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Jean-Paul Denuit, Marguerite Olivier, Marie-Julie Goffaux, Jean-Luc Herman, Jean-Pierre Goffart, Jean-Pierre Destain, Marc Frankinet

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Original article

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Jean-Paul Denuit*, Marguerite Olivier, Marie-Julie Goffaux, Jean-Luc Herman, Jean-Pierre Goffart, Jean-Pierre Destain, Marc Frankinet

Ministry of Small Enterprises, Traders and Agriculture
Agricultural Research Centre, Crop Production Department, Gembloux, Belgium

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Abstract – This paper presents experimental results from a new field-scale N management strategy for winter wheat and potato crops in Belgium. At the beginning of the season, a global N recommendation is given using the balance-sheet method. The crop development and related N needs are strongly influenced by unexpected factors during the growing season. Therefore, the N predictive recommendation needs to be adapted to the crop N status. For this assessment, the chlorophyll meter was preferred over several plant diagnostic tools. In order to eradicate environmental influences, the measurement procedure was defined. The proposed procedure was based on the establishment of chlorophyll meter relative values. In winter wheat, the procedure allowed the third N dressing amount to be modulated using an over-fertilized plot. The same approach was tested on potato crop to introduce N split-application. The results showed, however, that an over-fertilized plot as reference is not suitable for determining the supplemental N required.

nitrogen / fertilization / winter wheat / potato / chlorophyll meter / diagnostic tool

Résumé – Gestion de la fertilisation azotée des cultures de froment d'hiver et de pommes de terre à l'aide du chlorophyllomètre, outil rapide de diagnostic du statut azoté des cultures. L'objectif de cet article est de présenter de nouvelles stratégies de fertilisation azotée, à l'échelle de la parcelle, en blé d'hiver et pommes de terre en Belgique. En début de saison, un conseil global de fumure azotée est établi selon la méthode du bilan. Mais le développement de la culture et les besoins azotés correspondants sont fortement influencés par des facteurs imprévisibles. Ainsi le conseil de fumure doit être modulé par le statut azoté de la culture estimé grâce au chlorophyllomètre. Afin d'éliminer l'influence de facteurs extérieurs, un protocole d'utilisation a été défini. Cette procédure est basée sur l'établissement de valeurs relatives. En blé d'hiver, elle permet de moduler la quantité d'azote à apporter en troisième fraction grâce à une référence sur-fertilisée. La même approche a été testée en culture de pommes de terre en vue d'introduire le fractionnement dans la fertilisation azotée, mais les résultats ont montré qu'une placette sur-fertilisée ne permet pas de déterminer le besoin supplémentaire en azote.

azote / fertilisation / blé d'hiver / pomme de terre / chlorophyllomètre / outil de diagnostic

1. INTRODUCTION

In the research on N fertilization at the Crop Production Department of the Agricultural Research Centre there are two main objectives: to improve soil mineral N prediction and to improve knowledge of the N that crops need. Several studies have focused on the plant N status and the management of N fertilizer splitting.

The determination of total N requirement is the first step in N fertilization management. The balance-sheet method applied using the Azobil software (INRA, Laon, France) [4] gives this requirement. It is based on estimated values of crop N needs, particularly for winter wheat [2, 5] and potato, as well as other crops. For the split N fertilizer application the procedure is different for winter wheat and potato. For many years in Belgium, N fertilization of winter wheat was applied

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* Correspondence and reprints
prodveg@cragx.fgov.be
Present address: 4 rue de Bordia, 5030 Gembloux, Belgium.

in three dressings: at growth stages (GS) 25, 30 and 37–39 on the Zadoks scale [1]. The last N application is the most efficient for grain yield and protein content [3] and it is very important to modulate the amount to cover the specific crop N needs annually. For the potato crop, the N rate is usually applied once at planting time. The major part of the N absorption, however, occurs only after emergence (i.e. more than 1 month after planting) [11]. For the potato crop in particular, the split application is therefore recommended to minimize the N fertilizer losses by immobilization, denitrification or leaching as well as to meet crop N needs and supplies [10]. The strategy tested for the potato crop was to apply part of the N fertilizer requirement at planting time. For both crops, the assessment of crop N status during the growing season should enable the need (amount or time) for supplemental N to be detected.

