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EVALUATION OF NEW HERBICIDE MOLECULES, HERBICIDE MIXTURES, AND THEIR COMPATIBILITIES IN SORGHUM (SORGHUM BICOLOR L.) CULTIVATION UNDER THE PEDOCLIMATIC CONDITIONS OF THE AGRICULTURAL RESEARCH AND DEVELOPMENT STATION (ARDS) LIVADA

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ABSTRACT

This study was conducted at the Agricultural Research and Development Station (ARDS) Livada during the 2024–2025 growing season to systematically evaluate the selectivity and efficacy of novel herbicidal molecules and their combinations in grain sorghum (Sorghum bicolor L.) cultivation. The research focused on determining the tolerance of sorghum to the herbicides.Proman and Barracuda, establishing optimal application rates, and identifying the most effective timing for the control of both annual and perennial monocotyledonous and dicotyledonous weeds. The experiments were carried out under the pedoclimatic conditions characteristic of Livada, Satu Mare County, Romania, providing a robust assessment of the herbicides' agronomic performance, selectivity, and potential contribution to sustainable sorghum production systems.

INTRODUCTION

Currently, global agriculture faces challenges that differ from those of previous decades, including intensified climate change, soil degradation resulting from prolonged use of chemical fertilizers, environmental pollution, and increasing population pressure, which necessitates the production of food for a growing number of people(Alexandrescuet al., 2019).

Agricultural research can provide innovative solutions to address these challenges, especially in the context of rapidly advancing technologies (Shokirov et al., 2025). One approach involves the study and utilization of plant species to evaluate their behavior under specific conditions and the potential agronomic benefits they may offer (Csabai et al., 2019; Csabai et al., 2022; Csabai – Szabó, 2023; Kosztyuné et al., 2024).The species investigated in this study is sorghum (*Sorghum bicolor* L. Moench). Grain sorghum ranks fifth in terms of global cereal cultivation area. Between 2016 and 2021, it was cultivated on approximately 41.2 million hectares, with the main production areas located in several African countries (Mocanu, 2024: Boeriu et al., 1987).Compared to other crop species, sorghum is particularly notable for its superior adaptability to adverse conditions, including prolonged drought, high temperatures, and degraded or less fertile soils, earning it the nickname “the plant camel.” Its primary attribute is adaptability, which allows sorghum to be cultivated across a wide range of soil types, particularly in marginal soils where other crops often fail to produce satisfactory yields (Mocanu, 2024).

MATERIALS AND METHODS

The experiments were conducted at the Agricultural Research and Development Station (ARDS) Livada, which is located on an Albic Luvisol characterized by a pH of 5.1, 20.9 % clay content, and 1.8 % humus content.The experimental design followed a randomized complete block design (RCBD) with a plot size of 21 m², ten treatments, and three replications.To evaluate the effects of herbicides on sorghum plants, sowing was carried out on 12 May 2025 using the semi-early hybrid *ALIZE*, which exhibits excellent tolerance to lodging, drought, shattering, and *Fusarium* infection.Herbicide applications were performed using a PSGF 4.3 sprayer equipped with TeeJet nozzles (0.2 size), operating at a forward speed of 6 km/h. The spray volume was 500 L/ha, applied to all treatments at a uniform working pressure of 2 bar.

Table 1

Herbicides applied to sorghum crops 2025

No. Var	Herbicide	Dose (l, kg/ha)	Active ingredient
1	Untreated	-	-
2	Proman + Stomp Aqua	3+3	metobromuron 500g/l + 455g/l pendimetalin
3	Proman + Stomp Aqua	4+4	metobromuron 500g/l + 455g/l pendimetalin
4	Proman + Frontier Forte	3+1,3	metobromuron 500g/l + 720 g/l dimetenamid-p
5	Proman + Basagran	3+2	metobromuron 500g/l + **bentazonă480 g/l**
6	Proman + Dicopur Top	3+1	metobromuron 500g/l + 344 g/l acid 2,4 D din sare de dimetilamină şi 120 g/l dicamba
7	Stomp Aqua + Basagran	4 +2	455g/l pendimetalin + **bentazonă480 g/l**
8	Stomp Aqua + Dicopur Top	3 +1	455g/l pendimetalin + 344 g/l acid 2,4 D din sare de dimetilamină şi 120 g/l dicamba
9	Frontier Forte + Basagran	1,3 +2	720 g/l dimetenamid-p + **bentazonă480 g/l**
10	Stomp Aqua + Barracuda	4 +2	455g/l pendimetalin + mesotrione 100g/l

The herbicide application scheme is presented in Table 1.

