In: Nitrogen Fertilizer
Editor: Karlene Winslow
ISBN: 978-1-63321-585-6
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Chapter 4

REVIEW OF ANALYSES FOR NITROGEN SUPPLY IN MAIZE AND WINTER WHEAT - CASE OF DEVELOPING COUNTRIES I.E. SLOVENIAN EXPERIENCES

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ABSTRACT

In developing countries the supply of cash crops of nitrogen is usually based on unfounded rates and did not successfully change–with fertilization, based on N analyses and calculated nitrogen target values. In Slovenia, the first analyses of the sap test in winter wheat were done 30 years ago, but the soil Nmin analyses were not supported from university professors and even from the government until 2004. The soil Nmin sometimes reached more than 400 kg Nmin ha^{-1} up to 0.9 m soil depth, which was associated with nitrogen pollution of drinking water with over 50 mg $N0_3^-$ l^{-1}. In the late 1990s, three researchers (Bavec, Bavec and Briški) provided analyses of soil Nmin and established nitrogen target values despite objections. Analyses are involved for practical farm use with EU support as an agri-environmental scheme after establishing integrated field crop production standards. Slovenia is the only country that provided this measure at a national level in EU 27 in the period 2004-2014. The data from research and analyses of integrated crop production praxis with a defined system of soil Nmin analyses were done in this chapter. Presentation of Nmin data and some problems of introduction of soil Nmin analyses into the support system were analyzed and represented. The analyses of Nmin, based on 5075 soil samples, also showed that the timing of sampling was sometimes incorrect, but timely analyses showed appropriate levels of Nmin in the soil profiles. However, in the new Program of rural development for 2014-2020, the nitrogen fertilization based on the soil Nmin analyses, for the Slovenian Ministry of agriculture and the environment, is a system too complicated for money transfer for economically and environmentally acceptable N supply in field crop production, which complies to EU CAP and EU Nitrate directive. However, producers, professionals, non-governmental and governmental institutions need to renew calculations of economical benefits, impacts and environmental risks for better development and reasonable N supply in production of their main cash crop. Because of discrepancies among countries, the minimal N management standards due to production costs and negative environmental impacts needs to be regulated and supported around the world by the FAO and/or OECD.

INTRODUCTION

N supply based on analyses was one of the first topics of fertilization development in agronomy at the end of 20th century in developed countries, but their implication depends on societal, regional or national requirements associated with priorities of economical and environmental importance. Establishing the correct N fertilization and especially top dressing rates must be based on different factors such as crop genotype, expected yield and quality, available N in the soil, mineralization potential and plant needs during the growing period. European farmers usually meet the needs written in guidelines, but in investigation reports and papers we can find many pro et contra conclusions about appropriate analyses like total N, Nmic, N org, soil Nmin or NO_3-N analyses (as a main tool in USA), sap NO_3^- or total N plant tests, chlorophyll meter readings, canopy sensors, etc., and only a few of them are implemented into practice. Former traditional understanding and requirements were based on advised nitrogen rates without any analyses, where some leading professionals advised based on 'practical experiences' and this kind of practice is very difficult to transform into environmentally responsible field crop production. Furthermore in some developing countries we can find a discrepancy between scientific findings, fertilization knowledge transferred to farmers, and governmental supported and advised recommendations based on analyses. In some countries none of this type of support exists.

The first analyses of sap test in winter wheat in Slovenia were done 30 years ago. The soil Nmin analyses were not supported from university professors and even from government until 2004. The soil Nmin sometimes reached even more than 400 kg Nmin ha^{-1} up to 0.9 m soil depth, which was associated with nitrogen pollution of drinking water with over 50 mg $N0_3$- l^{-1}. Since the late 1990s, three researchers (Bavec, Bavec and Briški), provided analyses of soil Nmin and established nitrogen target values in spite of objections from leading researchers. Analyses are involved with practical farmer use with EU support as an agri-environmental scheme after establishing integrated field crop production guidelines in 2004, as the only country that provided this measure at a national level in EU 27 in the period 2004-2014.

