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A method for estimating nitrogen supply index in crop plants: case study on wheat

O metodă de estimare a indicelui de suplimentare a azotului la plantele de cultură: studiu de caz la grâu

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ABSTRACT

This paper aim was to adapt a physiological parameter which reflects plant growth and productivity for wheat plants in relation with the applied nitrogen dose. This index can be used for various plants due to the fact that can be easy calculated and gives information about the status and requirements of diverse crops. Nitrogen is the most widely used chemical fertilizer and the adjustment of the dose is really important for farmers, who are searching for an optimum cost-benefit ratio. For this study, five experimental N doses were utilized, between 0 and 200 kg/ha. Experimental field was located within Didactic Station of BUASMV Timisoara, Romania. Nitrogen supply index was determined for healthy leaves and mathematical models were developed. The optimum N amount used for this study was 119 kg/ha and the analysis of differences reflected the modifications for doses ranging between 0 and 200 kg/ha.

Keywords: nutrition stress, physiological index, productivity, wheat crop

REZUMAT

Scopul acestei lucrări a fost de a adapta un parametru fiziologic care reflectă creșterea și productivitatea plantei de grâu în relație cu dozele de azot. Acest indice poate fi folosit pentru numeroase specii de plante deoarece poate fi ușor calculat și oferă informații despre statusul și necesitățile diverselor culturi. Azotul este cel mai mult folosit fertilizator chimic și ajustarea dozei este foarte importantă pentru fermieri, care caută un optim cost-beneficiu. Pentru acest studiu au fost folosite cinci doze experimentale de N, între 0 și 200 kg/ha. Câmpul experimental a fost localizat în Stațiunea Didactică a USAMVB Timișoara, România. Indicele de suplimentare a azotului a fost determinat pentru frunze sănătoase și au fost dezvoltate modele matematice. Cantitatea optimă de N folosită în acest studiu a fost de 119 kg/ha și analiza diferențelor a relevat modificările pentru doze care au variat între 0 și 200 kg/ha.

Cuvinte cheie: stress nutritional, indice fiziologic, productivitate, cultura de grâu

INTRODUCTION

Wheat cultivation is crucial because this plant is an important calorie source for over 1.5 billion people worldwide (Manske et al., 2000; Kiliç, 2010). This type of crop is the third most important as regards to global production and its cultivation range has a major role for food security (Cakmak, 2008; Shewry and Hey, 2015). It is frequently not only for grain production, but also as a forage for cattle (Malinowski et al., 2018). Nowadays, agriculture has a big challenge due to the fact that it needs to attain approximatively a 70% increase in crop yield by the year 2050 (Friedrich, 2015; Joshi et al., 2016; Wang et al., 2016). Higher yields with a good quality are of interest and studies or new methods that can quickly and cheaply predict these features are in tendencies. One of the principal disadvantages of yield prediction regression models is that the models are only applicable for crop growth stages, specific crop cultivars, or certain geographical regions (Fang et al., 2011; Sala et al., 2016).

Moreover, grain yield is considered a quantitative character of high complexity, due to the fact that is influenced by several genes and involves a mixture of numerous components, making the direct selection of genotypes difficult because of the low heritability that it presents (Rigatti et al., 2018). It is thus necessary to use precision agriculture. The inference of precision agriculture is that better decision making will provide a wide range of benefits in economic, environmental and social aspects that may or may not be known or measurable today (Herbei and Sala, 2015; 2016). Also, there is a variety of designed networks in this domain: phenological networks observing wild plants, agricultural observation systems and measurements of some parameters (Ianovici, 2016; Constatinescu et al., 2018). It is also known that growth, development and the productivity of a plant are greatly determined by the active lifespan of the leaf, which is called leaf longevity. Leaf characteristics are known to vary along environmental gradients such as, altitude, soil fertility, moisture, precipitation, and light availability (Markesteijn, 2005).

