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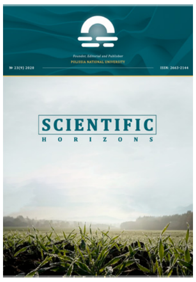

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Stochastic predetermination of bioproductivity component by the growth features of winter wheat upper leaf blades

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Abstract. The relative and absolute importance of a number of traits, in particular, agrophysiological, morpho-functional, at the level of individual organs and parts of an integral plant, and/or sowing for the development of features of biological traits, and other agroecologically significant components of the crop production process, has been discussed in research papers for a long time. The purpose of the study was to search for agroecologically significant signs of growth of the upper leaf blades (ULB), which can empirically and potentially determine the development of the grain

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dry mass (GDM) of winter wheat under "model" conditions of biological agrotechnical influences designated as biological fertiliser systems. Methods used in the research: methodological approaches of field experiments, gravimetric, convective drying, and stochastic methods. The development of GDM was largely driven by potentially scalable integral growth traits of ULB – leaf area duration, biomass duration (LAD_{ULB}, BMD_{ULB}, respectfully) or their combinations with potentially non-scalable features of the average growth rate ULB – net assimilation rate, relative growth rate (NAR_{ULB}, RGR_{ULB}, respectively). It is also highly probable that LAD_{ULB} may play a central role in the development of RGR_{ULB} or BMD_{ULB} (but not NAR_{ULB}). The coordination of RGR_{ULB} with NAR_{ULB} was not excluded, although it was overly complicated. The construction of such and similar studies in the line of an exhaustive explanation of consistent systemic and mechanistic predeterminations of the production process with signs of ULB growth under various agrotechnical and biological influences will improve discursive and mathematical simulation constructs that can characterise and integrate the differential effects of plant components on photosynthesis of leaf cover, crown, and ultimately on the processes of development of components of the final biological and economic yield of winter wheat

Keywords: signs or features of growth of upper leaf blades; leaf area and biomass durations; net assimilation and relative growth rates; winter wheat; "model" biologically improved agronomic conditions – biologically improved fertilisation systems

INTRODUCTION

To improve the final results of the production process, among the world's theoretical and applied aspects of biological, agronomic, and related sciences, various alternative ways to control and increase the efficiency of photosynthesis of agricultural leaves were proposed. The lack of proper success up to the day is mainly conditioned by the fact that the biological and economic productivity of agricultural plants is largely determined by photosynthetic capacity indices (PI) and related terms (size, duration, and architecture of green leaf cover, amount of captured radiation, RUE – radiation use efficiency of the crown, distribution of photoasimilates, size sinks strengths in the source-sink system of plants). PI of green organs and related terms are capable of being translated into growth indices (GI) and bioproductivity of plants. However, during the grain production of cereals, only two upper leaves produce more than 80% of the photoasimilates of the entire plant. Therefore, it is important to formulate scientific questions in the areas of clarifying the measure and methods of determining the components of bioproductivity by the GI of individual upper leaf blades (ULB) of winter wheat, developing a deeper understanding of the (mutual) subordination between the first and second in the "scaling down" coordinates under various agrotechnical influences. The results of such studies will become a meaningful basis for correcting theoretical, applied, and generalising constructs for the development of the "scaling up" yield components under various technologies for growing winter wheat.

Consistent with the classical analysis of plant growth outlined several decades ago, total dry matter (TDM) is directly proportional to the product of GI – net assimilation rate (NAR), leaf area duration (LAD); at the same time, crop growth rate (CGR) is directly proportional to the product of NAR, leaf area index (LAI) (theoretical and analytical equations (Eqs.) – TAE category 1 for plant growth analysis). It is also legitimate to predetermine TDM by the product of two other GI – relative growth rate (RGR), biomass duration (BMD), and the coordination of CGR with the product of RGR, biomass index (BMI) (TAE category 2). Modern definitions and formalisations of NAR and CGR are given by A. Khan *et al.* (2023); for LAD, LAI – by N. Mehboob *et al.* (2022); BMD, BMI in TAE category 2 – biomass-GI, similar to LAD, LAI.

Formalisation of the RGR, submitted by M. Tripathi (2020), can be supplemented by considerations of F.F.M. Oliveira *et al.* (2019), and interpreted as the rate at which a given amount of existing biomass can produce new biomass. Since RGR is the key to analytical understanding of growth, it is often presented as a product of NAR, LAR (LAR – product of LMF, SLA, or 1/LMA) (Yano *et al.*, 2018). In this TAE category 3 LAR, LMF, SLA, LMA – leaf area ratio, leaf mass fraction, specific leaf area, leaf mass per area ratio (specific leaf weight, SLW). In consistency with S. Tripathi *et al.* (2018), the latter TAE is important for intra- and interspecific variability of plant growth rates depending on environmental factors, availability of sources of alimentary reserves. As noted by M. Khirkhah *et al.* (2019), crop bioproductivity of GI components may be affected by insufficient or excessive intake of any of the main alimentary components.

I.C. Dodd and E.D. Elphinstone (2021) showed that N-supplements caused an increase in LAI, leaf longevity (LL), LAD, leading to an improvement in plant biological and/or economic productivity. Ukrainian researchers D.A. Kirizii and I.M. Sheheda (2019) proposed predicting the ability to photosynthesise (individual plants, seeding) by LNC (Area), LDMC (Area) (N-leaf content/area, leaf dry matter contet/area, respectfully), SLW, which characterise interspecific differences In N-allocation to proteins (Rubisco), cell walls, mesophyll conductivity, CO_2- partial pressure (leaf structure), etc. An increase in

N-concentration caused a decrease in LMF, RGR *Hordeum vulgare* L. (hydroponics); at higher N-concentration, the increase in LMF was offset by a decrease in NAR, without changes in SLA (Ge *et al.* 2019). M. Khirkhah *et al.* (2019) found that max-gain LAI, CGR, NAR, RGR of alfalfa (a two-year field experiment) was induced by P-biofertilisers + extracellular boron-supplements, extracellular or "intra-soil" manganese-supplements.

According to H. Tiwari *et al.* (2023), highest CGR, NAR, RGR *Triticum aestivum* L. 100%-recommended N-rate+farmyard manage + "Azatobacter" (biofertiliser) (comparison with other integrated crop cultivation systems) were determined. J.L. Miglioli *et al.* (2020) demonstrated that a decrease in RGR, NAR, an increase in DM of *Brassica oleracea* var. *gemmifera* was caused by treatment with 6-benzylaminopurine, while the opposite changes were caused by dopamine. An increase in LAI, NAR, %-light interception in rice was caused by the use of green manure crops with different N-dosage or N_{60}-only (Islam *et al.* 2019). L.S. Yeremko *et al.* (2019) showed that an increase in the rate of mineral fertilisers (using plant root feeding) caused an increase in photosynthetic potential = LAD, net photosynthesis productivity of pea crops, both without inoculation with Rhizohumin, and with inoculation, compared with control (without fertilisers, without inoculation) or non-inoculated plants, respectively.

The analysed scientific sources show that the study of aspects of GI coordination, components of bioproductivity, functional and ecological relations is expedient in hydroponics, agricultural systems of plant cultivation, and supplementation of the latter with biological factors. Thus, the biologised fertiliser systems used in this work (BFS, complex agrotechnical and biological fertilisers) can be a full-fledged model agroecosystem for elucidating the patterns of (inter-) subordination between the undicators of bioproductivity and growth of winter wheat. Over the past decade, a wide range of researchers have formed a consensus, highlighted in particular by J.L. Araus *et al.* (2021), according to which it is advisable to consider the most significant factors of increasing bio-productivity and economic grain yield in conjunction with changes in growth and development processes in the source-sink system of plants. However, there are no clear answers to questions about the aspects of predetermined results of the production process (the final sink) by the ULB-GI, *i.e.*, by the important attributes of growth and primary sources of photosynthate, which characterise the accumulation, preservation, and outflow of assimilates from the ULB to sinks in terms of "scaling down".

The structure of such considerations should be supplemented by the predestination of the RGR_{ULB} by the product of NAR_{ULB}, SLA_{ULB} (TAE category 4), similar to T. Inoue *et al.* (2022). The latter suggests the existence of growth-TAE that regulate TDM_{ULB} coordination on the one hand, and NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}, on the other. The assumption that sink size, e.g. grain dry mass (GDM), can be empirically coordinated with NAR_{ULB} and/or LAD_{ULB}, RGR_{ULB} and/or BMD_{ULB} (TAE categories 1, 2); RGR_{ULB} can be stochastically determined by NAR_{ULB} (TAE category 4) is logical. Given the importance of LAD for the development of NAR (TAE category 1), the subordination of NAR to the value of RGR (TAE category 3), the need for BMD for RGR (TAE category 2), and the scientific sources cited above, the authors of this paper suggested that within the framework of this experiment, NAR_{ULB}, RGR_{ULB}, BMD_{ULB} can be predefined by LAD_{ULB}.

Research objective: to establish whether NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}, empirically and statistically determine, and how exactly, the development of GDM of winter wheat under the conditions of biologised fertilisation systems (BFS); to find out functionally and ecologically feasible stochastic subordination between the described signs of ULB growth.

