

## FERTILIZATION EFFICIENCY EVALUATION IN RELATION TO WHEAT STARCH CONTENT

MACRA GABRIELA<sup>1</sup>, SALA FLORIN<sup>1,2\*</sup>

<sup>1</sup>University of Life Sciences "King Mihai I" from Timisoara, 300645, Timișoara, Romania

<sup>2</sup>Agricultural Research and Development Station Lovrin, 307250, Lovrin, Romania

\*Corresponding author's e-mail: florin\_sala@usvt.ro

**Abstract:** The study evaluated the performance of mineral fertilization on wheat crop, Alex variety, in relation to the starch content of grains. Nitrogen was applied in five doses (0 – 200 kg ha<sup>-1</sup>; variation step 50 kg). On each nitrogen level, the Super Fifty biofertilizer was applied in six doses (0 – 5 L ha<sup>-1</sup>; variation step, 1 L). The starch content in wheat grains was determined on the experimental variants. The Agronomic Efficiency (AE) and Partial Factor Productivity (PFP) indicators were calculated. Mann-Kendall train test confirmed the decreasing trend in the data series for AE in relation to the SF variable on nitrogen levels N0, N150 and N200 ( $S = -8$ ,  $p = 0.042$ ), and for PFP in relation to the SF variable (Super Fifty) on all nitrogen levels, ( $S = -10$ ,  $p = 0.0083$ ). Based on similarity, the experimental variants were grouped into three distinct clusters (Coph.corr. = 0.963). Polynomial models and graphical models in 3D format and in isoquant format described the variation of the AE and PFP indices in relation to the independent variables (N, SF) under statistical safety conditions.

**Key words:** agronomic efficiency, fertilizers, partial factor productivity, starch, wheat

### INTRODUCTION

Wheat is the main cereal crop in the world, with high importance for human nutrition, industrialization, animal feed, and a major role in food security [6,9,13]. Due to the importance of wheat for food security, new areas have been considered for the expansion of wheat cultivation [7,21]. Some studies have analyzed the distribution of wheat crops in relation to climate change and socio-economic conditions [17].

In different types of agricultural systems, conventional or organic, wheat is a crop that occupies an important place in the crop structure [4,11,15]. Wheat yield and quality indices were analyzed in relation to the agro-ecological conditions of the crop area, the impact of the environment, and agrotechnical cropping systems [8,22].

Fertilizers are important inputs for wheat cultivation, in order to support yields and quality indices [12,19]. Testing new fertilizer resources and optimizing fertilizers in relation to the cultivated gau genotypes, the specifics of the cultivation locations in terms of soil and climate conditions, and crop performance are permanent concerns [14,20].

Wheat crop fertilization was evaluated both in relation to classic chemical fertilizers, but also in relation to new types of fertilizers and bioactive substances, in different combinations and application rates, in order to support crop performance, adequate quality indices, but also environmental protection and sustainable use of agricultural land [2,5,24,35]. Wheat grains present a series of quality indices (e.g. protein, gluten, starch, glutenins, gliadins, etc.), which vary in relation to the fertilization applied, and which are important for the quality of production, the way of capitalization, and the quality of finished products [1,27,34].

The study evaluated the efficiency of nitrogen fertilization and algae extract-based biofertilizer, at different application rates to wheat crops, based on two indices, Agronomic Efficiency (AE) and Partial Factor Productivity (PFP), calculated in relation to the starch content values in wheat grains.

### MATERIALS AND METHODS

The experimental wheat crop, the Alex variety, was placed within the University of Life Sciences "King Mihai I" from Timisoara, Didactic and Experimental Resort (DER), during the agricultural years 2018 - 2022. Nitrogen was applied in five doses 0, 50, 100, 150, and 200 kg ha<sup>-1</sup> a.s. (a.s. – active substance). At each nitrogen level, six doses of algae-based biostimulant (Super Fifty – SF) were applied in six doses, 0, 1, 2, 3, 4, and 5 L ha<sup>-1</sup>. This resulted in 30 experimental variants. The starch content ST, (%) was determined from annual wheat grain samples, for each experimental variant.