In the EU, due to the Nitrate directive (Council Directive 91/676/EEC, Regulation (EC) No 1882/2003, Regulation (EC) No 1137/2008) concerning the protection of waters against pollution caused by nitrates from agricultural sources, the agricultural practice has to adapt nitrogen fertilization management.

The aim of this chapter is to analyze investigations of nitrogen fertilization in the case of maize and winter wheat in Slovenia and their implementation into the practical sector, with special attention on agronomical and environmental impacts.

DATA OF N SUPPLY BASED ON ANALYSES

Slovenian Experience

Amongst progression of small and undeveloped countries compared to well-organized developed countries there exists a lot discrepancies. However in Slovenia, a few basic extensive studies exist.

In maize (*Zea mays* L.), N fertilization trials at loam-sandy soils at experimental circumstances at Maribor, Slovenia (36^{o} 34 N, 15^{o} 38 E latitude, 274 a.s.l., yearly precipitation 1000 mm) concluded (Bavec, 1992) that influence of nitrogen fertilization rates (55, 150, 225, 300 and 0 kg N ha^{-1} – control plot) on maize expressed a small influence on grain yield (R: up to 0.19). But maize yield and soil Nmin before sowing was firmly correlated (R: 0.42 - 0.63) and even more firmly (R: 0.55 – 0.82) at the growth stage of 7 to 9 leaves (BBCH 17 – 19). The correlation coefficient between Nmin and yield were very firm; if the soil was 157 kg Nmin ha^{-1} before sowing then the fertilization was (r= 0.41 – 0.83), or 274 kg Nmin ha^{-1} at BBCH 17-19 (r: 0.56-0.75). In the case of low soil Nmin before fertilization at sowing time the effects of added nitrogen had a firm correlation with grain yield. In this case the maximum yields were established up to a total of 325 kg N (Nmin plus N added with fertilizers) ha^{-1}. This means that at 73 to 79 kg Nmin ha^{-1} before sowing the yields were increased up to 150 kg added N ha^{-1}, in split rates 75 kg N ha^{-1} before sowing and 75 kg N ha^{-1} at BBCH 17-19 stage. Also based on soil NO_3-N, firm correlations with grain yield were found. It was the main research, and when we took additional data (Bavec, 2001) into account, the advised nitrogen rate for maize top dressing is Kg N ha^{-1} = 225 to 325 kg N ha^{-1} – kg Nmin ha^{-1} (from 0-0.9 m soil deep), and as optimal NO_3-N in the soil 21 mg NO_3-N to soil depth 0.3 m was advised (Annon., 2014) as an approximate level that we begin to consider additional agronomical N needs in crops and negative nitrogen impacts of additional fertilization with nitrogen. In general, additional fertilization in this case is not necessary. Additional results of trials measuring N uptake of the total dry mass of above ground plants showed an increase from 159 to 255 kg N ha^{-1} (Bavec, 1992). However, the effects of fertilization, nitrogen use efficiency (NUE) and N accumulation were conditioned by the yearly circumstances (and Nmin), hybrids, plant densities, method of sowing and numerous other interactions.

