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MULTI-OBJECTIVE ANALYSIS OF PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSES OF WINTER WHEAT (*Triticum aestivum* L.) TO STRESS INDUCED BY LOW TEMPERATURE DURING AUTUMN ACCLIMATION

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Abstract. Based on the literature data, types of morphological and physiological changes occurring in plants during the process of autumn hardening were discussed, as an expression of adaptations to overwintering. They indicate that the level of plant preparation for surviving winter depends on the photosynthesis intensity, leaf area index (LAI) and the development of aboveground part and root system. It was assumed that the use of liquid humic fertilizers (LHF) for seed dressing and in the form of foliar application performed after emergences will have a favourable effect on intensification of processes which favour plant frost hardening. In two field experiments with winter wheat cv. Širvinta conducted in Lithuania in systems of conventional and organic farming in 2010 and 2011, a number of analyses were performed on young plants. In the aboveground part, dry matter of leaves, LAI, the content of chlorophyll and carotenoids were determined, and gross productivity of photosynthesis was calculated, whereas in the underground part – the root area, their diameter and total length. It was shown that the application of LHF affects an increase in values of evaluated biometric indices, and thus, indirectly, contributes to enhancing the potential resistance of plants to stress induced with low temperature. The following ranking of plant responses to the combinations of LHF use in both cropping systems was established (in descending order of favourable effects): 1) pre-sowing seed dressing – the organic farming system, 2) seed dressing and foliar spraying – organic farming system, 3) without preparation – organic farming system, 4) pre-sowing seed dressing – conventional farming system, 5) foliar spraying – organic farming system, 6) without preparation – conventional farming system. This ranking was established based on the presented multi-objective optimization analysis MULTIMOORA.

Key words: foliar spraying, liquid humic fertilizer, MULTIMOORA, organic farming, plant pigments, pre-sowing seed dressing

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INTRODUCTION

The problem of plant adaptation to environmental temperature remains crucial throughout the whole plant life cycle [Entz and Fowler 1984]. A range of physiological and morphological adjustments occurred in plants grown at low temperatures [Xin and Browse 2000, Equiza *et al*. 2001]. Thus temperature is one of the main factors that limiting the propagation of economically important plant species in temperate climate. Some herbaceous winter cereals such as wheat and rye are very frost-resistant and can tolerate winter temperatures lower than -15°C to -20°C. Like most plants, winter wheat becomes tolerant to frost if it is firstly exposed to low non-freezing temperatures [Gaudet *et al*. 2003]. This process is known as cold acclimation and depends on various environmental conditions and technological factors, e.g. fertilizing [Kosová *et al*. 2011]. Thus cold acclimation process governs the success of overwintering plants capacity of exhibiting high levels of cold tolerance [Koike *et al*. 2002]. Winter cereals have many different physiological and morphological mechanisms that allow them to survive at such low temperatures. Vojnikov *et al*. [1984] showed that thermogenesis occurred in winter wheat shoots during low-temperature stress. Moreover, the low autumn temperatures adjust winter crops vernalization requirement: to switch from the vegetative to the anthesis stage and flower normally in the spring [Herman *et al*. 2006, Trevaskis *et al*. 2007].

The low temperatures experienced during the autumn season enable winter wheat (*Triticum aestivum* L.) acclimate to cold, thereby preparing it to withstand freezing winter temperatures. During the process of cold acclimation, a plant undergoes a series of biochemical and physiological changes [Hekneby *et al*. 2006], which are rapid--regulated of genes and limiting crop peculiarities [Ganeshan *et al*. 2009, Rinalducci *et al*. 2011, Viña *et al*. 2011]. A temperature from 17°C to 23°C is generally recognized as the optimum range for wheat vegetative growth, whereas from 0°C to 37°C are considered the minimum and maximum tolerable limits, respectively. On the other hand, the plant ability in adjusting to extreme temperatures has been widely recognized [Streck *et al*. 2003]. The chilling requirement is mandatory and programmed, thus it is positively faced not only by genes, but also by environmental conditions and management technics [Zagoskina *et al*. 2005]. Wheat growth conditions fulfill diverse functions related to photosynthesis, respiration, and plant defense indices against cold stressors.