The efficiency of using the Super Fifty (SF) biostimulator on the starch content of wheat was evaluated by the Agronomic Efficiency (AE) index [10], [16], Equation (1), and the Partial Factor Productivity (PFP) index [16], Equation (2).

$$AE = (ST - ST_0) / F \tag{1}$$

where: AE – Agronomic Efficiency;  
 ST – starch content on each SF (Super Fifty) variant, on N levels;  
 ST<sub>0</sub> – starch content on the control variant (SF0);  
 F – SF dose corresponding to starch content (L ha<sup>-1</sup>).

$$PFP = ST / F \tag{2}$$

where: PFP – Partial Factor Productivity;  
 ST – starch content on each variant fertilized with SF, on N levels;  
 F – SF dose corresponding to starch content.

The experimental data calculated for the AE and PFP indices, based on the starch content values in relation to the SF and N products, were analyzed mathematically and statistically. Appropriate mathematical and statistical tests (e.g. ) were applied to assess the trend in the data series, differences between variants and the reliability of the data. Regression analysis was applied to assess the contribution of the two independent variables (N, SF) to the variation of the calculated indices (AE, PFP). The PAST software v4.17 [18], the Mathematica software (2024) [32] and the mathematical calculation module in EXCEL were used for the analysis of the experimental data.

### RESEARCH RESULTS

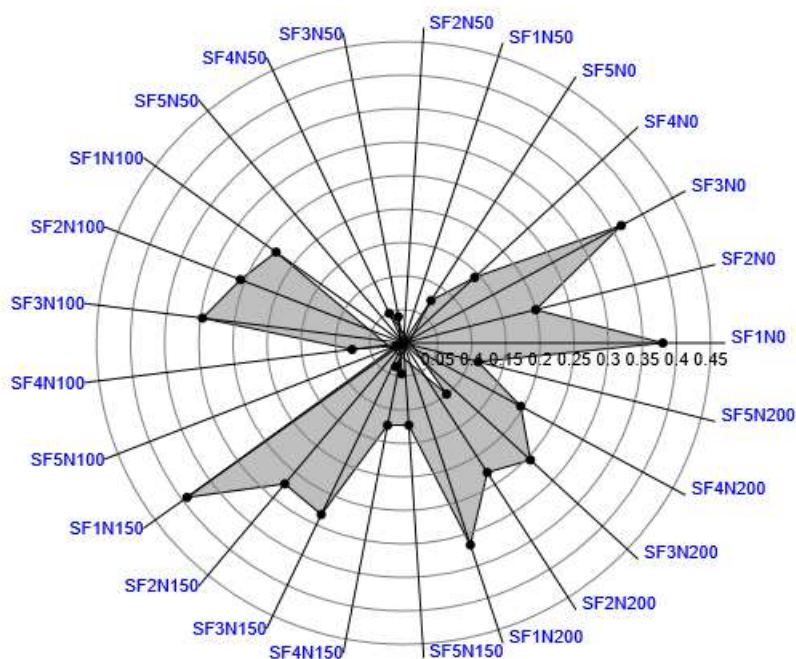
The results for Agronomic Efficiency (AE) calculated based on the starch content of wheat grains, in relation to the application rates of the Super Fifty biostimulator at each nitrogen fertilization level are presented in Table 1, Figure 1.

**Table 1.**

**AE values calculated based on starch content in wheat, 'Alex' variety**

	N0	N50	N100	N150	N200
<b>SF0</b>	-	-	-	-	-
<b>SF1</b>	0.380	-0.037	0.231	0.392	0.317
<b>SF2</b>	0.200	-0.046	0.257	0.273	0.229
<b>SF3</b>	0.364	0.040	0.297	0.283	0.255
<b>SF4</b>	0.143	0.049	0.076	0.125	0.196
<b>SF5</b>	0.075	-0.099	0.012	0.123	0.113

Source: original data



**Figure 1. Graphical distribution of AE values for wheat, 'Alex' variety**

Kruskal-Wallis test for equal medians, indicated significant differences between the median values of the calculated AE index in relation to nitrogen doses,  $H(\chi^2) = 11.28$ ,  $H_c$  (tie corrected) = 11.28,  $p = 0.0236$ .