MATERIALS AND METHODS

The study was carried out in 2017-2018 on grey forest surface gleyed light loamy soil in the conditions of a stationary experiment to investigate the scientific foundations of productivity management of short-rotation crop rotations in the Carpathian region (Institute of Agriculture of the Carpathian region of the National Academy of Agrarian Sciences of Ukraine). Plants of winter wheat (*Triticum aestivum L.*) of the Benefis variety (predecessor – peas, *Pisum sativum* L.) were used for the research within a 4-field crop rotation with the following crop rotation: oats, corn (for grain), peas, winter wheat. The area of the experimental microplot was 1 m^2; replication of plots was 3-fold; the arrangement of the plots – systemic. Physical and agrochemical parameters of the soil (substrate thickness 0-30 cm) were tested in 2016 before the field stationary experiment. For the sake of space, the authors of this paper consider it appropriate to mention that the values of the measured soil characteristics were presented in the previous paper. The content of research variants (technologies) for groups 1 and 2 is presented in Table 1.

***Table 1**. Content of research variants (Group 1 and 2 technologies)*

DRV(T)	Content of option (Group 1)	DRV(T)	Content of option (Group 2)
C.0	Control (no fertilisers or biologisation factors)		
1.1	PSS$^{1)}$	2.1	MF(FD)$^{7)}$
1.2	PSS$^{1)}$ + MF(HD)$^{2)}$	2.2	MF(FD)$^{7)}$ + BS(TS)$^{3)}$

Table 1. Continued

DRV(T)	Content of option (Group 1)	DRV(T)	Content of option (Group 2)
1.3	PSS$^{1)}$ + MF(HD)$^{2)}$ + BS(TS)$^{3)}$	2.3	MF(FD)$^{7)}$ + BS(TS)$^{3)}$ + CM(AE)$^{8)}$
1.4	PSS$^{1)}$ + MF(HD)$^{2)}$ + BS(TS)$^{3)}$ + HF(EI)$^{5)}$	2.4	MF(FD)$^{7)}$ + BS(TS)$^{3)}$ + HF(EI)$^{5)}$
1.5	PSS$^{1)}$ + MF(HD)$^{2)}$ + BS(TS)$^{3)}$ + MF(ES)$^{6)}$	2.5	MF(FD)$^{7)}$ + BS(TS)$^{3)}$ + MF(ES)$^{6)}$
1.6	PSS$^{1)}$ + MF(HD)$^{2)}$ + CF(RS)$^{4)}$	2.6	MF(FD)$^{7)}$ + CF(RS)$^{4)}$

Note: *DRV(T) – designation of research variant (technology); upper numerical indices* $^{1), 2), 3), 4), 5), 6), 7), 8)}$ *– Pisum sativum straw; mineral fertiliser (half of the dose); biostimulant Tera-Sorb; chelated fertiliser Rose-Salt 18-18-18+125+ME; humus-containing fertiliser Eco-Impuls; microbiological fertiliser Eco-Soil; mineral fertiliser (full dose –* $N_{60}P_{90}K_{90}$*); cattle manure (after-effect), respectively. The supplements, marked with indexes* $^{1)–6), 8)}$ *are biologisation factors of the corresponding biologised fertiliser systems (BFS)*
Source: *compiled by the authors*

Brief characteristics and methods of application of biologisation factors represented by commercial preparations (indices $^{2)–6)}$ in Table 1) were contained in the previous paper already cited above (Dubytskyi *et al*., 2020). Supplements PSS, CM(AE) (see note to the same table) represented non-commercial agricultural biologisation factors. N, P, K were added to the soil in the form of ammonium nitrate (34% of the active substance), superphosphate (18% of the active substance), and potassium salt (40% of the active substance), respectively, in doses of 30, 45, 45, or 60, 90, 90 kg/ha^{-1} (variants of Group 1 or Group 2 – MF(HD) or MF(FD), respectively), immediately after sowing winter wheat; PSS was applied for autumn ploighing (2.2 t/ha^{-1}); CM – for autumn ploughing (40 t/ha^{-1}) before spring corn sowing.

Fluctuations in typical climate characteristics during the growing seasons of 2016-2017 and 2017-2018 had a number of features. Among other things, the beginning of this interval of winter wheat growth in 2016 was marked by an oversaturation of precipitation and relatively low average ten-day temperatures; however, overwintering of plants was satisfactory. During the tubing–earing phase of 2017, weather conditions were acceptable. During the flowering-waxy ripeness period, there was a partial lack of moisture in the soil, and an increase in air temperatures by 1.0-1.9°C above the long-term average norms (LAN). In the interval of the initial stages of winter wheat ontogenesis in 2017-2018, the distributions of the sums of active temperatures and precipitation were uniform. During the 3rd-4th months of the specified interval of years, there was a lack of precipitation (95 mm against 52.7 LAN) and an increased temperature background. During the tubing-earing period of 2018, excessive soil moisture occurred. On the contrary, during flowering – waxy ripeness that year, there was a partial lack of moisture and an increase in air temperatures by 3.8°C, compared with the LAN. Summarising the properties of the climatic background of winter wheat vegetation during 2017-2018, it was clear that the ontogenesis of these plants, taking place against the background of changes in precipitation intensity and temperature, still typically contributed to the optimal growth of this crop.

The upper leaf blades (ULB; one the flag FLB and one the pre-flag PFLB – 1st and 2nd leaves of the upper tiers, respectively) from productive shoots of winter wheat were selected in the range of 8.00-11.30 h until noon under the conditions of the onset of the ontogenesis phases of tubing, earing, flowering, milk ripeness (T, E, F, MR, respectively; ~ 75% of plants in the proper phase), as previously noted (Dubytskyi *et al*., 2020). ULB was separated from 3 productive shoots in one field repetition (diagonally across the field plot) and on 3 field repetitions (total number *n* FLB + PFLB = 18). These operations were performed using scissors, ULB was placed in labelled open moistened plastic ice bags, which were placed in a moistened plastic ice container, and transported to the laboratory in this form. In the laboratory, the leafs were rinsed with tap water, dried with filter paper, and the length and maximum width of each ULB was measured using a ruler (in such a sequence as the leaves were placed in a plastic bag – important for subsequent calculations). 2 discs were cut out of each ULB using a cork drill, placed in glass buckets and fixed in a drying cabinet 2B-151 (USSR) at 105°C. During the next 2 days, the leaf discs were dried in a drying cabinet at 105°C to a constant mass (~ 8-14 hours) to determine the dry mass of ULB (Dubytskyi *et al*., 2020). The dry matter mass of ULB disks was measured on Radwag AS 220/R2 analytical scales, Poland (± 0.0001 g). Specific leaf weight*SLW*) = leaf disc weight/leaf disk area; found the average for each research variant *i* – $SLW_{av(i)}$. The area of ULB was calculated from the ratio represented by K. Liu *et al*., (2019): $A_{ULB} = 0.75 \cdot LBL \cdot LBW \cdot 10^{-2}$, where *LBL*, *LBW*, 10^{-2} – leaf blade length, leaf blade width, conversion factor mm^2 in cm^2. Mass of dry matter of *i*-th leaf blades found as a product of $SLW_{av(i)}$ and $LA_{i(i)}$: $LDM_i = LA_i \cdot SLW_{av(i)}$.

With the onset of the full grain ripeness phase (for ~ 75% of plants), wheat ears were cut from every 3 productive shoots in one field repetition (diagonally), and on 3 field repetitions ($n = 18$), and were transported to the laboratory in "dry" form. Grain from the ears was ground, the grain dry mass (GDM) was determined from the grinding part in the same way as described for upper leave blades. The values of this attribute were recalculated on grain dry weight per plant (GDM$_{\mathrm{Pl}}$, g plant^{-1}). The bio-productivity of winter wheat was estimated as GDM based on the area under cultivation (g/m^{-2} of the area of sowing; biologically and agro-ecologically important "dry" or net result of the production process); this plant trait was calculated as a product of GDM$_{\mathrm{Pl}}$ and S (average number of productive shoots in the waxy ripeness phase, pieces m^{-2}).

Average values of RGR and NAR attributes for each i-th ULB pair ($n = 18$) of winter wheat between the phases of ontogenesis $(j+1) - j = k$ ($RGR_{ULB\,k(i)}$, $NAR_{ULB\,k(i)}$, T – E, E – F, F – M) were calculated based on general approaches presented by S. Liu *et al.* (2019), considering the source (Dubytskyi *et al.*, 2020):

$$RGR_{ULBk(i)} \cdot 10^2 = 10^2 \cdot log_e(DMI_{ULBj+1(i)}/DMI_{ULBj(i)})/\Delta t_k, \quad (1)$$

$$NAR_{ULBk(i)} = \Delta DMI_{ULBk(i)}/\Delta AI_{ULBk(i)} \cdot log_e(AI_{ULBj+1(i)}/AI_{ULBj(i)})/\Delta t_k, \quad (2)$$

$$\Delta DMI_{ULBk(i)} = 10^{-3} \cdot S \cdot (DM_{ULBj+1(i)} - DM_{ULBj(i)}), \quad (3)$$

$$\Delta AI_{ULBk(i)} = 10^{-4} \cdot S \cdot (A_{ULBj+1(i)} - A_{ULBj(i)}), \quad (4)$$

