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Optimal time of plant growth regulator application to Sorghum canopy according to BBCH and Kuperman crop growth scales

Abstract. The relevance of the study is determined by the problem of choosing the optimal scale for identifying plant growth phases to determine the best terms for conducting agrotechnical operations for the care of sorghum plants. The purpose of the experiment was to apply a plant growth regulator with higher efficiency during crop growth stages 21, 31, 37 (BBCH) and III, IV, VI-VII on the Kuperman scale. Field and laboratory research methods were used in the study. The experiment was conducted in the Forest-Steppe zone of Ukraine, two sorghum varieties of *Sorghum bicolor* and *Sorghum saccharatum* were treated with PGR. Foliar application of PGR (0.5 L/ha) in the BBCH stages 21 and 31 provides 2.8 and 4.9% better results than in stages III and IV of the Kuperman scale (the latter is based on the complex morphophysiological analysis to identify I to VII CGS). Foliar application of the PGR in microstage 21 (BBCH) promoted faster development and an increase in grain yield in sorghum varieties (0.19 t/ha in Odeskyi 205 and 0.12 t/ha in Lan 59) compared to application in stage III (Kuperman). A similar effect of the PGR applied in microstage 21 (BBCH) compared to stage III (Kuperman) was recorded for two sweet sorghum hybrids: in Dovista, an increase in the yield of biomass was 1.6t/ha, dry matter – 0.7t/ha, and sugar content in the stem juice – 0.0%, while these indices in Huliver amounted to 1.6t/ha, 0.7t/ha, and 0.2% respectively. Therefore, the BBCH scale is recommended to adopt for PGR application, and foliar application of PGR should be conducted in the 21 and 31. The practical value of the study

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lies in the selection of the scale of growth and development of sorghum crops and the terms of application of foliar fertilisation, optimal for the conditions of Ukraine. The study is useful from the practical standpoint of conducting foliar fertilisation of plants in production and as a theoretical assessment of plant growth and development scales for students and researchers

Keywords: foliar application of fertilisers, identification of plant development stage, organogenesis stages, the yield of grain, biomass yield

INTRODUCTION

Correct identification of phenological stages in common and sweet sorghum is important for optimising cultivation technology since many agronomic measures of tending crops, especially the foliar application of fertilisers, plant protection products, and plant growth regulators require strict identification of the plant physiological state in different growth stages (Maw *et al.*, 2017; Chapke, 2019; Cuevas & Prom, 2020). The application of protective and stimulative products in inappropriate stages can harm plants and reduce crop yield. Other researchers state that besides proper management, the application of plant growth regulators (PGR) in the optimal stage of growth ensures maximum production (Sory *et al.*, 2017; Thapa *et al.*, 2017; Maiti & Singh, 2019). Similarly, other agronomic measures should be rationally applied based on the scale of growth and development of sorghum.

Several scales of growth and development for cereals have been developed over the years, and they were compared in earlier studies (Kalenska *et al.*, 2018). Dutch agronomist Willem Feekes is the author of the Feekes scale, which was introduced in 1941 (Maity *et al.*, 2021). This scale is used more often in the US, while other scales, such as the Zadoks or the BBCH, are less used. The Feekes scale is especially useful in stages 6 to 10.5 (stem elongation), which is relevant when it is necessary to decide on the best timing for fungicide application. The Keller and Baggiolini scale was developed in Switzerland in 1954. This scale is an extended version of the Feekes scale, with growth stages being coded with letters. In 1962, another scale was developed under the leadership of F.M. Kuperman. The scale describes 12 stages of plant growth and development into three periods: I-IV stages – embryonic period and youth (i), V-VIII stages – maturation and reproduction (ii), and IX-XII stages – senescence (iii) (Thomas, 2014; Maity *et al.*, 2021). The Haun scale is focused on leaf formation and describes the length of each emerging leaf. The Zadoks scale describes only critical plant development stages (Gulumser & Mut, 2016; Rasti *et al.*, 2022). Based on the Zadoks scale, BBCH uses a decimal code system and includes macro- and micro-stages (Thomas, 2014). BBCH scale is often used to determine the optimum timing for fertilisation, pesticide treatment, and other agronomic measures.

Today, in Ukraine, the following species are available: common sorghum (*Sorghum bicolor*), soryz (*S. oryzoidum*), sweet sorghum (high sugar content variety of *S. bicolor*), Sorghum-Sudan grass hybrid (*S. bicolor* x *Sorghum × drummondii*), broom sorghum **(***S. vulgare* var. *technicum*), perennial sorghum (*S. almum* Parodi), and Sudan grass (*S. bicolor* subsp. *drummondii*) (State Register of Plant Varieties..., 2020). Of them, the most common species are common sorghum and sweet sorghum (Fedorchuk *et al.*, 2017) grown on an area of 47 000 hectares. A considerable increase in sown area is observed in the Forest-Steppe zone (20%), which is characterised by unstable soil moisture. Meanwhile, sorghum has been conventionally grown in the Steppe zone characterised by insufficient soil moisture (Tretiakova *et al.*, 2022).

