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Integrated weed control strategies in irrigated maize cultivation: a case study from Poarta Albă, Southeastern Romania (2021–2024)

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Abstract: This study assessed the effectiveness of integrated weed control strategies in irrigated maize in southeastern Romania (Poarta Albă, 2021–2024). Three technological variants were compared: untreated control, pre-emergence herbicide plus one hoeing, and combined pre- and post-emergence herbicides with two hoeings. Weed infestation exceeded 78 plants/m² in untreated plots, dominated by *Sorghum halepense, Amaranthus retroflexus*, and *Setaria viridis*. The most intensive strategy reduced weed density by more than 90%, increased crop uniformity, and significantly improved plant biomass and yield components. Strong negative correlations (r = –0.99) were observed between weed density and biometric traits. A preliminary economic assessment indicated that the combined strategy provided the highest yield advantage relative to control costs. These findings highlight the importance of integrated approaches under irrigated conditions in southeastern Europe, where climate variability intensifies weed competition.

Keywords: Integrated weed management; Irrigated maize; *Sorghum halepense*; Climate stress; Weed–crop competition; Grain yield; Economic efficiency.

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1. Introduction

Maize (*Zea mays* L.) is one of the most widely cultivated cereal crops worldwide due to its high nutritional value, diverse industrial applications, and strategic role in food security. In Romania, maize covers over 2.5 million hectares annually, placing the country among the leading producers in the European Union (Ioniță et al., 2022; Velicu and Viorel, 2024). The continuous development of high-performing hybrids adapted to different pedoclimatic conditions has further strengthened its position in the national agricultural economy (Aedin et al., 2024; Ceclan et al., 2025).

Despite this adaptability, maize is highly vulnerable to weed competition, especially in the early growth stages, when yield losses can exceed 50% (Mihuț et al., 2023; Matei et al., 2024; Sălceanu et al., 2024). The weed flora in maize is diverse, including both monocotyledonous species such as *Echinochloa crus-galli* and *Sorghum halepense*, and dicotyledonous species such as *Amaranthus retroflexus* and *Chenopodium album* (Șerban et al., 2021; Lipianu et al., 2023). In particular, *S. halepense* and *A. retroflexus* are aggressive competitors that dominate untreated fields. The most critical window of maize sensitivity to weed competition occurs between the 3–4 and 8–10 leaf stages (Chețan and Chețan, 2022).

Chemical weed control remains the dominant approach, especially through selective pre- and post-emergence herbicides such as dicamba and tembotrione, which are highly effective against both annual and perennial weeds (Khanna et al., 2022; Mundt et al., 2024). However, prolonged reliance on herbicides has favored resistant biotypes and raised environmental concerns regarding residues and biodiversity loss (Simić et al., 2025).

These limitations have led to the development of integrated weed management (IWM) strategies, which combine chemical, mechanical, cultural, and agronomic methods into site-specific solutions (Aedin et al., 2024; Radu et al., 2025; Oltenacu et al., 2025; Ianculescu et al., 2026). Practices such as crop rotation, hoeing, and precision herbicide application contribute to sustainable and resilient systems, while the combination of chemical and mechanical methods has proven particularly effective in reducing weed pressure with lower chemical input.

The importance of integrated approaches is increasing under climate change, which intensifies abiotic stress and promotes weed proliferation. Southeastern Romania, especially the Dobrogea region, is characterized by high temperatures, recurrent droughts, and strong pressure from perennial weeds such as *S. halepense*. Yet few studies have assessed integrated weed control under irrigated conditions in this area (Stroe and Panaitescu, 2025; Simić et al., 2025). Recent climate modelling studies indicate that global warming will significantly alter the distribution dynamics of invasive plant species across Europe. For example, Miroshnyk and colleagues demonstrated that the invasive species *Reynoutria japonica* is expected to both expand and contract its distribution range under different climate scenarios, depending on regional climatic shifts (Miroshnyk et al., 2025). Such findings highlight climate change does not merely increase weed pressure uniformly but reshapes competitive interactions and regional infestation risks. In semi-arid areas such as southeastern Romania, where rising temperatures and water deficits already intensify crop–weed competition, adaptive and integrated weed management strategies become increasingly necessary.

In this context, the present study evaluates the effectiveness of three representative weed management strategies in irrigated maize at Poarta Albă, Constanța County: (i) untreated control, (ii) pre-emergence herbicide with one hoeing, and (iii) combined pre- and post-emergence herbicides with two hoeings. These variants were selected to reflect practices commonly adopted by farmers in the region, ranging from minimal to intensive intervention. The study further explores correlations between weed density and yield components, while providing a preliminary assessment of the economic feasibility of each strategy.

This research provides site-specific insights into the interaction between irrigation and weed pressure under the pedoclimatic conditions of southeastern Romania. The Poarta Albă area, located within the Dobrogea region, is particularly affected by seasonal droughts and high summer temperatures that favor aggressive weed communities. The quantified relationship between irrigation level, weed suppression efficiency, and yield formation demonstrates that water availability not only supports maize growth but also enhances the competitiveness of the crop against weeds. These locally derived results provide valuable guidance for optimizing integrated weed management under irrigated systems in the semi-arid areas of southeastern Europe.

Efficient irrigation management must also be considered within a broader risk assessment framework. Chernysh et al., (2025) emphasized that risk assessment tools play a crucial role in improving water resource management, particularly under conditions of climatic uncertainty and increasing environmental pressure. Integrating weed control strategies with optimized irrigation practices can therefore enhance both agronomic performance and environmental sustainability. In irrigated maize systems, such integration reduces resource losses, limits ecological risks, and strengthens resilience against climate variability.

2. Materials and Methods

The study was carried out between 2021 and 2024 in Poarta Albă Commune, Constanța County, southeastern Romania, on chernozem soils under irrigation supplied by the Danube–Black Sea Canal. The local climate is moderately continental, with high summer temperatures and recurrent rainfall deficits, conditions that justify maize cultivation under irrigation.

The experiment was established on a 15-hectare irrigated platform belonging to a 220-hectare farm in Poarta Albă, Constanța County. The site lies in the Dobrogea region, characterized by typical chernozem soils, high summer temperatures, and frequent rainfall deficits. Irrigation was provided through the Danube–Black Sea Canal, with approximately 2800 m^3/ha applied in four installments each season to ensure uniform water supply across treatments. Soil preparation followed conventional tillage, consisting of autumn plowing to a depth of 25 cm with reversible plows, followed by spring seedbed preparation with a combinator one day before sowing. These operations ensured good moisture conservation, seedbed leveling, and reduced initial weed pressure.