AGROCLIMATIC RESOURCES AT ARDS LIVADA DURING THE 2024–2025 GROWING SEASON

The plain area of the ARDS Livada territory is located within the Northern Pannonian subprovince and is influenced by a temperate climate with a subatlantic nuance. According to Köppen’s classification, the climatic formula for the area is

Cfbx. For agroclimatic characterization, both thermal resources and the features and fluctuations of moisture availability are analyzed.

THERMAL RESOURCES

Based on a 63-year average, the annual mean temperature is 9.9 °C. During the study period (September 2024 – September 2025), the mean annual temperature was 11.27 °C.

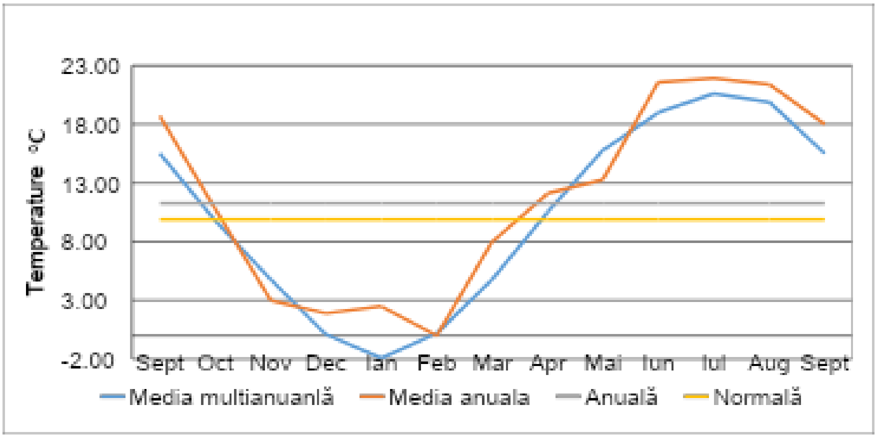

Figure 1. Annual and multi-year temperatures (°C) recorded at SCDA Livada

The mean annual temperature of 11.27 °C indicates a warming trend, with the air temperature increasing by 1.37 °C compared to the long-term average. The evolution of the multi-annual monthly mean temperatures and those of the study year are presented in Figure 1. The warmest month of the year is July, with a multi-annual mean of 20.6 °C, followed by August (19.9 °C) and June (19.0 °C). During the 2024–2025 growing season, monthly temperatures exceeded the multi-annual averages, except in November, February, and May, when they were lower by 1.0–2.5 °C.

COLD SEASON

The thermal characteristics of the cold season were analyzed through thermal limits, which reflect the severity of winter (chilling units and frost units). Chilling units, calculated as the sum of negative temperatures during December, January, and February, amounted to −25 °C in the study year. No frost units were recorded (defined as the conventional sum of temperatures below −15°C), indicating a mild winter. The most common values of chilling units are −100°C and −200°C.

TRANSITION PERIOD FROM WINTER TO SPRING

This period is characterized by the spring onset index, calculated as the sum of daily mean positive temperatures from 1 February to 10 April. In the study year, the index value was 334.6 °C, with historical extremes ranging from 162 °C in 1976 (late spring onset) to 419 °C in 1977 (early spring onset).

For a detailed analysis of the winter-to-spring transition, the dates when cumulative positive temperatures reached 100 °C, 250 °C, and 400 °C are presented. These milestones correspond to the onset of apricot vegetative growth, apricot flowering, and apple flowering, respectively. In the study year, these thresholds were reached on 13 March, 30 March, and 15 April.

