observed with pendimethalin applied as a POST-T (OT) treatment. Weeds were controlled between 92% (POROL) and 97% (DIGSA and AMARE). In 2021, the efficacy of PRE-T pendimethalin treatment ranged between 83% (AMARE) and 87% (CHEAL). A significant decrease in pendimethalin weed control occurred with the POST-T (OT) treatment, with efficacy ranging from 68% (POROL) to 75% (DIGSA) (Table 3). In the Titov Veles region (vertisol site), during the first experimental year (2020), pendimethalin applied at PRE-T and POST-T (OT) effectively controlled all predominant weeds (>84% and >96%, respectively). During the second year of experimentation (2021), the efficacy of pendimethalin was considerably reduced. In that context, the efficacy of pendimethalin PRE-T and POST-T (OT) treatments provided only marginal control (<75 and <77%, respectively) of predominant broadleaf weeds (Table 4).

Metobromuron. A significant interaction between treatment and year revealed two distinct years in terms of weed control effectiveness using PRE-T and POST-T (OT) applications of metobromuron across both regions (Tables 3 and 4).

In the Prilep region (fluvisol site), in 2020, metobromuron provided inadequate control of the investigated weeds with PRE-T treatment; efficacy ranged between 57% (DIGSA) and 66% (POROL). Metobromuron efficacy was significantly higher in POST-T (OT) treatment. Except for DIGSA, which was controlled at 90%, the rest of the weeds were controlled between 95 and 100%. In 2021, metobromuron applied at PRE-T controlled weeds between 76% (DIGSA) and 86% (AMARE). A substantial decrease in metobromuron efficacy was recorded in the POST-T (OT) application, with weeds controlled between 62% (DIGSA) and 77% (AMARE) (Table 3). Metobromuron provided good to excellent weed control in 2020 in the Titov Veles region (vertisol site). Predominant weeds were controlled between 84% (POLAV) and 88% (AMARE and POROL) with PRE-T treatment, but a significant increase in efficacy (>99%) was recorded in the POST-T (OT) application of metobromuron. Conversely, in 2021, due to arid soil conditions, the effectiveness of weed control was below 70% and 73% with PRE-T and POST-T (OT) treatment, respectively (Table 4).

Clomazone. A significant interaction between treatment and year revealed two distinct years in terms of weed control effectiveness using PRE-T and POST-T (OT) applications of clomazone across both regions.

Table 3. *Digitaria sanguinalis*, *Portulaca olearacea*, *Chenopodium album*, and *Amaranthus retroflexus* control (%) 28 days after PRE-T and POST-T (OT) herbicide applications in tobacco in 2020 and 2021 in Prilep region (fluvisol site).

Prilep Region (Fluvisol Site)																								
Treatments Weeds	**Pendimethalin 3.0 L/ha**				**Metobromuron 3.0 L/ha**				**Clomazone 1.0 L/ha**				**Aclonifen 2.5 L/ha**				**S-metolachlor 1.5 L/ha**				**Dimethenamid 1.7 L/ha**			
	2020		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**	
	PT	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**
28 DA PRE-T and POST-T (OT) A																								
DIGSA	77 ^{a}	97 ^{a}	86 ^{a}	75 ^{a}	57 ^{b}	90 ^{c}	76 ^{b}	62 ^{c}	75 ^{a}	100 ^{a}	86 ^{a}	73 ^{a}	64 ^{a}	94 ^{b}	77 ^{b}	66 ^{a}	74 ^{a}	100 ^{a}	85 ^{a}	74 ^{a}	71 ^{a}	100 ^{a}	84 ^{a}	72 ^{a}
POROL	68 ^{c}	92 ^{b}	84 ^{a}	68 ^{b}	66 ^{a}	95 ^{b}	83 ^{a}	71 ^{b}	63 ^{b}	95 ^{b}	79 ^{b}	68 ^{a}	71 ^{a}	99 ^{a}	82 ^{a}	72 ^{a}	70 ^{ab}	100 ^{a}	83 ^{a}	69 ^{ab}	68 ^{a}	94 ^{bc}	79 ^{b}	70 ^{a}
CHEAL	74 ^{ab}	95 ^{ab}	87 ^{a}	72 ^{ab}	62 ^{ab}	97 ^{b}	85 ^{a}	74 ^{ab}	71 ^{a}	95 ^{b}	81 ^{b}	68 ^{a}	68 ^{a}	100 ^{a}	80 ^{ab}	68 ^{a}	67 ^{ab}	93 ^{b}	81 ^{ab}	65 ^{b}	70 ^{a}	96 ^{b}	78 ^{b}	66 ^{a}
AMARE	71 ^{bc}	97 ^{a}	83 ^{a}	71 ^{ab}	64 ^{a}	100 ^{a}	86 ^{a}	77 ^{a}	62 ^{b}	78 ^{c}	69 ^{c}	59 ^{b}	70 ^{a}	98 ^{a}	83 ^{a}	71 ^{a}	65 ^{b}	100 ^{a}	77 ^{b}	70 ^{ab}	73 ^{a}	93 ^{c}	82 ^{ab}	71 ^{a}
LSD 0.05	5.40	3.63	6.21	8.37	6.76	2.64	5.49	5.52	5.90	2.85	3.79	5.43	7.64	2.58	4.80	6.85	7.59	1.48	5.90	5.50	5.23	2.82	4.20	6.04
interactions PT × PTOT	*		*		*		*		*		*		*		*		*		*		*		*	
interactions PT and PTOT × year	*				*				*				*				*				*			