The overall objective of the present study was to apply multi-objective analysis MOORA for evaluation the impact of liquid humic fertilizers on the changes of winter wheat *Širvinta 1* growth and photosynthesis capacity related indices, namely dry mass, LAI; root area, root mean diameter, root total length; RGR, pigments (Chl a, b and their ratio).

MATERIAL AND METHODS

Study site and experimental design

Winter wheat (*Triticum aestivum* L.) cv. *Širvinta 1* was grown in different rotation fields of conventional (CF) and organic (OF) farming of Training Farm at Aleksandras Stulginskis University (ASU) during 2010-2011 (Table 1). Soil type was classified in accordance with FAO/UNESCO [1997].

Winter wheat was sown on 07-21 September at the rate of 200 kg·ha^{-1} in accordance with autumn climatic conditions, namely soil humidity. Liquid humic fertilizer (LHF), 1 L·ha^{-1} was applied in different ways in organic field (OF): 1) control (blank), 2) seed felt (flt) with LHF, 3) seed felt and sprayed (flt + spr) with LHF, 4) sprayed with LHF. LHF application in conventional field (CF) was carried out as fallows: 1) control (blank), 2) seed felt with LHF. All treatments were performed in 4 replications. LHF presents aqueous solution of 11% humic acid (humic and fulvis acids) based on fertilizer with microelements supplement (Fe, Zn, Mg, Mn, Mo, Co, B). Fertilizer (operation solution 200 dm^3·ha^{-1}) was once sprayed after a month after winter wheat sowing. Pre-sowing treatment of 10 L·t^{-1} LHF aqueous solution (1:1) was applied for seed felting.

Table 1. Trial design

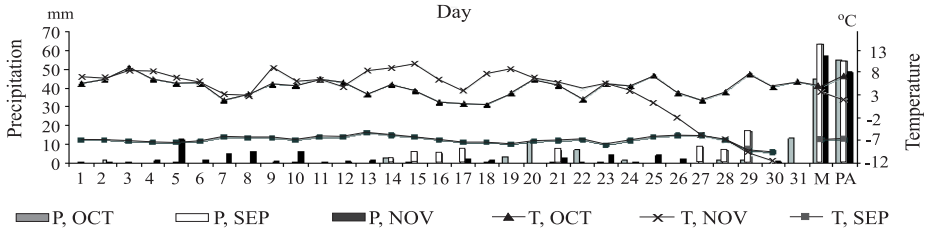
Management type	Crop rotation	Treatment acronym	Fertilizing	Soil classification	Location
Conventional farming (weed controlled by tillage and herbicide)	barley-grass mixture; 2 yrs grass; winter wheat; *Širvinta 1*	CF bg-g-w	$N_{120}P_{90}K_{60}$	*Albi-Epihypogleyic Luvisol* (*LVg-p-w-ab*)	54°52' N 23°51' E
Organic farming (certificated 15 yrs, Public organisation EkoAgros)	barley-clover; 2 yrs clover; winter wheat *Širvinta 1*	OF bc-c-w	Organic cattle manure 40 t·ha^{-1}	*Hapli-Epihypogleyic Luvisol* (*LVg-p-w-ha*)	54°52' N 23°51' E

Biometric assessments were carried out at the Analytic laboratory of the Research Station of ASU. Crop biometric parameters were assessed from 0.036 m^2 samples in 4 replications at winter wheat tillering stage in two terms with 2 weeks gap between them. Measurements have been acquired at the end of vegetation season from the beginning of October after seedlings started tillering stage (21-25 BBCH scale) [Growth… 2001]. Crop density was expressed via calculation of shoot number per plot unit (no.·m^{-2}). Height (cm), dry mass (DM, g·m^{-2}), and root system development were represented by indices of seedlings growth intensity. Finally, A3 light box was employed to scan the seedlings and Win DIAS programme was consequently applied to obtain seedling leaf area (cm^2), root total plot (mm^2), mean diameter (mm) and total length (mm). Green leaf area was used for calculation of leaf area index – LAI (m^2·m^{-2}) [Breda 2003].