With the introduction of sweet maize (*Zea mays* L. *sacharata* Sturt.) into temperate climates, additional information concerning fertilization is required, especially for developing an organic production system. Field experiments were carried out in the Slovenian region, Styria, suitable for growing only early-maturity maize hybrids (FAO100–400), with the aim of determining the effects of nitrogen applied to different nitrogen target values (70, 120, 170 and 220 kg ha^{-1} N) on growth, yield, photosynthetic activity and soil mineral nitrogen (Nmin – NO_3-N and NH4-N) dynamics, as compared to the control. Nitrogen was applied as organic by-products (pumpkin cake and pig manure digestate) and mineral fertilizers (CAN 27 and ENTEC® 26). The major points were as follows: 1) pumpkin cake had a similar effect as that of mineral fertilizers, and gave a significantly higher total and marketable yields (14.476 and 11.619 t ha^{-1}, respectively), higher values of cob characteristics and plant mass than for pig manure digestate; 2) there were no significant differences in total and marketable yields among the target values of 120, 170 and 220 kg ha^{-1} N, but the calculated nitrogen target value, expressed as the peak of a regression curve for yield, was 170 kg ha^{-1} N. However, the data showed that high yields of organic sweet maize could be obtained using pumpkin cake as nitrogen fertilizer based on a target value 120 kg ha^{-1} N (rate of kg ha^{-1} N = 120 kg ha^{-1} N – soil Nmin till 0.9 m depth) at the time of sowing (Bavec et al., 2013).

Experiences with chlorophyll meter readings and plant sap tests in maize are discussable. When we compare four different N rates at four hybrids, the differences among readings and hybrids had the same variation. It a reason that we concluded (Bavec[a], 1994) that optimization for maize N fertilization based on chlorophyll meter readings must be evaluated for each genotype, which is not a solution for practical applications. The same has happened with NO_3^- sap tests: there were no clear correlations between NO_3^- levels and grain yield (Bavec[b], 1994). In spite of our results recommendations were made (Leskošek, 1994), but after discussion they were never recommended again. (ii) In winter wheat the first advice came from analyses of sap nitrogen tests (Briški et al., 1996) which for many years were the only analyses for the 2nd and 3rd top dressing in winter wheat. The finding was as follows:

The analyses of soil Nmin and additional rates of N effects on winter wheat grain yields showed different N target values based on the regression curve for the 1st top dressing for maximum yields and for lower yields. The maximum yields (8.5 t ha^{-1}) were established at 220 to 260 kg ha^{-1} of available N (Nmin plus added nitrogen), but the yields from 6 to 7 t ha^{-1} were achieved at 110 to 140 kg ha^{-1} of available N (R: 0.40). It was concluded that the target value for the 1st top dressing for maximum yields needs to be around 150 kg N ha^{-1}, if there is more available nitrogen in the soil. Nmin rests after harvest on control plots and using 120 kg N ha^{-1} were 121 and 120 kg ha^{-1}, respectively, but only 40 to 48 kg of residual NO_3-N ha^{-1}, which is an appropriate value for water protected areas (Bavec,,1999).

According to the balance of environmental and agronomical impacts, advised recommendation for the 1st top dressing is as follows: N rate kg N ha^{-1} = 110 to 140 kg N ha^{-1} – kg Nmin (from 0 to 0.9 m soil depth).

Investigation of chlorophyll meter values of 13 winter wheat cultivars suggests that readings depend on cultivar (genotype), growth stage and yearly effects. Before 2nd top dressing at stage EC 31/32 the average value varied from 445 to 568, and before 3rd top dressing at stage EC 45/50 it varied from 487 to 580. At stage EC 45/50 the statistically identical values of six cultivars varied from 515 to 553, and the rest of the extreme readings were 487 or 580. At stage EC 31/32 there was no strong correlation (r=0.134) between chlorophyll meter readings and grain yield, but there was a stronger correlation between the chlorophyll meter values and grain yield (r=0.538, sig. at the 0.01 level) at stage EC 45/50. On the basis of results at stage EC 45/50 only, it is possible to explain the 37% effect of chlorophyll meter readings on grain yield with a quadratic or cubic regression curve (Bavec and Bavec, 2001, online 2006).

The use of chlorophyll meter readings was not in accordance with Wolring (1996) suggestions, because of problematic calibration for varieties and weak correlations of chlorophyll meter readings and grain yield and protein content in the grains. Also based on the project (Bavec, 1999-2001), it was not possible to establish clear guidelines for advisors. However we are collecting more data for establishing more appropriate recommendations for using chlorophyll meter readings in Slovenia.