$$\Delta t_k = t_{j+1} - t_j, \quad (5)$$

where the marking $DMI_{ULB\ k(i)}$, $AI_{ULB\ k(i)}$ – the indexes of dry weight and area of i-th ULB (flag or pre-flag), $DM_{ULB\ j(i)}$, $DM_{ULB\ j+1(i)}$, $A_{ULB\ j(i)}$, $A_{ULB\ j+1(i)}$, S, Δt_k – dry weight and area of i-th ULB on the stages j, j+1 (mg, cm^2), the number of productive shoots (m^{-2}), the duration of the period between phases $(j+1) - j = k$ (day), respectively; 10^2, 10^{-3}, 10^{-4} – coefficients for easy reading of numbers, for converting mg to g, for converting cm^2 to m^2, respectively, indicators of i-th ULB pair between the T – M ontogenesis phases – considered growing season ($RGR_{ULB\ (i)} \cdot 10^2$, $NAR_{ULB\ (i)}$ – $G_{ULB\ (i)}$) were calculated as averages for the periods T – E, E – F, F – M; average RGR$_{\mathrm{ULB}}$, NAR$_{\mathrm{ULB}}$ (10^2 day^{-1}, g/m^{-2} day) between ULB n = 18 – by dividing $G_{ULB\ (i)}$ by n:

$$G_{ULB(i)} = \sum_{k=1}^{k=K} \left(RGR_{ULBk(i)} \cdot 10^2 \ or NAR_{ULBk(i)} \right) \Big/ K; \quad (6)$$

$$RGR_{ULB} \cdot 10^2 \ or NAR_{ULB} = \sum_{i=1}^{i=n} G_{ULB(i)} \Big/ n, \quad (7)$$

where $G_{ULB\ (i)} = RGR_{ULB\ k(i)}$, $NAR_{ULB\ k(i)}$; $k = (j+1) - j$ – just like the previous Eqs.; $K = N - 1 = 3$ – number of interfacial periods.

Average LAD, BMD for each i-th ULB pair ($n = 18$) winter wheat between the phases of ontogenesis $(j+1) - j = k$($LAD_{ULB\ k(i)}$, $BMD_{ULB\ k(i)}$, T – E, E – F, F – M) were calculated based on the general approaches presented by W. Saeed *et al.* (2021), using numerical integration by the trapezoid method:

$$LAD_{ULB(i)} \ or BMD_{ULB(i)} = Z \cdot S \cdot \\ \cdot \sum_{i=1}^{j=N} 0.5\left(D_{ULB\ j(i)} + D_{ULB\ j+1(i)}\right)\left(t_{j+1} - t_j\right) \quad , \quad (8)$$

where $D_{ULB\ j(i)} = A_{ULB\ j(i)}$, $D_{ULB\ j+1(i)} = A_{ULB\ j+1(i)}$ for LAD$_{\mathrm{ULB}\ k(i)}$ or $D_{ULB\ j(i)} = DM_{ULB\ j(i)}$, $D_{ULB\ j+1(i)} = DM_{ULB\ j+1(i)}$ for BMD$_{\mathrm{ULB}\ k(i)}$, $N = 4$ – number of ontogenesis phases (T, E, F, M); Z – conversion factor cm^2 in m^2 (10^{-4}) or mg in kg (10^{-6}), S – see previous Eqs. Calculating average $n = 18$ (LAD$_{\mathrm{ULB}}$, BMD$_{\mathrm{ULB}}$; m^2 m^{-2}/day, kg/m^{-2} day) is similar to Eqs. (6), (7).

Average values of each trait T$_{\mathrm{ULB\ (i),\ IA}}$ (interannual trait) for the i-th pair of ULB (T – M) between 2017-2018:

$$T_{ULB(i)IA} = 1/2 \cdot (T_{ULB(i)2017} + T_{ULB(i)2018}), \quad (9)$$

where T$_{ULB,\ IA}$ – similar to Eq. (7).

Statistical reliability α of differences between numerical quantities of the data in groups (combinations) of research variants (technologies) C.0-2.6, 1.1-1.6, 2.1-2.6 were analysed using univariate analysis of variance (Libre Office Calc Version 5), while t-statistics was used for pairwise comparison (similar to O. Stasiv *et al.* (2023)); the last of these parameters was calculated as previously indicated by S. Brown *et al.* (2020) (the software mentioned above). 2D and part-relation coefficients (*tr*, *pr*, respectively), their α was found in the Statistica Version 10 package (StatSoft Inc). Standard stochastic OLS-dependencies (OLD; spatial data) were constructed and generated in the GNU Regression, Econometrics, and Time-Series Library (the GNU Unix operating system) (all the last specified statistical procedures were previously described by O. Stasiv *et al.* (2023)). The analytical achievement indicators and the autocorrelation (denoted as AC) were tested in the same way as in the previous paper (Stasiv *et al.*, 2023). Eqs. for evaluating D-criterion and the concept of weighing the presence or absence of AC were drawn from P. Das (2019).

The authors adhered to the standards of the Convention for the Protection of Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The study demonstrated that field technologies 1.1-2.6 caused a statistically significant increase in GDM of winter wheat by 31.7-298.6%, compared with C.0 (Fig. 1). Under the conditions of pre-existing technogies 1.2-1.6, 2.2-2.6, this trait of biological productivity of plants increased by 10.0-94.7%, compared to 1.1, 2.1.

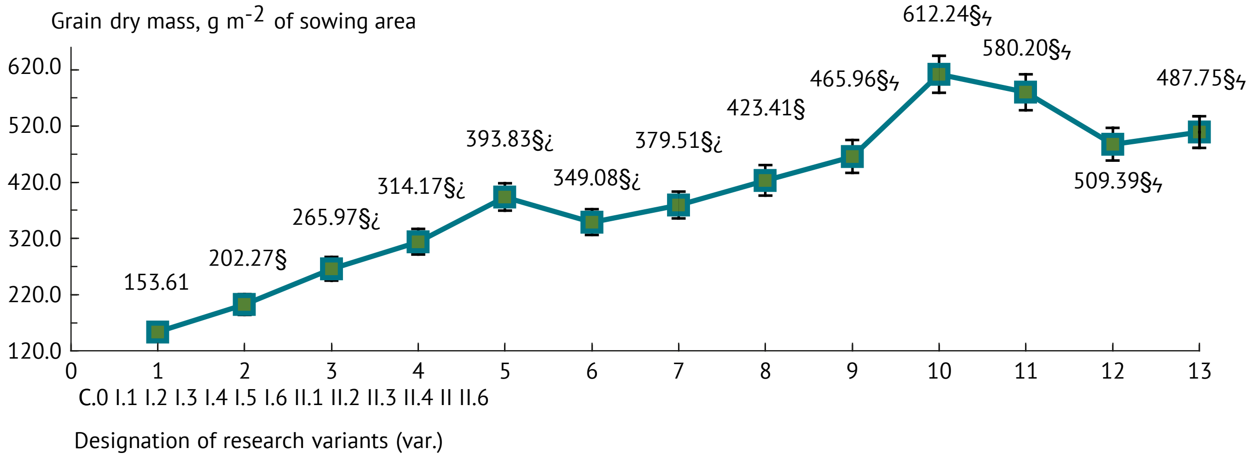

***Figure 1**. GDM of winter wheat depending on the applied field technologies (1.1-1.6, 2.1-2.6) and under control conditions (C.0) (full grain ripeness, 2017-2018)*
***Note:** statistical reliability of differences between one-factor analysis of variance data for C.0 – 2.6, 1.1 – 1.6, 2.1 – 2.6 – $\alpha < 0.001$; §, ¿, ϟ – probability of differences from C.0, 1.1, 2.1 according to the t-criterion – $\alpha < 0.001$*
***Source:** compiled by the authors*

Highly significant decline in NAR_{ULB}, RGR_{ULB} 42.1-61.0% was observed in winter wheat on research variants 1.1, 1.2 with typical comparisons with C.0 (Fig. 2). Simultaneously, there was a decrease in these indices of ULB plant growth rate in the case of field technologies 1.5-2.6 by 45.1-125.6% (*vs.* C.0). In winter wheat under 1.4 conditions, a significant decrease in RGR_{ULB} by 40.3% was observed and, at the same time, only downward trends in NAR_{ULB} (-36.6%, $\alpha < 0.1$), in the case of comparison with C.0. There were no statistically significant changes in NAR_{ULB}, RGR_{ULB} in plants under 1.3 conditions ($\alpha > 0.1$, matching with C.0). However, in 1.3 there was an increase in NAR_{ULB}, RGR_{ULB} of winter wheat by 65.8-103.1% compared to 1.1; in plants under 1.2, 1.4 there was only a tendency to increase NAR_{ULB} by 43.8-62.5%, and no statistically valid changes in RGR_{ULB}, when compared to 1.1. Similarly, there were no statistically reliable changes in the ULB growth rate indices of winter wheat under the conditions of research technologies 1.5, 1.6 (vs. 1.1). In the case of field technologies 2.2, 2.3, 2.5, 2.6, a significant decrease in NAR_{ULB}, RGR_{ULB} plants by 75.0-187.5% was noted, while in conditions 2.4 – only a downward trend in NAR_{ULB} (-120.8, $\alpha < 0.1$), and in addition – a decrease in RGR_{ULB} by 123.5% (all recent comparisons – from 2.1).