In the early stages, sorghum plants demonstrate slow growth of the stem and leaf. Because of this, they cannot compete with weeds, especially in conditions of the Forest-Steppe, where weed species diversity and their seed reserves in soil are considerable (Fedorchuk *et al.*, 2017). The lack of mobile forms of nutrients in the soil, along with drought, pests, and diseases can also decrease the yield potential of the crop (Marinov-Serafimov *et al.*, 2018; Kraig *et al.*, 2019). It is important to find effective ways of activating certain phenological stages of sorghum. Such agronomic measure may help avoid the stress in plants caused by adverse environmental factors during critical growth stages (Reddy *et al.*, 2014).

S.S. Dhaliwala, V. Sharmaa, & A.K. Shuklab (2022) showed the effectiveness of the foliar application of fertilisers in sorghum. In the field experiments, crop yield increased from 15 to 25% due to the use of proper commercial micronutrient fertiliser. When the fertiliser was applied 4 and 6 weeks after sowing, biomass yield was 7-11% higher compared to the control (Stipešević *et al.*, 2018). Application of spray foliar fertiliser Boost Extra 30, 60, and 90 days after planting at a rate of 2 L/ha ensured the highest yield of sorghum (Ogundare, *et al.*, 2015). D. Vasundhara & V. Chhabra (2021) reported that the optimum timing of foliar nutrient application for corn and sorghum is in the 5-7 leaf stage, and the second application – after 14 days. In winter wheat, PGR is applied before and/or during the stem elongation stage (BBCH 30-32) aiming to produce lower internodes with shorter lengths, thicker stems and, stem cell walls (Gandee *et al.*, 1997). Experiments by B. Bodson & M-H. Durdu (1996) on winter wheat showed that PGR can be applied not only in the period from the end of tillering to the beginning of stem elongation as conventionally recommended but also in more advanced stages of the vegetative period: 1st or 2nd node and even flag leaf emergence. Late applications do not cause any substantial reduction in yield compared to applications at beginning of the stem elongation stage. In field experiments with spring wheat, the optimum timing for trinexapac ethyl application is Zadoks growth stages (GS) 30, 32, or 37. The application of trinexapac-ethyl in GS 37 resulted in less crop damage, shorter stands, and more erect plants than in GS 30 or 32 (Wiersma *et al*., 2011). Early application of growth regulators in tillering stage increased the number of tillers, ears, and grain yield of winter wheat (Ghuman & Ram 2021). In experiments by Z. Hussain & M.H. Leitch (2007) on applications of PGR in spring wheat in growth stages 30 and 32, the grain yield was unaffected. However, the stem length decreased, while the specific stem weight increased.

Studies by many researchers contain a variety of information on the timing of the foliar feeding of sorghum. Among them, calendars of foliar applications of fertilisers (Ogundare *et al*., 2015; Stipešević *et al*., 2018; Dhaliwala *et al*., 2022) and certain phenological stages are identified (Vasundhara, & Chhabra 2021); Sebrina *et al*., 2020). Thus, there is no consensus on the correct timing of the foliar feeding (Sebrina *et al*., 2020).

Now, the most frequently used scales are Keller & Baggiolini, BBCH, Zadoks, and Haun, Feekes (Thomas, 2014; Lambright, 2019; Rasti *et al*., 2022; López-Sandin *et al*., 2022). In Ukraine, it is common to use the Kuperman scale (Kalenska *et al*., 2018). The BBCH scale, which is based on more precise knowledge of plant development physiology, can hardly be compared to simpler scales (Kuperman, 1984; Reddy, 2017; Lambright, 2019).

The scientific originality of this study consists of the theoretical analysis of the practice of using plant growth and development scales and the practical selection of optimal scales of growth and development of sorghum for use in agronomic operations of tending crops, specifically, optimisation of the plant growth regulator application.

The purpose of this study is to evaluate the effectiveness of two scales (BBCH and Kuperman) for plant growth and development for the determination of the most suitable time of PGR application to increase the yield of two common sorghum varieties and two sweet sorghum hybrids.

MATERIALS AND METHODS

Experimental site and soil condition

The study was conducted in the years 2012–2020 in two field experiments (two locations): state farm Salyvinkivske (Ksaverivka 2, Vasylkiv district, Kyiv region) and Bila Tserkva Research and Breeding Station (Mala Vilshanka. Bilotserkivskyi district, Kyiv region). Both locations belong to the Central Forest-Steppe of Ukraine, the zone of unstable moisture.