Several methods were tested as crop N status diagnostic tools, including total N content of the crop (dynamic of N uptake and critical curve), nitrate content of the basal stem (winter wheat), petiole sap nitrate concentration (potato crop) and leaf chlorophyll content. The last-mentioned involved using a chlorophyll meter and was preferred for both crops. It is more accurate, especially on potato crops, and quicker and easier to use than other methods [6, 7]. However, factors such as site, climate and cultivar can greatly affect chlorophyll meter measurements. Therefore, it is essential to define the conditions of use in order to manage the N fertilization.

The chlorophyll meter (HNT model) is proposed as part of a global N management strategy. For winter wheat, the aim is to adapt the amount of the third N application according to crop needs using the chlorophyll meter. For the potato crop, the N split application is a new approach. The purpose is to determine whether supplemental N is required and when it should be applied.

This paper discusses the use of the chlorophyll meter in these strategies and the establishment of reference values for the HNT chlorophyll meter, based on establishing an over-fertilized plot, and leading to the determination of supplemental N requirements.

2. MATERIALS AND METHODS

2.1. Brief description of the new strategies used for N management on winter wheat and potato crops

At the beginning of the season, the Azobil software provides a global field-specific N fertilization recommendation. To assess the crop N status, the chlorophyll meter is used. To detect the supplemental N requirement, the usefulness of an over-fertilized plot was investigated. The aim is to establish relevant chlorophyll meter values to determine the amount of the third N application for winter wheat. On the other hand, for potato crops, 70% of the Azobil recommendation is applied at planting. The chlorophyll meter is used to determine the need for the remaining 30% N.

2.2. Azobil software description: principle and characteristics

The Azobil software, developed by the INRA of Laon [4], predicts the N fertilizer needs using the balance-sheet method. Total N requirement are the total crop N needs and the soil mineral N residues at harvest. In the current version of Azobil, for winter wheat, the estimation of crop N needs is based on fixed values of N requirements per yield unit and on potential yield calculated for each situation. For potato, crop N needs are fixed according to maximal yield. Total N supply are the soil mineral N content at the end of winter (SCW), measured by soil analysis, and a prediction of mineral N soil supply (SS) during the growing season. SS corresponds to net mineralization from humus, crop residues and organic manure and does not include the SCW.

2.3. HNT chlorophyll meter description: characteristics and instructions

The chlorophyll meter (Hydro-Agri N-tester (HNT)) is a hand-held instrument that measures leaf transmittance at two wavelengths. At 650 nm no light is transmitted, due to absorption by chlorophyll, while at 940 nm the light is transmitted. There is a strong link between the HNT value and the plant N concentration [9]. The HNT value (without unit) is an average of 30 leaf readings. The advantages of this tool are the simplicity of use and the possibility of doing numerous repetitions in order to take the field variability into account. In winter wheat, measurements have to be made on the last unfolded leaf. In potato, HNT readings are done from 25–55 days after emergence (DAE), when total N uptake by the crop is well correlated with tool values [7]. Only the tip leaflet in the first fully developed leaf at the top of the main stem is used, one reading per plant.

2.4. Description of the trials conducted to determine the use of HNT

2.4.1. Winter wheat

Since 1998, 20 winter wheat trials with five N fertilization rates and several cultivars (Baltimor, Beaufort, Cactus, Charger, Corvus, Drifter, Hyno-Esta, Mercury, Pajero, Tilburi, Trémie, Vivant) have been conducted in two locations differing in soil and climate in Belgium. The soil N supply is generally higher in the loamy region than in the Condroz area, characterized by shallow soils. The N fertilizer was applied as ammonium nitrate (solid granules 27% N) at GS 25, 30 and 39. When possible (12 situations), the general protocol included five N fertilization levels: 0, 75, 150, 225 and 300 kg N per hectare, applied according to seven modes. In practice, 22 combinations were adopted (Tab. I). This experimental diagram allowed us to estimate the maximum and optimal yield for any N rate between 0 and 300 kg N per hectare and any split applications [8]. Thus, the site was perfectly characterized. The treatments were set up in a complete randomized block design with four replicates. The soil N supply (SS) was measured monthly by soil profile analysis.