Nitrogen is the most important element in contemporary high-yield agriculture because a big amount is necessary in plant tissues in order to help converting solar radiation into metabolites that drive plant growth (Ladha et al., 2016). Nitrogen has important roles in physiological functions (Kaur et al. 2016) and is a major component in protein structure (Blandino et al., 2015; Duncan et al., 2018). If the amount of available N from the soil through the growing season is low relative to the crop yield potential, crop yield and protein concentration usually both increase with application of N fertilizer (Fowler, 2003; Zörb et al., 2018). In the last 40 years, the amount of synthetic nitrogen (N) applied to crops has risen dramatically, from 12 to 104 Tg / year (Mulvaney et al., 2009), resulting in significant increases in yield but with considerable impacts on the environment throughout the world. The amount of nitrogen from grains determines the percentage of the storage protein fractions, but also the ratio of storage to non-storage proteins, and the ratios of storage protein polymers to monomers (García-Molina and Barro, 2017).

Leaf features analysis is important due to the fact that it gives information about supply in plants, including crops. There are some largely used synthetic parameters such as fractal dimensions (FD), which represent the space filled by the plants (Fuentes et al., 2018). Also, there are many environmental factors that can have an influence on crop yield and quality. Among these pathogens, temperature, precipitations predominate, but also the nutritional status. Water stress can happen in plants both under drought and excess water (Peña-Rojas et al., 2005). The leaves, being the main site of photosynthetic activity, seem to have an obvious relation to the plant's grain yield capability (Sharma et al., 2003). In the case of cereals, flag leaf has a major contribution towards the grain weight, and represents the main photosynthetic site during the grain filling time (Gaju et al., 2016). Some studies reported that not only increasing the N fertilization dose, but also separating the N fertilization into two or more soil applications positively influenced grain protein content

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and wheat rheological quality (Fuertes-Mendizábal et al., 2010). In many agricultural systems, N is uniformly applied across the field despite field heterogeneity in available soil water, solar irradiation, and soil type (Diacono et al., 2012).

Specific leaf weight - SLW represents an interesting feature in plant growth (Dier et al., 2018) widely used in agronomical sciences, forestry and plant ecology, but less so in plant physiology (Poorter et al., 2009). It is also a significant indicator of plant strategies (Grime, 2001; Westoby et al., 2002). A higher SLW can be obtained because of a thick leaf and/or high leaf density, and a higher chloroplast area (Poorter et al., 2009). This is often reported to be a major driver of interspecific variation in photosynthetic capacity per unit of leaf area (Ellsworth and Reich, 1993).

The aim of this paper is to adapt SLW parameter to become a descriptor of nitrogen fertilization dose effect on wheat plant growth.

MATERIALS AND METHODS

The investigated species was *Triticum aestivum* ssp. vulgare, Ciprian cv. The experimental field was located within Didactic Station of Banat's University of Agricultural Sciences and Veterinary Medicine from Timisoara. The study was realized in the agricultural year 2018-2019 on a slightly gleized cambic chernozem, with a neutral reaction (pH = 6.7-6.8), medium fertility and good humus supply (H = 3.2%) (Sala et al., 2016). According to Meteorology National Administration, monthly precipitations varied between 33.7 and 78.1 l/m^2 in the last years. Wheat was fertilized with ammonium azotate in five experimental doses. These doses were: 0, 50, 100, 150 and 200 kg active substance/ha. Wheat samples were harvested in May 2019 (BBCH scale 41). Healthy and intact flag leaves were taken to laboratory and were perforated, 120 disks/variant with a 0.5 mm diameter being acquired. Next, the samples were placed into an oven (Sauter Model), at 100 °C for 2 hours. Then, dry weight of the samples was obtained, using an analytical balance (Kern model).

Specific leaf weight was calculated by dividing probe weight to surface. SLW values depending on N dose were named NSI (N supply index) values. Statistic processing was realized using PAST v 3.0 (Hammer et al., 2001). The diagram representing the procedure for obtaining NSI can be observed in Figure 1.