Mann-Kendall train test confirmed the decreasing trend in the AE data series in relation to the SF (Super Fifty) variable on nitrogen levels N0, N150 and N200 ( $S = -8$ ,  $p = 0.042$ ).

In the case of Partial Factor Productivity (PFP), calculated based on the starch content of wheat grains, in relation to the doses of the Super Fifty biostimulator, at each level of nitrogen fertilization, are presented in Table 2, Figure 2.

**Table 2.**

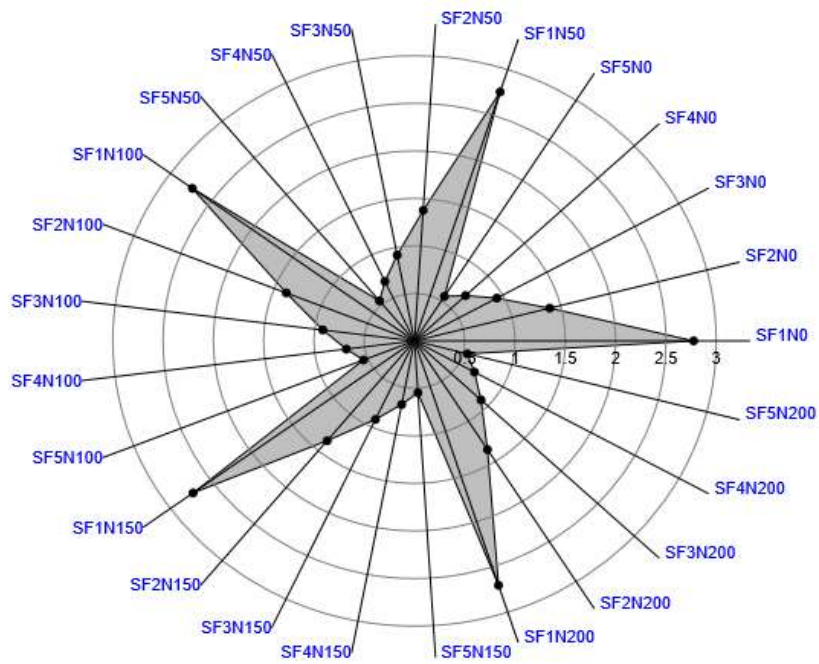
**PFP values calculated for starch content in wheat, 'Alex' variety**

	N0	N50	N100	N150	N200
SF0	-	-	-	-	-
SF1	2.775	2.754	2.730	2.720	2.703
SF2	1.388	1.376	1.371	1.363	1.354
SF3	0.934	0.920	0.919	0.913	0.907
SF4	0.696	0.691	0.683	0.681	0.680
SF5	0.555	0.547	0.545	0.546	0.543