Table I. Description of the general protocol according to Roisin [8] for winter wheat trials. Rates of the three N dressings (kg N/ha).

	Growth stage			
Treatments	22	30	39	Total (kg N/ha)
1	0	0	0	0
2	75	0	0	75
3	0	75	0	75
4	0	0	75	75
5	37.5	37.5	0	75
6	150	0	0	150
7	0	150	0	150
8	0	0	150	150
9	75	75	0	150
10	75	0	75	150
11	0	75	75	150
12	50	50	50	150
13	225	0	0	225
14	0	225	0	225
15	0	0	225	225
16	112.5	112.5	0	225
17	112.5	0	112.5	225
18	0	112.5	112.5	225
19	75	75	75	225
20	150	0	150	300
21	0	150	150	300
22	100	100	100	300

2.4.2. Potato crop

For the potato crop, 12 trials were conducted from 1997 to 2000 with cv. Bintje on Belgian non-irrigated loamy soils. Treatments were replicated four times and laid out in a complete randomized block design. The balance-sheet method was used to provide the full N recommendation (Azobil, INRA, Laon, France). The N treatments at planting represented 0%, 75%, 100% and 125% (1997–1998) or 0%, 70%, 100% and 130% (1999–2000) of the recommended rate. At planting time, N fertilizer was broadcast as ammonium nitrate (solid granules 27% N). The N status of each plot was assessed using chlorophyll meter measurements that began 20 days after emergence and were repeated 4 to 6 times during the season.

Four trials illustrate the results. The characteristics of these trial sites are described in Table II.

Table II. Description of four trial sites for potato crop.

Site	Year	Soil type	Previous crop	Soil mineral N (kg N/ha – 60 cm)	Soil humus content (%)	Manure application before potato	N advice (kg N/ha)	N applied at plantation (kg N/ha)
1	1997	sandy-loam	cereal	72	2.3	no	115	86
2	1999	loam	cereal	7	1.78	poultry	150	105
3	1999	loam	cereal	13	1.47	poultry	125	88
4	2000	loam	cereal	33	1.97	no	145	102

2.5. First step of strategy validation on winter wheat

The proposed method is being validated for winter wheat. In 2001, trials were conducted in two locations in the loamy region (Tab. III). Site 2 is a long-term experiment focusing on organic manure. The new strategy using the balance-sheet method and the chlorophyll meter is being compared with the traditional method, called "Livre Blanc", used by the Faculty of Agriculture, University of Gembloux, and the Agricultural Research Centre of Gembloux. It is based on a standardized system allowing a standard application to be modulated during the growing season. The comparison criteria are the yield, the economical yield (= [price of winter wheat × yield] – [price of an N unit × N fertilizer applied] – [price of an N fertilizer application × number of applications]), the quality (grain protein content, zeleny) and the soil N residue after harvest.

3. RESULTS AND DISCUSSIONS

3.1. Winter wheat

The HNT value reflecting crop N status is correlated to yield and r^2 increases during the growing season. Values at GS 37 are more interesting than those at GS 32 because there is a longer period of environmental effects. Furthermore, the HNT values correlate highly with the N fertilizer rate at GS 37 and 39 [9], generally corresponding to the third N application. Measurements could be made at GS 37 or GS 39, but always on the last unfolded leaf.

Table III. Description of four trial sites for validation in winter wheat in 2001.