Total Chls and carotens concentration in methanol solvent (mg·g^{-1}) in two replications was estimated by employing UV-Vis spectrophotometry analyser Genesys 6 (ThermoSpectronic, USA) for detecting the absorbance at 662 nm (Chl *a*), 644 nm (Chl *b*) and 750 nm [Wettstein 1957]. Additionally photosynthesis gross productivity (PGP) was estimated [Raven *et al*. 2005]. The dry matter (DM) content was obtained by drying fresh mass at 105°C to constant mass.

Meteorological conditions

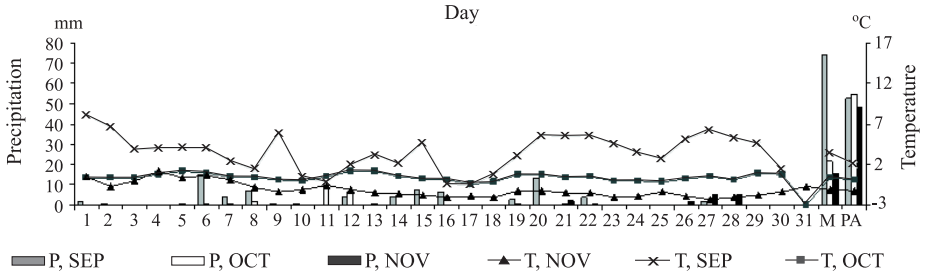
Mean month meteorological conditions varied throughout September-November, but remained favourable for wheat germination and tillering stage during autumns of 2010--2011 (Fig. 1, 2).



M – mean value of month precipitation (P) and temperature (T)
PA – means for many years of month precipitation (P) and temperature (T)

Fig. 1. Precipitation and temperature variation during cold acclimation period of September--November 2010 (SEP-NOV)

Monthly mean temperatures (T) were lower in September (12.0°C) and October (4.8°C), but higher in November (3.8°C) of 2010 than that of the averages for many years (PA) (12.2, 7.1, and 1.9°C respectively) (Fig. 1). October 2010 was exceptionally dry (18.2 mm). September (63.6 mm) and November (56.7 mm) of 2010 precipitation rate (P) exceeded the averages for many years (53.8 and 48.2 mm respectively).



M – mean value of month precipitation (P) and temperature (T)
PA – means for many years of month precipitation (P) and temperature (T)

Fig. 2. Precipitation and temperature variation during cold acclimation period of September--November 2011 (SEP-NOV)

Autumn of 2011 was specific with higher mean monthly temperature than that of 2010 (Fig. 2). Monthly mean temperature was higher by 1.4, 0.3 and 1.6°C for September, October and November of 2011. Month precipitation rate was exceptionally high in September (73.9 mm), but remained below multi-annual averages in October (21.6 mm) and November (15.5 mm). Noticeable, November 2011 was dryer to that margin of 3 times than that of 2010 and averages for many years.

The confidence intervals of the estimates were obtained by employing one-way analysis of variance by ANOVA (in case of significant interactions) followed by post hoc Tukey theoretical criterion. The least significant differences between treatment means were determined using Fisher's least significant differences (LSD_{05}). LSD, standard error (SE) has been calculated at level of statistical significance $P < 0.05$.

The MULTIMOORA method

Multi-Objective Optimization by Ratio Analysis (MOORA) method introduced by Brauers and Zavadskas [2006] on the basis of previous research. The same authors [2010, 2011] extended the method and in this way it became more robust as MULTIMOORA (MOORA plus the full multiplicative form).

The MULTIMOORA method begins with a response matrix X where its elements x_{ij} denote i^{th} alternative of jth objective (i = 1,2,..., m and j = 1,2,..., n). The method consists of three parts, viz. the Ratio System, the Reference Point approach, and the Full Multiplicative Form.

The Ratio System of MOORA. Ratio system employs the vector data normalization by comparing alternative of an objective to all values of the objective:

$$x_{ij}^{*} = w_j \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{1}$$

where x_{ij}^{*} denotes i^{th} alternative of jth objective and w_j is weight of the jth criterion, $\sum_j w_j = 1$. In the absence of negative values, these numbers belong to the interval [0; 1]. These indicators are added (if desirable value of indicator is maximum) or subtracted (if desirable value is minimum). Thus, the summarizing index of each alternative is derived in this way:

$$y_i^{*} = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*} \tag{2}$$

where g = 1,2,..., n denotes number of objectives to be maximized. Then every ratio is given the rank: the higher the index, the higher the rank.