PRE-T (PT, pre transplantation) and POST-T-OT (PTOT, post transplantation over-the-top); 28 DAA—days after application; DIGSA—*Digitaria sanguinalis*, POROL—*Portulaca oleracea*; AMARE—*Amaranthus retroflexus*; CHEAL—*Chenopodium album*; * significant at the 5% level according to a Fisher's protected LSD test at $p < 0.05$.; PRE-T treatments were applied two days before tobacco transplantation. POST-T (OT) treatments were applied five days after tobacco transplantation; weed control efficacy was estimated 28 DAA; means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$; color-cod: red-efficacy < 75%, yellow 75–90%, and green > 90%.

Table 4. *Amaranthus retroflexus*, *Portulaca olearacea*, *Chenopodium album*, and *Polygonum aviculare* control (%) 28 days after PRE-T and POST-T (OT) herbicide applications in tobacco in 2020 and 2021 in Titov Veles region (vertisol site).

Titov Veles (Vertisol Site)																								
Treatments Weed	**Pendimethalin 3.0 L/ha**				**Metobromuron 3.0 L/ha**				**Clomazone 1.0 L/ha**				**Aclonifen 2.5 L/ha**				**S-metolachlor 1.5 L/ha**				**Dimethenamid 1.7 L/ha**			
	2020		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**		**2020**		**2021**	
	PT	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**	**PT**	**PTOT**
28 DA PRE-T and POST-T (OT) A																								
AMARE	85 ^{a}	98 ^{a}	70 ^{ab}	74 ^{ab}	88 ^{a}	100 ^{a}	72 ^{b}	76 ^{ab}	72 ^{b}	79 ^{b}	61 ^{c}	70 ^{b}	86 ^{ab}	100 ^{a}	73 ^{a}	76 ^{ab}	84 ^{ab}	99 ^{a}	69 ^{c}	74 ^{b}	87 ^{a}	98 ^{a}	69 ^{b}	75 ^{b}
POROL	84 ^{a}	96 ^{a}	67 ^{b}	70 ^{b}	88 ^{a}	99 ^{b}	73 ^{ab}	76 ^{ab}	87 ^{a}	99 ^{a}	72 ^{b}	78 ^{a}	83 ^{b}	100 ^{a}	75 ^{a}	78 ^{a}	87 ^{a}	97 ^{a}	76 ^{a}	78 ^{ab}	83 ^{a}	96 ^{a}	77 ^{a}	80 ^{a}
CHEAL	84 ^{a}	96 ^{a}	72 ^{ab}	77 ^{a}	85 ^{a}	100 ^{a}	76 ^{a}	78 ^{a}	84 ^{a}	97 ^{a}	74 ^{b}	78 ^{a}	87 ^{a}	100 ^{a}	70 ^{a}	74 ^{b}	86 ^{ab}	99 ^{a}	71 ^{b}	74 ^{b}	85 ^{a}	98 ^{a}	69 ^{b}	76 ^{ab}
POLAV	87 ^{a}	97 ^{a}	75 ^{a}	77 ^{a}	84 ^{a}	100 ^{a}	70 ^{b}	73 ^{b}	88 ^{a}	100 ^{a}	78 ^{a}	80 ^{a}	88 ^{a}	98 ^{b}	75 ^{a}	77 ^{a}	82 ^{b}	94 ^{b}	74 ^{ab}	79 ^{a}	86 ^{a}	99 ^{a}	72 ^{b}	78 ^{ab}
LSD 0.05	4.76	2.91	5.50	6.15	5.52	0.88	3.69	4.29	4.57	4.48	3.86	5.64	3.88	1.85	5.79	2.73	4.54	2.74	4.74	4.60	5.71	3.12	4.64	4.74
interactions PT × PTOT	*		NS		*		NS		*		NS		*		NS		*		NS		*		NS	
interactions PT and PTOT × year	*				*				*				*				*				*			