Site	Soil	Previous crop	Organic supply
1	loam	pea	crop residues incorporated, no organic supply
2.1	loam	sugar beet	crop residues always incorporated, lime from sugar beet factory and slurry manure
2.2	loam	sugar beet	crop residues exportation and dung
2.3	loam	sugar beet	crop residues incorporated, no organic supply, green manure

Tables IV and V show that the site (climate and soil) has an influence on measured HNT values. In favorable conditions (loamy soil, warmer climate) – i.e. high soil N supply – the N fertilizer needs are low, as is the response to N fertilization. HNT values are also low (Tab. IV). This does not mean that the crop N status is low. In a less favorable location (shallow soil, colder climate), the N fertilizer needs are high and the response to N fertilizer, as well as HNT values, are high (Tab. V). This observation is paradoxical and indicates that the HNT values must be used as a relative value and not as an absolute one.

The HNT index (H.I.) at GS 39 is defined as the ratio between HNT values observed for the treatment and the maximum HNT value for this site measured on an over-fertilized plot. It could explain 84% of the variation of the yield index (ratio between yield observed for the treatment and maximum yield for the site) and 82% of the variation of the fertilization index (F.I.) (Eqs. (1) and (2)) (ratio between [N needs from GS 39 to harvest] and [total N needs]) (Figs. 1 and 2), where N needs include mineralization and fertilization.

The relationship between H.I. and F.I. allows us to determine the N amount of the third application. Actually, F.I. is based on the SCW measured in the field and on the Azobil prediction. The equations are:

$$\text{F.I.} = 1 - \frac{(D_1 + D_2 + SS_{39} + SCW)}{(SCW + SS + N_{opt})} \qquad (1)$$

or

$$D_3 = \text{F.I.}\ (SCW + SS + X_{opt}) - SS_{39} \qquad (2)$$

where F.I. is the fertilization index
D_1, D_2 and D_3 are the amount of the first, second and third N fertilizer dressings;
SS_{39} is the soil supply at the flag-leaf stage (GS 39);
SCW is the mineral N content in the soil at the end of winter;
SS is the mineral N soil supply;
N_{opt} is the total N fertilizer requirement of the crop.

The soil supply at the flag-leaf stage (SS_{39}) is approximately half of the total soil supply (SS) predicted by Azobil software. The total N fertilizer requirement (N_{opt}) is also predicted by this software.

In practice, the HNT index (H.I.) is measured in the field. It gives the fertilization index according to the reference curve (Eq. (3) – Fig. 4).

$$\text{F.I.} = -5{,}0882\ \text{H.I.}^2 + 6{,}75\ \text{H.I.} - 1{,}3755 \qquad (3)$$

1. F.I.: fertilization index;
2. H.I.: HNT index.

An over-fertilized plot covering a small field area is needed to establish the HNT maximum value of the site. It corresponds to a two-fold increase in the first two N applications.

The validation of this method is currently being undertaken (Tab. VI). For trial 1, after a legume crop, the Azobil prediction and the Livre Blanc recommendation were very close 142 kg N/ha and 147 kg N/ha, respectively. The HNT precisely estimated the high yield potential at GS 37, so the recommended amount for the third application was high. The

Table IV. HNT value obtained under favorable soil N conditions at several growth stages (GS – Zadoks) and for different N rates of the first two applications in 1998.

N fertilizer (kg N/ha)	GS 31	GS 32	GS 37	GS 39	GS 45
50-0-0	629	602	601	541	529
50-50-0	638	611	623	568	552
50-100-0	629	619	638	590	589
50-150-0	635	631	627	605	597
50-200-0	628	628	642	599	604

Table V. HNT value obtained under unfavorable soil N conditions at several growth stages (GS – Zadoks) and for different N rates of the first two applications in 1998.