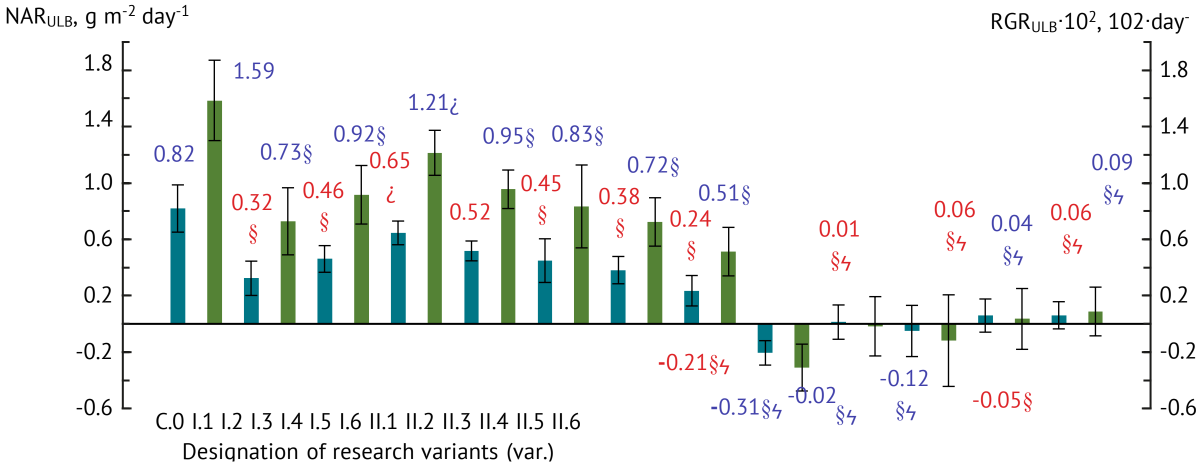

***Figure 2**. Average net assimilation rate NAR_{ULB} and relative growth rate RGR_{ULB} of the upper leave blades (flag leaves and pre-flag leaves) of winter wheat under the conditions of BFS (research variants using of the biologisation factors: 1.1– 1.6, 2.2– 2.6), MF(FD) (2.1) and without fertilisers and biologisation factors (C.0) (tubing-milk ripeness, 2017-2018)*
***Note:** Statistical validity of differences between features based on one-factor analysis of variance for C.0 – 2.6 $\alpha < 0.001$, for 1.1 – 1.6 – $\alpha = 0.069$, $\alpha = 0.080$, 2.1 – 2.6 – $\alpha < 0.001$; §, ¿, ϟ – reliability of differences from C.0, 1.1, 2.1 according to the T-criterion – $\alpha < 0.001$-0.05*
***Source:** compiled by the authors*

Briefly summarising the above-mentioned variations in the growth rate of winter wheat ULB alone, it is clear that all fertilisation systems (field technologies 1.1-2.6) caused a decrease in NAR$_{ULB}$, RGR$_{ULB}$ of winter wheat during the evaluated phases of ontogenesis, compared with C.0. The nuance in this pattern is described under conditions 1.3, 1.4, respectively, or statistically unreliable changes in NAR$_{ULB}$, RGR$_{ULB}$ plants, or just a tendency to decrease NAR$_{ULB}$ fluently with a reliable decrease in RGR$_{ULB}$ of these organisms (vs. C.0). The negative values of NAR$_{ULB}$ and RGR$_{ULB}$ for winter wheat presented here are not unique or incorrect (among other things, an artefact). S. Mohammadi Alagoz *et al*. (2023) reported, respectively, negative RGR, NAR values of triticale variety Giannillo-92 86-93 days after sowing under conditions of 3 levels of salinity and 4 levels of drought, in saffron (*Crocus sativus*), negative growth of leaves of macrophytes *Vallisneria natans* (depending on nitrogen load, fish abundance).

The combined effects in 1.1 – 2.6 caused a significant and statistically reliable increase in the integral growth indicators of ULB in winter wheat LAD$_{ULB}$, BMD$_{ULB}$ by 9.1-233.5% (compared to C.0; Fig. 3). Similarly, in the case of 1.2-1.6, 2.2-2.6, these plant ULB growth indices increased by 12.9-133.3% compared to 1.1, 2.1.

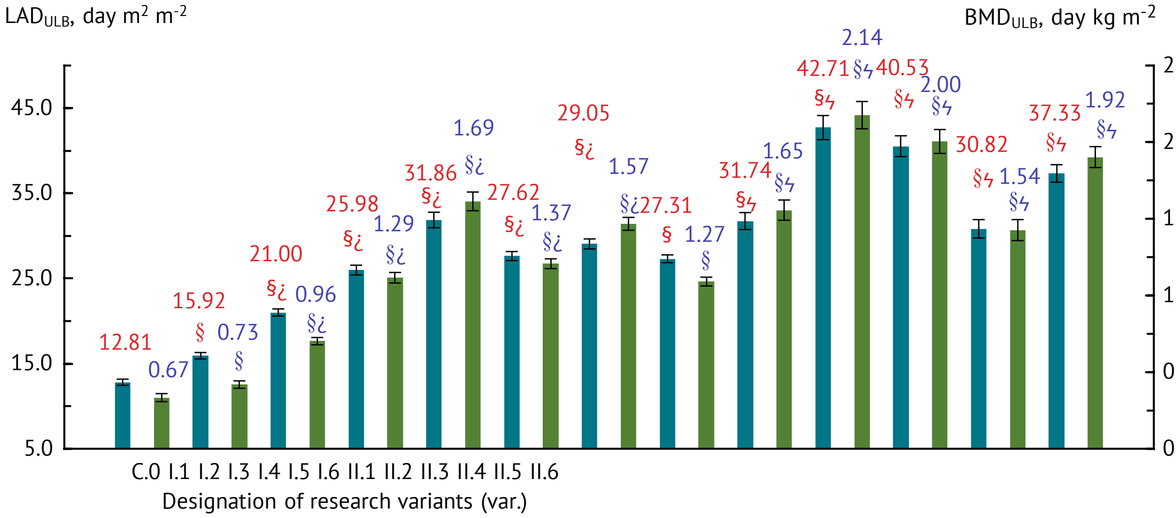

Figure 3. *Average leaf area duration LAD$_{ULB}$, biomass duration BMD$_{ULB}$ of the upper leave blades (flag leaves and pre-flag leaves) for the actions of applied field technologies (1.1-1.6, 2.1-2.6), and under conditions without fertilisation and biologisation factors (C.0); tubing – milk ripeness, 2017-2018)*
Note: *statistical reliability of differences between one-factor analysis of variance data for C.0 – 2.6, 1.1 – 1.6, 2.1 – 2.6 – $\alpha < 0.001$; §, ¿, ϟ – probability of differences from C.0, 1.1, 2.1 according to the t-criterion – $\alpha < 0.001$-0.05*
Source: *compiled by the authors*

The tendencies to mostly statistically reliable decrements of NAR$_{ULB}$, RGR$_{ULB}$, in conjunction with highly reliable increments LAD$_{ULB}$, BMD$_{ULB}$, indicate the opposite response of the Indicated categories of ULB growth signs of winter wheat to agrotechnical influences in the research technology groups both 1 and 2, compared with C.0. Significant increases in LAD$_{ULB}$, BMD$_{ULB}$ of plants and much less statistically defined variations in their NAR$_{ULB}$, RGR$_{ULB}$ in the case of 1.2-1.6, 2.2-2.6, create opportunities for identifying different responses of these two categories of ULB growth traits of these organisms to technologies of groups 1 and 2, also in comparison with 1.1, 2.1. Higher values and higher increments of LAD$_{ULB}$, BMD$_{ULB}$ of winter wheat on 2.1-2.6, 2.2-2.6 (comparison with C.0, 2.1), than on 1.1-1.6, 1.2-2.6 (comparison with C.0, 1.1), at the same time lower values and larger decrements of NAR$_{ULB}$, RGR$_{ULB}$ of plants on 2.1-2.6, 2.2-2.6 (comparison with C.0, 2.1), than on 1.1-1.6, 1.2-1.6 (comparison with C.0, 1.1) may indicate different sensitivity of the two categories of ULB growth traits of these organisms to experimental groups 1 or 2.

However, questions about the detailed reasons for these inventions are beyond the scope of this section and, in general, this study. Other important findings are that the patterns of variation of LAD$_{ULB}$, BMD$_{ULB}$ but not NAR$_{ULB}$, RGR$_{ULB}$, were, in general, similar to those for GDM. The presented statements highlight a certain intrigue around the subordination between the classical "interval" signs of ULB growth and the ecological and physiological features of the production process of winter wheat under the conditions of the studied agrotechnical influence (P.0, 1.1-1.6, 2.1-2.6). This provides quite natural grounds for elucidating the (mutually) predestination of GDM by the ULB growth traits presented here, and the (mutually) subordination of the latter to each other using typical tr analysis approaches. The comparisons of GDM with

NAR_{ULB} or RGR_{ULB} revealed statistically significant negative correlations between them (Table 2). On the contrary, there are highly probable but positive tr between GDM and LAD_{ULB}, BMD_{ULB}. In this case, all empiric correspondences between independent variables (Vrb.; IV) for the discussed correlation matrix (NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}) were high in absolute value and statistically significant.