PRE-T (PT, pre transplantation) and POST-T-OT (PTOT, post transplantation over-the-top); 28 DAA—days after application; AMARE—*Amaranthus retroflexus*; POROL—*Portulaca oleracea*; CHEAL—*Chenopodium album*, POLAV—*Polygonum aviculare;* NS—not significant; * significant at the 5% level according to a Fisher's protected LSD test at $p < 0.05$; PRE-T treatments were applied two days before tobacco transplantation. POST-T (OT) treatments were applied five days after tobacco transplantation; weed control efficacy was estimated 28 DAA; means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$; color-cod: red-efficacy < 75%, yellow 75–90%, and green > 90%.

Clomazone weed control differed significantly among treatments, with the exception of the Titov Veles region (vertisol site) in 2021 (Tables 3 and 4). In 2020, in the Prilep region (fluvisol site), PRE-T weed control efficacy was poor, ranging from 62% (AMARE) to 75% (DIGSA). In the POST-T (OT) treatment, clomazone efficacy was substantially higher. Although AMARE was not effectively managed (78%), the remaining weeds were almost completely controlled (>95%). In 2021, the efficacy of clomazone applied PRE-T ranged between 69% (AMARE) and 86% (DIGSA). A significant reduction in clomazone efficacy was recorded in the POST-T (OT) treatment. The herbicide provided control between 59% (AMARE) and 73% (DIGSA) (Table 3). Unlike the Prilep region (fluvisol site) in 2020, in the Titov Veles region (vertisol site) PRE-T treatment of clomazone provided good control of CHEAL (84%), POROL (87%), and POLAV (88%), and excellent control with POST-T (OT) treatment (>97%). Inadequate clomazone efficacy (72% and 79%) was noted for the control of AMARE during both herbicide treatments. In 2021, clomazone applied PRE-T and POST-T (OT) provided no more than 78% and 80% weed control, respectively (Table 4).

Aclonifen. PRE-T and POST-T (OT) treatments with aclonifen showed distinct efficacy profiles over two years in both regions, and significant variations in weed control effectiveness were observed among them, except in the Titov Veles region (vertisol site) in 2021 (Tables 3 and 4). In 2020, in the Prilep region (fluvisol site), PRE-T aclonifen weed control efficacy ranged from 64% (DIGSA) to 71% (POROL). Aclonifen efficacy was significantly improved in the POST-T (OT) treatment. All predominant weeds were controlled between 94% and 100%. In 2021, aclonifen applied at PRE-T controlled weeds between 77% (DIGSA) and 83% (AMARE). Due to leaching, the efficacy of aclonifen applied POST-T (OT) was significantly reduced, ranging from 66% (DIGSA) to 72% (POROL) (Table 3). Unlike the Prilep region (fluvisol site), in 2020, in the Titov Veles region (vertisol site), the efficacy of aclonifen applied PRE-T was substantially higher. Aclonifen provided control of the dominant weeds between 83% (POROL) and 88% (POLAV). Near-complete weed control (>98%) was recorded with aclonifen applied POST-T (OT). In 2020, this herbicide provided no more than 75% and 78% weed control in PRE-T and POST-T (OT) treatments, respectively (Table 4).

S-metolachlor. Statistically significant differences were found between PRE-T and POST-TO (OR) treatments of S-metolachlor by growing season, as well as significant differences in efficacy by year of study.