N fertilizer (kg N/ha)	GS 31	GS 32	GS 37	GS 39	GS 45
50-0-0	546	528	559	466	456
50-50-0	583	616	665	595	554
50-100-0	589	646	701	634	632
50-150-0	597	662	720	666	678
50-200-0	598	669	720	685	694

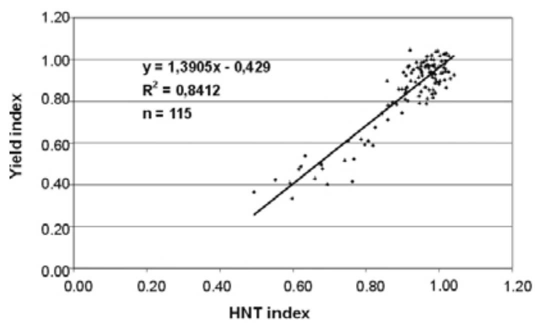

Figure 1. Relationship between the HNT index (H.I.) and the yield index and GS 39.

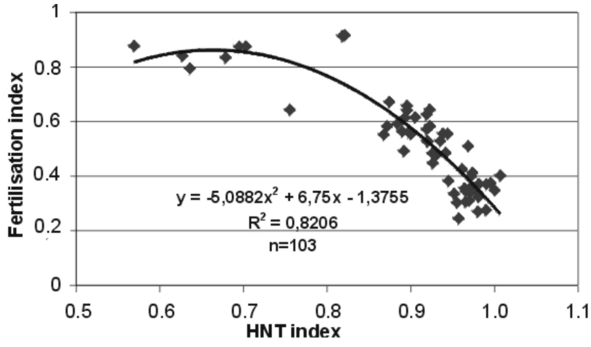

Figure 2. Relationship between HNT index and fertilization index.

Table VI. Comparison of results obtained in 2001 for the N fertilization method "Livre blanc" and the proposed Azobil-HNT method.

	Site 1		Site 2.1	
	Livre blanc	Azobil-HNT	Livre blanc	Azobil-HNT
Total N supply (kg N/ha)	147	175	185	264
Splitting (kg N/ha)	40-32-75	40-62-73	60-60-75	60-111-93
Yield (kg/ha)	11.251	11.525	8.162	8.945
Economical yield (kg/ha)	10.396	10.559	7.094	7.132
Grain protein content (%)	11.7	12.3	11.6	11.8
Soil N residues (kg N/ha)	37	36	51	109
	Site 2.2		Site 2.3	
	Livre blanc	Azobil-HNT	Livre blancl	Azobil-HNT
Total N supply (kg N/ha)	195	242	195	205
Splitting (kg N/ha)	60-60-75	60-112-75	60-60-75	60-121-24
Yield (kg/ha)	8.318	8.590	7.949	8.326
Economical yield (kg/ha)	7.250	7.326	6.881	7.217
Grain protein content (%)	11.2	11.0	11.0	11.0
Soil N residues (kg N/ha – 150 cm)	67	44	48	35

Table VII. Chlorophyll meter (HNT) values and coefficients of variation at site 4 in Gembloux (2000) for four nitrogen treatments (4 replications). Bintje Cultivar.

Nitrogen	Date (D/M)	8/6	15/6	23/6	29/6	6/7	13/7	20/7
treatment	DAE	24	32	40	46	53	60	67
0 N	Average	491	484	491	510	466	450	443
	C.V.	2	3	4	3	4	4	2
102 kg N/ha	Average	537	585	614	603	571	528	508
	C.V.	1	0	2	2	3	2	3
145 kg N/ha	Average	539	597	643	636	575	554	541
	C.V.	4	2	4	4	3	2	1
189 kg N/ha	Average	533	610	638	650	595	566	570
	C.V.	1	1	2	3	2	4	2

DAE: days after emergence.

total N fertilizer amount of the Azobil-HNT method was 175 kg N/ha. This was justified with regard to economical yield, grain protein content and low soil N residue after harvest. For the other crop situations, the yield potential was low due to water excess in winter and poor drainage. Consequently, crop establishment was not favorable and the yield potential was very low. Nevertheless, apart from site 2.1 where the residue after harvest was too high, the HNT results came up to expectations.