Table 2*. Values of tr for the winter wheat indicators under study*

Trait	*M*	*N*	*L*	*R*
N	-0.8098$^{\times}$	–	-0.7121ǂ	0.9955$^{\times}$
L	0.9726$^{\times}$	-0.7121ǂ	–	-0.7608ǂ
R	-0.8519$^{\times}$	0.9955$^{\times}$	-0.7608ǂ	–
B	0.9503$^{\times}$	-0.6786†	0.9906$^{\times}$	-0.7297ǂ

Note: *N, L, R, B, M – $NAR_{(ULB)}$, $RGR_{(ULB)}$, $LAD_{(ULB)}$, $BMD_{(ULB)}$, GDM; $^{\times}$, ǂ, † – $\alpha < 0.001$, $\alpha < 0.01$, $\alpha < 0.05$, respectively*
Source: *developed by the authors based on O. Stasiv et al. (2023)*

To better understand the internal configuration of interdependencies, the detection of collinearity (denoted as the MC) or statistical elimination (SE), an analysis *pr* was performed between considered Vrb. (Table 3) and comparison of this criterion with *tr*, similarly to (Stasiv *et al.*, 2023). Only 3 statistically reliable differences were found ($\alpha < 0.001$-0.05) *pr* for *M-L*, *N-R*, *L-B* (control Vrb., respectively, *N*, *R*, *B*; *M*, *L*, *B*; *M*, *N*, *R*).

Table 3*. Values of pr between the winter wheat indicators under study*

Index	*M*	*N*	*L*	*R*
N	0.4049	–	-0.2346	0.9927$^{\times}$
L	0.7226†	-0.2346	–	0.2689
R	-0.4810	0.9927$^{\times}$	0.2689	–
B	-0.3966	0.2597	0.8955$^{\times}$	-0.2648

Note: *N, L, R, B, M – $NAR_{(ULB)}$, $RGR_{(ULB)}$, $LAD_{(ULB)}$, $BMD_{(ULB)}$, GDM; pr for any 2 indexes are presented considering that the remaining 3 belong to the control Vrb.; $^{\times}$, † – $\alpha < 0.001$, $\alpha < 0.05$, respectively*
Source: *developed by the authors based on O. Stasiv et al. (2023)*

Comparative assessments of *tr*, *pr* in Table 2 and Table 3 provided the following results: 1) between IV *N*, *L*, *R*, *B* there is an MC (by absolute values *tr* and comparison *tr* with *pr*, according to A. Kalnins (2018) and P. Das (2019)); 2) SE of the Vrb. (Martinez Gutierrez & Cribbie, 2021) between the considered traits is absent. Nevertheless, the analysis of *tr*, *pr* does not allow predicting exactly how GDM can be determined by NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB} separately or in combinations according to TAE categories 1, 2 in the "INTRODUCTION" section, and what is the probable form of consistency between RGR_{ULB} and NAR_{ULB} (TAE categories 3, 4; "INTRODUCTION" section) or NAR_{ULB}, RGR_{ULB}, BMD_{ULB} on the one hand and LAD_{ULB} – on the other hand (hypotheses of the authors of this paper). Within the outlined framework and considering TAE categories 1, 2, it is clear that $\log_e$TDM is an allomeric function $\log_e$NAR and $\log_e$LAD, or $\log_e$RGR and $\log_e$BMD. However, $\log_e$GDM is not identical to $\log_e$TDM plants, nor $\log_e$DM of the ULB and therefore cannot be immediately represented in a list of terms containing $\log_e NAR_{ULB}$ and $\log_e LAD_{ULB}$, or $\log_e RGR_{ULB}$ and $\log_e BMD_{ULB}$. (Since among the NAR_{ULB}, RGR_{ULB} if there are values less than 0, then instead of $\log_e N$, $\log_e R$ in the future, the logarithms of the squares corresponding to Vrb. were used.)

Such considerations are valid for *R* = *f(N)* (TAE categories 3, 4, and for assumed predestinations *N*, *R*, *B* with index *L*. In connection with the above, the authors of this paper found conceptually characterised coordinates as OLD with the use of an untransformed criterion variable and IV, using making a linear path(MLP) exponential-power (LE), semi-*log* (SL), *log* (LG) and modified *logit* or *log*-normal (ML) Eqs., power-univariate polynomial (PP) functions; selected the best and at the same time the simplest OLD; for each univariate Eq . or multivariate multinomials Eq. sequential IV exclusion based on two-way values was performed α = 0.01-0.1 (typical approach in GNU Regression, Econometrics and Time-Series Library) (all this is similar to the previous post (Stasiv *et al.*, 2023)). Depending on "single-" or "multi-regression", the type of criterion Vrb. (*M*, or *N*, or *N*, *R*, *B*), and compliance with TAE classical analysis of plant growth (TAE categories 1, 2, 3, 4), or to the consistency of N, R, B with the L trait assumed by the authors of this paper, the obtained OLD were divided into 4 categories. This classification of OLD certainly differs from the one previously presented by O. Stasiv *et al.* (2023), but to a certain extent consistent with the principles of the conditional process analysis and, among other things, contains components of moderation and mediation of the Vrb. (Hayes & Rockwood, 2020; Igartua & Hayes, 2021).

Category 1. 2-regressor polynomial predestination $\log_e M$ signs N, L (LE-function – (10A-1), (10b-1)), $\log_e M$ by IV $\log_e R^2$, $\log_e B$ (LG-function, or "logarithm dependence" of the LE – (11-1) type), and $\log_e (M_m \cdot 10^4/M) = b_0 + b_2 L + b_3 R + b_6 L^2$ as a result of sequential exclusion of IV from the OLD type $\log_e (M_m \cdot 10^4/M) = b_0 + b_1 N + b_2 L ++ b_3 R + b_4 B + b_5 N^2 + b_6 L^2 + b_7 R^2 + b_8 B^2 + b_9 N \cdot L + b_{10} R \cdot B$ (multinomial ML-function – (12-1)).

$$\log_e M = 4.001 + 0.311 \cdot L - 0.010 \cdot L^2 - 0.030 \cdot N \cdot L$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01, \quad (10a\text{-}1)$$

$$\log_e M = 4.272 - 0.282 \cdot N + 0.262 \cdot L - 0.008 \cdot L^2$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01 \quad ,(10b\text{-}1)$$

$$\log_e M = 6.109 - 0.096 \cdot \ln R^2 - 0.428 \cdot \ln^2 B - 0.007 \cdot \ln^2 R^2$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.05, \quad (11\text{-}1)$$

$$\log_e (615 \cdot 10^4/M) = 11.314 - 0.258 \cdot L + 0.162 \cdot R + 0.008 \cdot L^2$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.05, \quad (12\text{-}1)$$

where $\alpha < 0.1$, $\alpha < 0.05$, $\alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 2. Linear and power polynomial coordinates $\log_e M$ separately from IV N, L, R, B (LE functions – (13A-2) – (16-2)).

$$\log_e M = 6.216 - 1.070 \cdot N$$
$$\alpha < 0.01 \; \alpha < 0.01, \quad (13a\text{-}2)$$

$$\log_e M = 6.362 - 1.902 \cdot N - 7.231 \cdot N^2 + 30.586 \cdot N^3 - 26.084 \cdot N^4$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.1 \; \alpha < 0.05 \; \alpha < 0.05, (13b\text{-}2)$$

$$\log_e M = 4.004 + 0.281 \cdot L - 0.008 \cdot L^2,$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.05, \quad (14\text{-}2)$$

$$\log_e M = 6.234 + 0.587 \cdot R,$$
$$\alpha < 0.01 \; \alpha < 0.01, \quad (15a\text{-}2)$$

$$\log_e M = 6.290 - 10.588 \cdot R^4 + 40.002 \cdot$$
$$\cdot R^6 - 42.034 \cdot R^7 + 12.242 \cdot R^8$$
$$\alpha < 0.01 \; \alpha < 0.05 \; \alpha < 0.1 \; \alpha < 0.1 \; \alpha < 0.1, (15b\text{-}2)$$

$$\log_e M = 4.134 + 5.271 \cdot B - 3.007 \cdot B^2$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.1, \quad (16\text{-}2)$$

where $\alpha < 0.1$, $\alpha < 0.05$, $\alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 3. ML-predestination R by N.

$$\log_e\big((1.65/R + 4 \cdot 10^2) \cdot 10^5\big) = 17.765 + 0.357 \cdot \log_e N^2 +$$
$$+0.210 \cdot \log_e \log_e^2 N^2 +$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.01,$$
$$+0.098 \cdot \log_e^2 \log_e N^2 - 0.049 \cdot \log_e \log_e^2 \log_e N^2$$
$$\alpha < 0.01 \; \alpha < 0.1 \quad (17\text{-}3)$$

where $\alpha < 0.1$, $\alpha < 0.05$, $\alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients.)

Category 4. Coordinations N, R, B with a trait L (ML-multimomials – (18-4), (19-4), PP-functions – (20-4)).

$$\log_e(-0.395 \cdot 10^5/\log_e N^2) = 11.103 - 0.051 \log_e L^4$$
$$\alpha < 0.01 \; \alpha < 0.01, \quad (18\text{-}4)$$

$$\log_e((1.65/R + 4 \cdot 10^2) \cdot 10^5) = 17.590 - 0.002 \cdot L^3 +$$
$$+ 0.332 \cdot 10^{-3} \cdot L^4 - 1.427 \cdot 10^{-5} \cdot L^5$$
$$\alpha < 0.01 \; \alpha < 0.05 \; \alpha < 0.05 \; \alpha < 0.05, \quad (19\text{-}4)$$

$$B = 0.105 + 0.648 \cdot 10^{-2} \cdot L^2 - 0.024 \cdot 10^{-2} \cdot L^3$$
$$\alpha < 0.01 \; \alpha < 0.01 \; \alpha < 0.1, \quad (20\text{-}4)$$

where $\alpha < 0.1$, $\alpha < 0.05$, $\alpha < 0.01$ under OLD – corresponding statistical reliability of OLD coefficients).