The soil of the state farm Salyvinkivske is podzolic chernozem, with the following characteristics, determined by methods of agrochemical analysis (Hospodarenko, 2013): the content of humus is 3.21% (by Turin) (DSTU 4289:2004, 2005), pH_{sal} – 6.4, alkaline hydrolysed nitrogen – 156 mg/kg (by Kornfeld) (DSTU 7863:2015, 2016), mobile phosphorus and potassium – 77 mg/kg and 89 mg/kg (by Chirikov) (DSTU 4115-2002, 2002). The soil of the Bila Tserkva Research and Breeding Station is typical low-humus chernozem, the content of humus is 3.50% (DSTU 4289:2004, 2005), pH_{sal} – 6.2, alkaline hydrolysed nitrogen – 134 mg/kg (DSTU 7863:2015, 2016), mobile phosphorus and potassium – 76 mg/kg and 98 mg/kg, respectively (DSTU 4115-2002, 2002).

Weather conditions

The analysis of weather conditions and their variability in the research years 2012–2020 compared to the average long-term data was performed based on the formula:

$$Ks = \frac{(X1 - X2)}{S}, \quad (1)$$

where K_S is the significance coefficient of deviations of the agrometeorological regime; *X*1 is the element of the current weather; *X*2 is the indicator of the long-term average value (1980-2020); *S* is the standard deviation (Rozhkov *et al*., 2016).

Table 1. Significance coefficient (Ks) of deviations of precipitation and average monthly temperatures from long-term averages, 2012-2020

Months	Precipitation									Air temperature								
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2012	2013	2014	2015	2016	2017	2018	2019	2020
April	0.8	0.4	0.4	-1.5	0.9	-1.0	-1.6	-0.1	-1.5	2.5	1.0	1.0	0.7	2.9	1.4	0.5	1.2	0.6
May	-0.5	2,1	2.1	-0.2	1.8	-0.4	-0.1	0.2	1.7	2.2	1.1	1.1	1.2	0.3	0.5	2.5	1.4	-0.8
June	-0.5	0.2	0.2	-1.5	-2.4	-1.7	0.4	0.2	-0.5	1.4	-0.4	-0.4	1.1	0.6	1.2	2.8	2.6	2.1
July	-1.1	0.3	0.3	-0.4	-1.3	-0.7	-2.1	-1.4	-0.2	2.4	1.4	1.4	1.4	2.3	0.9	2.7	0.3	1.1
August	1.2	-0.3	-0.3	-1.6	-0.9	-1.5	-1.2	-1.2	-0.4	0.8	1.4	1.4	1.4	1.7	2.3	3.0	1.2	0.9
September	-0.4	0.3	0.3	-0.5	-1.8	-1.7	0.5	-1.0	-0.5	1.5	0.2	0.2	2.2	1.3	1.8	0.7	0.8	1.8

Note: green indicates conditions close to normal (Ks 0-1), gray – conditions that differ substantially from the average perennials (Ks 1-2), orange – conditions close to the extreme (Ks>2)

In 2012, 2015, 2016, 2017, and 2018 the most substantial deviations in precipitation were observed. In 2015 and 2017, all the months of the vegetation period corresponded to insufficient precipitation. Extreme conditions of the average daily air temperature were in the years 2012 (April, May, July) and 2018 (May, June, July, August). The systematic lack of precipitation in 2015-2016 resulted in a moisture shortage in 2017 and the productivity of sorghum was rather low.

Experimental scheme and treatments

Field experiment I with two common sorghum varieties (Sorghum bicolor) was conducted at the state farm Salyvinkivske in 2012-2015: *Factor A*: varieties Odeskyi 205 and Lan 59; *Factor B*: the timing of foliar fertilisation: stages 21, 31, and 37 (BBCH) and III, IV, and VI-VII (Kuperman). The PGR used in the study was Vympel 2 (0.5 L/ha; active ingredients: polyatomic alcohols 300±30 g/L, humic acids 30±0.3 g/L, carboxylic acids 3.0±0.3 g/L). In the control treatment, the plants were treated with water only. The application rate of the working solution was 200 L/ha. The single plot area was 35 m^2; the accounting area was 25 m^2.