3.2. Potato crop

For the potato crop, the results from the first years showed that the chlorophyll meter has interesting features. The first is its feasibility. Hydro N-Tester (HNT) is very easy to use. It is a non-invasive method. It is very quick, with only 5 minutes required to obtain one value. It is sensitive to N supply as the values increase with N fertilizer rates. The low variability between the measurements in the same N treatment indicates good accuracy (Tab. VII).

But as for winter wheat, some shortcomings are reported; mainly the lack of specificity caused by the environmental effect on HNT values. The potato cultivar, the soil, the climate and the water status of the crop are the main factors affecting HNT values [7]. To use this method efficiently, it is necessary to take these characteristics into account. The yield of the four trials showed that for sites 1 and 2, no supplemental N was needed during the growing season to achieve the crop maximum potential. For both other sites, Nos. 3 and 4, the N rate applied at planting was not sufficient to reach the maximum yield. N supplies added after emergence were very useful for the crop without increasing the N soil residues after harvest. Figure 3 illustrates the evolution of the HNT values for the four investigated sites. It shows that HNT absolute values do not correlate with the crop supplemental N need.

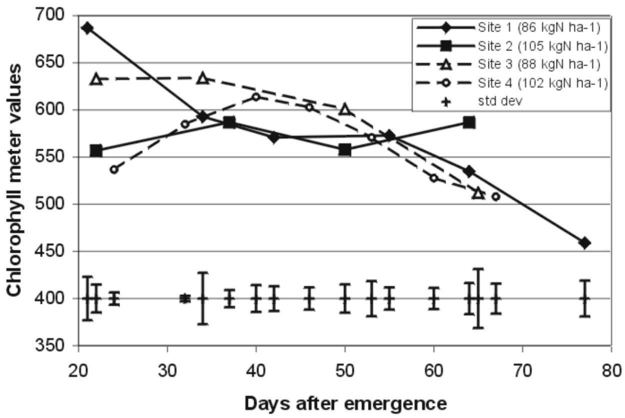

Figure 3. Time course of the chlorophyll meter (HNT) values in four potato trial sites (1997, 1999 and 2000). The nitrogen treatments are 75% (1997) or 70% (other years) of the Azobil nitrogen advice. Nitrogen was enough in sites 1 and 2 and had to be supplemented in sites 3 and 4. Bintje Cultivar.

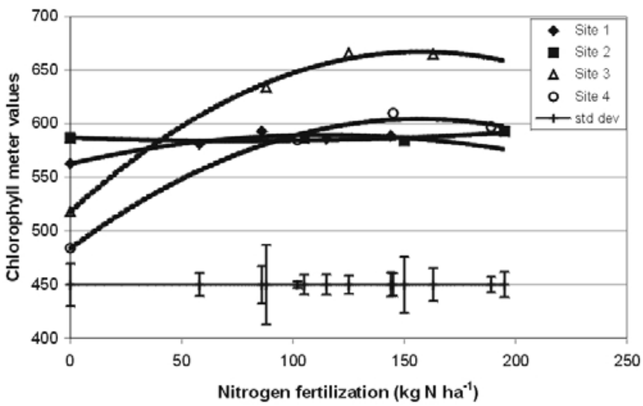

Figure 4. Chlorophyll meter (HNT) values for four nitrogen treatments in four trials (1997, 1999, 1999 and 2000) with four replications. Quadratic curves have been added. Bintje cultivar.

As for winter wheat, a relative value integrating the site factor would be more relevant. The first idea was to set up an N over-fertilized plot in the field to show the maximum HNT values. The answer to the question "Is supplemental N needed to reach the field potential?" should be given by a HNT relative index based on this over-fertilized plot.

Each one of the 12 N trials had a plot with a N rate exceeding the recommended rate. This plot can be regarded as the over-fertilized plot. The HNT measurements were then made for each treatment and showed that the differences between the values of the fertilized plots were very low. It therefore seems irrelevant to use a relative HNT comparing two N treatments. Figure 4 illustrates this observation in the four experimental sites. The HNT values' variation between the treatment plots and the over-fertilized plot is not very high. In the two sites where N additions were needed, only the plots without N showed values significantly different from the fertilized plots.