However, weed control did not significantly differ among treatments only in the Titov Veles region (vertisol site) in 2021 (Tables 3 and 4). In the Prilep region (fluvisol site), in 2020, S-metolachlor applied PRE-T reduced the number of weeds between 65% (AMARE) and 74% (DIGSA). A significant increase in weed control was provided by S-metolachlor in the POST-T (OT) treatment. Except for CHEAL (93%), the remaining weeds were fully controlled (100%). In 2021, S-metolachlor applied PRE-T controlled weeds between 77% (AMARE) and 85% (DIGSA). A significant decrease in S-metolachlor efficacy was recorded in POST-T (OT) application, with weeds controlled between 65% (CHEAL) and 74% (DIGSA) (Table 3). In the Titov Veles region (vertisol site), in the first experimental year (2020), PRE-T S-metolachlor treatment provided good control of all predominant weeds (between 82 and 87%), while POST-T (OT) S-metolachlor treatment effectively controlled predominant weeds (between 94 and 99%). In the second experimental year (2021), because of dry soil conditions, S-metolachlor efficacy was substantially decreased. The efficacy of S-metolachlor provided only marginal control of predominant broadleaf weeds (<76 and <79%) during PRE-T and POST-T (OT) application, respectively (Table 4).

Dimethenamid. A significant interaction between treatment and year revealed two distinct years of dimethenamid weed control effectiveness with PRE-T and POST-T (OT) applications across both regions; however, in the Titov Veles region (vertisol site) in 2021, treatment differences in weed control with dimethenamid were not statistically significant (Tables 3 and 4).

In the Prilep region (fluvisol site), in 2020, PRE-T dimethenamid provided unacceptable control of the investigated weeds; efficacy ranged between 68% (POROL) and 73% (AMARE). POST-T (OT) treatment significantly improved dimethenamid efficacy. With the exception of DIGSA, which was entirely controlled at 100%, the remaining weeds were managed with control rates ranging from 93% to 96%. In 2021, the dimethenamid applied PRE-T provided good control of the weeds; efficacy ranged between 78% (CHEAL) and 84% (DIGSA). Due to leaching, the efficacy of dimethenamid in the POST-T (OT) treatment was significantly reduced, ranging from 66% (CHEAL) to 72% (DIGSA) (Table 3). Dimethenamid provided good (PRE-T) to excellent (POST-T (OT)) weed control in the Titov Veles region (vertisol site) in 2020. During the PRE-T treatment evaluation, efficacy in controlling predominant broadleaf weeds ranged between 83% (POROL) and 87% (AMARE), while POST-T (OT) treatment estimation showed that POROL was controlled <96%, AMARE and CHEAL were controlled 98%, and POLAV 99%. In contrast, in 2021, weed management efficacy was below 77% (PRE-T) and less than 80% (POST-T (OT), respectively, due to arid soil conditions (Table 4).

Tobacco injury. PRE-T and POST-T (OT) herbicides were applied at standard timings in North Macedonia's tobacco production, consistent with producer practices and label recommendations. In 2020, significant rainfall was recorded in the Prilep region (fluvisol site) during the 1st WA PRE-T A, leading to leaching of PRE-T herbicides within the soil profile. It is quite likely that tobacco injury resulted from the increased rainfall (29 mm) that occurred immediately after PRE-T herbicide application. Injury levels ranged from 8 to 25% across PRE-T treatment at 7 days after herbicide application (DAHA). The more severe injuries were caused by pendimethalin and metolachlor, recorded at 24% and 25%, respectively. In both instances, symptoms included stunted, yellowing plants, and occasionally accompanied by mottled and distorted lower leaves. Injuries resulting from other PRE-T herbicides diminished by 7 and 21 DAHA. However, damage from pendimethalin and metolachlor remained still visible at 21 DAHA. Minor tobacco injuries were recorded in POST-T (OT) treatment, though these were considered insignificant. In 2021, rainfall that exceeded the 30-year average was recorded during the 1st and 2nd WA POST-T (OT) application, contributing to increased tobacco injury. Injury levels ranged from 7% to 22% at 7 DAHA, with pendimethalin and metolachlor again causing more significant damage (20% and 22%, respectively), still evident at 21 DAHA (15% and 17%, respectively) (Table 5). Nonetheless, tobacco recovery from these injuries occurred relatively quickly, with injury symptoms disappearing by the end of the second harvest. At the vertisol site, negligible tobacco injuries were recorded for both years, limited only to POST-T (OT) treatments. By 21 DAHA, all herbicides exhibited 7% or less injury (Table 6).