Field experiment II with two sweet sorghum hybrids (*Sorghum saccuratum* Jakuschev.) Huliver and Dovista was conducted at the Bila Tserkva Research and Breeding Station in 2016-2020. The scheme of the experiment: *Factor A*: hybrids: Huliver and Dovista; *Factor B*: foliar application of fertilisers: stages 21, 31, and 37 (BBCH) and III, IV, and VI-VII (Kuperman). Plants were treated with the PGR (application rate 0.5 L/ha; active ingredients: polyatomic alcohols 300±30 g/L, humic acids 30±0.3 g/L, carboxylic acids 3.0±0.3 g/L). Control: the plants were treated with water only, as described in Experiment I. The single plot area was 35 m^2; the accounting area was 25 m^2.

The experiment was established in a randomised plot scheme were planned according to the general methodology of experiments in agronomy (Rozhkov *et al*., 2016; Tkachyk, 2015).

Plant treatment

The cultivation technology sorghum was typical for the Right-Bank Forest-Steppe of Ukraine. Mineral fertiliser $N_{45}P_{60}K_{60}$ was applied in the experiment. Phosphate-potassium fertiliser was incorporated before tillage, while nitrogen fertiliser – before seedbed preparation. The seeds were sown to a depth of 2-4 cm at soil temperature >12°C. Common sorghum was sown with a plant density of 160-180 plants per hectare (at harvest) at a row spacing of 70 cm. Sweet sorghum was sown in wide rows at a row spacing of 45 cm, at a seeding rate of 10-12 seeds/m and plant density of 190-230 thousand plants per hectare (at harvest). Common sorghum was harvested at grain humidity of <20% using a combine harvester, sweet sorghum was harvested using silo-harvesters in the stage of middle dough (Fedorchuk *et al*., 2017).

The seeds were treated with the antidote Concep® III (Syngenta, USA), which is approved for pre-emergence application to ensure efficient weed control. Post-emergence treatment of crops was performed using preparations based on S-metolachlor (Primextra TZ Gold 500 SC, Primextra Gold 720 SC, Dual Gold 960 EC, all Syngenta, USA). Dicotyledonous weeds were controlled by post-emergence herbicides of the 2.4 D group (Prima SE, Peak 75 WG, all Syngenta, USA) before the five-leaf stage (Fedorchuk *et al*., 2017). Before sowing, the seeds were treated with the fungicide Maxim XL 035 FS (Syngenta, USA). During the growing season, Karate Seon 050 SC and Engio 247 SC (all Syngenta, USA) were used to control such pests as aphids, European corn borer (*Ostrinia nubilalis*), and beet webworm (*Loxostege sticticalis*).

PGR Vympel 2 (Dolyna-Tsentr LLC, Ukraine) contains polyatomic alcohols (300 g/L), humic acids (30 g/L), carboxylic acids (3.0 g/L), and natural growth promoters-adaptogens. The product accelerates plant growth and development, activates nutrient consumption and leaf surface formation (Storozhyk & Muzyka, 2017).

Biochemical seed quality

Biochemical indicators of seed quality were determined by the following methods: protein content by the method of mineralisation with sulfuric acid in the presence of a catalyst according to Stein-Moore; starch – by the method of dissolution in a hot solution of hydrochloric acid followed by a polarimeter examination. The content of dry matter was determined by drying in a drying chamber at a temperature of 105°C for 4-6 h. The total sugar content in the juice of sugar sorghum stems was determined by the Luff-Schoorl method (Tkachyk, 2015).

Data analysis

The statistical processing of the experimental data was performed using ANOVA at LSD_{05} using the Statistica 10.0 package (StatSoft). The share of influence of the factors was determined based on the results of variance analysis (ANOVA) with the display of only reliable variances in the graphs (pie chart graph).

The summary statistics of the analysis of variance, specifically the sum of squares (SS), were used to build a graph of factor influence (Urdan, 2010). Only the influence of the effects at a substantiality level of $p<0.05$ was used, setting this parameter when building the graph. Therewith, factors with values of $p>0.05$ were automatically considered as an experimental error, thus the distribution of influencing factors was not disturbed.

RESULTS AND DISCUSSION

Tables 2 and 3 demonstrate the specific features of the impact of the PGR (0.5 L/ha) on the productivity of two sorghum varieties and two sorghum hybrids when applied in different growth stages by the BBCH and the Kuperman scales.