The experimental design was a randomized complete block with three replications, each plot measuring 300 m^2 and separated by 1.5 m buffer strips to prevent herbicide drift and cross-contamination. Three technological variants were tested: an untreated control (V1); a pre-emergence application of mesotrione (330 ml/ha) combined with one mechanical hoeing at the 4–6 leaf stage (BBCH 14–16, mid-May) (V2); and a more intensive strategy consisting of pre-emergence mesotrione (330 ml/ha) followed by post-emergence nicosulfuron (1.5 L/ha) and two hoeings, performed at BBCH 14–16 (mid-May) and BBCH 18–20 (early June) (V3). These treatments were chosen to reflect the levels of weed control intensity most frequently used by farmers in the region, ranging from minimal to fully integrated chemical and mechanical interventions.

All plots received identical fertilization and crop protection. Fertilization included 200 kg/ha NPK (20:20:20) before sowing, 100 kg/ha urea during vegetation, and foliar nutrition with an NPK + micronutrient mixture (Plonvit, 2 L/ha). Pest control was carried out with deltamethrin (125 ml/ha) against *Diabrotica virgifera* and *Helicoverpa armigera*, while foliar diseases were prevented with two fungicide applications of azoxystrobin + cyproconazole and pyraclostrobin + epoxiconazole (1 L/ha each).

The maize hybrid used was DKC 5092, certified (C1) with >90% germination and 98% purity. Sowing was carried out annually in the last decade of April with precision seeders, at 70 cm row spacing, 6 cm depth, and a planned density of 77,000 plants/ha. Favorable rainfall in spring 2024 ensured uniform crop emergence, while drought conditions in June–August required supplementary irrigation, reflecting the climatic variability typical for southeastern Romania (Velicu and Viorel, 2024; Stroe and Panaitescu, 2025).

Maize was sown in the last decade of April each year, using the hybrid DKC 5092 at a target density of 77,000 plants/ha, with 70 cm row spacing and 6 cm sowing depth. The preceding crop was winter wheat. Soil plowed to 25 cm in autumn and prepared with a combinator in spring. Fertilization included 200 kg/ha NPK (20:20:20) before sowing and 100 kg/ha urea during vegetation. Foliar nutrition was applied using an NPK + micronutrient mixture (Plonvit, 2 L/ha). Crop protection against insects and diseases was ensured uniformly across all treatments using deltamethrin (125 ml/ha), azoxystrobin + cyproconazole (1 L/ha), and pyraclostrobin + epoxiconazole (1 L/ha). To eliminate water availability as a confounding factor, all plots received identical irrigation, amounting to approximately 2800 m^3/ha in four applications per season.

Data were collected at key phenological stages: BBCH 14 (four leaves), BBCH 39 (stem elongation), and BBCH 60 (flowering). Measurements included plant density, plant height, cob insertion height, number of ears per plant, and plant biomass. Weed infestation was assessed using the quadrat method (1 m^2) with floristic identification of dominant species. At physiological maturity, plant biomass was determined from representative samples, and yielded components (ear length, cob weight, kernels per ear, thousand kernel weight) were measured from cleaned grain standardized to 14% moisture.

All data were statistically analyzed using Microsoft Excel with XLSTAT (version 2023.3). Analysis of variance (ANOVA) was applied to test treatment effects, with differences verified by the

Least Significant Difference (LSD) test at $p < 0.05$. Pearson correlation coefficients were also calculated to describe relationships between weed density and key biometric or yield parameters.

3. Results and Discussion

3.1. Climatic conditions during the experimental period

An analysis of climatic data for the 2021–2024 period revealed significant deviations from multiannual averages (Figure 1). The mean annual temperature was 13.2 °C, approximately 2.1 °C higher than the regional norm of 11.1 °C, while annual precipitation averaged only 336.7 mm compared to the multiannual average of 438.9 mm. The deficit was particularly critical in spring and summer, coinciding with key vegetative and reproductive stages of maize development. Such conditions: warmer springs and drier summers, are increasingly frequent in southeastern Europe and have been reported to intensify weed competition and crop stress (Aedin et al., 2024; Simić et al., 2025; Stroe and Panaitescu, 2025). Although irrigation compensated for water shortages and ensured uniform crop establishment, these climatic anomalies underline the importance of adaptive technologies that integrate weed control with efficient water management and hybrid selection in southeastern Romania.

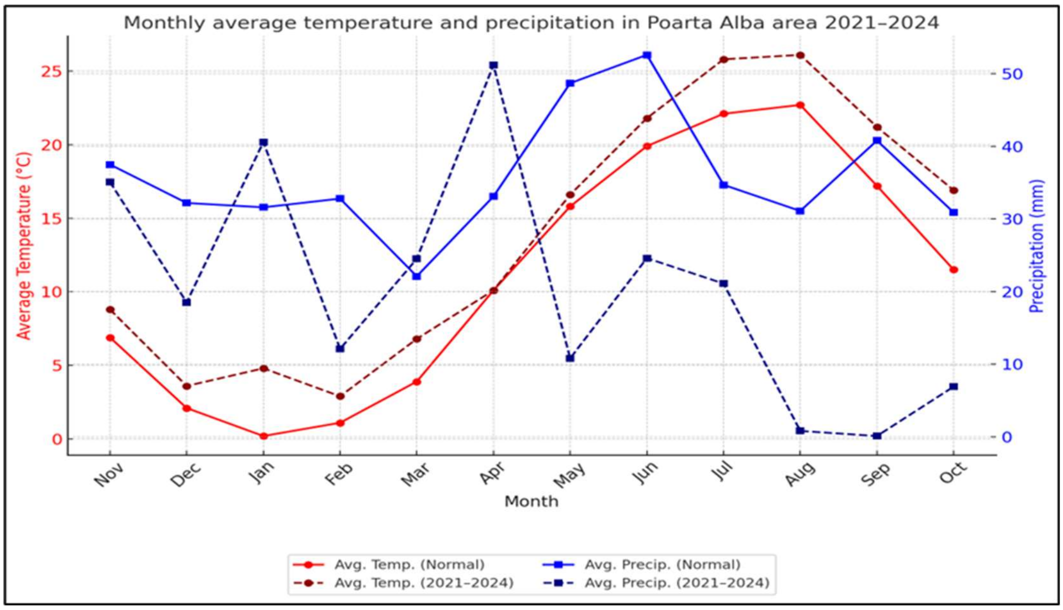

Figure 1. Evolution of temperature and precipitation (2021–2024 vs normal).