ACTUAL GROWING SEASON

The thermal potential of the growing season is evaluated from two main perspectives:

- Global temperatures – the sum of temperatures above 0 °C during the period from 1 February to 30 November.
- Effective temperatures – the sum of biologically effective temperatures above 10 °C during the period from 10 April to 31 October.

The thermal potential of the study area, as indicated by global temperatures, was 3800 °C, with historical minimum and maximum values of 3250 °C (1978) and 3950 °C (1966), respectively.

The sum of biologically effective temperatures was 1558 °C, with a historical maximum of 1634 °C (1963) and a minimum of 918 °C (1980).

MOISTURE RESOURCES DURING THE PERIOD SEPTEMBER 2024 – AUGUST 2025

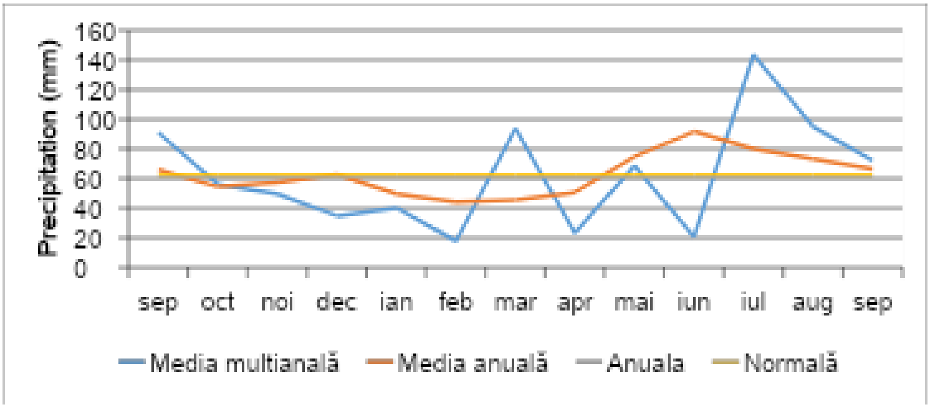

Figure 2. Annual and multi-annual precipitation (mm) recorded at ARDS Livada

Between September and October 2024, the autumn sowing period, 147.1 mm of precipitation were recorded, providing optimal conditions for seedbed preparation and autumn crop sowing.

During the cold winter period (November–March), 236 mm of precipitation accumulated, compared to the multi-annual average of 259 mm. Precipitation during the autumn–winter period generally defines the character of the agricultural year.

Accumulated precipitation of 280–340 mm is indicative of a wet year, whereas cumulative precipitation of 130–170 mm reflects a dry year.

For the active growing season of autumn crops (April–July), the average precipitation is 297 mm. In 2025, the precipitation during this period was 255.8 mm.

During the spring 2025 sowing period at Livada, 91.7 mm of rainfall was recorded, compared to the multi-annual average of 125.5 mm.

For the growing season of spring crops (April–October), the average cumulative precipitation is 490.9 mm. In 2025, precipitation during this period totaled 479.2 mm.

RESULTS AND DISCUSSION

During the growing season, observations were made to evaluate the selectivity and efficacy of the herbicide treatments on weeds in the grain sorghum crop.

Most of the herbicides applied in the experiment exhibited very good selectivity, with EWRS scores of 1 (where 1 = no phytotoxic symptoms and 9 = 90–100 % of plants destroyed). The post-emergence application of *Barracuda* at 1 L/ha (active ingredient – mesotrione 100 g/L) caused slight phytotoxicity immediately after application, manifested as whitening of the basal leaves; these symptoms were reversible 21 days after herbicide application.

The highest efficacy was observed in treatments 3 and 4, with weed control levels of 91 % and 94 %, respectively (Table 2). Treatments 2, 5, and 9 showed lower efficacy, ranging between 76 % and 88 %. Treatments 6, 7, 8, and 10 exhibited less satisfactory efficacy, ranging from 45 % to 65% (Table 2), which can be attributed to high weed pressure from *Ambrosia artemisiifolia* and *Setaria viridis*.

