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**Address of Editorial office**:
Agricultural Science and Technology
Faculty of Agriculture, Trakia University
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Bulgaria
Telephone.: +359 42 699330
+359 42 699446
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**Technical Assistance:**
Nely Tsvetanova
Telephone.: +359 42 699446
E-mail: editoffice@agriscitech.eu

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# Selectivity and stability of herbicides and herbicide combinations for the grain yield of maize (*Zea Mays* L.)

G. Delchev[1]*, T. Barakova[2]

[1]Department of Plant Production, Faculty of Agriculture, Trakia University, 6000 Stara Zagora, Bulgaria
[2]Field Crops Institute, 6200 Chirpan, Bulgaria

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***Abstract.*** *The research was conducted during 2012 - 2014 on pellic vertisol soil type. Under investigation was cycloxydim tolerant maize hybrid Ultrafox duo (Zea mays L.). Factor A included the years of investigation. Factor B included no treated check and 3 soil-applied herbicides – Adengo 465 SC (isoxaflutol + tiencarbazon) – 440 ml/ha, Wing P (pendimethalin + dimethenamid) – 4 l/ha and Lumax 538 SC (S-metolachlor + terbuthylazine + mesotrione) – 4 l/ha. Factor C included no treated check and 5 foliar-applied herbicides – Stellar 210 SL (topramezon + dicamba) – 1 l/ha, Principal plus (nicosulfuron + rimsulfuron + dicamba) – 380 g/ha, Ventum WG (foramsulfuron + iodosulfuron) – 150 g/ha, Monsun active OD (foramsulfuron + tiencarbazon) – 1.5 l/ha and Laudis OD (tembotrione) – 2 l/ha. In addition to these variants by conventional technology for maize growing one variant by Duo system technology is also included in the experiment. It includes soil-applied herbicide Merlin flex 480 SC (isoxaflutole) – 420 g/ha and tank mixture of antigraminaceous herbicide Focus ultra (cycloxydim) - 2 l/ha + antibroadleaved herbicide Kalam (tritosulfuron + dicamba) – 300 g/ha. It is found that herbicide combination of soil-applied herbicide Merlin flex with tank mixture Focus ultra + Kalam by Duo system technology leads to obtaining high grain yield. High yields of maize grain are also obtained by herbicide combinations Lumax + Principal plus, Lumax + Laudis and Wing + Principal plus. The most unstable are the non-treated check and single use of soil-applied herbicides Adengo, Wing and Lumax. Technologically the most valuable are herbicide combination Merlin flex + Focus ultra + Kalam by Duo system technology, followed by combinations of foliar-applied herbicides Principal plus and Laudis with soil-applied herbicides Adengo, Wing and Lumax by conventional technology. Single use of herbicides has low estimate due to must to combine soil-applied with foliar-applied herbicides for full control of weeds in maize crops*

**Keywords:** grain maize, herbicides, herbicide combinations, grain yield, selectivity, stability

## Introduction

In recent years, with the creation of cool-resisting maize hybrids for cultivation in early sowing in rainfed conditions, maize starts to recover in southern Bulgaria. Weeds are one of the main limiting factors for maize production (Vancetovic et al., 2010; Dragičević et al., 2012). The main species weeding maize crops are the group of late spring weeds. When growing cool-resisting maize hybrids weed composition is altered and serious competitors and also early spring weeds that are characteristic of the sunflower (Sinzar et al., 1998; Michel, 2001). From an economic and ecological view point, the combination of chemical and mechanical weed control is very positive. Limiting soil tillage on mechanical weed control reduces the risk of soil erosion, especially in hilly areas and decreasing herbicide treatments reduces the risk of contamination of soil and water (Dawoud et al., 2006; Pajić et al., 2009; Korpanovet et al., 2010). In conventional technology for grain maize growing there are unsolved problems of control of some perennial grassy weeds such as *Cynodon dactylon* and *Agropyron repens*, which necessitated the introduction of the new Duo system technology for maize growing (Jovovic et al., 1999; Asadi et al., 2009).