3.2. Effect of weed management on maize growth and biometric traits

The climatic stress observed during the experimental years directly influenced maize establishment and the intensity of weed competition. Plant density at harvest proved to be a sensitive indicator of treatment effectiveness. In the untreated control (V1), strong weed pressure reduced plant survival to an average of 5.8 plants/m², and very few plants were able to produce two ears. In contrast, V2 (pre-emergence herbicide plus one hoeing) maintained a higher density of nearly 7 plants/m², with a noticeable increase in plants forming double cobs. The most intensive strategy, V3 (two herbicide applications combined with two hoeings), secured the highest density, averaging 7.5 plants/m², and the largest proportion of plants with two ears. These results clearly demonstrate the positive relationship between weed control intensity and stand stability. Under conditions of severe infestation by *Sorghum halepense* and *Amaranthus retroflexus*, untreated maize stands suffered heavy losses despite irrigation, highlighting the vulnerability of seedlings to early-season competition. Similar reductions in plant density due to uncontrolled weed growth have been reported in other studies from southeastern Europe (Matei et al., 2024; Simić et al., 2025).

Another key indicator of crop performance was ear number, which reflects reproductive success under stress. In the untreated control (V1), ear production was lowest, while V2 (pre-emergence herbicide + hoeing) showed a clear improvement. The most intensive treatment, V3 (two herbicide applications plus two hoeings), recorded the highest ear count, with about 45% more cobs compared to the control. The increase in cob formation in V2 and V3 can be attributed to reduced weed competition, which allowed for more vigorous vegetative growth and better reproductive allocation. Plant height, measured at the flowering stage (BBCH 60), also increased in line with the intensity of weed control. Untreated maize (V1) remained shortest, while V2 gained nearly 30 cm in height, and V3 exceeded 2.3 m on average. These results confirm that effective suppression of aggressive species such as *Sorghum halepense* and *Amaranthus retroflexus* enables maize to fully express its genetic potential. Similar findings have been reported in other IWM studies under water-limited conditions in southeastern Europe (Stroe and Panaitescu, 2025; Simić et al., 2025). Similar trends were observed for cob insertion height, which serves as an indicator of plant vigor and structural stability. The lowest values were recorded in the untreated control (V1), while V2 showed a moderate increase, and V3 achieved the highest insertions, exceeding the control by more than 10 cm on average. Such differences reflect improved nutrient uptake and light interception under reduced weed competition (Chețan and Chețan, 2022).

These results confirm that effective weed management supports both vegetative growth and reproductive development. The progressive increases in cob insertion height observed in V2 and V3 are consistent with the findings of Sălceanu et al. (2024), who highlighted the importance of early-season weed suppression for morphological traits and yield formation. In contrast, unchecked weed growth in V1 severely reduced plant vigor and productivity potential. These differences are further illustrated in Figure 2, which highlights the variation in average cob insertion height among the three technological variants.

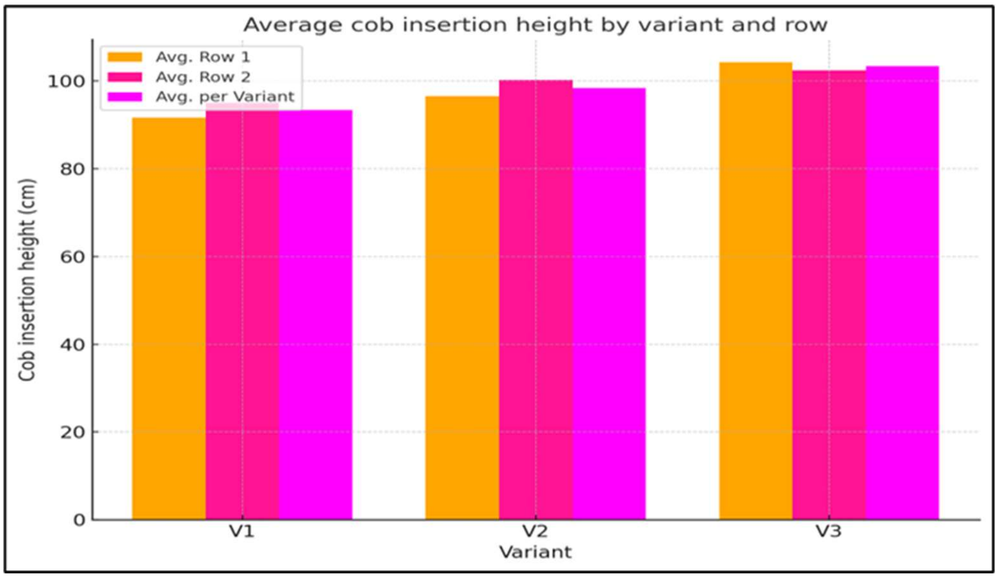

Figure 2. Average cob insertion height by variant

Individual plant weight at physiological maturity was used as an indicator of cumulative vegetative growth. This parameter proved highly sensitive to early weed competition. In the untreated control (V1), average plant weight was lowest, around 630 g, while V2 (pre-emergence herbicide + hoeing) increased to over 820 g. The highest biomass accumulation was recorded in V3 (two herbicides + two hoeings), exceeding 850 g per plant. These differences highlight the negative impact of unchecked weed pressure, which restricted nutrient, water, and light availability in V1, resulting in smaller and less uniform plants. By contrast, V2 and V3 allowed maize to better express its genetic potential, leading to greater vegetative growth and improved uniformity. Similar results were reported by Chețan and Chețan (2022), who found that early-season weed suppression significantly increases biomass accumulation and canopy consistency.