Table 2. The impact of the growth regulator (0.5 L/ha) on the productivity of two common sorghum (*Sorghum bicolor* L.) varieties when applied in different growth stages by the BBCH and the Kuperman scales (average for 2012-2015)

Variety	Stage	PGR	Duration of vegetation period (day)	Yield of grain (t/ha)	Protein content (%)	Starch content (%)
Odeskyi 205	BBCH microstage 21	Control	110	4.70	10.8	73.5
		GR	102 (-8)	5.26 (+ 0.56)	10.9 (+0.1)	73.8 (+0.3)
	Kuperman stage III	Control	110	4.73	10.9	73.5
		GR	103 (-7)	5.10 (+0.37)	10.8 (-0.1)	73.6 (+0.1)
	BBCH microstage 31	Control	110	4.68	10.8	73.6
		GR	104(-6)	5.05 (+0.37)	11.0 (+0.2)	73.9 (+0.3)
	Kuperman Stage IV	Control	110	4.71	10.7	73.5
		GR	104 (-6)	5.01 (+0.3)	11.0 (+0.3)	73.9 (+0.4)
	BBCH microstage 37	Control	110	4.74	10.8	73.2
		GR	107(-3)	4.92 (+0.18)	11.2 (+0.4)	74.1 (+0.9)
	Kuperman stage VI-VII	Control	110	4.70	10.9	73.3
		GR	108 (-2)	4.90 (+0.2)	11.3 (+0.4)	74.2 (+0.9)
Lan 59	BBCH microstage 21	Control	110	5.22	11.0	75.1
		GR	103 (-7)	5.70 (+0.48)	11.2 (+0.2)	75.3 (+0.2)
	Kuperman stage III	Control	110	5.20	11.1	75.0
		GR	104 (-6)	5.56 (+0.36)	11.1 (+0.0)	75.2 (+0.2)
	BBCH microstage 31	Control	110	5.25	11.0	74.8
		GR	105 (-5)	5.50 (+0.25)	11.4 (+0.4)	75.2 (+0.4)
	Kuperman stage IV	Control	110	5.18	10.9	74.9
		GR	105 (-5)	5.44 (+0.26)	11.5 (+0.6)	75.3 (+0.4)
	BBCH microstage 37	Control	110	5.17	11.2	75.0
		GR	108 (-2)	5.35 (+0.18)	11.6 (+0.4)	75.7 (+0.7)
	Kuperman stage VI-VII	Control	110	5.22	11.1	75.1
		GR	109 (-1)	5.32 (+0.1)	11.6 (+0.5)	75.9 (+0.8)
ANOVA (LSD_{05})			1	0.12	0.3	0.8

The application of the PGR in BBCH microstage 21 and Kuperman stage III reduced the vegetation period of Odeskyi 205 by 8 and 7 days, respectively, and Lan 59 – by 7 and 6 days. Application of PGR in later stages for common sorghum practically did not affect the duration of the vegetation period. The differences between these varieties and control treatments after the application of the regulator in BBCH microstage 37 and Kuperman stage VI-VII were 1-2 days for Lan 59 variety and 2-3 days for Odeskyi 205.

Faster growth and development of common sorghum plants promoted the foliar application of the PGR in BBCH microstage 21 and Kuperman stage III, which resulted in higher grain productivity – in Odeskyi 205 by 0.56 t/ha and 0.37 t/ha, respectively, and in Lan 59 – by 0.48 t/ha and 0.36 t/ha, respectively.

Application of the PGR in later stages of common sorghum (*Sorghum bicolor L.*) is interesting from the standpoint of the quality of the obtained harvest. Foliar fertilisation in BBCH microstage 31 and Kuperman stage IV in varieties Odeskyi 205 increased the content of protein by 0.2-0.33%, respectively, in Lan 59 by 0.4-0.6%, respectively, compared to control. Similarly, the content of starch was higher by 0.3-0.4 and 0.4%, respectively. In the case of foliar application of PGR in BBCH microstage 37 and Kuperman stages VI-VII, the yield of Odeskyi 205 was higher by 0.18 t/ha and 0.20 t/ha, respectively, compared to the control, and Lan 59 – by 0.18 t/ha and 0.10 t/ha, respectively. This data only slightly exceeded the indices of the experimental error. However, the quality characteristics of sorghum harvest increased considerably compared to the earlier application of the PGR. For example, the fertilisation in BBCH microstage 31 ensured an increase in protein content of 0.2% and starch – of 0.3% in Odeskyi 205 and 0.3% and 0.4%, respectively, in Lan 59. The variant with the fertilisation in Kuperman stage IV yielded 0.3% higher content of protein and 0.6% higher content of starch in Odeskyi; in Lan 59, the increase was 0.6% and 0.4%, respectively.

The results of the analysis of the factors that affect common sorghum yield are shown in Figure 1.

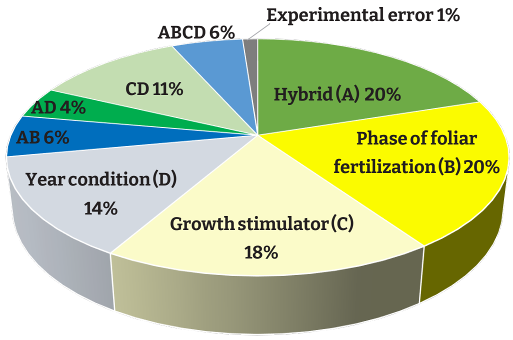

Figure 1. The influence of factors on the formation of common sorghum yield (only substantial factors of influence, p<0,05 are defined)

It was identified that varietal characteristics and stage of foliar fertilisation are the most effective factor in sorghum productivity (20%). The PGR allows influencing the harvest formation at the level of 18%. Weather conditions contributed to the deviations in sorghum yield with a share of influence of 14%, with interaction with the factor of PGR (CD) of 11% and variety (AD) – 4%.