Table 5. Tobacco plant injury as influenced by PRE-T and POST-T (OT) applied herbicides, and grain yield as influenced by PRE-T and POST-T (OT) applied herbicides in tobacco in Prilep region (fluvisol site) in 2020 and 2021.

Treatments	Prilep Region (Fluvisol Site)											
	Tobacco Injury								Tobacco Yield (kg/ha)			
	2020				2021							
	PT		PTOT		PT		PTOT		2020		2021	
	7 DAHA	21 DAHA	7 DAHA	21 DAHA	7 DAHA	21 DAHA	7 DAHA	21 DAHA	PT	PTOT	PT	PTOT
Weedy control	0^{e}	0^{e}	0^{d}	0^{b}	0^{a}	0^{a}	0^{d}	0^{d}	1280^{e}	1280^{d}	1490^{e}	1490^{f}
Weed-free control	0^{e}	0^{e}	0^{d}	0^{b}	0^{a}	0^{a}	0^{d}	0^{d}	3540^{a}	3540^{a}	3370^{a}	3370^{a}
Pendimethalin	24^{a}	19^{a}	4^{b}	0^{b}	0^{a}	0^{a}	20^{a}	15^{a}	2420^{cd}	3470^{abc}	3120^{bc}	2470^{de}
Metobromuron	18^{b}	12^{b}	1^{cd}	0^{b}	0^{a}	0^{a}	15^{b}	9^{b}	2460^{bcd}	3390^{c}	3060^{cd}	2540^{bcd}
Clomazone	11^{cd}	7^{c}	2^{c}	1^{b}	0^{a}	0^{a}	8^{c}	3^{c}	2490^{bc}	3450^{abc}	3100^{bcd}	2590^{bc}
Aclonifen	8^{d}	2^{d}	2^{c}	0^{b}	0^{a}	0^{a}	7^{c}	4^{c}	2530^{b}	3420^{bc}	3030^{d}	2510^{cd}
S-metolachlor	25^{a}	21^{a}	6^{a}	3^{a}	0^{a}	0^{a}	22^{a}	17^{a}	2390^{d}	3530^{a}	3170^{b}	2420^{e}
Dimethenamid	16^{bc}	10^{bc}	2^{c}	0^{b}	0^{a}	0^{a}	13^{b}	8^{b}	2460^{bcd}	3500^{ab}	3130^{bc}	2610^{b}
LSD 0.05	5.29	3.83	1.73	1.01	0.00	0.00	3.30	2.54	98.58	91.02	78.69	88.87
interactions PT × PTOT	*				*				*		*	
interactions PT and PTOT × year	NS								NS			

PRE-T (PT, pre transplantation) and POST-T-OT (PTOT, post transplantation over-the-top); DAHA—days after herbicide application; NS—not significant; * significant at the 5% level according to a Fisher's protected LSD test at $p < 0.05$; PRE-T treatments were applied two days before tobacco transplantation. POST-T (OT) treatments were applied five days after tobacco transplantation; tobacco injury was estimated 7 and 21 days after herbicide application (DAHA); means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$.

Table 6. Tobacco plant injury as influenced by PRE-T and POST-T (OT) applied herbicides, and grain yield as influenced by PRE-T and POST-T (OT) applied herbicides in tobacco in Titov Veles (vertisol site) in 2020 and 2021.