Crop uniformity, expressed as the coefficient of variation, also improved with weed control intensity: from 8.4% in V1 to below 7% in V3. The ANOVA test confirmed these differences as highly significant ($p < 0.001$), validating the effect of weed management intensity on plant development. Although biomass values remained slightly below the potential of the hybrid under optimal conditions, this reduction can be attributed to climatic stress during the 2024 season, particularly the prolonged summer drought. These patterns are clearly illustrated in Figure 3, which shows the progressive increase in plant biomass and the reduction in variability from V1 to V3, emphasizing the role of integrated weed control in enhancing both growth and crop uniformity.

Beyond the effect on vegetative biomass, the results also demonstrate that weed control intensity strongly influences the crop's ability to allocate resources toward reproductive structures. Higher individual plant weights in V2 and V3 were accompanied by better cob development and more consistent grain set, confirming the close link between vegetative growth and reproductive output. These findings reinforce the principle that early suppression of competitive weeds is critical not only for securing stand density and uniformity, but also for ensuring that maize plants can reach their full productive potential under irrigated conditions.

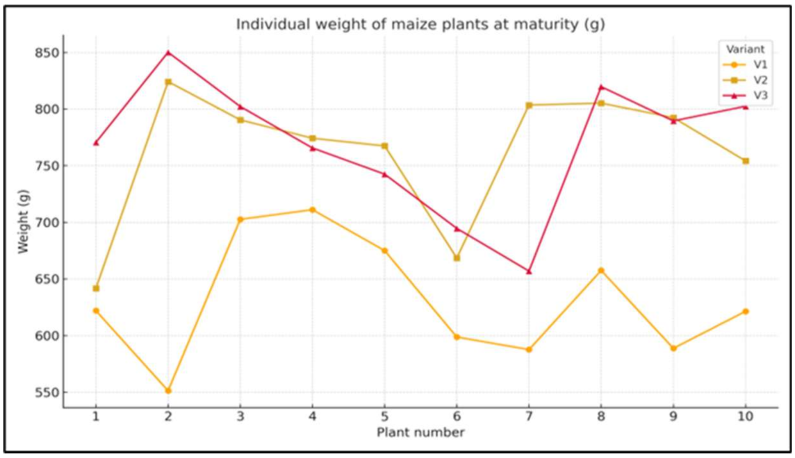

Figure 3. Individual weight of maize plants at maturity (g)

The statistical analysis confirmed that weed management intensity had a decisive effect on plant biomass. One-way ANOVA revealed highly significant differences among treatments ($p < 0.001$), demonstrating that the increases observed in V2 and V3 were attributable to the applied technologies rather than random variation. Post-hoc comparisons using the Least Significant Difference (LSD) test confirmed significant pairwise differences between all treatments (V1, V2, and V3). This reinforces the reliability of the ANOVA results and indicates that the observed trends in biomass and yield are statistically consistent across replications. Detailed statistical reporting was added to improve transparency. The ANOVA tests confirmed highly significant treatment effects ($p < 0.001$) for all major agronomic parameters, including plant biomass, ear number, and grain yield. The results were consistent across replications, confirming that differences among treatments were due to the applied weed management strategies rather than random variation. Regarding the very strong negative correlations ($r \approx -0.99$) between weed density and biometric or yield parameters, these were verified at both average and replication levels. Such high coefficients reflect the stability of the inverse relationship rather than data aggregation bias. Nevertheless, this magnitude should be interpreted as indicating an almost linear tendency rather than an absolute deterministic link. These findings are consistent with Simić et al. (2025), who also reported that integrating herbicide applications with mechanical hoeing improves plant vigor under stress conditions.

It is noteworthy that average biomass values across all treatments remained slightly below the theoretical potential of the DKC 5092 hybrid. This reduction can be explained by the climatic stress of the 2024 season, when limited rainfall and elevated temperatures during June–August constrained growth, particularly in the untreated control were weed pressure further exacerbated competition for scarce resources. Correlation analysis further clarified the interaction between water availability and weed management. A strong positive relationship was observed between effective precipitation (May–August) and plant biomass, with a Pearson coefficient of r ≈ 0.99. This near-linear association indicates that in environments with limited natural water supply, the benefits of weed suppression are magnified, as plants can exploit irrigation and residual soil moisture more efficiently. Figure 4 illustrates this trend, showing how biomass increased with both water availability and weed control intensity, with V1, V2, and V3 positioned progressively along the regression curve. These results highlight the dual role of integrated weed management: reducing direct competition while mitigating the impact of water stress, a function of growing importance under climate variability.

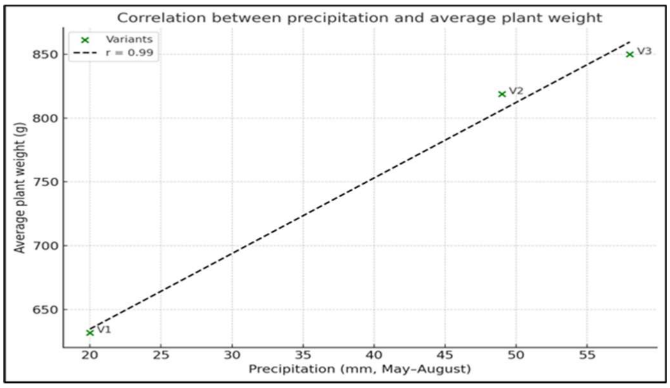

Figure 4. Correlation between precipitation and average plant weight

3.3. Weed flora composition and weed suppression efficiency

The weed flora recorded during the experimental period was diverse and representative of irrigated maize systems in southeastern Romania. Both annual and perennial species were present, forming a highly competitive community. Among the dominant annuals were *Amaranthus retroflexus, Chenopodium album, Setaria viridis*, and *Polygonum spp*., while the perennial group included *Sorghum halepense, Elymus repens, Convolvulus arvensis*, and *Cirsium arvense*. Such species are well adapted to fertile and irrigated soils, where they exert strong competitive pressure on maize (Șerban et al., 2021; Lipianu et al., 2023). Weeds were taxonomically classified as monocotyledonous (e.g. *Setaria viridis, Sorghum halepense, Elymus repens*) and dicotyledonous (e.g. *Amaranthus retroflexus, Chenopodium album, Polygonum spp.*), a spectrum consistent with previous reports from Romania and the Balkans (Chețan and Chețan, 2022; Simić et al., 2025). Particularly problematic were perennials such as *Sorghum halepense* and *Convolvulus arvensis*, whose underground regenerative structures make them difficult to suppress.