The Reference Point of MOORA

Reference point approach is based on the Ratio System. The Maximal Objective Reference Point (vector) is found according to ratios found in Eq. 1. The jth coordinate of the reference point can be described as $r_j = \max_i x_{ij}^{*}$ in case of maximization. Every coordinate of this vector represents maximum or minimum of certain objective (indicator). Then every element of the normalized response matrix is recalculated and final rank is given according to deviation from the reference point and the Min-Max Metric of Tchebycheff:

$$\min_i \left(\max_j \left| r_j - x_{ij}^{*} \right| \right) \tag{3}$$

The Full Multiplicative Form and MULTIMOORA

Brauers and Zavadskas [2010] proposed MOORA to be updated by the Full Multiplicative Form method embodying maximization as well as minimization of

purely multiplicative utility function. Overall utility of the ith alternative can be expressed as dimensionless number:

$$U_i' = \frac{A_i}{B_i} \tag{4}$$

where $A_i = \prod_{j=1}^{g} (x_{ij})^{w_j}$ denotes the product of objectives of the ith alternative to be maximized with $g = 1,..., n$ being the number of objectives to be maximized and where $B_i = \prod_{j=g+1}^{n} (x_{ij})^{w_j}$ denotes the product of objectives of the ith alternative to be minimized with $n - g$ being the number of objectives (indicators) to be minimized. Thus MULTIMOORA summarizes MOORA (i.e. Ratio System and Reference point) and the Full Multiplicative Form. Researchers [Brauers and Zavadskas 2011, Brauers *et al.* 2011] proposed the dominance theory to summarize the three ranks provided by different parts of MULTIMOORA.

Absolute Dominance means that an alternative, solution or project is dominating in ranking all other alternatives, solutions or projects which are all being dominated. This absolute dominance shows as rankings for MULTIMOORA: (1–1–1). *General Dominance in two of the three methods* is of the form with a < b < c < d:

(d–a–a) is generally dominating (c–b–b);
(a–d–a) is generally dominating (b–c–b);
(a–a–d) is generally dominating (b–b–c);
and further transitiveness plays fully.

Transitiveness

If *a* dominates *b* and *b* dominates *c* then also *a* will dominate *c*. *Overall Dominance of one alternative on the next one.* For instance (a–a–a) is overall dominating (b–b–b) which is overall being dominated, with (b–b–b) following immediately (a–a–a) in rank (transitiveness is not playing). *Absolute Equability* has the form**:** for instance (e–e–e) for 2 alternatives. *Partial Equability* of 2 on 3 exists e.g. (5–e–7) and (6–e–3). Despite all distinctions in classification some contradictions remain possible in a kind of *Circular Reasoning*. We can cite the case of:

Object A (11–20–14) $\succ$ Object B (14–16–15);
Object B (14–16–15) $\succ$ Object C (15–19–12); but
Object C (15–19–12) $\succ$ Object A (11–20–14).

Here, the operator $\succ$ represents a *General Dominance*. In such a case the same ranking is given to the three objects.

RESULTS AND DISCUSSION

In accordance with Houlès *et al.* [2007], we also determined that cold acclimation depends on various environmental conditions and technologic factors, e.g. fertilizing. Winter wheat is properly ready for wintering, at the start of tillering stage and when optimal assimilation (leaf) and absorption surface (root) is developed [Sellers *et al.* 1992, Stupnikova *et al.* 2002, Rinalducci *et al.* 2011]. Results of this study showed, that

the application of liquid humic fertilizer contributed to enhancing growth and physiological indices during winter wheat autumn acclimation in both organic and conventional farming. Noticeably, the assessed biometrical indices were higher in OF than in CF possibly due to different fertilizer background application and delayed sowing term for 2 weeks due to high soil humidity of CF.