(Accompanying descriptions: 615, 1.65, -0.395 represent the theoretical (expected) maximum values of the criterion Vrb.; 10^2, 10^4, 10^5 – a posteriori values for "fitting" OLD; M, N, L, R, B – GDM, NAR_{ULB}, LAD_{ULB}, RGR_{ULB}, BMD_{ULB}, respectively). Of course, the fact of suboptimal complexity for Eq. interpretations (21-3) is an additional reason and substantiation for the search for alternative predestinations N, R, B by L (OLD category 4). However, all the OLD presented above were marked with statistically suitable characteristics in the plans for checking linearity (squares, cubes, squares + cubes, logarithms), heteroskedasticity (White, Breusch-Pagan), normal distribution of residuals, and structural stability of the data sample (See O. Stasiv *et al.* (2023)).

To evaluate the analytical achievement indicators generated by OLD, the study used "standard" highly professional measures, in particular for the field of "Econometrics", built into the GNU Regression, Econometrics and Time-Series Library: 1) standard sampling error (*SSE*); 2) Fisher's coefficient (Φ); 3) adjusted coefficient of determination (*ACD*); 4) mean absolute %-error ($E_{MA\%}$); 5) logarithm of the likelihood (*lL*), Akaike, Bayesian, Hennan-Quinn information measures – AIM, BIM, HQM; 6) Theil *U* decomposition criterion; 7) AC-criterion; 8) MC-criterion - fractions of variances (ϕ), variance-inflation coefficients (ν), predestination numbers (η) (similar to the previous study by O. Stasiv *et al.* (2023)). All generated Eqs. described Φ C $\alpha \leqslant 0.001-0.01$ (Table 4). Least satisfactory *SSE*, *ACD*, $E_{MA\%}$ were inherent to Eqs. (13a-2), (18-4); most suitable *SSE*, *ACD*, $E_{MA\%}$ – in (10a-1)-(12-1), (14-2), (16-2), (20-4); intermediate *ACD*, *SSE*, $E_{MA\%}$ – in Eqs. (13b-2), (15a-2), (15b-2), (17-3), (19-4).

***Table 4**. Key analytics dashboard of the generated OLD (of the individual and by category)*

# and category of OLD	**General criteria of statistical reliability**				***lL***	**Highly specific information measures**		
	$E_{MA\%}$	**Φ**	***ACD***	***SSE***		***AIM***	***BIM***	***HQM***
Category 1								
10a-1	0.612	176.592ʃ	0.9777	0.061	20.361	-32.723	-30.463	-33.187
10b-1	0.652	178.814ʃ	0.9780	0.060	20.441	-32.882	-30.623	-33.347
11-1	0.637	153.864ʃ	0.9745	0.065	19.482	-30.964	-28.704	-31.428
12-1	0.388	188.456ʃ	0.9791	0.059	20.777	-33.554	-31.294	-34.019
Category 2								
13a-2	3.492	17.657ʃʃ	0.5813	0.263	-0.013	4.027	5.157	3.795
13b-2	2.125	8.910ʃʃ	0.7250	0.213	4.790	0.420	3.244	-0.161
14-2	1.008	128.278ʃ	0.9550	0.086	15.102	-24.201	-22.510	-24.553
15a-2	3.154	23.769ʃ	0.6549	0.239	1.243	1.514	2.644	1.281
15b-2	2.212	9.650ʃ	0.7425	0.207	5.217	-0.434	2.391	-1.014
16-2	1.637	56.966ʃ	0.9032	0.127	10.124	-14.249	-12.554	-14.597
Category 3								
17-3	0.164	8.013ʃʃ	0.7004	0.047	24.342	-38.685	-35.860	-39.266
Category 4								
18-4	4.106	18.946ʃʃ	0.5993	0.550	-9.594	23.188	24.318	22.956
19-4	0.155	14.245ʃ	0.7680	0.042	25.241	-42.481	-40.221	-42.946
20-4	3.321	357.598ʃ	0.9834	0.020	34.259	-62.518	-60.8234	-62.867

Note: *ʃ, ʃʃ – $\alpha \leqslant 0.001$, $\alpha \leqslant 0.01$; $E_{MA\%}$, Φ, ACD, SSE, lL, AIM, BIM, HQM – mean absolute %-error, Fisher's statistics, adjusted coefficient of determination, standard sampling error, logarithm of the likelihood, Akaike, Bayesian, Hennan-Quinn information measures, respectively*

Source: *developed by the authors based on O. Stasiv et al. (2023)*

Mostly, clear correspondences between *SSE*, *ACD*, $E_{MA\%}$ on the one hand and *lL*, and AIM, BIM, HQM – on the other hand, detected for the groups of Eqs. (10a-1)-(12-1), (14-2), (16-2), (20-4), and for Eqs. (17-3), (19-4) (Table 4; comparison with O. Stasiv *et al.* (2023)). Low *lL* (among other things *lL* < 0), significant AIM, BIM, HQM (among other things > 0) confirm the low probability of analytical forms of predestination *M* sign *N*, or *N* trait *L* in Eqs. (13a-2), (18-4), *M* by Vrb. *N* or *R* in Eqs. (13b-2), (15a-2), (15b-2).

Value of Theil (*U1*) inequality coefficients for all subordinates were << 1 (0.00099-0.02596) and > 0, certifying their total forecast accuracy and quality (Fang *et al.*, 2020). Other relevant measures of Theil U decomposition of the mean error MSE – the disturbance proportion (UD – is a result from source of the random error), the regression proportion and the bias proportion (UR, UM, respectfully; they are the result from sources of systemic errors in model parameters) had optimal values for each OLD, *i.e.,* 1, 0, 0, respectively, thus confirming the totals in the previous sentence (Ferrentino & Vota, 2020).

None of the AC were found in the list of generated Eqs. However, unlike the previous notice (Stasiv *et al.*, 2023) Eqs. (10a-1), (10b-1), (12-1) – (15b-2), (17-3), (19-4), (20-4) had unknown zones for AC (Table 5). It is worth noting that the Vrb. *M*, *N*, *L*, *R*, *B* are estimates of ecological and physiological processes in winter wheat crops. Anumber of researchers, in particular J. Martínez-Minaya *et al.* (2018), G. Gaspard *et al.* (2019), formulated the idea that the structure of the development of ecological or biological processes is developed under the conditions of interaction of "spatial" and "temporal" abiotic and biotic factors, causing spatial autocorrelation (SAC), rSAC (residual SAC), and temporal correlation. In addition, the researchers emphasise that the potential source of AC, rSAC, may be some features that arise in the course of obtaining and processing environmental data, for example, failure to take into account of the contagious biotic processes (growth, mortality, etc.), scales and distances, inability to choose the appropriate localised and Vrb. with SAC (omitted Vrb), sample design, hypotheses and methodological approaches, etc. The authors of this paper are inclined to assume that the uncertain zones for AC in the above-mentioned OLD (this paper) are at least partly conditioned by the failure to take into account the not yet established aspects of (inter-) coordination between ULB growth traits, an insufficiently perfect analytical form, and/or omitted Vrb. Optimal ways out of this situation could be to change the analytical forms of the corresponding OLD using basic functions, including Moran I (Pedersen *et al.*, 2019), and in the directions of the generalised additive model (GAM), the hierarchical generalised linear models (HGLM) (Pedersen *et al.*, 2019), the generalised additive mixed models (GAMM) (Baayen *et al.*, 2018). A well-known alternative to such approaches – consideration of AC in OLD – can be done by looking for AC coefficients and data lags, and constructing AR, MA, ARMA and ARIMA, as mentioned by P. Das (2019).

***Table 5**. The most important benchmarks of the AC and MC for the OLD (of the individual and by category)*

# and category of OLD	***AC-criteria***			***MC-criteria***		
	D-criterion	**ρ>0 or ρ<0**	***Uncertainty zone***	**η (max)**	**ϕ (total interval)**	**ν (total interval)**
Category 1						
10a-1	3.03861	None	Yes^{b}	47.525	0.885-1.000	1.433-37.027
10b-1	2.86054	None	Yes^{b}	46.460	0.861-1.000	2.030-33.490
11-1	1.83745	None	None	10.629	0.915-0.988	1.769-14.533
12-1	2.85631	None	Yes^{b}	10.074-46.673^{c}	0.767-1.000^{d}	2.375-33.859
Category 2						
13a-2	1.10258	None	Yes^{a}	–^{e}	–^{e}	–^{e}
13b-2	1.13358	None	Yes^{a}	18.927-87.332^{c}	0.693-1.000^{d}	12.580-862.448
14-2	1.47929	None	Yes^{a}	43.006	0.942-1.000	32.683-32.683^{f}
15a-2	1.16510	None	Yes^{a}	–^{e}	–^{e}	–^{e}
15b-2	1.12215	None	Yes^{a}	12.134-6438.357^{c}	0.567-1.000^{d}	14429.852-5710158.011
16-2	1.83822	None	None	44.468	0.944-1.000	38.110-38.110^{f}
Category 3						
17-3	1.81374	None	Yes^{a}	64.594	0.598-1.000	7.536-223.971
Category 4						
18-4	1.66049	None	None	–^{e}	–^{e}	–^{e}
19-4	1.40682	None	Yes^{a}	19.945-409.846^{c}	0.678-1.000	2834.572-14396.170
20-4	2.81928	None	Yes^{b}	31.429	0.815-1.000	46.188-46.188^{f}