Weed infestation was assessed with the fixed quadrat method (1 m²), applied at three standardized points within each plot, during the 8–10 leaf stage of maize, when competition with the crop is most intense. Species identification was carried out in the field using floristic keys.

As shown in Table 1, *Sorghum halepense* was the most aggressive species in the untreated control (24 plants/m²), followed by *Amaranthus retroflexus* (18 plants/m²) and *Setaria viridis* (12 plants/m²). In contrast, in the most intensive treatment (V3), these species were either absent or reduced to negligible densities. This confirms the efficiency of integrated weed control strategies, where chemical applications combined with hoeing can drastically reduce infestation and limit the persistence of problematic perennials.

Table 1. Distribution of weed species on one replicate (1 m²)

Species	Variant – number of weeds		
	V1	V2	V3
Sorghum halepense	24	7	1
Setaria viridis	12	6	3
Amaranthus retroflexus	18	3	0

Chenopodium album	10	4	2
Polyginum aviculare	4	1	0
Polygonum persicaria	2	0	0
Convolvulus arvensis	3	0	0
Cirsum arvense	3	1	0
Elymus repens	2	1	0

The quantitative assessment of weed density provided further insight into treatment effectiveness (Table 2). In the untreated control (V1), infestation levels exceeded 75 plants/m², confirming the highly competitive pressure exerted by the weed flora under irrigated conditions. Such densities are typical of systems without chemical or mechanical intervention and illustrate the strong capacity of both annuals and perennials to dominate the crop stand. In V2, where mesotrione was combined with a single hoeing, weed density declined sharply to about 20 plants/m². Although this strategy provided clear benefits, perennial species such as *Sorghum halepense* and *Convolvulus arvensis* persisted at reduced levels, showing that single-pass approaches may not be sufficient to control regenerating weeds. The greatest suppression was achieved in V3, where the integration of two herbicide applications with two hoeings reduced total densities to fewer than 7 plants/m², a reduction of over 90% compared with the control. At this level of intervention, most problematic perennials were either absent or negligible, confirming the superiority of multi-phase control strategies. These results are consistent with Sălceanu et al. (2024), who also emphasized the need for repeated interventions to limit perennial regrowth in maize.

The consistency of these trends across replications, reflected in the low variability of treated plots, highlights not only the agronomic but also the economic value of integrated weed management, particularly in high-risk environments.

Table 2. Total number of weeds per variant and replication

Variant	Replication 1	Replication 2	Replication 3
V1 control no weed control	76	81	79
V2 1 herbicide, 1 hoeing	21	18	19
V3 2 herbicides, 2 hoeings	6	7	5

The conversion of weed counts to per-the-hectare values further emphasized the scale of infestation differences among treatments (Table 2). In the untreated control (V1), densities corresponded to nearly 800,000 weeds/ha, creating severe competition for crop resources. In V2, infestation was reduced to around 190,000 weeds/ha, while in V3, densities dropped below 60,000 weeds/ha, more than a tenfold reduction compared with the control. Such contrasts have major agronomic implications.

Previous studies have shown that uncontrolled weeds can consume up to one-third of available water and nutrients in maize systems (Simić et al., 2025). Extrapolating these values to the present trial suggests that resource losses in V1 could have reached 30–35%, while in V2 they likely fell to below 15%, and in V3 under 5%. These reductions created more favorable conditions for crop development, canopy closure, and yield formation. The trend is clearly illustrated in Figure 5, which shows the steep decline in weed pressure from V1 to V3 and the narrow error bars for the treated variants, highlighting treatment reliability across replications. Beyond reducing direct competition, the integrated strategy applied in V3 also contributed to improved soil moisture conservation, enhanced nutrient uptake, and a more favorable microclimate within the crop canopy, all factors that ultimately support higher biomass accumulation and grain yield.

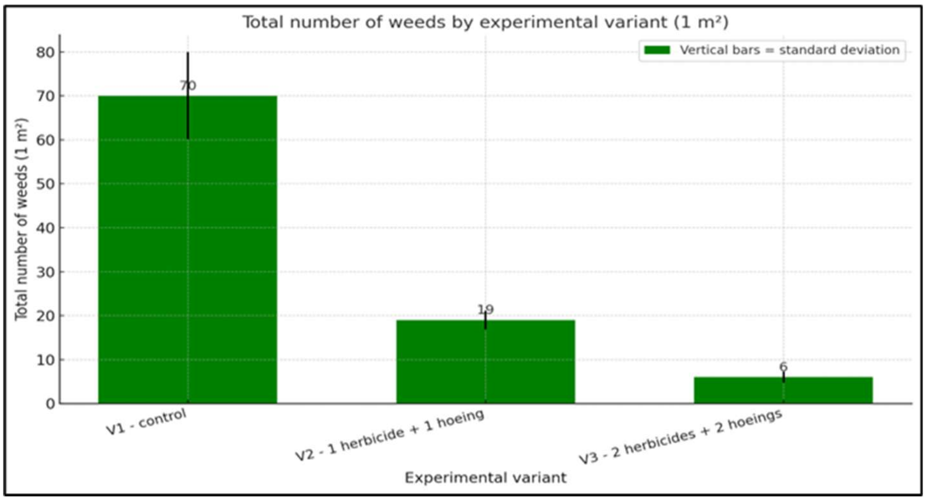

Figure 5. Total number of weeds per variant (with standard deviation)

3.4. Relationships between weed density and crop performance

Correlation analysis further clarified the relationship between weed pressure and crop performance (Figure 6). Total weed density showed a very strong negative association with key biometric parameters. Higher infestation levels were closely linked to lower individual plant biomass, reduced plant density at harvest, and decreased cob insertion height. In all cases, correlation coefficients were close to –1, indicating an almost linear inverse relationship.

These results are consistent with physiological expectations and earlier studies (Chețan and Chețan, 2022; Matei et al., 2024), which showed that weeds deprive maize plants of water, nutrients, and light during critical early stages, leading to stunted growth and reduced vigor. The scatterplot in Figure 6 visually confirms this trend, with a steep downward regression line illustrating the direct negative effect of increasing weed density on maize biomass.

Such strong correlations highlight that weed pressure simultaneously limits multiple aspects of plant development, compounding its overall impact on yield potential. This reinforces the conclusion that maintaining low weed densities through integrated control is essential for sustaining both vegetative growth and reproductive performance in irrigated maize systems.