The purpose of this investigation was to establish the selectivity and stability of some herbicides and herbicide combinations on grain maize by influence of different meteorological conditions.

* e-mail: delchevgd@dir.bg

## Materials and methods

The research was conducted during 2012 – 2014 on pellic vertisol soil type. Under investigation was cycloxydim tolerant maize hybrid Ultrafox duo (*Zea mays* L.). Three factors' experiment was conducted under the block method, in 4 repetitions; the size of the crop plot was 15 $m^2$. Factor A included the years of investigation. Factor B included no treated check and 3 soil-applied herbicides – Adengo 465 SC, Wing P and Lumax 538 SC. Factor C included no treated check and 5 foliar-applied herbicides – Stellar 210 SL, Principal plus, Ventum WG, Monsun active OD and Laudis OD. In addition to these variants by conventional technology for maize growing one variant by Duo system technology is also included in the experiment. It includes soil-applied herbicide Merlin flex 480 SC and tank mixture of antigraminaceous herbicide Focus ultra + antibroadleaved herbicide Kalam. Active substances of herbicides and their doses are shown in Table 1.

Soil-applied herbicides were treated during the period after sowing before emergence. Foliar-applied herbicides were treated during 5 – 7 leaf stage of the maize. All herbicides and herbicide combinations were applied in a working solution of 200 l/ha. Due to low adhesion of the herbicides Stellar 210 SL and Kalam they were used in addition with adjuvant Dash HC – 1 l/ha, herbicide Principal plus – with adjuvant Trend – 0.2% and herbicide Ventum WG with

**Table 1.** Investigated variants

| № | Variants | Active substance | Doses |
|---|---|---|---|
| | | Conventional technology | |
| After sowing, before emergence | | | |
| 1 | Check | - | - |
| 2 | Adengo 465 SC | isoxaflutol + tiencarbazon | 440 ml/ha |
| 3 | Wing P | pendimethalin + dimethenamid | 4 l/ha |
| 4 | Lumax 538 SC | S-metolachlor + terbuthylazine + mesotrione | 4 l/ha |
| 5 - 7 leaf stage | | | |
| 1 | Check | - | - |
| 2 | Stellar 210 SL | topramezon + dicamba | 1 l/ha |
| 3 | Principal plus | nicosulfuron + rimsulfuron + dicamba | 380 g/ha |
| 4 | Ventum WG | foramsulfuron + iodosulfuron | 150 g/ha |
| 5 | Monsun active OD | foramsulfuron + tiencarbazon | 1.5 l/ha |
| 6 | Laudis OD | tembotrione | 2 l/ha |
| | | Duo system technology | |
| After sowing, before emergence | | | |
| 1 | Merlin flex 480 SC | isoxaflutole | 420 g/ha |
| 5 - 7 leaf stage | | | |
| 2 | Focus ultra + | cycloxydim | 2 l/ha |
| | Kalam | tritosulfuron + dicamba | 300 g/ha |

Herbicides Stellar 210 SL and Kalam were used in addition with adjuvant Dash HC - 1 l/ha, herbicide Principal plus - with adjuvant Trend - 0.2 % and herbicide Ventum WG - with adjuvant Mero 80 EC - 2 l/ha.

adjuvant Mero 80 EC – 2 l/ha.

The selectivity of herbicides has been established through their influence on grain yield. The math processing of the data was done according to the method of analyses of variance (Shanin 1977; Barov, 1982; Lidanski 1988). The stability of herbicides and herbicide combinations for seed yield with relation to years was estimated using the stability variances $\sigma_i^2$ and $S_i^2$ of Shukla (1972), the ecovalence $W_i$ of Wricke (1962) and the stability criterion $YS_i$ of Kang (1993).