After germination mean LAI of winter wheat seedlings varied significantly and ranged between 0.35 (CF 0) and 1.57 $m^2 \cdot m^{-2}$ (OF LHF flt) in different treatments (Table 1). This green leaf area index characterizes carbon assimilation and organic material synthesis in plants [Viňa *et al*. 2011]. Seed felting with LHF caused LAI increase by 0.74 and 0.25 $m^2 \cdot m^{-2}$ in OF and CF, respectively, as compared to control or only LHF spraying. Consequently, LHF felt contributed to formation of seedlings with higher LAI which is essential in plant organics synthesis and guarantees growth process supplementation with proper constitutional materials in low temperature stress during autumn acclimation. These issues of LHF impact on acclimation correspond with the results obtained when applying nitrogen fertilizers [Bahrman *et al*. 2004, Houlès *et al*. 2007]. Two weeks later and after LHF spray photosynthetically functional LAI geminated and approached between 1.2-2.3 $m^2 \cdot m^{-2}$ in OF and 0.8-1.5 $m^2 \cdot m^{-2}$ in CF. Notwithstanding, LHF spray applied in OF did not enhance LAI, possibly due to low temperatures and short vegetation period during autumn acclimation. These results correspond with those obtained by using close-range remote sensing techniques [Choudhury 2000].

Gross photosynthesis productivity indicates intensity of carbon accumulation, cycle, and climate change [Choudhury 2000, Wu *et al*. 2010]. It varied in dependence on fertilizing and environment conditions [Wang *et al*. 2006]. We also found out, that GFP positively responded to LHF application during the experiment (Table 1). The highest mean GFP rates of 0.51-0.58 $g \cdot m^{-1} \cdot day^{-1}$ were observed in OF LHF flt or flt + spr treatments. Therefore more intensive wheat seedlings growth occurred in previous treatments. Later wheat sowing and mineral fertilizing possibly predetermined lower GFP rates of 0.12 $g \cdot m^{-1} \cdot day^{-1}$ (CF 0) and 0.25 $g \cdot m^{-1} \cdot day^{-1}$ (CF LHF flt) in conventional farming field. Though seed felting with LHF increased GFP, the observed GFP rates showed low carbon use efficiency if compared to referred data [Choudhury 2000, Wang *et al*. 2006]. Low GFP rates prevent wheat seedlings from overgrowth during autumn acclimation. Thus LHF is to be applied for stimulation of physiological processes and promotion of the seedling formation up to a sufficiently development for wintering.

Accordingly to Hoyaux *et al*. [2008], GFP depends on LAI rate and pigments content, which, in our case, varied along environmental gradient. Moreover, pigments content is a measure of the productivity of primary producers and provides the sustainable management of ecosystems [Fitzgerald *et al*. 2010]. Therefore we evaluated LHF impact on content of photosynthetic pigments as a prerequisite for seedlings more intensive growth and development. Consequently, bioassay of pigments indicated photosynthesis efficiency response to LHF application (Table 1). Chl and carotens content with exception of CF gradually increased thus gaining sufficient rates for normal photosynthesis during 2 weeks. LHF spray, different form of felting, did not affect Chls content, therefore the lowest Chls rates were observed in control and LHF spr treatments. Contrary to the case of Chls, carotenoid content varied significantly across all treatments. Chls ratio gained adequate rates before LHF spray, thus the optimal [Eberhard *et al*. 2008] values were observed in OF LHF flt (2.8), OF LHF flt + spr, and spr (2.7). Indeed, Chls ratio shrunk in all treatments saving those of OF 0 and

CF LHF flt, after 2 weeks. LHF flt increased pigments content, and thus stimulates photosynthesis, accumulation soluble sugars in shoots and roots [Equiza *et al*. 2001], seedlings growth and development, and thus provides important substance for the plant acclimation as well as development of new strategies for the sustainable management of ecosystems [Fitzgerald *et al*. 2010].