The impact of the PGR on the productivity of the two sweet sorghum hybrids when applied in different growth stages by the BBCH and the Kuperman scales is shown in Table 3.

Table 3. The impact of the PGR (05 L/ha) on the productivity of two hybrids of sweet sorghum (*Sorghum saccharatum* Jakuschev) when applied in different growth stages according to the BBCH and the Kuperman scales (average for 2016-2020)

Hybrid	Stage	PGR	Duration of vegetation period (day)	Biomass yield (t/ha)	Dry matter yield (t/ha)	Total sugars (%)
Huliver	BBCH microstage 21	Control	114	88.5	17.6	14.5
		GR	105 (-9)	93.5 (+5.0)	18.9 (+1.3)	14.9 (+0.4)
	Kuperman stage III	Control	114	88.7	17.8	14.6
		GR	107 (-7)	92.1 (+3.4)	18.4 (+0.6)	14.8 (+0.2)
	BBCH microstage 31	Control	114	88.4	17.8	14.5
		GR	108 (-6)	90.8 (+2.4)	18.0 (+0.2)	15.1 (+0.6)
	Kuperman stage IV	Control	114	88.9	17.8	14.5
		GR	108 (-6)	90.9 (+2.0)	18.2 (+0.4)	15.0(+0.5)
	BBCH microstage 37	Control	114	88.6	17.7	14.5
		GR	112 (-2)	89.9 (+1.3)	18.2 (+0.5)	15.3 (+0.8)
	Kuperman stage VI-VII	Control	114	88.5	17.6	14.6
		GR	113 (-1)	89.7 (+1.2)	18.0 (+0.4)	15.2 (+0.6)
Dovista	BBCH Microstage 21	Control	136	92.9	18.5	15.1
		GR	129(-7)	98.8 (+5.9)	19.8 (+1.3)	15.7 (+0.6)
	Kuperman stage III	Control	136	93.0	18.7	15.0
		GR	130 (-6)	97.3 (+4.3)	19.3 (+0.6)	15.6 (+0.6)
	BBCH microstage 31	Control	136	92.6	18.6	15.0
		GR	132 (-4)	96.5 (+3.9)	19.3 (+0.7)	15.8 (+0.8)
	Kuperman stage IV	Control	136	92.9	18.4	15.1
		GR	132 (-4)	96.4 (+3.5)	19.2 (+0.8)	16.0 (+0.9)
	BBCH Microstage 37	Control	136	93.2	18.5	15.0
		GR	133 (-3)	95.2 (+2.0)	19.1(+0.6)	16.5 (+1.5)
	Kuperman stage VI-VII	Control	136	93.3	18.6	15.1
		GR	134 (-2)	94.8 (+1.5)	18.9 (+0.3)	16.4 (+1.3)
ANOVA (LSD_{05})			1	1.3	0.5	0.4

When PGR was applied in BBCH microstage 21, Huliver hybrid showed a decrease in vegetation period of 9 days and Dovista hybrid – 7 days; when applied in Kuperman stage III, the decrease was 7 and 6 days. After application of the PGR in BBCH microstage 37 and Kuperman stage VI-VII, the vegetation period was shorter, compared to control, by 2 and 1 day, respectively, in Huliver and by 3 and 2 days, respectively, in Dovista. This proves the low efficiency of the application of PGR in the later stages for sweet sorghum.

As for the common sorghum varieties, foliar application of the PGR in BBCH microstage 21 and Kuperman stage III also stimulated the yield and quality of the crop (Table 3). The yield of Huliver biomass was 5.0 t/ha higher and dry matter – 1.3 t/ha higher. The total sugar content in the stem juice increased by 0.4% but it was statistically insubstantial. In Dovista, an increase amounted to 5.9 t/ha, 1.3 t/ha, and 0.6% respectively. When the PGR was applied in Kuperman stage III, the above-mentioned indices were in Huliver 3.4 t/ha, 0.6 t/ha, and 0.2%, respectively, and in Dovista 4.3 t/ha, 0.6 t/ha, and 0.6%, respectively which was statistically insubstantial. Thus, the optimal timing for the PGR application (BBCH microstage 21) contributed to obtaining higher productivity of the studied cultivars: in Dovista, biomass yield was higher by 1.6 t/ha, dry matter yield – by 0.7 t/ha and there was no increase in the sugar content of juice; while in Gulliver, these indicators were 1.6 t/ha and 0.7 t/ha, respectively, with the sugar content in juice increase of 0.2%.