## Results and discussion

Data about the influence of the investigated herbicides and herbicide combinations on maize grain yields (Table 2) show that the lowest yield was obtained from the untreated check. The single use of soil-applied herbicides Adengo, Wing and Lumax increases grain yield average for the period from 114.5% to 116.2%. These herbicides cannot control perennial broadleaved weeds *Cirsium arvense* Scop. and *Convolvulus arvensis* L. and perennial graminaceous weeds *Cynodon dactylon* Pers., *Agropyron repens* L. and *Sorghum helepense* Pers. from rhizomes. Adengo destroys *Sorghum helepense* Pers. from seeds at 100%, Wing – at 96%, and Lumax – at 80%. These three soil-applied herbicides have also low efficacy against some annual broadleaved weeds. Herbicide Lumax has low efficacy against *Xanthium strumarium* L. and herbicides Adengo and Wing are completely ineffective against this weed. Herbicide Wing has fewer efficacies against *Sinapis arvensis* L. and *Chenopodium album* L.

Single use of vegetation-applied herbicides Stellar, Principal plus, Ventum, Monsun active and Laudis increased grain yield from 116.1% to 118.2%. Stellar has fewer efficacies against *Cirsium arvense* Scop. and *Convolvulus arvensis* L. and is ineffective against *Cynodon dactylon* Pers., *Agropyron repens* L. and *Sorghum helepense* Pers. from rhizomes. Ventum and Monsun are less effective against *Convolvulus arvensis* L. and *Agropyron repens* L. and ineffective against *Cynodon dactylon* Pers. These two herbicides are less effective also against some annual weeds such as *Echinochloa crus-galli* L. and *Panicum sanguinale* L. Laudis is less effective against *Sorghum helepense* Pers. and *Agropyron repens* L. and is not effective against *Cynodon dactylon* Pers.

The herbicide combinations of the soil-applied herbicides Adengo, Wing and Lumax on the one hand and vegetation-applied herbicides Stellar, Principal plus, Ventum, Monsun active and Laudis on the other hand, lead to a bigger increase in yield compared with single use of these herbicides during the three years of investigation. Herbicide combinations provide full control of all annual and perennial weeds in maize crops except *Cynodon dactylon* Pers. and *Agropyron repens* L. The highest grain yield by conventional technology is obtained by the herbicide combination Lumax + Principal plus – 125.7% over the no treated check, followed by Lumax + Laudis – 124.9% and Wing + Principal plus – 1246 %.

Combination of soil-applied herbicide Merlin flex with tank herbicide mixture Focus ultra + Kalam by Duo system technology increases the grain yield most – 127.0% compared no treated check. This is due to the complete control of all broadleaved and graminaceous weeds, including *Cynodon dactylon* Pers. and *Agropyron repens* L.

Analysis of variance for grain yield (Table 3) shows that the years have the biggest influence on grain yield – 61.2% on the