Roots area a major sink for assimilates, requiring twice as much photosynthate to produce dry matter as the shoots [Liu *et al*. 2004]. Moreover, it has been shown that more than 50% of assimilates are lost through root respiration or to maintain the root biomass increases. We observed, that root mean area ranged between 4900.4 mm^2 (OF LHF flt + spr) and 3787.5 mm^2 (CF 0). Due to later sowing term lower values of root area and diameter (Table 1) were observed in CF than in OF. Across two seasons, LHF application resulted in significant increase in root mean area only in CF LHF flt (4376.2 mm^2) if compared to control (Table 1). In accordance with Kosová *et al*. [2011] sufficient root area increases wheat cold tolerance, consequently applied LHF flt contributes to adaptation of wheat seedlings to autumn low temperature stress. Root area was lower in 2011 than in 2010 possibly due to lower precipitation rate (Fig. 1, 2).

The minimal LHF effect scale was observed on root diameter (Table 1). Variation in root mean diameter was insignificant across OF (0.74-0.75 mm) or CF treatments (0.68--0.69 mm). As referred by Liu *et al*. [2004], vegetative organs usually act as a temporary sink for nutritional materials storage. Moreover, this process is greatly altered by fertilizers (N) level. Nonetheless, the application of LHF has not enhanced root diameter and thus prospective temporary sink of seedling organic materials. Moreover, it is due to Jackson *et al*. [1997] that LHF encourages fine root (<2 mm in diameter) formation for water and nutrient uptake by plants, and thus fostering seedlings acclimation.

Root length ranged between 4926.15-4904.65 in OF 0-LHF spr and 6118.75 in CF LHF flt + spr (Table 2). The higher LHF impact on root length was observed in CF if compared to that in OF, and thus enhanced better seedling capacity for water uptake [Equiza *et al*. 2001]. Total root length was equated 6207.6 mm in CF LHF flt treatment. Summarizing, LHF efficiently stimulated wheat root growth and formation of the optimal seedling root system during autumn period. As root growth is environmentally controlled [Saidi *et al*. 2010], LHF flt application contributes to appropriate management techniques inducing balance between root water uptake and leaf transpiration [Jackson *et al*. 1997]. Consequently, formation of optimal root system guarantees satisfactory seedlings autumn acclimation [Raven *et al*. 2005].

Given the root systems of crop plants may be unnecessarily large; however their optimal rate may result in more photosynthates being available for shoots and higher grain production [Streck *et al*. 2003, Liu *et al*. 2004]. Moreover, root area is considered a critical factor with respect to the functional relationship between the plant parts and the environment [Equiza *et al*. 2001]. As for the discussed case, the observed normal root length values suggest LHF flt could be considered as an appropriate measure to growth stimulation of seedlings root system. As referred Saidi *et al*. [2010], developed root system improves seedling capacity for water uptake, enhances their resistance to frosts and thus better adaptation to low-temperature stress.

Application of multi-objective analysis MOORA defined the rank of the investigated fertilizing regimes which represent the alternatives (Tables 2-5). The best treatments were evaluated OF LHFflt (1) and OF LHFfl + spr (2) in accordance to Multiplicative Form (Table 2). CF 0 represented the worst values of investigated indices.

Table 2. Initial ranking data

Treatment	Leaf area index $m^2 \cdot m^{-2}$	Dry mass g	Photosynthesis gross productivity $g \cdot m^{-2} \cdot day^{-1}$	Root area mm^2	Root mean diameter mm	Root length mm	Chl a $mg \cdot g^{-1}$	Chl b $mg \cdot g^{-1}$	Chl a:b	Carotenoids $mg \cdot g^{-1}$
	1	2	3	4	5	6	7	8	9	10
OF 0	0.83	3.26	0.21	4770.65	0.75	4926.15	12.37	4.8775	2.5	4.47
OF LHFflt	1.57	2.34	0.51	4843.1	0.75	6092.55	17.1075	4.5525	3.8	4.48
OF LHFfl + spr	1.53	1.75	0.48	4900.4	0.74	6118.75	12.52	4.555	2.7	4.45
OF LHF spr	0.85	2.36	0.16	4578	0.74	4904.65	12.225	4.545	2.7	4.42
CF 0	0.35	0.52	0.12	3787.5	0.68	5025.05	14.68	5.8125	2.5	4.15
CF LHFflt	0.60	1.42	0.25	4376.2	0.69	6207.6	15.22	5.9525	2.6	4.99

Normalized data matrix and ranking according to the Ratio System is presented in Table 3.