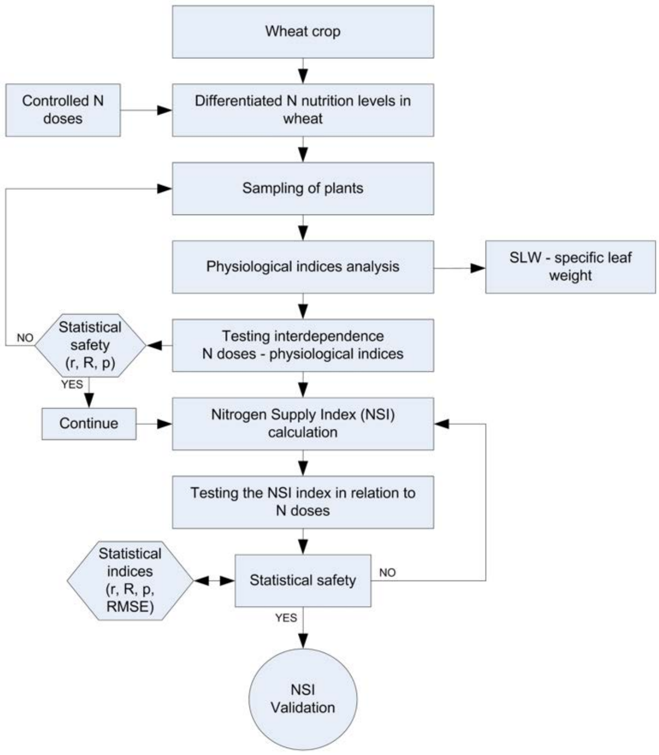

Figure 1. Nitrogen supply index determination diagram

RESULTS AND DISCUSSION

Table 1 contains data regarding NSI values for the five experimental N variants used in this study. NSI was proposed as an index which defines the wheat plants stress degree in relation with N nutrition. Based on experimental data, a second-degree polynomial model was obtained, relation (1), which described NSI behaviour depending on the used N doses, with a R^2=0.982 and $P<0.01$.

$$NS = -\ 0.0008N^2 + 0.1904N + 52.775 \qquad (1)$$

where:

NSI – Nitrogen Supply Index (g/m^2)

N – N dose (kg/ha)

Starting on the obtained base model, a broad spectrum of values for N dose was determined, in the specific interval between 0-200 kg/ha, for which NSI values were determined (Table 2).

Table 1. Experimental data for NSI depending on N dose

Variant	N (kg/ha)	NSI (g/m²)
N 0	0	52.9512±0.093
N 50	50	59.6178±0.091
N 100	100	64.5011±1.42
N 150	150	62.4628±1.28
N 200	200	58.3015±1.09

From the data series, NSI maximum value was obtained for 119 kg/ha, value on which NSI differences were calculated for a 0 – 200 N kg/ha range. After the determination of NSI indices differences in the 0 – 200 kg/ha range, it was determined that minimum value of the difference for N =119 kg/ha dose, which confirmed this value as being optimum for the determined parameter (NSI_{opt}). Graphical distribution of the differences can be observed in Figure 2.

$$NSI_{opt} - N = MD \qquad (2)$$

where:

NSI_{opt} – optimum NSI;

NSI_{det} – determined NSI;

MD – Minimal Differences.

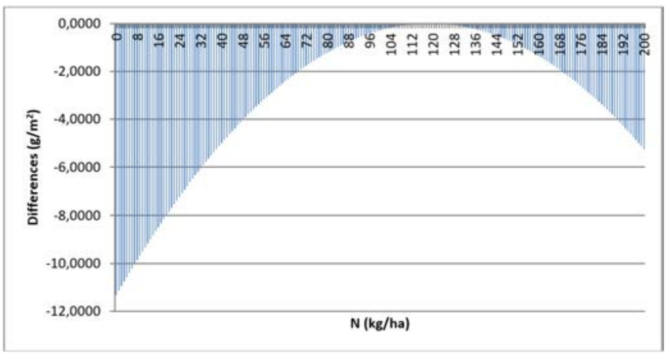

Figure 2. Graphical distribution of NSI differences in relation with N dose

After this, in order to differentiate between the two zones of N doses in relation with the technical maximum dose (at which NSI is optimum), it was opted to assign positive values to differences (*Dif*) over NSI_{opt}, according to relation (3), and graphical representation in Figure 3.

$$Dif = (NSI_{det} - NSI_{opt}) \times (-1) \qquad (3)$$

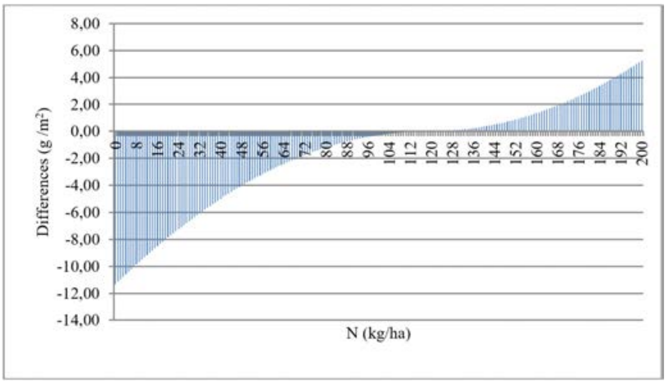

Figure 3. Graphic distribution of differences in relation with NSI_{opt}

Therefore, when the differences are negative in relation with NSI_{opt}, the applied N dose is below the optimum and wheat plants are in a N stress generated by N deficit.