Source: original data

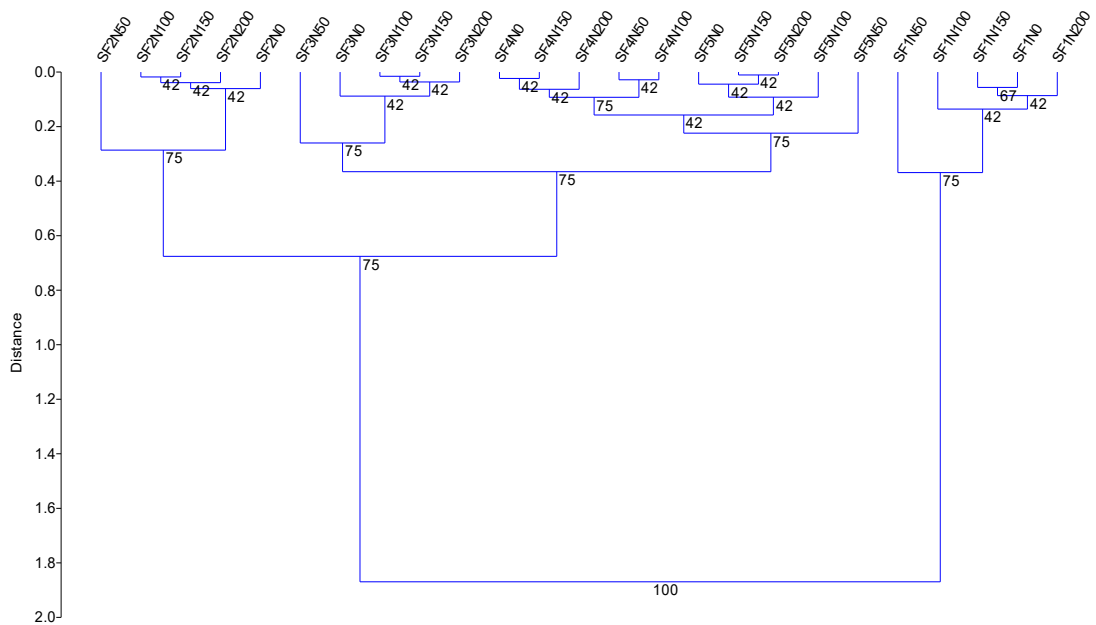
Kruskal-Wallis test indicated that there were no significant differences between the median values of the PFP index in relation to nitrogen doses,  $H(\chi^2) = 0.895$ ,  $H_c$  (tie corrected) = 0.895,  $p > 0.05$ .

Mann Kendall trend test confirmed the decreasing trend in the data series for PFP in relation to the SF (Super Fifty) variable across all nitrogen levels, ( $S = -10$ ,  $p = 0.0083$ ).



**Figure 2. Graphical distribution of PFP values for wheat, 'Alex' variety**

According to the Cluster Analysis, the variants were grouped based on similarity in different clusters and subclusters, in relation to the values of the AE and PFP indices (Coph.corr. = 0.963), Figure 3.



**Figure 3. Cluster dendrogram based on AE and PFP indices**

Two distinct clusters resulted, and each cluster contained several variants, at different levels of similarity.

On the left side of the dendrogram, five variants were grouped, with average values for the PFP index, ranging between PFP = 1.354 (SF2N200) and PFP = 1.388 (SF2N0). On the right side of the dendrogram, five variants were grouped with high values for the PFP

index, ranging between PFP = 2.703 (SF1N200) and PFP = 2.775 (SF1N0). In the central area of the dendrogram, 15 variants were positioned, based on similarity.

The regression analysis described the variation of the AE and PFP indices in relation to the variables N and SF, according to Equation (3), and Equation (4), respectively, with the values of the coefficients of the equations and the statistical safety parameters in Table 3.

$$AE = ax^2 + by^2 + cx + dy + exy + f \quad (3)$$

$$PFP = ax^2 + by^2 + cx + dy + exy + f \quad (4)$$

where: AE – Agronomic Efficiency;  
 PFP – Partial Factor Productivity;  
 x – N doses (kg ha<sup>-1</sup>),  
 y – SF doses (L ha<sup>-1</sup>);  
 a, b, c, d, e, f - the coefficients of Equation (3), and Equation (4), with values in Table 3.