Table 2

Selectivity and efficacy of herbicide treatments in grain sorghum – 2025

No. Var.	Herbicide	Dose (l, kg/ha)	Application timing	Selectivity EWRS Notes		Eficacy %
				3 days	21 days	
1	Untreated	-	-	-	-	-
2	Proman + Stomp Aqua	3+3	preem	1	1	88
3	Proman + Stomp Aqua	4+4	preem	1	1	91
4	Proman + Frontier Forte	3+1,3	preem	1	1	94
5	Proman + Basagran	3+2	preem + post	1	1	76
6	Proman + Dicopur Top	3+1	preem + post	1	1	61
7	Stomp Aqua + Basagran	4 +2	preem + post	1	1	45
8	Stomp Aqua + Dicopur Top	3 +1	preem + post	1	1	61
9	Frontier Forte + Basagran	1,3 +2	preem + post	1	1	80
10	Stomp Aqua + Barracuda	4 +2	preem + post	3	1	65

The effect of herbicides on sorghum phenology is presented in Tables 4 and 5, showing plant height and the number of tillers per plant, respectively.

Analysis of the variability in plant height, based on the least significant difference, revealed highly significant positive differences in all treatments containing the herbicide *Proman*, regardless of the associated herbicide (Treatments 2–6). Highly significant positive differences were also observed in Treatment 9, where *Frontier Forte* (1.3 L/ha, pre-emergence) was combined with *Basagran* (2 L/ha, post-emergence) (Table 4). A distinctly significant difference was observed only in Treatment 8 (*Stomp Aqua* 3 L/ha + *Dicopur Top* 1 L/ha). Treatments with *Stomp Aqua* 4 L/ha + *Basagran* 2 L/ha and *Stomp Aqua* 4 L/ha + *Barracuda* 2 L/ha also showed significant increases in plant height compared to the untreated control (Table 3).

The regression of plant height on herbicide efficacy was positive, with a correlation coefficient of 0.912, indicating a very significant relationship between the two variables. The regression coefficient of 0.303 shows that for each unit increase in herbicide efficacy, plant height increased by 0.3 cm (Figure 3).

Table 3

Effect of herbicides on sorghum plant height

No. Var	Herbicide	Dose (l, kg/ha)	Application timing	Plant height (cm)	Differences	Significance
1	Untreated	-	-	79,92	0,00	Ct.
2	Proman + Stomp Aqua	3+3	preem	104,55	24,63	***
3	Proman + Stomp Aqua	4+4	preem	106,87	26,95	***
4	Proman + Frontier Forte	3+1,3	preem	107,85	27,93	***
5	Proman + Basagran	3+2	preem + post	103,07	23,15	***
6	Proman + Dicopur Top	3+1	preem + post	106,80	26,88	***
7	Stomp Aqua + Basagran	4 +2	preem + post	96,70	16,78	*
8	Stomp Aqua + Dicopur Top	3 +1	preem + post	97,15	17,23	**
9	Frontier Forte + Basagran	1,3 +2	preem + post	104,67	24,75	***
10	Stomp Aqua + Barracuda	4 +2	preem + post	96,07	16,15	*