After the application of the growth promoter in BBCH microstage 31, the increase in biomass yield in Dovista was 3.9 t/ha, dry matter 0.7 t/ha, and an increase in total sugar content 0.8% as compared to the control, and in Huliver the increase was 2.4 t/ha, 0.2 t/ha, and 0.6% respectively.

When the PGR was applied later, in BBCH microstage 37 and Kuperman stage VII, the biomass yield increase in Huliver was 1.3 t/ha and 1.2 t/ha, respectively, and in Dovista 2.0 t/ha and 1.5 t/ha, respectively. In Huliver, the increase was statistically insubstantial, while in Dovista it was. Therefore, it can be concluded that the application of PGR in later stages is less efficient for common sorghum varieties.

The results of the analysis of the factors that affect sweet sorghum biomass yield are shown in Figure 2.

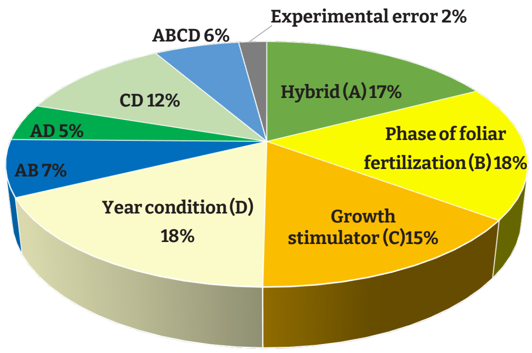

Figure 2. The influence of factors on the formation of sugar sorghum biomass yield (only substantial factors of influence, p<0,05 are defined)

It was identified that the stage of foliar fertilisation (18%) and varietal characteristics (17%) are the most effective factor in sorghum productivity. The PGR allows influencing the harvest formation at the level of 15%. Weather conditions contributed to the deviations in sorghum yield with a share of influence of 18%, with interaction with the factor of PGR (CD) of 12% and variety (AD) – 5%.

Quality characteristics of sweet sorghum more substantially differed from the control in the case of foliar application of the PGR in BBCH microstage 37 and Kuperman stages VI-VII. The total sugar content in stem juice in Huliver increased by 0.8% and 0.6%, respectively, compared to control, and in Dovista – by 1.5% and 1.3%, respectively. The obtained data clearly shows that the foliar applications of the PGR (0.5 L/ha) in common sorghum and sweet sorghum sowings during the period of active growth and development considerably improve the quality and quantity of the obtained produce due to the activation of growth processes.

Nowadays, the investigation of the efficiency of growth and formation of common and sugar sorghum yield has gained new emphasis in connection with the active use of the crop as a feedstock for bioenergy. However, the papers of researchers are mainly focused on determining the efficiency of the main fertilisation, in particular, nitrogen fertilisation (Pannacci & Bartolini 2018; Bartzialis *et al.*, 2020). However, in Ukraine, on the most common soil types, the optimal doses of fertilisers are quite well investigated (Fedorchuk *et al.*, 2017), while the optimal timing of application of foliar fertilisers needs clarification (Kalenska *et al.*, 2018).

This study on the correspondence of stages and microstages of sorghum was conducted on the background of long-term experiments on the foliar application of fertilisers as the method of intensification of plant growth at the beginning of their vegetation. It is known that sorghum plants grow slowly during the first 40-50 days after germination, which affects their adaptation to adverse conditions of cultivation (Reddy, 2017; Marinov-Serafimov *et al.*, 2018). In the case of foliar fertilisation with a PGR, the stage of plant growth and development is very important as everything that is applied, penetrates the plant very fast and there is no buffer concentration in the soil.

The specific features of the growth of sorghum and the ways of enhancing the efficiency of its cultivation through the optimisation of agronomic measures were investigated by a number of researchers (Calvino & Messing, 2012; Saadat & Homaee, 2015; Masaka *et al*., 2019). The application of PGR was shown in earlier studies to be an efficient agrotechnical practice for the reliable intensification of plant growth, consequently, the yield and quality of the sweet sorghum crop, ensuring an average increase in the total sugar content in stem juice by 1.4% (Storozhyk & Muzyka, 2017).

Results in many aspects also correspond to other recent studies, proving that PGR affects the rate of photosynthesis processes, productivity, and general resistance to adverse cultivation conditions (Narayanan *et al*., 2013; Stipešević *et al*., 2018; Sebrina *et al*., 2020). Therewith, the examples of using the BBCH and the Kuperman scales in the determination of the time for efficient application of PGR have not been identified in the scientific literature.