**Table 3.**

**Values of coefficients and statistical safety parameters**

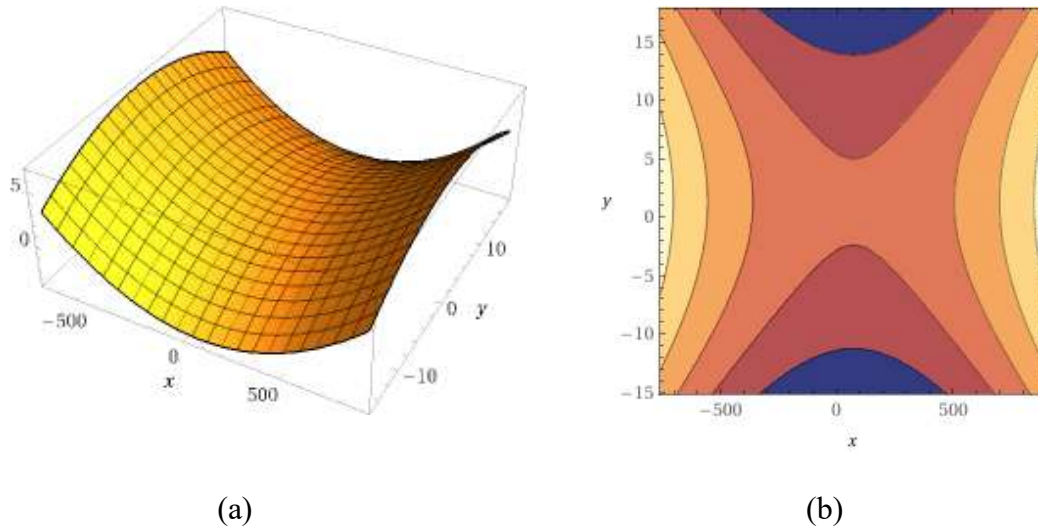
Equation coefficients and statistical parameters	Coefficient values	
	Equation (3) AE index	Equation (4) PFP index
<i>a</i>	0.00000967	0.00000035
<i>b</i>	-0.01380741	0.19092299
<i>c</i>	-0.00133754	-0.00043168
<i>d</i>	0.03809667	-1.65872050
<i>e</i>	-0.00004101	0.00006902
<i>f</i>	0.20858788	4.14499912
<b>R<sup>2</sup></b>	0.439	0.977
<b>p</b>	0.0379	<0.001

The graphical representation of the variation of the two indices in relation to N (x – axis) and SF (y – axis) is presented in Figure 4 (AE index) and in Figure 5 (PFP index).

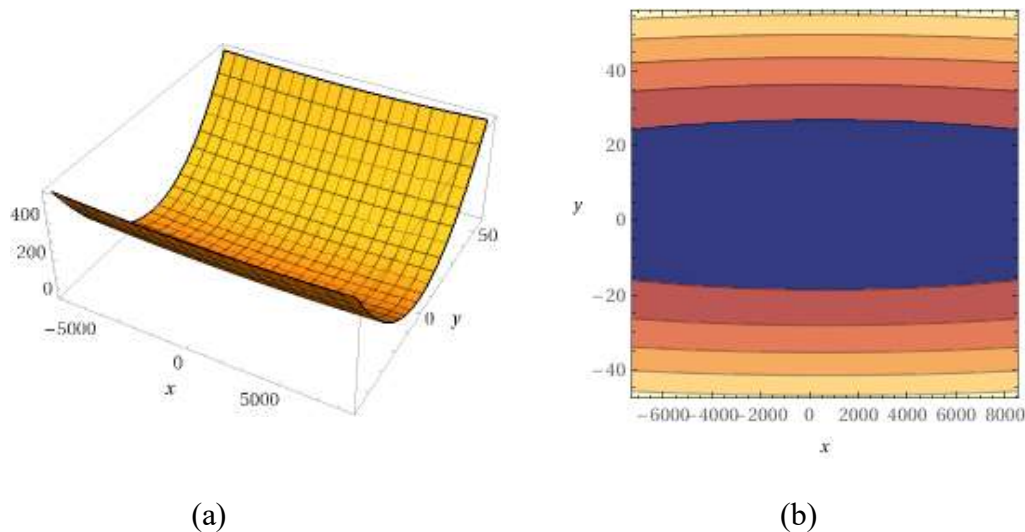
From the analysis of the values of the coefficients of Equation (3) and from the graphic representation (Figure 4), the divergent action of the two variables (N, SF) in the variation of the AE index was observed.

From the analysis of the coefficient values of Equation (4) and the graphical distribution (Figure 5) it was observed the differentiated contribution of the two variables to the formation of the PFP values.

A high contribution was recorded for the SF (Super Fifty) variable, which confirms the favorable influence of the treatment with the seaweed-based biofertilizer on the quality of wheat production.