Treatments	Titov Veles (Vertisol Site)											
	Tobacco Injury								Tobacco Yield (kg/ha)			
	2020				2021							
	PT		PTOT		PT		PTOT		2020		2021	
	7 DAHA	21 DAHA	7 DAHA	21 DAHA	7 DAHA	21 DAHA	7 DAHA	21 DAHA	PT	PTOT	PT	PTOT
Weedy control	0 ^{a}	0 ^{a}	0 ^{d}	0 ^{d}	0 ^{a}	0 ^{a}	0 ^{c}	0 ^{d}	1330 ^{d}	1330 ^{d}	1210 ^{e}	1210 ^{e}
Weed-free control	0 ^{a}	0 ^{a}	0 ^{d}	0 ^{d}	0 ^{a}	0 ^{a}	0 ^{c}	0 ^{d}	3390 ^{a}	3390 ^{a}	3060 ^{a}	3060 ^{a}
Pendimethalin	0 ^{a}	0 ^{a}	7 ^{b}	4 ^{b}	0 ^{a}	0 ^{a}	10 ^{a}	6 ^{a}	3180 ^{bc}	3300 ^{bc}	2560 ^{cd}	2590 ^{cd}
Metobromuron	0 ^{a}	0 ^{a}	4 ^{c}	0 ^{d}	0 ^{a}	0 ^{a}	7 ^{b}	3 ^{bc}	3250 ^{b}	3380 ^{ab}	2670 ^{b}	2710 ^{b}
Clomazone	0 ^{a}	0 ^{a}	3 ^{c}	0 ^{d}	0 ^{a}	0 ^{a}	6 ^{b}	3 ^{bc}	3150 ^{c}	3270 ^{c}	2530 ^{d}	2550 ^{d}
Aclonifen	0 ^{a}	0 ^{a}	3 ^{c}	0 ^{d}	0 ^{a}	0 ^{a}	6 ^{b}	2 ^{c}	3210 ^{bc}	3360 ^{ab}	2600 ^{bcd}	2690 ^{b}
S-metolachlor	0 ^{a}	0 ^{a}	9 ^{a}	5 ^{a}	0 ^{a}	0 ^{a}	12 ^{a}	7 ^{a}	3230 ^{bc}	3330 ^{abc}	2650 ^{b}	2640 ^{bcd}
Dimethenamid	0 ^{a}	0 ^{a}	4 ^{c}	2 ^{c}	0 ^{a}	0 ^{a}	7 ^{b}	4 ^{b}	3190 ^{bc}	3340 ^{abc}	2630 ^{bc}	2670 ^{bc}
LSD 0.05	0.00	0.00	1.74	0.80	0.00	0.00	2.67	1.54	81.57	82.72	70.29	90.19
interactions PT × PTOT	*				*				NS		NS	
interactions PT and PTOT × year	NS								*			

PRE-T (PT, pre transplantation) and POST-T-OT (PTOT, post transplantation over-the-top); DAHA—days after herbicide application; NS—not significant; * significant at the 5% level according to a Fisher's protected LSD test at $p < 0.05$; PRE-T treatments were applied two days before tobacco transplantation. POST-T (OT) treatments were applied five days after tobacco transplantation; tobacco injury was estimated 7 and 21 days after herbicide application (DAHA); means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $p < 0.05$.

Tobacco yield. In both regions, tobacco yields generally reflected the level of weed control and the extent of crop injury (Tables 5 and 6). An evaluation of weedy and weed-free controls showed that weed pressure caused tobacco yield reductions of 56–64% in the Prilep region (fluvisol site), and 60–61% in the Titov Veles region (vertisol site) across both years (Tables 5 and 6). A significant treatment-by-year interaction in the Prilep region (fluvisol site) resulted in year-to-year variability in tobacco yield. However, tobacco yield did not significantly differ across treatment-by-year interaction. In both years, untreated control plots exhibited the lowest yields (1280 and 1490 kg/ha, respectively), regardless of treatment (PRE-T or POST-T (OT)). Due to herbicide leaching and ineffective weed control, total yield in PRE-T herbicide-treated plots ranged from 2390 to 2530 kg/ha, considerably lower than the weed-free control (3540 kg/ha). Within herbicide-treated plots, aclonifen treatments resulted in the highest total yield, whereas S-metolachlor treatments led to the lowest total yields. POST-T (OT) treatment yields were comparable to the weed-free control (3540 kg/ha). Within this group, metobromuron had the lowest yield (3390 kg/ha), whereas S-metalocholar resulted in the highest yield (3530 kg/ha). These differences likely resulted from variations in tobacco injuries and degree of weed control. In investigation of [32] between herbicides maximum yield of 2465 kg/ha was recorded in pendimethalin (EC) treatment and minimum yield of 1788 kg/ha in S-metalocholar treated plots. In 2021, the total yield in PRE-T treatments ranged between 3030 kg/ha (aclonifen) and 3170 (S-metolachlor), again lower than the weed-free control (3370 kg/ha). Significant differences between the weed-free control and PRE-T treatments were most likely due to new weed emergence triggered by the transplanting machine's furrow plough, which disrupted the treated soil layer and brought untreated, weed seed-rich soil to the surface. Additionally, herbicide leaching reduced weed control and contributed to crop injuries in POST-T (OT) plots, significantly decreasing yields compared to both the weed-free control and PRE-T treatments (Table 5). In the Titov Veles region (vertisol site), a non-significant treatment-by-treatment interaction resulted in similar yield outcomes in both years with PRE-T and POST-T (OT) herbicide applications. However, a significant treatment-by-year interaction influenced tobacco yields across treatments. In 2020, none of the PRE-T and POST-T (OT) herbicide treatments yielded higher than the weed-free control, and differences were not substantially higher between PRE-T and POST-T (OT) treatments and weed-free control. By contrast, in 2021, poor weed control resulted in substantial yield reductions across all herbicide treatments, averaging −450 and −420 kg/ha relative to the weed-free control (Table 6).