(iii) If we compare just a few basic reviews from other countries, such as Germany (Olfs et al., 2005), we find that many soil-based methods have been developed to measure the soil mineral N available to plants at a given sampling date. Soil sampling at the start of the growing period and analyzing the amount of NO_3-N (and NH_4-N) is a widespread approach in Europe and the USA. Strategies in the USA for reducing NO_3^- loss through drainage include using nitrate soil tests, improved timing of N application at appropriate rates, and plant monitoring, diversifying crop rotations, using cover crops, reducing tillage, optimizing N application techniques, and using nitrification inhibitors (Dinnes et al., 2002). Due to technical procedures Olfs et al. (2005) suggested that based on data from field calibrations, the soil N pool is filled up with fertilizer N to a recommended amount. Depending on the pre-crop, use of organic manure, or soil characteristics, the recommendation might be modified (±10–50 kg N ha^{-1}). Another set of soil methods has been established to estimate the amount of N that is mineralized from organic soil matter, plant residues, and/or organic manure. Plant-analytical procedures cover the whole range from quantitative laboratory analysis to semi-quantitative “quick” tests carried out in the field. The main idea is that the plant itself is the best indicator for the N supply from any source within the growth period. In-field methods like the nitrate plant sap/petiole test and chlorophyll measurements with hand-held devices or *via* remote sensing are regarded as the most promising, because with these methods an adequate adjustment of the N-fertilizer application strategy within the season is feasible.

Extensive and complex data of plant nitrogen tests in winter wheat in France (Justes et al., 1994), with a combination of soil and plant analyses, were named the JUBIL method (Justes et al., 1994).

As reported by Wood et al. (1992) the field chlorophyll measurements in maize were highly correlated with N tissue concentrations at both growth stages during both years of the study (Wood et al., 1992). But, comparing chlorophyll meter readings and correlations with grain yield in maize showed both hybrid specific (Bavec, 2001) and site-year specific (Ziadi et al., 2008). However, authors doubt that chlorophyll meter indicators are clear indicators for maize N status.

The Use of Application Tools in Slovenia vs. Other Countries

The use of decision support tools by farmers and advisors show discrepancies between basic findings and advice, and the farmer's application. As reported by Olfs et al. (2005) in the huge range of methods proposed so far, the simple mild extraction procedures have gained the most interest, but introduction into practical recommendation schemes has been rather limited. Also the previous question, which supports decision tools for the environmental management of nitrogen (Meynard et al., 2002), is generally unanswered and depends on the development of the country. In theory numerous possibilities exist from direct practical methods (Dinnes et al., 2002) and model based decision support (Meynard et al., 2002). The fact is that non-point loss of N from commercial N fertilizer and decreased demand from the fields to water resources is not caused by any single factor. More likely, the age of crops in crop rotations, with a combination of factors, including tillage, drainage, and a general substitution of purchased N for biological crop selection, organic soil matter levels, hydrology, and temperature (Dinnes et al., 2002) all have significant effects on fertilization efficiency and loss of nitrates into the soil surface. For those in the USA, suggestions were made (Dinnes et al., 2002) to improve monitoring of soil nitrogen for split nitrogen application programs, manage variable rate nitrogen application models and methodologies, develop perennial cash-crop systems, cover crop options and management strategies, and nitrate removal strategies. As a strategy for the USA (Dinnes et al., 2002), in Switzerland and some parts of Germany, permanent control of the water table during the growing season by drainage lines and lysimeters were established more than 25 years ago. Also in Austria, Lithuania, Latvia, Lithuania and Poland, state monitoring of Nmin of some reference locations is performed, which serves as an advisory for nitrogen fertilization for winter cereals in surrounding areas. However, these technologies are usable for flat or slightly sloped fields and are economically limited because of existing field tile drainage lines and organization of the system at the country level. It is not possible to establish this kind of system in less developed countries and regions mainly due to economical reasons. In

Slovenia and most EU eastern countries this kind of system is not established (except very few lysimeters). According to the EU common agriculture policy, good agriculture practice and also nitrogen management supports direct or/and indirect measures depending on each country and usually the EU nitrate directive towards soil sampling to support good agriculture practice in this scope is not clear.