Table 3. Multiplicative Form

Treatment	MF sum	Rank
OF 0	6688411741	3
OF LHFflt	5,4229E+10	1
OF LHFfl + spr	1,9563E+10	2
OF LHF spr	3609575822	5
CF 0	253892465	6
CF LHFflt	4562332663	4

In accordance with deviations from the Maximal Objective Reference Point (MORP), unfertilized treatment of OF 0 significantly influenced DM yield. LAI, GFP, root mean diameter, Chl a and carotenoids and root area were for OF LHFflt (Table 4). CF LHFflt application showed the highest impact on LAI, DM and GFP. The values of these indices showed the lowest deviations from MORP point and thus appointed significant effect of LHFflt mean.

The highest DM (0.471), GFP (0.526), root area (0.489) and diameter (0.100), Chl b (0.178), chlorophylls ratio (0.077) deviations from MORP point confirm the most unfavorable growth conditions in CF 0 treatment.

The final ranks were retrieved on a basis of the MULTIMOORA (Table 5). The applied quantitative analysis assumes that studied indices of winter wheat cold acclimation can be fully grasped and thus satisfactorily simplified within a final rank. Application LHFflt enhanced values of biometric characteristics, namely LAI, chlorophyll content, root and shoot development, in both organic and conventional farming background during cold acclimation. Nonetheless the highest rank (i. e. rank of 1) was assigned for OF LHFflt. Therefore the application of LHF and seed felting (OF LHFflt) contributed to adaptation to the autumn low temperature stress.

Treatment OF LHFfl + spr appeared to be less effective and followed OF LHFflt in the ranking.

The lowest results were obtained for CF 0 and OF LHF spr (ranks of 6 and 5, respectively).

Table 4. Normalized data matrix and ranking according to the Ratio System

Treatment	1	2	3	4	5	6	7	8	9	10	RS Sum	Rank
OF 0	0.321	0.627	0.259	0.427	0.423	0.361	0.357	0.392	0.365	0.405	3.937	3
OF LHFflt	0.607	0.450	0.639	0.434	0.424	0.446	0.494	0.366	0.542	0.406	4.808	1
OF LHFfl + spr	0.589	0.337	0.601	0.439	0.416	0.448	0.362	0.366	0.395	0.403	4.355	2
OF LHF spr	0.329	0.454	0.208	0.410	0.414	0.359	0.353	0.365	0.387	0.401	3.680	5
CF 0	0.137	0.101	0.150	0.339	0.383	0.368	0.424	0.467	0.363	0.376	3.108	6
CF LHFflt	0.232	0.273	0.314	0.392	0.387	0.454	0.440	0.478	0.368	0.453	3.790	4

Table 5. Maximal Objective Reference Point (MORP), deviations from it, and respective ranks

Treatment	1	2	3	4	5	6	7	8	9	10	Max	Rank
MORP	0.607	0.627	0.639	0.439	0.424	0.454	0.494	0.478	0.542	0.453		
OF 0	0.286	0	0.379	0.012	0.002	0.094	0.137	0.086	0.177	0.048	0.379	4
OF LHFflt	0	0.177	0	0.005	0	0.008	0	0.112	0	0.047	0.177	1
OF LHFfl + spr	0.018	0.291	0.038	0	0.009	0.007	0.132	0.112	0.146	0.050	0.291	2
OF LHF spr	0.279	0.173	0.430	0.029	0.010	0.095	0.141	0.113	0.155	0.052	0.430	5
CF 0	0.471	0.526	0.489	0.100	0.041	0.087	0.070	0.011	0.178	0.077	0.526	6
CF LHFflt	0.375	0.355	0.325	0.047	0.037	0	0.055	0	0.174	0	0.375	3

Table 6. Final ranking according to MULTIMOORA

Treatment	Ratio System	Reference Point	Multiplicative Form	MULTIMOORA (Final rank)
OF 0	3	4	3	**3**
OF LHFflt	1	1	1	**1**
OF LHFfl + spr	2	2	2	**2**
OF LHF spr	5	5	5	**5**
CF 0	6	6	6	**6**
CF LHFflt	4	3	4	**4**