**Table 2.** Influence of some herbicide combinations on maize grain yield (2012 – 2014)

| Herbicides | | 2012 | | 2013 | | 2014 | |
|---|---|---|---|---|---|---|---|
| Soil-applied | Vegetation-applied | kg/ha | % | kg/ha | % | kg/ha | % |
| Conventional technology | | | | | | | |
| - | - | 3510 | 100 | 4688 | 100 | 5555 | 100 |
| | Stellar – 1 l/ha | 4037 | 115.0 | 5429 | 115.8 | 6499 | 117.0 |
| | Principal plus 380 – g/ha | 4114 | 117.2 | 5532 | 118.0 | 6605 | 118.9 |
| | Ventum – 150 g/ha | 4103 | 116.9 | 5485 | 117.0 | 6583 | 118.5 |
| | Monsun active – 1.5 l/ha | 4082 | 116.3 | 5466 | 116.6 | 6555 | 118.0 |
| | Laudis – 2 l/ha | 4068 | 115.9 | 5466 | 116.6 | 6583 | 118.5 |
| Adengo – 440 ml/ha | - | 4012 | 114.3 | 5335 | 113.8 | 6499 | 117.0 |
| | Stellar – 1 l/ha | 4233 | 120.6 | 5626 | 120.0 | 6788 | 122.2 |
| | Principal plus 380 – g/ha | 4342 | 123.7 | 5757 | 122.8 | 6960 | 125.3 |
| | Ventum – 150 g/ha | 4258 | 121.3 | 5644 | 120.4 | 6855 | 123.4 |
| | Monsun active – 1.5 l/ha | 4282 | 122.0 | 5682 | 121.2 | 6888 | 124.0 |
| | Laudis – 2 l/ha | 4310 | 122.8 | 5719 | 122.0 | 6927 | 124.7 |
| Wing – 4 l/ha | - | 3994 | 113.8 | 5307 | 113.2 | 6444 | 116.0 |
| | Stellar – 1 l/ha | 4247 | 121.0 | 5644 | 120.4 | 6760 | 121.7 |
| | Principal plus 380 – g/ha | 4370 | 124.5 | 5785 | 123.4 | 6977 | 125.6 |
| | Ventum – 150 g/ha | 4324 | 123.2 | 5766 | 123.0 | 6888 | 124.0 |
| | Monsun active – 1.5 l/ha | 4293 | 122.3 | 5696 | 121.5 | 6833 | 123.0 |
| | Laudis – 2 l/ha | 4352 | 124.0 | 5719 | 122.0 | 6922 | 124.6 |
| Lumax – 4 l/ha | - | 4037 | 115.0 | 5419 | 115.6 | 6527 | 117.5 |
| | Stellar – 1 l/ha | 4324 | 123.2 | 5715 | 121.9 | 6855 | 123.4 |
| | Principal plus 380 – g/ha | 4419 | 125.9 | 5827 | 124.3 | 7038 | 126.7 |
| | Ventum – 150 g/ha | 4370 | 124.5 | 5766 | 123.0 | 6949 | 125.1 |
| | Monsun active – 1.5 l/ha | 4352 | 124.0 | 5752 | 122.7 | 6899 | 124.2 |
| | Laudis – 2 l/ha | 4388 | 125.0 | 5785 | 123.4 | 7000 | 126.0 |
| Duo system technology | | | | | | | |
| Merlin flex – 420 g/ha | Focus ultra – 2 l/ha + Kalam – 300 g/ha | 4461 | 127.1 | 5893 | 125.7 | 7111 | 128.0 |

LSD, kg/ha:

| | | | |
|---|---|---|---|
| F.A | p≤5%=126 | p≤1%=138 | p≤0.1%=165 |
| F.B | p≤5%=120 | p≤1%=159 | p≤0.1%=185 |
| F.C | p≤5%=125 | p≤1%=150 | p≤0.1%=180 |
| AxB | p≤5%=180 | p≤1%=199 | p≤0.1%=218 |
| AxC | p≤5%=219 | p≤1%=250 | p≤0.1%=287 |
| BxC | p≤5%=314 | p≤1%=362 | p≤0.1%=432 |
| AxBxC | p≤5%=395 | p≤1%=488 | p≤0.1%=599 |

variants. The reason is the large differences in the meteorological conditions during the three years of investigation. The strength of influence of soil-applied herbicides is 10.4 % and the strength of influence of vegetation-applied herbicides is 10.8%. The influence of years, soil-applied herbicides and vegetation-applied herbicides is very well proven at $p \leq 0.01$. There is a proven interaction between soil-applied herbicides and meteorological conditions of years (AxB) – 5.5% and between vegetation-applied herbicides and meteorological conditions of years (AxC) – 5.3%. They are well proven at $p \leq 0.5$. Interaction between soil-applied herbicides and vegetation-applied herbicides (BxC) – 1.2% is not proven. The interaction between the three experiment factors (AxBxC) is 2.4% and it is proven at $p \leq 0.5$.

Based on proven soil-applied herbicide x year interaction and vegetation-applied herbicide x year interaction, it was evaluated stability parameters for each variant for maize grain yield with relation to years (Table 4). The stability variances $\sigma_i^2$ and $S_i^2$ of Shukla, the ecovalence $W_i$ of Wricke and the stability criterion $YS_i$ of Kang were calculated.