For the remediation of nutritive stress N dose can be supplemented as a difference between N_{max} and $N_{current}$, with the purpose of attaining the optimum NSI, at which the physiological parameters are in the optimum and in which a biomass and grains yield is optimum.

For the estimation of supplemental N dose required for correcting the nutritive stress due to the N deficit, a 6-degree polynomial equation (Relation 4) was calculated, with R^2 = 0.998, P<0.001. Graphical distribution of N_{suppl} variation in relation with NSI differences can be seen in Figure 4.

$$N_{suppl} = 119 - (0.0055x^5 - 0.1713x^4 - 2.0132x^3 - 11.228x^2 - 38.144x + 6.4292) \qquad (4)$$

where:

N_{suppl} – N dose which can be added for optimization;

x – NSI difference determined.

Table 2. NSI calculated values and differences depending on N dose

N	NSI	Dif	N	NSI	Dif	N	NSI	Dif	N	NSI	Dif	N	NSI	Dif
0	52.7750	-11.3288	40	59.1110	-4.9928	80	62.8870	-1.2168	120	64.1030	-0.0008	160	62.7590	-1.3448
1	52.9646	-11.1392	41	59.2366	-4.8672	81	62.9486	-1.1552	121	64.1006	-0.0032	161	62.6926	-1.4112
2	53.1526	-10.9512	42	59.3606	-4.7432	82	63.0086	-1.0952	122	64.0966	-0.0072	162	62.6246	-1.4792
3	53.3390	-10.7648	43	59.4830	-4.6208	83	63.0670	-1.0368	123	64.0910	-0.0128	163	62.5550	-1.5488
4	53.5238	-10.5800	44	59.6038	-4.5000	84	63.1238	-0.9800	124	64.0838	-0.0200	164	62.4838	-1.6200
5	53.7070	-10.3968	45	59.7230	-4.3808	85	63.1790	-0.9248	125	64.0750	-0.0288	165	62.4110	-1.6928
6	53.8886	-10.2152	46	59.8406	-4.2632	86	63.2326	-0.8712	126	64.0646	-0.0392	166	62.3366	-1.7672
7	54.0686	-10.0352	47	59.9566	-4.1472	87	63.2846	-0.8192	127	64.0526	-0.0512	167	62.2606	-1.8432
8	54.2470	-9.8568	48	60.0710	-4.0328	88	63.3350	-0.7688	128	64.0390	-0.0648	168	62.1830	-1.9208
9	54.4238	-9.6800	49	60.1838	-3.9200	89	63.3838	-0.7200	129	64.0238	-0.0800	169	62.1038	-2.0000
10	54.5990	-9.5048	50	60.2950	-3.8088	90	63.4310	-0.6728	130	64.0070	-0.0968	170	62.0230	-2.0808
11	54.7726	-9.3312	51	60.4046	-3.6992	91	63.4766	-0.6272	131	63.9886	-0.1152	171	61.9406	-2.1632
12	54.9446	-9.1592	52	60.5126	-3.5912	92	63.5206	-0.5832	132	63.9686	-0.1352	172	61.8566	-2.2472
13	55.1150	-8.9888	53	60.6190	-3.4848	93	63.5630	-0.5408	133	63.9470	-0.1568	173	61.7710	-2.3328
14	55.2838	-8.8200	54	60.7238	-3.3800	94	63.6038	-0.5000	134	63.9238	-0.1800	174	61.6838	-2.4200
15	55.4510	-8.6528	55	60.8270	-3.2768	95	63.6430	-0.4608	135	63.8990	-0.2048	175	61.5950	-2.5088