Note: *ρ – AC-coefficient; ^{a}, ^{b} – zones of uncertainty AC at intervals $dL < D < dU$, $4\text{-}dU < D < 4\text{-}dL$, respectively; n, ϕ, ν – predetermination numbers, fractions of variances, variance-inflation coefficients, respectively; ^{c}, ^{d} – intervals for N (max) and ϕ in the presence of $N \geqslant 10$ - $N \geqslant 30$; ^{e} – MC-criteria are missing because Eq. contains only one variable; ^{f} – ν is the same in the case of the 1st and 2nd Vrb*

Source: *developed by the authors based on O. Stasiv et al. (2023)*

Similarly, to the report by O. Stasiv *et al.* (2023), in multi-step polynomial and single-step multi-step multi-step Eqs. generated in this paper, ((10a-1) – (12-1), (13B-2), (14-2), (15b-2) – (17-3), (19-4), (20-4)), a significant MC in terms of ϕ, ν, η was observed (Das, 2019; Kim, 2019) (Table 5). According to A. Kalnins (2018), MC can often be driven by a common cause with IV (a common source of measurement error or a statistically robust unobserved Vrb.) and a significant but idiosyncratic term. This phenomenon can cause type 1 errors (false positive results) – an overestimation of the β of the OLD, their statistical validity, and a change in the sign to the opposite. Therefore, MC, like AC or uncertainty zones for AC, can be caused by the influence of the omitted reasons on the behaviour of IV; however, the nature of such reasons and their effect on IV is different in each case.

Additionally, attention should be paid to the fact that Eqs. (10a-1)-(12-1), (14-2), (16-2) are mostly non-hierarchical (with the exception of (14-2), (16-2)) polynomial predestinations of the criterion Vrb. by the IV, it is clear that such properties of analytical forms will lead to overfitting OLD (Montgomery, 2021). However, D. C. Montgomery (2021) noted that the use of multilingual OLD is appropriate for approximating functions with unknown and possibly very complex nonlinear dependencies, i.e., similar to those found in this paper. Interesting in this sense is, in particular, that polynomial regression can be both an "essential" process in artificial neural networks and an alternative to the latter (Cheng *et al.* 2018). Therefore, polynomial regression can be considered as, to some extent, an alternative to machine learning algorithms, and as a means for solving complex nonlinear problems.

The authors of this study suggest that Eqs. (10a-1)-(12-1), (14-2), (16-2) for predestination *M* by the IV *N*, *L*, *R*, *B*, and also *R*, *B* by the IV *L* (OLD (19-4), (20-4)) empirically and stochastically satisfactorily describe the conditionality and subordination between the evaluated ecological and physiological characteristics of winter wheat under the studied agrotechnical influences. Naturally, the presence of omitted Vrb., that affect such coherence is an objective condition for the existence of the latter. Eqs. (17-3), which characterises predestination of *R* by the *N* unfortunately, cannot be conbsidered properly due to the excessive complexity of its interpretations.

DISCUSSION

Decrease to positive values or immutability of NAR_{ULB}, RGR_{ULB} in research variants *vs.* C.0, 1.1, 2.1, at least to some extent, were conditioned by the balance between (i) increase or stabilisation of DM, DMI_{ULB}, $LDMC_{ULB}$ (explained by J.L. Miglioli *et al.* (2020), at defoliation – K.E. Mueller *et al.* (2024)), respectively, with unidirectional AI_{ULB} changes, and probably LAR, LNC, LPC (under defoliation – R. Bhadouria *et al.* (2023)), a decrease in the intensity of photosynthesis (Rezvani-Moghaddam, 2020) (tubing – flowering; early leaf ageing), (ii) a subsequent decrease in photosynthetic activity, typical increases in the rate of respiration (Rezvani-Moghaddam, 2020), outflow of photoasimilates and remobilisation of ULB resources, accompanied by a decrease in DMI_{ULB}, $LDMC_{ULB}$, AI_{ULB} (earing – milky ripeness). The changes in DMB_{ULB}, AI_{ULB} specified in (ii) can lead to RGR_{ULB}, $NAR_{ULB} \leqslant 0$ (Lamont *et al.*, 2023). Since, according to J. Gu *et al.* (2018), negative leaf growth is accompanied by a decrease in plant RGR, then winter wheat with RGR_{ULB}, $NAR_{ULB} < 0$ reached full ripeness the fastest. Simultaniously, LAD_{ULB}, BMD_{ULB} changed reciprocally, relative to NAR_{ULB}, RGR_{ULB}. Such trade-offs can be scaled to the level of plants, leaf cover, and mediate the development of optimal eco-resistant results of the winter wheat production process.

A. Bilal *et al.* (2019) demonstrated that for TDM–seed Bt. cotton yield $tr = 0.94$, $\alpha \leqslant 0.05$. Therefore, the components of bioproductivity can be significantly determined by GI – NAR, LAD, RGR, BMD. For example, after exposure to biological agrotechnical factors on alfalfa, both NAR, RGR, and CGR grew, parts of which are components of biological products (Khirkhah *et al.* 2019). Confirming this, H. Tiwari *et al.* (2023) documented unidirectional increase of RGR, NAR, CGR, bio-productivity components, wheat harvest index (HI), whereas P. Kumar and S.K. Brar (2021) cited studies in which there were simultaneous increases in LAD, NAR, CGR, and HI. Simultaneous increases in LAI, CGR, and yield structure indicators in wheat (Khan *et al.*, 2023), LAI, NAR, dry matter volumes and economic productivity of rice (Islam *et al.* 2019). It is well known that FLB ("functional leaves") is important for providing 45-58% of wheat's photosynthetic activity at the grain completion stage (Liu *et al.,* 2019), the contribution of more than 80% of the top three leaves of cereals to photosynthesis of the entire plant at the grain maturation stages (Du *et al.* 2019). However, the authors of this paper did not find scientific reports with a comprehensive analysis of the (inter-) conditions of the classical interval GI of the upper leaves (in particular, FLB, PFLB) and a bioproductivity of winter wheat (*Triticum aestivum* L.) due to the influence of agrotechnical and technological factors on it.

This paper documents the presence of stochastic essential 2D GDM–LAD_{ULB} co-subordination of, low-expressive 2D GDM-BMD_{ULB} co-ordinations, and the absence of statistically clear subordination of GDM-$NAR_{ULB,}$ GDM-BMD_{ULB}. The presentation of the determinants of the GDM growth trait ULB, and then the individual GI analytical forms of OLD among themselves, allowed a deeper and more diverse understanding of the complex principles of development of the final bioproductivity of winter wheat (primarily in terms of $\pm \Delta DMI_{ULB}$, $\pm \Delta AI_{ULB}$) under "model" conditions of BFS. Among the generated OLD that characterise the development of GDM depending on GI of the ULB, Eqs. (10a-1)-(12-1), (14-2), (16-2) is completely statistically satisfied. It follows from them that not *M*, but $\log_e M$ are non-linearly determined by 2-regressor conjugations *N*, *L* or *R*, *B* ((10a-1), (10b-1)), whereas MLP ML function *M* – combinations of *L* and *R* (12-1) (multinomials). In (10a-1), (10b-1) $\log_e M$ is positively coordinated with *L*, but negative – with L^2, N, $N \cdot L$, at the same time, in (12-1) the MLP ML function *M* is negatively predetermined *L*, but positive – L^2, R. In (11-1), $\log_e M$ is effectively coordinated with $\log_e R^2$, $\log_e B$ but not with *R*, *B*.

Considering TAE category 3 ("INTRODUCTION"), the basis of the relevant ideas published by S. Tripathi *et al.*, (2018), it is clear that (i) light intensity, (ii) reach, capture of alimentary resources from the soil and/or atmosphere, (iii) their interactive effects affect RGR, and each of the growth components: an increase in (ii) causes an increase in LAR by increasing LMF, RMF (root mass fraction), a decrease in LMA; an increase in (i) causes an increase in NAR, LMA, and a decrease in LAR; multivariate studies are important for understanding (iii) (Tripathi *et al.*, 2018). Typically, NAR variations lead to RGR changes if NAR does not have a negative covariance with LMF or SLA (Gómez-Fernández *et al.*, 2022). In accordance with the presented ideas, plant biomass allocation (BA) takes place in line with the "theory of optimal biomass allocation": for optimal growth, plants will distribute biomass to the organ that captures the most growth-limiting resources. Differences in ontogenetic drifts of GI and BA also lead to trade-offs, in particular between NAR and LAI, or RGR, and investment in structural components, tissue renewal, and self-shading (Islam *et al.*, 2019). The trade-offs (NAR_{ULB}, RGR_{ULB}) – (LAD_{ULB}, BMD_{ULB}) found in this paper, statistically reliable negative values *tr* for LAD_{ULB}–NAR_{ULB}, BMD_{ULB}–RGR_{ULB} resemble the constructs of plant GI ratios outlined in this paragraph; significant *tr*, *pr* for RGR_{ULB}-NAR_{ULB} allow predicting $RGR_{ULB} \sim NAR_{ULB}$ (as confirmation – TAE category 4 ("INTRODUCTION"). Through nonlinear coordination of the ML function *R* with $\log_e N^2$ (Eq. (17-3), interpretive suboptimality) a likely alternative would be $RGR_{ULB} \sim SLA_{ULB}$ or the involvement of the nearest morphological Vrb. – LAD_{ULB}: this is consistent with significant positive and negative values *tr* for LAD_{ULB}-BMD_{ULB}, LAD_{ULB}-NAR_{ULB}, LAD_{ULB}-RGR_{ULB}, statistically reliable positive *pr* for LAD_{ULB}-BMD_{ULB}; mathematically SLA ~ LAI (LAD component) and SLA ~ 1/LDM (Bosi *et al.* 2020). Therefore, non-hierarchical polynomial OLD was generated between ML functions N^2, *R*, *B* and *L*, among which the second (19-4) and third (20-4) are statistically satisfied; these Eqs. are less difficult than (17-3).