LSD (p 5%) 12,34 cm
LSD (p 1%) 16,92cm
LSD (p 0.1%) 23,03 cm

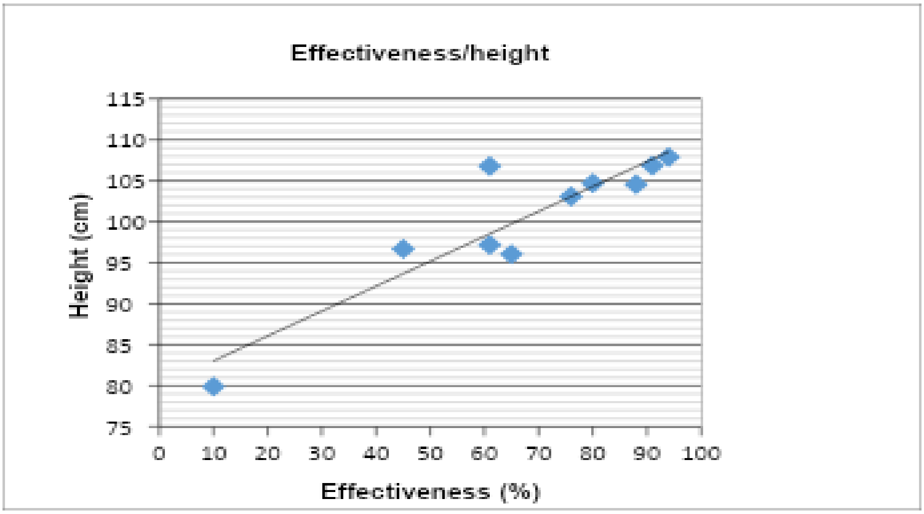

Figure 3. Relationship between herbicide efficacy and plant height

The influence of herbicides on plant tillering showed that only the combination of *Proman* 3 L/ha + *Frontier Forte* 1.3 L/ha applied pre-emergence resulted in highly significant tillering. Distinctly significant tillering was observed in treatments where *Proman* was combined with *Stomp Aqua* or *Basagran*, and significant tillering occurred with *Proman* + *Dicopur Top* (Treatment 6). In treatments without *Proman*, sorghum plants did not exhibit significant tillering (Table 4).

Table 4

Influence of herbicides on sorghum plant tillering

No.	Herbicide	Dose l,kg/ha	Application timing	No.of tillers/plant	Differences	Significance
1	Untreated	-	-	0,27	0,00	Mt.
2	Proman + Stomp Aqua	3+3	preem	0,87	0,60	**
3	Proman + Stomp Aqua	4+4	preem	0,87	0,60	**
4	Proman + Frontier Forte	3+1,3	preem	1,13	0,87	***
5	Proman + Basagran	3+2	preem + post	0,90	0,63	**
6	Proman + Dicopur Top	3+1	preem + post	0,70	0,43	*
7	Stomp Aqua + Basagran	4 +2	preem + post	0,10	-0,17	-
8	Stomp Aqua + Dicopur Top	3 +1	preem + post	0,47	0,20	-
9	Frontier Forte + Basagran	1,3 +2	preem + post	0,57	0,30	-
10	Stomp Aqua + Barracuda	4 +2	preem + post	0,23	-0,03	-

LSD (p 5%): 0.42 tillers
LSD (p 1%): 0.57 tillers
LSD (p 0.1%): 0.78 tillers

Analysis of the significance of yield differences according to the tested herbicides indicated that herbicide treatments ensured highly significant differences in grain sorghum yield, ranging from 1894 kg/ha (*Stomp Aqua* 4 L/ha + *Barracuda* 2 L/ha) to 6350 kg/ha (*Proman* 3 L/ha + *Frontier Forte* 1.3 L/ha). It is also noteworthy that the untreated control produced a low yield of only 1523 kg/ha due to heavy weed infestation (Table 5).

The regression of yield on herbicide efficacy is described by an increasing linear function. The regression coefficient of 66.81 indicates that for each unit increase in herbicide efficacy, yield increases by 66.81 kg/ha. The relationship between efficacy and yield is highly significant, with a correlation coefficient of 0.822 (Figure 4).

Table 5

Influence of herbicides on grain yield in sorghum

No. Var	Herbicide	Dose l,kg/ha	Application timing	Yeld (kg/ha)	Differences	Significance
1	Untreated	-	-	1523	0	Ct.
2	Proman + Stomp Aqua	3+3	preem	6615	5091	***
3	Proman + Stomp Aqua	4+4	preem	7431	5908	***
4	Proman + Frontier Forte	3+1,3	preem	7873	6350	***
5	Proman + Basagran	3+2	preem + post	7176	5653	***
6	Proman + Dicopur Top	3+1	preem + post	7363	5840	***
7	Stomp Aqua + Basagran	4 +2	preem + post	4370	2847	***
8	Stomp Aqua + Dicopur Top	3 +1	preem + post	5543	4020	***
9	Frontier Forte + Basagran	1,3 +2	preem + post	5101	3578	***
10	Stomp Aqua + Barracuda	4 +2	preem + post	3418	1894	***