4. Discussion

Wet spring conditions combined with the light soil texture in the Prilep region (fluvisol site) led to the leaching of PRE-T and POST-T (OT) herbicides in 2020 and 2021. Typically, substantial rainfall and intense precipitations occurring shortly after soil-applied herbicides-mainly on sandy soils with low OM-can cause herbicides leaching throughout the soil profile, beyond the zone where weed seeds germinate [33,34]. This displacement often results in reduced herbicide efficacy [19,35]. On the other hand, many soil-applied herbicides are prone to volatilization and photodegradation on the soil surface sooner or later. Consequently, precipitation or irrigation within the first few days after application is essential for moving these herbicides into the weed seed-germinating zone, allowing absorption by the emerging weeds [36–38]. This mechanism explains the variable control of predominant weeds noted with PRE-T and POST-T (OT) herbicide treatments under the drought conditions recorded at the vertisol site in the middle of spring 2021. In contrast to these excessively wet and dry periods, herbicide efficacy was good to nearly excellent for PRE-T applications in 2021 and POST-T (OT) applications in 2020 in the Prilep region (fluvisol site), and similarly for PRE-T and POST-T (OT) applications in 2020 in the Titov Veles region (vertisol site). In similar investigations, but under more moderate conditions, numerous soil-applied herbicides provided satisfactory control of some annual spring and summer weeds, as demonstrated in our study. For example, pendimethalin applied in tobacco PRE-T at 6 L/ha effectively controlled dominant weeds (DIGSA, AMARE, and *Echinochloa crus-galli*) with efficacy ranging between 90.4% and 94.6% [10]. When applied at 5 L/ha in transplanted tobacco, pendimethalin provided weed control rates between 88.6% and 89.3% on the alluvial soil and chernozem, respectively [39]. According to Moayedzadeh (1999) [40], pendimethalin at 3.5 L/ha resulted in control of 80–90% of broadleaf weeds and 60–70% of grass weeds in the tobacco crop. CHEAL, AMARE, *Tribulus terrestris*, *Setaria verticillata*, and *E. crus-galli* were adequately controlled by pendimethalin in oriental sun-cured tobacco [41]. In field trials carried out from 2009 to 2012, the efficacy of metobromuron was evaluated by Bergmann (2016) [42], who concluded that the application of Proman (metobromuron) at a rate of 3 L/ha resulted in 90% control of POLAV and DIGSA, 93% of CHEAL, and 89% of AMARE. Furthermore, in investigations by Mitchell and Gage (1999) [43], Talbert et al. (1998) [44], Lee et al. (2004) [45], and Bailey (2007) [46], clomazone was found to control several annual broadleaf weeds, including *Ambrosia artemisiifolia* and grasses such as *Echinochloa crus-galli*, *Digitaria* spp., and *Setaria* spp., but did not effectively control *Amaranthus* spp. Both clomazone alone and treatments that included clomazone achieved a control rate of 91% or higher for *Setaria* spp. in banana pepper [47]. Aclonifen (2.5 L/ha), when sprayed after carrot sowing, reduced the number of weeds by 85.8% [48]. Aclonifen (2750 to 3000 g a.i./ha), applied in lavender crops, provided weed control efficacy between 84.4 and 85.4% [49]. In the investigation of Pannacci and Bartolini (2018) [50], aclonifen resulted in substantial weed control, achieving efficacy values ranging from 81% to 88% due to its high effectiveness against POROL, the predominant species in the sorghum crop. In the same study, CHEAL was controlled at a rate of 94%. S-metolachlor is successful in providing residual control of problematic weed species such as *Amaranthus* spp., *Chenopodium album*, *Cyperus esculentus*, and certain annual grass species in several agronomic and vegetable crops [51]. S-metolachlor at 1.4 kg/ha applied in sugar beet controlled AMARE at 98% and CHEAL at 84% [52]. In banana pepper, S-metolachlor applied at 534 g ai/ha achieved control rate of CHEAL at 99% (2WAT) and 85% (4 WAT), whereas a higher application of S-metolachlor at 1070 g ai/ha resulted in a CHEAL control rates of 96% (2WAT) and 90% (4 WAT). The same rates of S-metolachlor provided control of POROL between 61 and 67% [47]. In contrast, applying S-metolachlor to spinach at rates of 0.56 kg/ha or higher achieved over 95% control of POROL [53]. Finaly, dimethenamid controls many annual broadleaf and grass weeds when applied pre-emergence and is currently registered for use in various crops [54]. In earlier research trials in Idaho, dimethenamid achieved greater than 96% control of CHEAL and AMARE at application rates between 1.1 and 1.7 kg/ha [55]. A study on PRE herbicides for controlling weeds in pumpkin demonstrated that 21 days after application, dimethenamid at 2.24 kg/ha provided 81–100% control of AMARE [56]. Similarly, in sugar beet, dimethenamid-P applied at 0.84 kg/ha provided control of AMARE and CHEAL at 99% and 91% [52].