Stability variances ($\sigma_i^2$ и $S_i^2$) of Shukla, which recorded respectively linear and nonlinear interactions, unidirectionally evaluate the stability of the variants. These variants which showed lower values are considered to be more stable because they interact less with the environmental conditions. Negative values of the

**Table 3.** Analysis of variance for grain yield

| Source of variation | Degrees of freedom | Sum of squares | Influence of factor, % | Mean squares |
|---|---|---|---|---|
| Total | 215 | 2170288 | 100 | - |
| Tract of land | 2 | 30313 | 1.8 | 16962.8** |
| Variants | 71 | 2038877 | 96.2 | 30563.1*** |
| Factor A – Years | 2 | 986889 | 61.2 | 173354.6*** |
| Factor B – Soil-applied herbicides | 3 | 583224 | 10.4 | 8743.9*** |
| Factor C – Vegetation-applied herbicides | 5 | 646820 | 10.8 | 9367.2*** |
| AxB | 6 | 17246 | 5.5 | 2713.0* |
| AxC | 10 | 14758 | 5.3 | 1920.3* |
| BxC | 15 | 13203 | 1.2 | 1705.4 |
| AxBxC | 30 | 18012 | 2.4 | 1571.5* |
| Pooled error | 142 | 40457 | 2.0 | 311.2 |

*p≤5%     **p≤1%     ***p≤0.1%

**Table 4.** Stability parameters of herbicides for grain yield with relation to years

| Herbicides: Soil-applied | Herbicides: Vegetation-applied | $\overline{X}$ | $\sigma_i^2$ | $S_i^2$ | $W_i$ | $YS_i$ |
|---|---|---|---|---|---|---|
| Conventional technology | | | | | | |
| - | - | 4584 | 525.8** | 333.3 | 948.9 | -8 |
| | Stellar – 1 l/ha | 5322 | 327.5 | 19.7 | 544.5 | 8 |
| | Principal plus 380 – g/ha | 5417 | 246.8 | 21.7 | 456.7 | 11 |
| | Ventum – 150 g/ha | 5390 | 293.9 | 30.0 | 464.2 | 10 |
| | Monsun active – 1.5 l/ha | 5368 | 363.4 | 24.7 | 543.1 | 9 |
| | Laudis – 2 l/ha | 5372 | 300.3 | 21.2 | 476.5 | 10 |
| Adengo – 440 ml/ha | - | 5282 | 425.0* | 10.8 | 898.0 | 7 |
| | Stellar – 1 l/ha | 5549 | 146.8 | -9.7 | 156.7 | 13+ |
| | Principal plus 380 – g/ha | 5686 | 100.4 | -1.8 | 65.4 | 19+ |
| | Ventum – 150 g/ha | 5586 | 108.8 | -5.6 | 88.0 | 14+ |
| | Monsun active – 1.5 l/ha | 5617 | 134.5 | -6.7 | 87.2 | 15+ |
| | Laudis – 2 l/ha | 5652 | 103.1 | -2.0 | 60.6 | 18+ |
| Wing – 4 l/ha | - | 5248 | 511.3* | 8.3 | 936.3 | 6 |
| | Stellar – 1 l/ha | 5550 | 66.6 | 15.0 | 134.5 | 12+ |
| | Principal plus 380 – g/ha | 5711 | 45.6 | 10.0 | 78.9 | 19+ |
| | Ventum – 150 g/ha | 5659 | 47.8 | 11.3 | 70.9 | 17+ |
| | Monsun active – 1.5 l/ha | 5607 | 81.0 | 22.4 | 104.7 | 14+ |
| | Laudis – 2 l/ha | 5664 | 77.7 | 21.8 | 103.2 | 18+ |
| Lumax – 4 l/ha | - | 5328 | 404.0* | 15.1 | 842.7 | 8 |
| | Stellar – 1 l/ha | 5631 | 13.3 | -0.8 | 44.4 | 16+ |
| | Principal plus 380 – g/ha | 5761 | 20.2 | -5.6 | 60.6 | 20+ |
| | Ventum – 150 g/ha | 5695 | 12.2 | -3.5 | 41.4 | 17+ |
| | Monsun active – 1.5 l/ha | 5668 | 13.7 | -4.8 | 48.0 | 16+ |
| | Laudis – 2 l/ha | 5724 | 33.3 | -1.4 | 55.5 | 19+ |
| Duo system technology | | | | | | |
| Merlin flex – 420 g/ha | Focus ultra – 2 l/ha + Kalam – 300 g/ha | 6822 | 60.1 | 12.3 | 123.4 | 21+ |