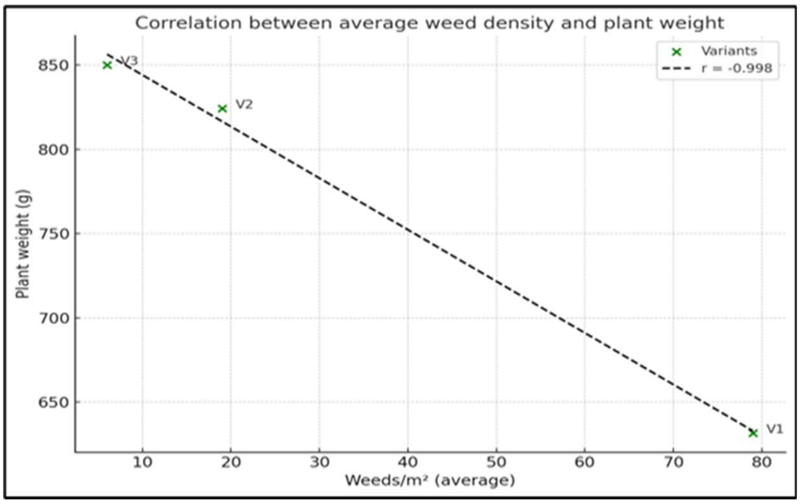

Figure 6. Correlation between weed density and average plant weight

Weed pressure also had a marked effect on reproductive development, as reflected in ear formation. Pearson correlation analysis revealed a very strong negative association between total weed density and the number of ears per plot, with correlation coefficients close to –1. This indicates that increasing weed infestation consistently reduces ear production, a trend that is physiologically explained by reduced light interception, limited nutrient partitioning, and, in severe cases, abortion of reproductive structures. Similar relationships were reported by Sălceanu et al. (2024), who observed that uncontrolled weeds in maize fields suppress ear initiation and increase barrenness.

Across the three treatments, ear number followed the same pattern as vegetative growth. The untreated control (V1) produced the fewest ears, while V2 showed a moderate improvement, and V3 achieved the highest ear count, with nearly 50% more ears than the control. Importantly, variability was lowest in V3, indicating that integrated weed control not only increased productivity but also ensured greater uniformity in reproductive development. This relationship is clearly illustrated in Figure 7, where the descending trendline demonstrates the inverse correlation between weed density and ear number. The graph highlights how heavy infestations, as in V1, constrained ear formation and increased the proportion of barren plants, while V3 maintained high ear numbers and greater population stability. Moreover, the reduction in ear number under high weed pressure reflects a critical disruption of the source–sink relationship during the early reproductive stages. When assimilate availability is limited due to intense interspecific competition, maize plants prioritize survival over reproductive investment, resulting in fewer and less uniformly developed ears. This further emphasizes the importance of maintaining low weed densities during the critical period of ear initiation.

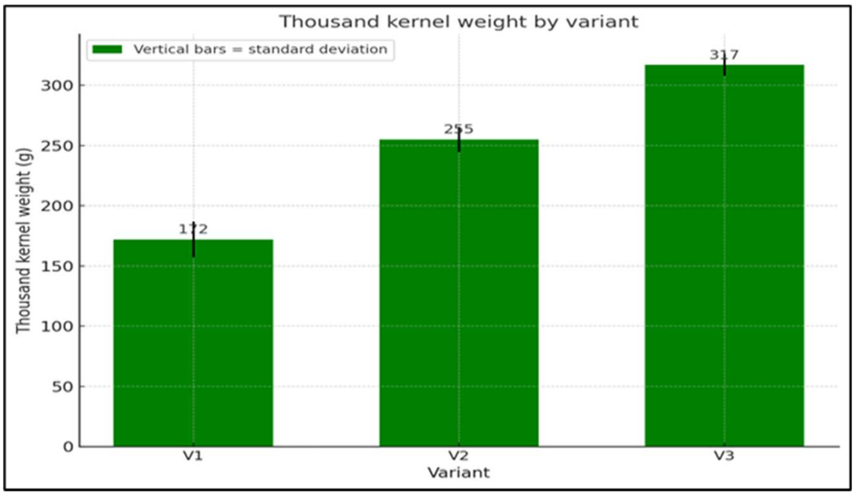

Figure 7. Thousand kernel weight according to the technological variants

Cob insertion height, a parameter often used as an indirect indicator of plant vigor and yield potential, was also strongly affected by weed infestation. Correlation analysis revealed a very strong negative relationship between weed density and cob height, confirming that higher infestation systematically reduced the level at which ears were formed. This finding is agronomically relevant, since lower cob placement not only reflects suppressed plant growth but can also complicate mechanical harvesting. In the untreated control (V1), insertion height was lowest, while V2 showed a moderate increase, and V3 achieved the highest values, exceeding the control by more than 10 cm. These results align with the observations of Chețan and Chețan (2022), who reported that early-season stress, particularly from weeds, affects internode elongation and final ear placement. The relationship is illustrated in Figure 8, where the descending trendline clearly shows how increasing weed density lowers cob insertion height. The figure also highlights that the differences among the three variants are not only statistically significant but also practically relevant, with direct implications for crop uniformity and harvest efficiency.

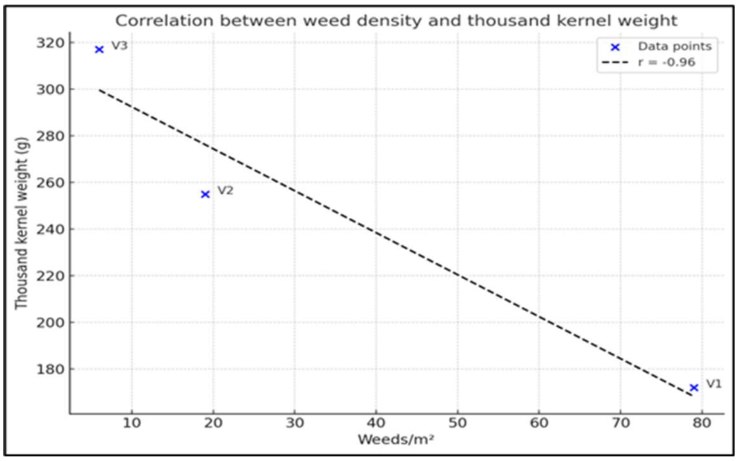

Figure 8. Correlation graph of weed density vs thousand kernel weight (TKW)

Although the correlations presented here were based on average values per variant, their strength and consistency provide meaningful evidence of the agronomic impact of weed infestation. Across all parameters evaluated, plant biomass, ear number, and cob insertion height, higher weed densities were almost perfectly and negatively correlated with crop performance, with r values close to –1. These results reinforce the conclusion that weed pressure is a critical limiting factor in irrigated maize production, particularly under climatic stress.