(a) (b)  
**Figure 4. Graphical distribution of AE index values in relation to N (x – axis) and SF (y – axis); (a) – 3D model; (b) isoquants model**



(a) (b)  
**Figure 5. Graphical distribution of PFP index values in relation to N (x – axis) and SF (y – axis); (a) 3D model; (b) isoquants model**

Optimizing fertilization in agricultural crops is a permanent concern of farmers and researchers, in relation to new cultivated genotypes, types of fertilizers, and growing conditions [3], [30], [26], [20].

The starch content in wheat grains is an important carbohydrate, with a content of around 70%, but variable in relation to the wheat genotype, environmental and technological conditions [36], [23].

Experiments with mineral and organic fertilizers, in different combinations and application rates, have highlighted the variation of some quality parameters in grass cereals, including starch, and the quality of finished products [25], [33].

Productivity indicators, such as AE, and PFP, have been studied in relation to different fertilization rates in wheat in order to optimize crop technologies and production quality [31], [28], [29].

In the present study, the fertilizers used (N, SF) in different combinations and application rates led to certain values of starch content in wheat grains, and the calculations

made showed the differentiated variation of the productivity indices, AE and PFP.

The variations of the two productivity indices were more strongly influenced by the Super Fifty biofertilizer at the tested N levels. The data resulting from the calculation were within the limits of statistical safety, and showed a decreasing trend in relation to the fertilizer doses, under the study conditions.

### CONCLUSIONS

Fertilization with nitrogen (N) and the Super Fifty (SF) biofertilizer, based on seaweed extract, influenced starch accumulation in wheat grains, Alex variety, in a differentiated manner. Based on starch content, agronomic efficiency (AE) and partial factor productivity (PFP) indices highlighted the performance of fertilization with the two products.

Kruskal-Wallis test for equal medians, indicated significant differences between the median values of the calculated AE index in relation to nitrogen doses ( $p = 0.0236$ ) and indicated that there were no significant differences between the median values of the PFP index in relation to nitrogen doses ( $p > 0.05$ ).

Mann-Kendall trends test confirmed the decreasing trend in the AE data series in relation to the SF (Super Fifty) variable on nitrogen levels N0, N150 and N200 ( $S = -8$ ,  $p = 0.042$ ), and the decreasing trend in the PFP data series in relation to the SF (Super Fifty) variable on all nitrogen levels, ( $S = -10$ ,  $p = 0.0083$ ).

Cluster analysis generated the grouping of experimental variants based on similarity, in relation to the AE and PFP indices. Regression analysis led to polynomial models and graphical models (3D, isoquants), which described the variation of the AE and PFP indices in relation to the independent variables (N, SF) under conditions of statistical certainty.

### ACKNOWLEDGMENTS

The authors thank the ULS "King Mihai I" from Timisoara, and Didactic an Experimental Resort for facilitating this study.

### REFERENCES

- [1]. AGAPIE A.L., HORABLAGA M.N., GORINOIU G., HORABLAGA A., HERBEI M.V., SALA F., 2025, Variation of protein and protein fraction content in wheat in relation to NPK mineral fertilization, *Agronomy*, 15(9), 2076
- [2]. BO P., HE Q., LAN Y., LI J., LIU H., LI X., WANG H., 2025, Reducing mineral fertilizer can improve the soil quality and increase the wheat yield and nutrient utilization efficiency: The fertilizing effect of organic-inorganic compound fertilizers, *Agriculture*, 15(12), 1294
- [3]. BOLDEA M., SALA F., 2010, Optimizing economic indicators in the case of using two types of state-subsidized chemical fertilizers for agricultural production, *AIP Conference Proceedings*, 1281(1), 1390-1393
- [4]. CARR P.M., 2024, Organic wheat: Lessons learned and challenges remaining, *Agronomy Journal*, 116(6), 2715-2718
- [5]. CHANG X., HE H., CHENG L., YANG X., LI S., YU M., ZHANG J., LI J., 2024, Combined application of chemical and organic fertilizers: effects on yield and soil nutrients in spring wheat under drip irrigation, *Agronomy*, 14(4), 655
- [6]. CURTIS T., HALFORD N.G., 2014, Food security: the challenge of increasing wheat yield and the importance of not compromising food safety, *Annals of Applied Biology*, 164(3), 354-372