CONCLUSIONS

The results of this study confirmed the significant LHF influence on improving winter wheat biometrical indices and seedling growth. Nonetheless, LHF application technique has different stimulation affect. Seed felting exhibited stronger effect on LAI (increase by 0.7-1.1 $g \cdot m^{-1} \cdot day^{-1}$ in OF and 0.25-0.7 $g \cdot m^{-1} \cdot day^{-1}$ in CF), Chl a (increased by2.35 $mg \cdot g^{-1}$ in Of and 1.01 $mg \cdot g^{-1}$ in CF) and carotens content (increased by 0.36 $mg \cdot g^{-1}$ in OF and 0.54 $mg \cdot g^{-1}$ in CF), root length (increased by 1166 mm in OF and 1182.55 in CF) and area (increased by 72.45 mm^2 in OF and 588.7 in CF) during autumn acclimation than seedling spraying did.

In this study, we employed the multi-criteria decision making method MULTIMOORA to facilitate the comparison of different patterns of application of liquid humic fertilizers. The impact of fertilizing was assessed with respect to morphological and physiological indices of winter wheat seedling across organic and conventional land management. The MULTIMOORA analysis has enabled to objectively prioritize the efficiency of applied fertilizing treatment. Given the results of analysis, the following order of preference (in descending order) was established: OF LHFflt> OF LHFfl + spr> OF 0> CF LHFflt> OF LHF spr> CF 0.

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WIELOOBIEKTOWA ANALIZA FIZJOLOGICZNYCH I MORFOLOGICZNYCH REAKCJI PSZENICY OZIMEJ (*Triticum aestivum* L.) W TRAKCIE JESIENNEJ AKLIMATYZACJI NA STRES WYWOŁYWANY NISKĄ TEMPERATURĄ

Streszczenie. W oparciu o dane literatury omówiono rodzaj zmian morfologicznych i fizjologicznych zachodzących w roślinach w trakcie procesu jesiennego hartowania jako wyraz przystosowań do przezimowania. Wskazują one, że poziom przygotowania do przetrwania zimy roślin zależy od natężenia fotosyntezy, wielkości indeksu liściowego (LAI) oraz stopnia rozwoju części nadziemnej i systemu korzeniowego. Założono, że zastosowanie płynnego nawozu huminowego (LHF) do zaprawienia ziarna siewnego oraz w formie aplikacji nalistnej wykonanej po wschodach wpłynie korzystnie na intensyfikację procesów sprzyjających hartowaniu roślin. W dwóch doświadczeniach polowych z pszenicą ozimą odmiany Širvinta, prowadzonych na Litwie w systemie rolnictwa konwencjonalnego i ekologicznego w latach 2010 i 2011, wykonano na młodych roślinach szereg oznaczeń, przy czym w części nadziemnej oznaczono: suchą masę liści, LAI, zawartość chlorofilu i karotenoidów oraz obliczono produktywność fotosyntezy brutto, a na części podziemnej – powierzchnię korzeni, ich średnicę i łączną długość. Wykazano, że zastosowanie LHF wpływa na zwiększenie wartości ocenianych wskaźników biometrycznych, czyli – pośrednio – przyczynia się do zwiększenia potencjalnej odporności roślin na stres wywoływany niską temperaturą. Ustalono następujący ranking reakcji roślin na kombinacje stosowania LHF w obu systemach rolnictwa (w kolejności zmniejszania się korzystnych efektów): 1) zaprawianie przedsiewne ziarna – system rolnictwa ekologicznego, 2) zaprawianie ziarna oraz oprysk

nalistny – system rolnictwa ekologicznego, 3) bez preparatu – system rolnictwa ekologicznego, 4) zaprawianie przedsiewne ziarna – system rolnictwa konwencjonalnego, 5) oprysk nalistny – system rolnictwa ekologicznego, 6) bez preparatu – system rolnictwa konwencjonalnego. Ranking ten został ustalony na podstawie zaprezentowanej wieloobiektowej analizy optymalizacyjnej MULTIMOORA.

Słowa kluczowe: MULTIMOORA, oprysk nalistny, pigmenty roślinne, płynny nawóz humusowy, przedsiewne zaprawianie nasion, rolnictwo organiczne

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