Such strong correlations also suggest that weed infestation levels could serve as early indicators of crop performance decline. While further multi-year data at the replication level would strengthen statistical modeling, the trends observed here are fully consistent with physiological expectations and prior findings (Sălceanu et al., 2024; Simić et al., 2025).

3.5. Effect of weed management on yield components

Figure 9 illustrates the average ear weight without husks for the maize hybrid DKC 5092, depending on the three weed control technologies applied. The data reveal significant differences determined by the intensity of applied technology. In the untreated control variant (V1), the average ear weight was the lowest, with a value of approximately 185 g, reflecting the strong competition from weeds for water and nutrients. In variant V2 (pre-emergence herbicide + one mechanical hoeing), the average weight increased significantly, reaching 243 g, which confirms the beneficial effect of partial weed suppression. The highest values were recorded in variant V3, where the combined application of two herbicides and two hoeings allowed for an average ear weight of 267 g, more than 40% higher than in the control.

This behavior highlights the sensitivity of the hybrid DKC 5092 to weed competition and the importance of applying integrated weed management technologies. While the minimal approach (V2) ensures a clear improvement, the intensive variant (V3) best capitalizes on the genetic potential of the hybrid, with direct implications both for final grain yield and for technological management decisions at the farm level.

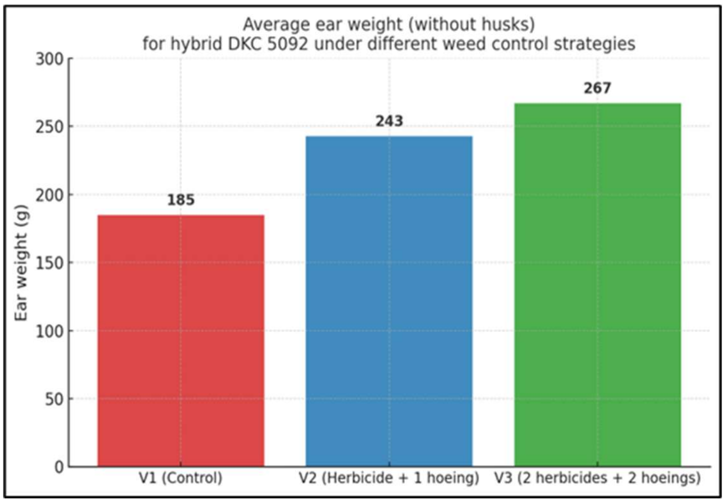

Figure 9. Average ear weight – without husks according to the technological variants

Figure 10 illustrates two of the most important indicators of grain productivity: the thousand-kernel weight (TKW) and the average grain weight per ear for the maize hybrid DKC 5092, under the three weed management technologies. In the untreated control (V1), both indices recorded the lowest values, with TKW averaging around 312 g and average grain weight per ear reaching only 198 g. These reduced values reflect the intense competition from weeds, which limited nutrient availability and grain filling. In V2 (pre-emergence herbicide + one hoeing), both parameters improved significantly, with TKW increasing to approximately 348 g and grain weight per ear to 227 g. The most intensive treatment, V3 (two herbicides + two hoeings), achieved the highest results, with a TKW of 364 g and an average grain weight per ear of 247 g, values that are more than 15–20% higher than in the control. These results emphasize the decisive role of integrated weed control in ensuring proper grain development. While partial suppression in V2 improved kernel filling, the intensive approach in V3 allowed the hybrid to approach its full productive potential. The data also confirms that weed competition not only reduces vegetative growth but also directly limits grain size and filling capacity, with implications for both yield quantity and quality. Furthermore, the progressive increase in TKW across treatments suggests that effective weed suppression enhanced assimilate translocation during the grain-filling period. Reduced competition for water and nutrients under integrated management likely prolonged photosynthetic activity, thereby supporting more efficient kernel development and improving overall grain quality parameters.

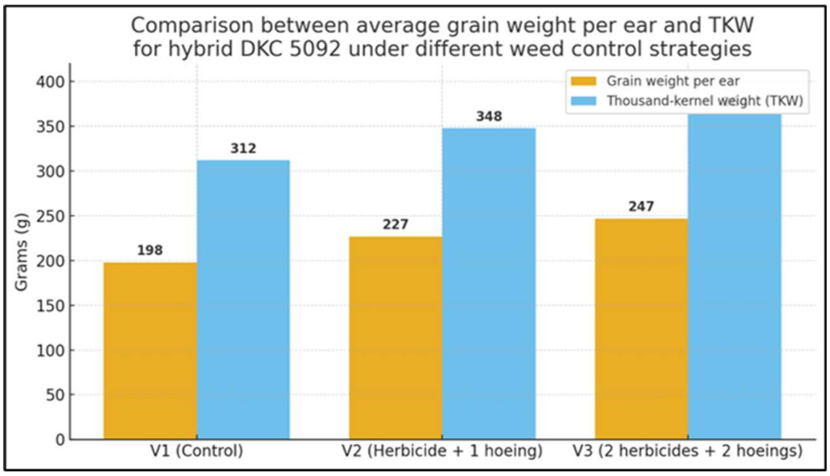

Figure 10. Comparison between average grain weight per ear and thousand-kernel weight

Figure 11 presents the comparative productivity, expressed in kg/ha, of the maize hybrid DKC 5092 under the three weed control strategies applied. Clear differences were observed between the technological variants, reflecting the strong influence of weed pressure on final yield. In the untreated control (V1), grain yield was the lowest, averaging 6,450 kg/ha, due to the intense competition with weeds throughout the growing season. In V2 (pre-emergence herbicide + one hoeing), productivity increased substantially to 8,720 kg/ha, highlighting the positive effect of partial weed suppression. The highest performance was recorded in V3 (two herbicides + two hoeings), where yield reached 9,630 kg/ha, representing an increase of nearly 50% compared with the control. This distribution underscores not only the importance of integrated weed management in ensuring stable maize yields, but also the hybrid's responsiveness to technological intensity. DKC 5092 proved highly capable of capitalizing on resources when weed competition was minimized, achieving productivity levels close to its potential under irrigated conditions. In contrast, the absence of weed control in V1 significantly limited the crop's ability to translate its genetic potential into yield.