- [7]. **DADRASI A., CHAICHI M., NEHBANDANI A., SHEIKHI A., SALMANI F., NEMATI A.**, 2023a, Addressing food insecurity: An exploration of wheat production expansion, PLoS ONE, 18(12), e0290684
- [8]. **DADRASI A., CHAICHI M., NEHBANDANI A., SOLTANI E., NEMATI A., SALMANI F., HEYDARI M., YOUSEFI A.R.**, 2023b, Global insight into understanding wheat yield and production through Agro-Ecological Zoning, Scientific Reports, 13, 15898
- [9]. **DE SOUSA T., RIBEIRO M., SABENÇA C., IGREJAS G.**, 2021, The 10,000-Year Success Story of Wheat!, Foods, 10(9), 2124
- [10]. **DOBERMANN A.R.**, 2005, Nitrogen use efficiency - State of the art, Agronomy and Horticulture, Faculty Publications, 316, 1-17
- [11]. **DÖRING T.F., NEUHOFF D.**, 2021, Upper limits to sustainable organic wheat yields, Scientific Reports, 11, 12729
- [12]. **EJIGU D., PUSHPALATHA R., JAYAPRAKASH S.K., GANGADHARAN B., HIMANSHU S.K., GOPAKUMAR S.**, 2025, Integrated fertilizers for sustainable wheat production to improve food security - A comprehensive review, Journal of Plant Nutrition and Soil Science, 188(1), 5.16
- [13]. **ERENSTEIN O., JALETA M., MOTTALEB K.A., SONDER K., DONOVAN, J., BRAUN HJ.**, 2022, Global trends in wheat production, consumption and trade, In: Reynolds, M.P., Braun, HJ. (eds) Wheat Improvement, Springer, Cham. pp 47-66.
- [14]. **FEYISA D.S., JIAO X., MOJO D.**, 2024, Wheat yield response to chemical nitrogen fertilizer application in Africa and China: A meta-analysis, Journal of Soil Science and Plant Nutrition, 24, 102-114
- [15]. **FELEDYN-SZEWCZYK B., JOŃCZYK K., STALENGA J.**, 2024, The effect of crop production systems and cultivars on spring wheat (*Triticum aestivum* L.) yield in a long-term experiment, Agriculture, 14(4), 625
- [16]. **FIXEN P., BRENTRUP F., BRUULSEMA T., GARCIA F., NORTON R., ZINGORE S.**, 2015, Nutrient/fertilizer use efficiency: Measurement, current situation and trends. In Managing Water and fertilizer for Sustainable Agricultural Intensification, 1st ed.; Drechsel, P., Heffer, P., Magen, H., Mikkelsen, R., Wichelns, D., Eds.; International Fertilizer Industry Association (IFA); International Water Management Institute (IWMI); International Plant Nutrition Institute (IPNI); International Potash Institute (IPI): Paris, France, 1, 1-30
- [17]. **GUO X., ZHANG P., YUE Y.**, 2024, Prediction of global wheat cultivation distribution under climate change and socioeconomic development, Science of the Total Environment, 919, 170481
- [18]. **HAMMER Ø., HARPER D.A.T., RYAN P.D.**, 2001, PAST: Paleontological Statistics software package for education and data analysis, Palaeontologia Electronica, 4(1), 1-9
- [19]. **HOU S., DANG H., HUANG T., HUANG Q., LI C., LI X., SUN Y., CHU H., QIU W., LIU J., SHI M., HE G., SIDDIQUE K.H.M., WANG Z.**, 2023, Targeting high nutrient efficiency to reduce fertilizer input in wheat production of China, Field Crops Research, 292, 108809.
- [20]. **HOU P., LI B., CAO E., LIU Z., LI Y., SUN Z., XIAO Y., MA C.**, 2025, Optimizing nitrogen and phosphorus fertilizer application for wheat yield on alkali soils: mechanisms and effects, Agronomy, 15(3), 734
- [21]. **KETTLEWELL P., BYRNE R., JEFFERY S.**, 2023, Wheat area expansion into northern higher latitudes and global food security, Agriculture, Ecosystems & Environment, 351, 108499
- [22]. **KHEIRALIPOUR K., BRANDÃO M., HOLKA M., CHORYŃSKI A.**, 2024, A

review of environmental impacts of wheat production in different agrotechnical systems, Resources, 13, 93