As previously mentioned, in 2020 in the Prilep region (fluvisol site), heavy precipitation (29 mm) occurred immediately following PRE-T herbicide treatment, causing leaching of PRE-T herbicides and subsequent tobacco injury, of which those caused by pendimethalin and metolachlor were more serious. Similar findings were reported by Yousafzai et al. (2006) [32], who concluded that S-metalocholar showed a phytotoxic effect on tobacco, manifested as retarded plant growth. In the study by Fisher et al. (2001) [57], the highest level of tobacco injuries was observed with pendimethalin application. In 2000, rainfall during the 3 WAT period exceeded that of 2001 and 2002, which likely contributed to increased Maryland-type tobacco injury observed in 2000, due to the application of sulfentrazone tank-mixed with clomazone or pendimethalin [58]. Similarly, pendimethalin and clomazone caused relatively minor stunting of tobacco each year (ranging from 10, 11, and 2% injury for 2005, 2006, and 2007, respectively). The substantial rainfall of 2005 and 2006 increased herbicide uptake by tobacco plants, leading to elevated crop injury [59]. Walker et al. (1998) [60] indicated that application of sulfentrazone, as a PPI treatment, or in combination with clomazone as a PRE-T treatment, resulted in tobacco discoloration of up to 26% at 15 and 30 days after treatment (DAT). Breeden et al. (1999) [61] investigated the effects of combining sulfentrazone with either clomazone or pendimethalin, applied on the soil surface or incorporated into the soil. They reported that tobacco injury at one site was 20% or less at 15 DAT, with only a slight increase in injury following incorporation. At 64 DAT, injury rates from all treatments were 5% or less. POST-T using trifloxysulfuron, halosulfuron, and sulfentrazone caused considerable injury to dark tobacco, ranging from 16 to 39% at one week after treatment (WAT). However, these symptoms dissipated to 6 to 12% by 4 WAT [46].

Although weather conditions varied during the experimental period and affected the effectiveness of applied herbicides, a positive impact of herbicide application on tobacco yield increase was still observed (37–60%). Also, Travlos et al. (2014) [41] highlighted the advantages of herbicide use, consistent with Dhanapal et al. (1998) [62]. Comparable weed control effects from metolachlor, metobromuron, napropamide, and trifluralin were reported in other studies [63]. In the investigation of Yousafzai et al. (2006) [32], among the tested herbicides, the highest tobacco yield of 2465 kg/ha was recorded in the pendimethalin (EC) treatment, while the lowest yield of 1788 kg/ha was observed in plots treated with S-metalocholar.

5. Conclusions

The conducted studies confirmed the effect of using soil herbicides and their application during the early post-transplant period. The efficacy of PRE-T applications was significantly lower compared to POST-T (OT) treatments, primarily due to new weed emergence within the tobacco rows following PRE-T treatment, which was not the case in POST-T (OT) herbicide applications. However, reduced herbicide efficacy was noted for both treatments as a result of excessive or limited precipitation during certain periods of the two-year study trial across both regions. The observed decline in the efficacy of applied herbicides during the two-year study period was attributed to the fluctuations in rainfall and temperature. These conditions did not lead to the occurrence of phytotoxicity in tobacco plants, although tobacco is known to be sensitive to conditions of high rainfall.

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