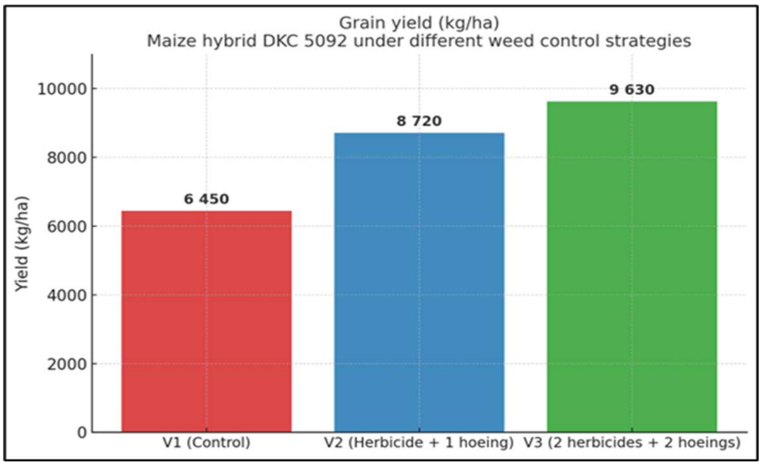

Figure 11. Grain yield (kg/ha) of maize hybrid DKC 5092 according to the technological variants

Taken together, these results emphasize that integrated weed management is not simply a supporting measure, but a determining factor in optimizing both vegetative and reproductive performance in high-yield maize systems.

Economic analysis of the three technological variants confirmed that the additional costs associated with herbicide applications and hoeings were more than compensated by the increase in grain yield. While the untreated control (V1) had no input costs, it generated the lowest income, averaging only ~1160 €/ha. In contrast, V2 (pre-emergence herbicide + one hoeing) required an estimated cost of ~75 €/ha but produced an additional ~430 €/ha in revenue compared with the control. The most intensive technology (V3), with an estimated cost of ~135 €/ha, achieved the highest profitability, yielding nearly 1600 €/ha, which is ~40% higher than in the untreated variant. These results demonstrate that integrated weed control not only improves maize growth and yield but also ensures superior economic efficiency, even when more intensive technologies are applied.

The findings of this study are in agreement with research conducted under similar semi-arid and Mediterranean conditions in Serbia (Simić et al., 2025), Greece, and southern Spain, where integrated chemical and mechanical weed control under irrigation resulted in comparable yield improvements. However, the present work provides novel, site-specific evidence from the Dobrogea region, where irrigation through the Danube–Black Sea Canal interacts with chernozem soils and high evapotranspiration rates. The quantified relationships between irrigation level, weed suppression efficiency, and maize yield contribute to a better understanding of how integrated weed management can mitigate the combined stress of drought and weed pressure. Compared to previous studies, the results emphasize that water availability amplifies the benefits of integrated control, as irrigated maize can more effectively outcompete weeds under timely and sustained management.

Several limitations must be acknowledged. The analysis was based on averaged plot data with a limited number of replications (n = 3), which may slightly overestimate correlation coefficients. Moreover, the study covered only one hybrid (DKC 5092) and a single irrigated site, so further research across multiple hybrids and non-irrigated systems would strengthen the generalizability of these findings. Despite these constraints, the trends observed here are consistent and physiologically well-grounded, underscoring the practical relevance of integrated weed management under climate variability in southeastern Europe.

Beyond the numerical differences, the economic analysis emphasizes the practical feasibility of adopting integrated weed control strategies under the specific pedoclimatic conditions of southeastern Romania. In irrigated maize systems of Dobrogea, where recurrent drought and high temperatures already increase production risks, the additional costs of herbicides and mechanical hoeings represent a relatively small fraction of total expenses compared to the potential yield losses caused by unchecked weed pressure. The results obtained suggest that even in seasons with suboptimal rainfall, technologies such as V2 and especially V3 provide a clear return on investment and secure yield stability. For farmers, this means that integrated weed control is not merely an agronomic recommendation, but a necessary condition for ensuring both productivity and profitability in high-risk environments.

5. Conclusions

The results obtained over the 2021–2024 experimental period in the Poarta Albă area provide clear evidence of the decisive role of weed control in maize production under irrigated conditions typical of southeastern Romania. The aggressiveness of dominant species such as *Sorghum halepense*, *Amaranthus retroflexus*, and *Setaria viridis* led to severe yield losses in the absence of interventions, confirming that unchecked weed pressure remains the primary limiting factor even when water is supplied through irrigation.

All key biometric parameters, including plant density, plant height, cob insertion height, ear formation, and individual biomass, were negatively and strongly correlated with weed density, with correlation coefficients exceeding –0.99. These near-perfect associations highlight the extent to which interspecific competition undermines crop performance and demonstrate that early and sustained suppression of weeds is essential for maintaining yield stability.

Importantly, the inclusion of an economic analysis strengthens the practical relevance of these findings. While integrated technologies (V2 and V3) incurred additional input costs, these were more than compensated for by yield increases, with the most intensive variant (V3) generating the highest net profit per hectare. This confirms that integrated weed management is not only an agronomic necessity but also an economically viable solution for maize producers in high-risk environments such as Dobrogea.

Taken together, the results emphasize that achieving high and stable maize yields in southeastern Romania requires more than hybrid selection and irrigation. The adoption of comprehensive weed management strategies, combining chemical and mechanical control in a timely and site-specific manner, is a fundamental prerequisite for both agronomic success and economic sustainability. Although the experimental design and results provide robust evidence for the benefits of integrated weed management, certain limitations should be noted. The study was based on three replications at a single irrigated site and included only one maize hybrid, which may restrict the extrapolation of results to broader agroecological conditions. Nonetheless, the consistency of the observed patterns across years supports the validity of the conclusions and underlines their practical relevance for southeastern Romania. Future studies should extend this analysis across additional hybrids and cropping systems to refine recommendations and further support the development of resilient and cost-effective maize production technologies under climate change conditions.

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