[23]. KIM. K.H., KIM J.Y., 2021, Understanding wheat starch metabolism in properties, environmental stress condition, and molecular approaches for value-added utilization, Plants (Basel), 10(11), 2282

[24]. LI X., LI B., CHEN L., LIANG J., HUANG R., TANG X., ZHANG X., WANG C., 2022, Partial substitution of chemical fertilizer with organic fertilizer over seven years increases yields and restores soil bacterial community diversity in wheat–rice rotation, European Journal of Agronomy, 133, 126445

[25]. LIU H., LIU B., ZHOU H., HUANG Y., GAO X., 2023, Nitrogen fertilizer affects the cooking quality and starch properties of proso millet (*Panicum miliaceum* L.), Food Science & Nutrition, 12(1), 602-614

[26]. LIU P., LIN Y., LI Z., YANG Q., LIU X., WANG L., CHENG M., REN X., CHEN X., 2024, Optimization of fertilization scheme based on sustainable wheat productivity and minor nitrate residue in organic dry farming: An empirical study, Science of The Total Environment, 912, 169238

[27]. MOHAN D., SENDHIL R., GUPTA O.P., PANDEY V., KRISHNAPPA G., SINGH G.P., 2022, Wheat quality index: new holistic approach to identify quality superior genotypes, Cereal Research Communications, 50, 1105-1115

[28]. RAWAL N., VISTA S.P., KHADKA D., KHATRI N., PANERU P., 2025, Nitrogen accumulation, use efficiency, and productivity of wheat (*Triticum aestivum* L.) as influenced by different rates of nitrogen in Lalitpur, Nepal, Applied and Environmental Soil Science, 2025, 4247685

[29]. REN Z., ZHANG H., LI H., WU Q., HUANG Y., YE Y., ZHAO Y., 2025, Improving wheat yield, fertilizer use efficiency, and economic benefits through farmer-participation nutrient management, Sustainability, 17(8), 3481

[30]. SALA F., BOLDEA M., RAWASHDEH H., NEMET I., 2015, Mathematical model for determining the optimal doses of mineral fertilizers for wheat crops, Pakistan Journal of Agricultural Sciences, 52(3), 609-617

[31]. SHARMA S., KAUR G., SINGH P., ALAMRI S., KUMAR R., SIDDIQUI M.H., 2022, Nitrogen and potassium application effects on productivity, profitability and nutrient use efficiency of irrigated wheat (*Triticum aestivum* L.), PLoS One, 17(5), e0264210

[32]. WOLFRAM RESEARCH, 2024, Inc., Mathematica, Version 14.2, Champaign, IL.

[33]. WEN J., LI Z., YAO J., WANG S., LIU Y., LIU Y., 2024, The combined application of organic and inorganic fertilizers improved the quality of colored wheat by physicochemical properties and rheological characteristics of starch, International Journal of Biological Macromolecules, 282(Part 1), 137175

[34]. WU H., WANG Z., ZHANG X., WANG J., HU W., WANG H., GAO D., SOUZA E., CHENG S., 2022, Effects of different fertilizer treatments, environment and varieties on the yield-, grain-, flour-, and dough-related traits and cookie quality of weak-gluten wheat, Plants (Basel), 11(23), 3370

[35]. ZHANG J., LI S., JIANG P., WANG R., GUO J., XIAO H., WU J., SHAABAN M., LI Y., HUANG M., 2024, Organic fertilizer substituting 20% chemical N increases wheat productivity and soil fertility but reduces soil nitrate-N residue in drought-prone regions, Frontiers in Plant Sciences, 15, 1379485

[36]. ZI Y., DING J., SONG J., HUMPHREYS G., PENG Y., LI C., ZHU X., GUO W., 2018, Grain yield, starch content and activities of key enzymes of waxy and non-waxy wheat (*Triticum aestivum* L.), Scientific Reports, 8, 4548