In conclusion, the application of the PGR as a component of cultivation technology in the early stages of sorghum plant development can be easier when using the BBCH scale because the Kuperman scale requires morphophysiological analysis to identify certain growth stages. Moreover, applications of the PGR (0.5 L/ha) in the BBCH 21 and 31 stages appear to give slightly better results than its applications in the Kuperman stages III and IV. In reality, the application dates based on the BBCH scale differed by 5-7 and 2-3 days compared to the Kuperman scale over the years of the study. This could be further investigated in more detail.

CONCLUSIONS

Foliar application of PGR (0.5 L/ha) in the early stages of sorghum growth and development requires accurate identification of stages and microstages of organogenesis. Foliar application of the PGR in Kuperman stage III ensured an increase in sorghum grain yield, compared to the control, by 0.37 t/ha in Odeskyi 205 and 0.36 t/ha in Lan 59. With the application of PGR in BBCH microstage 21, the obtained increase in yield was 0.56 t/ha in Odeskyi 205 and 0.48 t/ha in Lan 59. Similarly, the increase in the biomass yield of sweet sorghum was 3.4 t/ha in Huliver and 4.3 t/ha in Dovista using of the Kuperman scale, and 5.0 t/ha and 5.9 t/ha using the BBCH scale. In the early stages it is easier and more profitable to use relevant microstages by the BBCH scale to plan the application of a PGR, than equivalent ones of the Kuperman scale.

It was identified that application of the PGR at a rate of 0.5 L/ha in BBCH microstage 37 provided an increase in protein content in common sorghum grain of 0.4% in Odeskyi 205 0.4% in Lan 59, and starch content – 0.9% and 0.7%, respectively. Similarly, the application of the PGR at a rate of 0.5 L/ha in sweet sorghum hybrids lead to an increase in total sugar content in stem juice of 0.8% in Huliver and 1.5% in Dovista.

In this study, only two scales of growth and development, the most widely used in Ukraine, were considered. However, the value of simple scales lies in their ease and accuracy of use; therefore, the issue of the effectiveness of identifying plant growth and development stages using scales other than the BBCH and the Kuperman scales is relevant.

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Оптимальний час застосування регулятора росту рослин на посівах сорго за шкалою ВВСН та Купермана

Анотація. Актуальність досліджень зумовлена проблемою вибору оптимальної шкали ідентифікації фаз росту рослин для визначення кращих строків проведення агротехнічних операцій догляду за рослинами сорго. Метою експерименту було визначення ефективного часу застосування регулятора росту рослин на 21, 31, 37 фазах (шкала ВВСН) та III, IV, VI-VII (шкала Куперман). У роботі використовували польові та лабораторні методи досліджень. Дослід проводився в зоні Лісостепу України, два сорти сорго *Sorghum bicolor* і *Sorghum saccharatum* були оброблені регулятором росту рослин. Позакореневе підживлення регулятором росту рослин (0,5 л/га) на стадіях 21 і 31 BBGH дає на 2,8 та 4,9 % кращі результати, ніж на стадіях III і IV за Куперман (остання шкала базується на комплексному морфофізіологічному аналізі для ідентифікації I-VII періодів росту рослин). Позакореневе підживлення регулятором росту рослин на мікростадії 21 (ВВСН) сприяло швидшому розвитку рослин сорго та збільшенню врожаю зерна сортів сорго (0,19 т/га сорту «Одеський 205» та 0,12 т/га сорту «Лан 59») порівняно з застосуванням в III стадії (Куперман). Подібний ефект регулятора росту рослин, застосованого на мікростадії 21 (ВВСН) порівняно з III фазою (Куперман), зафіксовано для двох гібридів сорго цукрового: у сорту «Довіста» приріст урожайності біомаси становив 1,6 т/га, сухої речовини 0,7 т/га та цукристості стеблового соку 0,0%, тоді як у сорту «Гулівер» ці показники становили 1,6 т/га, 0,7 т/га та 0,2% відповідно. Таким чином, шкалу ВВСН рекомендується використовувати для застосування регулятора росту рослин, а позакореневе підживлення слід проводити в мікростадії 21 і 31. Практична цінність роботи полягає у виборі, оптимальної для умов України, шкали росту та розвитку соргових культур та строків застосування позакореневого підживлення. Робота корисна з практичної точки зору проведення позакореневих підживлень рослин у виробництві так, а також як теоретичне дослідження шкал росту і розвитку рослин, для студентів та науковців

Ключові слова: позакореневе підживлення, визначення стадії розвитку рослин, етапи органогенезу, урожайність зерна, вихід біомаси