indicators $\sigma_i^2$ and $S_i^2$ are considered 0. At high values of either of the two parameters - $\sigma_i^2$ and $S_i^2$, the variant is regarded as unstable. At the ecovalence $W_i$ of Wricke, the higher the values of the index, the more unstable the variant.

On this basis, using the first three parameters of stability, it is found that the most unstable are the untreated check and the single use of soil-applied herbicides Adengo, Wing and Lumax. In these variants values of stability variance $\sigma_i^2$ and $S_i^2$ of Shukla and ecovalence $W_i$ of Wricke are the highest and mathematically proven. The reason for this high instability is greater variation in grain yields during years of experience as weather conditions affect those most. The efficacy of soil-applied herbicides is heavily dependent on soil moisture and soil tillage. At these variants instability is linear type-proven values of $\sigma_i^2$. The values of $S_i^2$ are not proven. Vegetation-applied herbicides and herbicide combinations have high stability because they interact poorly with the conditions of years.

To evaluate the complete efficacy of each combination between soil-applied herbicide and vegetation-applied herbicide, its effect on maize grain yield and its stability - the reaction of maize during the years – should be considered. Valuable information about the value of technologic value of the variant gives the stability criterion $YS_i$ of Kang for simultaneous assessment of yield and stability based on the reliability of differences in yield and variance of interaction with the environment. The value of this criterion has shown that using non-parametric methods and warranted statistical differences we get a summary assessment aligning variants in descending order according to their economic value.

Generalized stability criterion $YS_i$ of Kang, considering both the stability and value of yields gives negative assessments of untreated check, characterizing it as the most unstable or as the lowest yield. According to this criterion, the most valuable technology appears herbicide combination Merlin flex + Fucus ultra + Kalam by Duo system technology and combinations of vegetation-applied herbicides Principal plus and Laudis with soil-applied herbicides Adengo, Wing and Lumax. These variants combine high levels of grain yield and high stability of this index during the years. From the viewpoint of technology for maize growing, high rating also have combinations of vegetation-applied herbicides Ventum, Monsun active and Stellar with soil-applied herbicides Adengo, Wing and Lumax. They combine relatively good grain yields with high stability during the years of the investigation. Variants with single use of soil-applied or foliar-applied herbicides get low ratings and they are to be avoided. This is due to insufficient control of some existing weeds.

## Conclusion

It is found that herbicide combination of soil-applied herbicide Merlin flex with tank mixture Focus ultra + Kalam by Duo system technology lead to obtaining high grain yield. High yields of maize grain are also obtained by herbicide combinations Lumax + Principal plus, Lumax + Laudis and Wing + Principal plus. The most unstable are the non-treated check and the single use of soil-applied herbicides Adengo, Wing and Lumax. Technologically the most valuable are herbicide combination Merlin flex + Focus ultra + Kalam by Duo system technology, followed by combinations of foliar-applied herbicides Principal plus and Laudis with soil-applied herbicides Adengo, Wing and Lumax by conventional technology. The single use of herbicides has low estimate due to must to combine soil-applied with foliar-applied herbicides for full control of weeds in maize crops.

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**Thesis:**

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