16	55.6166	-8.4872	56	60.9286	-3.1752	96	63.6806	-0.4232	136	63.8726	-0.2312	176	61.5046	-2.5992
17	55.7806	-8.3232	57	61.0286	-3.0752	97	63.7166	-0.3872	137	63.8446	-0.2592	177	61.4126	-2.6912
18	55.9430	-8.1608	58	61.1270	-2.9768	98	63.7510	-0.3528	138	63.8150	-0.2888	178	61.3190	-2.7848
19	56.1038	-8.0000	59	61.2238	-2.8800	99	63.7838	-0.3200	139	63.7838	-0.3200	179	61.2238	-2.8800
20	56.2630	-7.8408	60	61.3190	-2.7848	100	63.8150	-0.2888	140	63.7510	-0.3528	180	61.1270	-2.9768
21	56.4206	-7.6832	61	61.4126	-2.6912	101	63.8446	-0.2592	141	63.7166	-0.3872	181	61.0286	-3.0752
22	56.5766	-7.5272	62	61.5046	-2.5992	102	63.8726	-0.2312	142	63.6806	-0.4232	182	60.9286	-3.1752
23	56.7310	-7.3728	63	61.5950	-2.5088	103	63.8990	-0.2048	143	63.6430	-0.4608	183	60.8270	-3.2768
24	56.8838	-7.2200	64	61.6838	-2.4200	104	63.9238	-0.1800	144	63.6038	-0.5000	184	60.7238	-3.3800
25	57.0350	-7.0688	65	61.7710	-2.3328	105	63.9470	-0.1568	145	63.5630	-0.5408	185	60.6190	-3.4848
26	57.1846	-6.9192	66	61.8566	-2.2472	106	63.9686	-0.1352	146	63.5206	-0.5832	186	60.5126	-3.5912
27	57.3326	-6.7712	67	61.9406	-2.1632	107	63.9886	-0.1152	147	63.4766	-0.6272	187	60.4046	-3.6992
28	57.4790	-6.6248	68	62.0230	-2.0808	108	64.0070	-0.0968	148	63.4310	-0.6728	188	60.2950	-3.8088
29	57.6238	-6.4800	69	62.1038	-2.0000	109	64.0238	-0.0800	149	63.3838	-0.7200	189	60.1838	-3.9200
30	57.7670	-6.3368	70	62.1830	-1.9208	110	64.0390	-0.0648	150	63.3350	-0.7688	190	60.0710	-4.0328
31	57.9086	-6.1952	71	62.2606	-1.8432	111	64.0526	-0.0512	151	63.2846	-0.8192	191	59.9566	-4.1472
32	58.0486	-6.0552	72	62.3366	-1.7672	112	64.0646	-0.0392	152	63.2326	-0.8712	192	59.8406	-4.2632
33	58.1870	-5.9168	73	62.4110	-1.6928	113	64.0750	-0.0288	153	63.1790	-0.9248	193	59.7230	-4.3808
34	58.3238	-5.7800	74	62.4838	-1.6200	114	64.0838	-0.0200	154	63.1238	-0.9800	194	59.6038	-4.5000
35	58.4590	-5.6448	75	62.5550	-1.5488	115	64.0910	-0.0128	155	63.0670	-1.0368	195	59.4830	-4.6208
36	58.5926	-5.5112	76	62.6246	-1.4792	116	64.0966	-0.0072	156	63.0086	-1.0952	196	59.3606	-4.7432
37	58.7246	-5.3792	77	62.6926	-1.4112	117	64.1006	-0.0032	157	62.9486	-1.1552	197	59.2366	-4.8672
38	58.8550	-5.2488	78	62.7590	-1.3448	118	64.1030	-0.0008	158	62.8870	-1.2168	198	59.1110	-4.9928
39	58.9838	-5.1200	79	62.8238	-1.2800	**119**	**64.1038**	**0.0000**	159	62.8238	-1.2800	199	58.9838	-5.1200
												200	58.8550	-5.2488