According to K. Kikuzawa *et al.* (2018), and according to TAE category 3, the larger the RGR, the smaller the LMA and is directly proportional to it by LL. According to this, leaf economic spectrum (LES) is considered: long-lived plant species with structurally valuable leaves (high LL, LMA), low instantaneous net photosynthetic rate Aarea, NAR – fast-growing species with short-lived leaves, high RGR, Aarea (NAR), low LL, LMA. Both in the case of TAE categories 1, 2 and in terms of functional ecology, the increase in carbon over plant life (net production) is proportional to the products of (i) functional LL or biomass duration, respectively, and (ii) of the average instantaneous rate of photosynthesis normalised by weight. This implies a close or identical essence of LAD, BMD, and LL. The influence of LAI on LL was previously noted by I.C. Dodd and E.D. Elphinstone (2021). Consequently, LAD, BMD play a central role in classical plant growth analysis, whereas LAD_{ULB}, BMD_{ULB} – significantly determine the remaining signs of ULB growth and probably GDM. This opinion corresponds to the correlation matrices presented in this paper (the value and statistical reliability of mutual agreements with *L*, *B*). The contribution of *L* is significant and statistically reliable in the development of $\log_e M$ in (10a-1), (10b-1), (12-1), (14-2), ML functions *R* (19-4), in deployment *B* (20-4); it is important that $\log_e M \sim \log_e{}^2 B$ (11-1).

Since OLD $\log_e M$ from *N* or *R* in (13A-2), (13B-2), (15A-2), (15B-2) are characterised by unsatisfactory *lL*, and AIM, BIM, HQM, then GDM should not depend on NAR_{ULB} or RGR_{ULB}, either depend on them weakly, or non-linearly. This corresponds to the basic concepts proposed by J.L. Araus *et al.* (2021): the result of the production process of agricultural crops is not determined or insufficiently, or is not directly determined by the efficiency of leaf photosynthesis, but source-sink relations, RUE, architecture and duration of the (green) leaf cover play a crucial role in its development. The latter type of traits will be determined by the functional LL, LAD size of the culture population. This makes it fundamentally possible to scale to the level of leaf cover of LAD_{ULB}, BMD_{ULB} – the most important GI of the ULB for GDM development. Thus, in the "successful" OLD (10A-1) – (12-1), except *L* or *B*, also present *N* or *R*. Since NAR_{ULB}, RGR_{ULB} characterise the average rate of BA in the area or ULB biomass, then it is reasonable to assume that GDM can be caused by BA, both at the level of ULB and at the level of parts of the whole plant, in particular the structures of reproductive organs.

Thus, the statistically reliable (inter-) dependence of winter wheat GDM (full maturity) on LAD_{ULB} and BMD_{ULB} (tubing – milky ripeness), i.e., on ULB growth traits that can be scaled to the level of crop leaf cover, is fundamentally explainable. These subordinates do not contradict, but rather correspond to, (mutually) coordinated ULB-growth terms, similar to multipliers in TAE category 3 ("INTRODUCTION"), with the LAD_{ULB} trait.

The authors of this study consider a middle way between the approaches proposed by M. Weemstra *et al.* (2023) to consider plant functional traits (PFT) of the whole plant (underground + aboveground parts) and, for example, the findings of N. An *et al.* (2021), which attest to the influence of agroclimatic conditions on resource capture and leaf construction costs (SLA, LMA, LDMC, LNC), and, in particular, the findings of J.L. Araus *et al.* (2021) in terms of prioritisation of plant traits that scale to leaf cover, crown, and seeding. It is clear that in subsequent studies, it is advisable to search for similar allometric Eqs. (10A-1)-(16-2) GDM predeterminations not only by the GI of the ULB, but also by features similar to BA (DM investment in the ULB – LMA_{ULB} area, area reinvestment in DM of ULB-SLA_{ULB}, average leaf area, leaf DM – dimensions of source), of the reproductive allocation (RA, see G. Li *et al.* (2019); average volumes of ULB biomass outflow on leaf DM, or GDM, or GDM/leaf DM), among other things, for the purpose of "embedding" the GI of classical growth analysis of even ULB itself in broader, but still compact systems of causal relationships woven into the processes of formation of potential, relevant bio-, eco-important and economically valuable features under various agrotechnical and technological influences. The development of appropriate networks and/or groups of plant traits can help solve a number of inconsistencies in the scientific area.

CONCLUSIONS

The potential possibilities and significance of empirical and statistical (mutually) predeterminations of the levels of an agroecologically important component of the production process of winter wheat (grain dry mass, single-character designation – *M*) potentially scalable integral growth traits of the upper leaves blades (ULB), which characterise the development power of their photosynthetic apparatus – leaf area duration or biomass duration (*L*, *B*, respectively), under the conditions of "model" biological and agrotechnical influences (biologised fertilisation systems – BFS). For the development of *M*, the consolidated additive effects of one of the above-mentioned ULB growth traits and non-scaled features of the average ULB growth rate (net assimilation rate, relative growth rate – *N*, *R*), for example, combinations *N* and *L*, or *R* and *B*, or *L* and *R*. Statistically reliable unidirectional changes of *L*, *B*, on the one hand, and *M* – on the other hand, and simultaneous inversely directed variations *N*, *R*, found obvious trade-offs (in terms of reciprocity of changes in the indices under consideration) between potentially scalable and non-scalable ULB growth traits (*L*, *B vs. N*, *R*, respectively).

In passing with the expected statistically reliable empirical (mutually) consistency between *R* and *N* in the direction of well-established regularities of functional ecology and classical analysis of plant growth, the analytical form of predestination of the first of these features of the second was too complex for semantic and abstract-logical interpretations. Analytical forms of predetermination of criteria can be quite appropriate partial alternatives to such subordination between the specified ULB growth traits of winter wheat *R* or *B* sign *L*. However, *N*, most likely, did not depend, or was difficult to coordinate with *L*. The identification of semantic and statistical weights of growth traits, the distribution of biomass in the components of the plant and/or sowing within existing and/or newly found networks and groups of such indices can be important for deepening ideas about the patterns of development of the final biological results of the production process in winter wheat.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Стохастичні зумовленості складника біопродуктивності рисами росту пластинок верхніх листків пшениці озимої

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Анотація. Відносна та абсолютна важливість низки ознак, зокрема, агрофізіологічних, морфофункціональних, на рівні окремих органів і частин цілісної рослини та/або посіву для розвитку особливостей біологічних ознак та інших агроекологічно значущих складових продукційного процесу рослинництва, обговорюється в наукових працях вже тривалий час. Метою роботи був пошук агроекологічно значущих ознак росту верхніх листкових пластинок (GDM), які можуть емпірично та потенційно визначати розвиток сухої маси зерна (ULB) пшениці озимої за «модельних» умов біологічних агротехнічних впливів, позначених як системи біологічного удобрення. Методи дослідження: методичні підходи польового досліду, гравіметричний, конвективного сушіння та стохастичні методи. Розвиток GDM значною мірою визначався потенційно масштабованими інтегральними ростовими ознаками ULB – тривалістю листкової поверхні, тривалістю біомаси (LAD_{ULB}, BMD_{ULB}, відповідно) або їх комбінаціями з потенційно немасштабованими характеристиками середньої швидкості росту ULB – чистою асиміляційною швидкістю, відносною швидкістю росту (NAR_{ULB}, RGR_{ULB}, відповідно). Також дуже ймовірно, що LAD_{ULB} може відігравати центральну роль у розвитку RGR_{ULB} або BMD_{ULB} (але не NAR_{ULB}). Координація RGRULB з NAR_{ULB} не була виключена, хоча вона була надто складною. Побудова таких і подібних досліджень у руслі вичерпного пояснення послідовних системно-механістичних зумовленостей продукційного процесу з ознаками зростання ULB за різних агротехнічних і біологічних впливів сприятиме вдосконаленню дискурсивних і математичних імітаційних конструкцій, здатних характеризувати та інтегрувати диференційовані впливи рослинних компонентів на фотосинтез листкового покриву, крони і, зрештою, на процеси розвитку складових кінцевого біологічного та економічного врожаю озимої пшениці

Ключові слова: ознаки або особливості росту верхніх листкових пластинок; тривалість періоду формування листкової поверхні та біомаси; чиста асиміляція та відносна швидкість росту; озима пшениця; «модельні» біологічно покращені агрономічні умови – біологічно покращені системи удобрення