LSD (5%): 622.22 kg
LSD (1%): 853.33 kg
LSD (0.1 %): 1161.48 kg

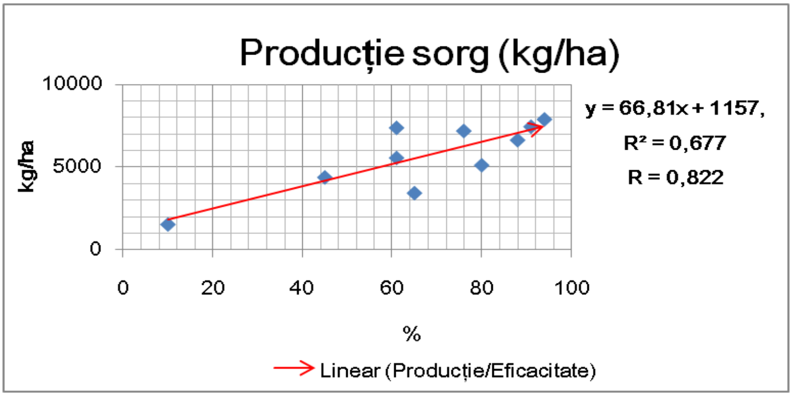

Figure 4. Relationship between herbicide efficacy and grain yield

To determine the profit or loss resulting from the different herbicide treatment schemes tested, the revenue in RON for the year 2025 was calculated based on the yield per treatment, from which the additional expenses associated with herbicide treatments were subtracted.

Table 6 shows that herbicide application ensured profit in all treatments, with values ranging from 2,121 RON/ha (Variant 10 – Stomp Aqua 4 L/ha + Barracuda 2 L/ha) to 8,189 RON/ha (Variant 4 – Proman 3 L/ha + Frontier Forte 1.3 L/ha). The most effective and profitable treatments were Variants 3, 4, 5, and 6, which included the pre-emergent herbicide Proman at doses of 3 and 4 L/ha, combined with the pre-emergent herbicides Stomp Aqua or Frontier Forte, as well as the post-emergent herbicides Basagran or Dicopur Top.

The costs for growing sorghum in 2025 were 1,837 RON/ha, an amount covered by the 2025 price of 1.4 RON/kg for a yield of 1,312 kg/ha. Therefore, the control yield of 1,523 kg/ha generated a profit of 295 RON/ha.

Table 6.
Additional yield value and herbicide costs compared to the control in grain sorghum – 2025

No. Var	Herbicide	Dose l,kg/ha	Costs of applied technology Ron/ha	D.C.Herbicide costs Ron/ha	Value of increase Ron/ha	Profit Ron/ha
1	Untreated	-	1837	0	2132	295
2	Proman + Stomp Aqua	3+3	2549	701	7127	6426
3	Proman + Stomp Aqua	4+4	2783	935	8271	7336
4	Proman + Frontier Forte	3+1,3	2549	701	8890	8189
5	Proman + Basagran	3+2	2671	812	7914	7102
6	Proman + Dicopur Top	3+1	2376	517	8176	7659
7	Stomp Aqua + Basagran	4 +2	2485	627	3986	3359
8	Stomp Aqua + Dicopur Top	3 +1	2117	258	5628	5370
9	Frontier Forte + Basagran	1,3 +2	2412	553	5009	4456
10	Stomp Aqua + Barracuda	4 +2	2389	531	2652	2121

The additional yield was calculated at a price of 1.4 RON/kg.

CONCLUSIONS

The main characteristic of sorghum is its adaptability, a trait that makes it suitable for cultivation on all soil types, particularly poor soils.

Compared to other crops, sorghum is better able to adapt to changing climatic conditions, especially prolonged drought and heat stress.

Most of the herbicides applied in the experiment exhibited very good selectivity, except for *Barracuda* applied post-emergence, which caused slight, reversible phytotoxicity immediately after application..

Proman applied pre-emergence stands out in terms of both yield and profit, due to its high efficacy against *Ambrosia artemisiifolia*.

An important conclusion is that to obtain a clean sorghum crop and increase production, herbicide application is an important link, without which the other technological links cannot be exploited.

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