4. CONCLUSION

The proposed methods allow the N fertilization in winter wheat and potato to be managed dynamically, adjusting the N recommendations to the crop N requirements during the growing season. A useful plant diagnostic tool, the chlorophyll meter Hydro N Tester (HNT), was used to determine the appropriate growth stage (potato crop) or the exact N rate (winter wheat) to complete the first N applications. HNT absolute values are not exploitable on this view. The subject of this paper was to present a new strategy for both crops using HNT to overcome the problem of the site factor.

For winter wheat, the HNT values are more relevant at GS 37 and GS 39. The maximum HNT value for the site is obtained in an over-fertilized area of the field. The HNT index, defined as the ratio between the crop HNT value and the maximum HNT value, was calculated. It permits us, using the reference curve, to give the theoretical value of the fertilization index, which predicts the amount of the third N fertilizer dressing. The validation of this strategy is still in progress.

For potato, the use of the HNT to manage N split applications proved adequate. However, the approach using a relative value based on an over-fertilized plot in the field as reference is not the best one. The comparison with a non-fertilized plot is more promising, and is the subject of current research.

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REFERENCES

[1] Bodson B., Destain J.P., Iorgiu A., Study of the dynamic of uptake by winter wheat of split applied nitrogen and the role of each dressing to improve nitrogen balance and crop's economic optimum, 3rd ESA Congress, Padova, 1994, pp. 448–449

[2] Denuit J.P., Goffaux M.J., Herman J.L., Destain J.P., Évolution de la fumure du Livre blanc, Livre Blanc « céréales » F.U.S.A. et C.R.A. Gembloux, 2002, 7 p.

[3] Destain J.P., Bodson B., Herman J.L., François E., Franc J., Uptake and efficiency of split applications of nitrogen fertilizer in winter wheat, in: Ando T. et al. (Eds.), Plant Nutrition for sustainable food production and environment, 1997, pp. 633–634.

[4] Machet J.M., Dubrulle P., Azobil: a computer program for fertilizer N recommendations based on a predictive balance sheet method, in: Scaife A. (Ed.), Proceedings of first congress of the European Society of Agronomy, Paris, 1990.

[5] Maes N., Franc J., Herman J.L., Bodson B., Falisse A., Destain J.P., Meeus K., État d'avancement de la recherche en conseil de fumure azotée en froment d'hiver, Livre Blanc « céréales » F.U.S.A. et C.R.A Gembloux, 1999, 13 p.

[6] Maes N., Hallaux B., Herman J.L., Destain J.P., Research on diagnostic tools of nitrogen status of winter wheat in Crop development for the cool and wet regions of Europe (Cost 814), Proceedings of the final conference, Pordedone, 2000, pp. 437–442.

[7] Olivier M., Goffart J.P., Sinnave G., Evaluation of invasive method to assess the nitrogen status of the potato in the course of the season, 14th triennal Conference of the EAPR, Sorrento, Italy, 1999, pp. 134–135.

[8] Roisin C., Sur l'importance du choix des dispositifs expérimentaux dans les études relatives au fractionnement de la fumure azotée en céréales. Résultats d'une étude méthodologique, Bull. Rech. Agron. Gembloux 29 (1994) 315–338.

[9] Vos J., Bom M., Hand-held chlorophyll meter: a promising tool to assess the nitrogen status of foliage, Potato Res. 36 (1993) 301–308.

[10] Vos J., MacKerron D.K.L., Basic concepts of the management of supply of nitrogen and water in potato production, in: Haverkort A., MacKerron D.K.L. (Eds.), Management of nitrogen and water in potato production, Wageningen Pers., 2000, pp. 15–33.

[11] Westerman D.T., Kleinkopf G.E., Nitrogen requirements of potatoes, Agron. J. 77 (1985) 616–621.