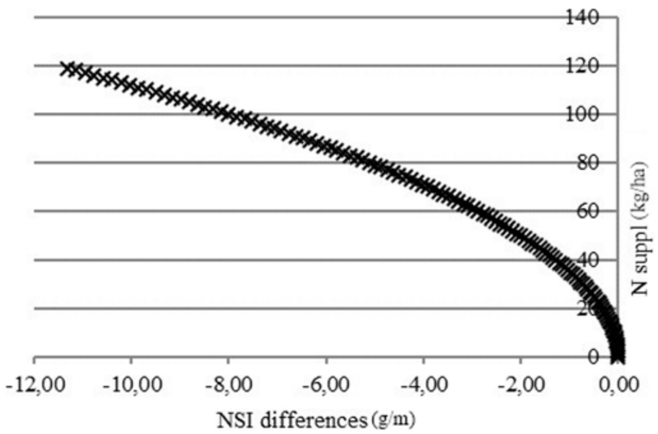

Figure 4. The distribution of theoretical values for N_{suppl}

After the calculations, based on the relation (4), a data set for the calculated supplemental N (N_{suppl} C) was realized, and the fitting between the two data sets (N_{opt} exp and N_{suppl} C) was described by a linear equation, relation (5), with R^2 = 0.997, P<0.001, and graphical distribution in the Figure 5.

$$N_{suppl} = 1.031x - 1.0638 \qquad (5)$$

where:

N_{suppl} C – calculated supplemental N;

x – N_{opt} exp –i, where i∈(0-119); N_{opt} = 119 kg/ha

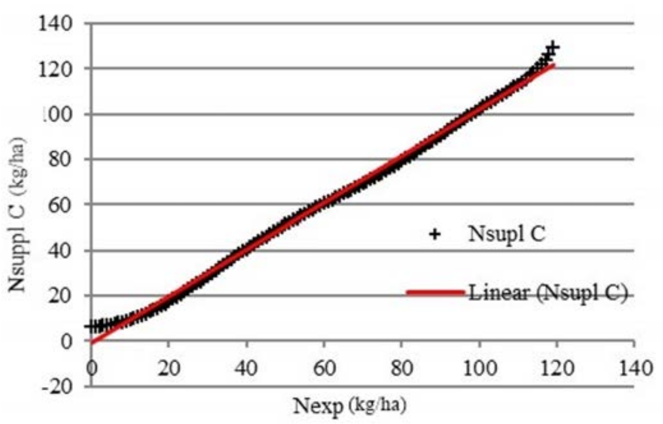

Figure 5. The fit line between the experimental values (N_{exp}) and the values calculated for (N_{suppl} C) (kg/ha)

Positive values of differences from NDI_{opt} afferent for N_{opt} (119 kg/ha for this study) suggest that optimum N dose was exceeded and the plants are into nutrition, growth and development phases marked by a N excess.

NSI is developed starting with SLW values depending on N doses. Adapting this parameter is useful because nowadays N application has a great significance for yield. Thus, the correlation between N dose and the values of this index is important due to the fact that is a reflection of crop physiological efficiency and possible productivity values. Also, it is a known fact that specific leaf weight or leaf mass per area is an indicator of leaf toughness (de la Riva et al., 2016). Moreover, leaf thickness plays a role in plant functioning and is correlated to species' strategies of resource acquisition and use (Vile et al., 2005). This parameter was used as a tool for productivity screening of various plants (White and Montes, 2005) or as an ecological performance index (Diaz et al., 2004). SLW has an interesting behavior (Valdebenito et al., 2018) and it used in canopy photosynthesis, dry matter accumulation and plant growth studies (Amanullah, 2015).

It is also known that water deficit inhibits photosynthesis, affecting leaves features through impaired photochemical reactions (Wu and Bao, 2011). In some studies, water deficit determined a specific leaf weight decrease of 41.86% for a durum wheat crop when compared with the values obtained for irrigated plants (Guendouz et al., 2016). In addition, leaf area and the accumulation of fresh biomass in leaves are affected by salinity (Zhang et al., 2012) and testing this parameter in relation with this factor can be of interest. Moreover, this index is generally reduced with 23.06% in shade versus normal light conditions (Bharali and Chack, 2018). Also, this parameter can also be calculated after dividing the leaf area of fully expanded leaf lamina determined with a LI-COR LI-3000 area meter and dry weight of the entire leaf (Heckman et al., 2001). This type of index is determined relatively quick and cheap and can be proposed as a indicator of plant status in relation with N supply.

CONCLUSIONS

Nitrogen fertilization assure a greater productivity and is widely used worldwide for many plants, including cereals. Thus, a method for predicting crop physiological responses as an answer to nitrogen fertilization can be useful. Nitrogen supply index can be determined quickly and cheaply for wheat. This study results lead to an optimum amount of N fertilizer, 119 kg/ha, specific for the studied environment. Also, mathematical models were developed for a large interval of N kg/ha, between 0 and 200, quantities widely used.

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