In Slovenia and Slovakia farmers take soil samples by themselves and take them to the lab where lab Nmin analysis is performed. In contrast, some countries like Hungary provide soil N analyses only partially, and Estonia and some Balkan countries do not use any analyses at farm level.

For example, US guidelines encourage use of other nutrient management technologies such as stabilizers, slow release fertilizers, incorporation or injection of organic manures, soil nitrate testing, and other technologies that minimize loss to surface or ground water resources and other supporting practices like: tile line DE nitrification bioreactor, constructed wetland, conservation stream buffer and fall cover cropping system (2013, Code practice for nitrogen fertilization).

If we compare the N approach, information sources and new data in developed countries, like the UK, with its improved farming practices with knowledge transferred to growers (Richards, 2007), with Slovenian activities, then large discrepancies would occur.

In countries like Slovenia, nitrogen supply needs more attention especially if we compare it to the UK proposal for their development, which is the best mirror for further development in less developed systems of knowledge and thinking about practical applications. Again, as we extensively cited, their (Richards, 2007) main tasks are:

– The different methods for quantifying soil nitrogen supply, by estimation, measurement, or both, must be validated and compared. The relative contributions of soil mineral nitrogen, nitrogen mineralized during spring and nitrogen taken up by the crop over the winter, or by maize must be clarified. Guidance is needed for the choice of method for different circumstances taking into account the cost and degree of accuracy to be expected.
– A method is needed for monitoring or modeling seasonal effects on soil nitrogen supply and for providing timely guidance on their impact on fertilizer recommendations.
– The extent to which soil nitrogen is utilized by crops affects nitrogen use efficiency and is a key component of many recommendation

systems. Factors that affect the utilization of soil nitrogen should be identified with a view towards improving nitrogen use efficiency. The assumption that soil mineral nitrogen is recovered by the crop with 100% efficiency (around 60% is the corresponding figure for applied inorganic nitrogen) requires validation for different agronomic conditions. (No experience with the models such as SUNDIAL).

- The need for current protein specifications for bread making wheat (usually minimum 13%) should be reviewed. Developments in varieties, in bread making techniques or in market requirements might allow the use of lower protein grain and smaller nitrogen applications.
- Improving the nitrogen economy.
- The biological basis for grain protein concentration as a retrospective indicator of nitrogen supply must be established. Any other practical indicators must be identified for both cereals and oilseed rape. Once methods are established, guidance for growers in their use is needed.
- Guidance is needed on the relative benefits of standard values and chemical analysis in estimating the nitrogen in livestock manures. Where analysis is preferred, guidance is also needed on sampling methods and on the interpretation of analytical reports. Actions in this area must be coordinated with developments in appropriate software.
- The genetic potential of crops for improved nitrogen uptake and utilization should be explored.
- Growers need greater awareness of the environmental issues associated with nitrates. Clear guidance is needed on identification of high-risk fields and farming practices and on practical mitigation methods.

Similar tasks needs to be discussed and provided elsewhere, where similar protocols were not taken into account.

In the UK more than 200 licensed advisors exist. In other EU countries, especially Eastern European countries and also in Slovenia, there are no special licensed advisers for N management. Most advisers do not read and study N fertilizer requirements.

ENVIRONMETAL IMPACTS

As we mentioned, in European countries like Switzerland and some regions of Germany, Austria, Lithuania, Latvia, Lithuania, etc., state monitoring of Nmin as a basis for nitrogen fertilization advising is connected with analyses of the nitrate level in groundwater. Most use of separate, more extensive monitoring, according to the Nitrate directive, which is on an area or regional basis, cover the main cash crops N management only indirectly.

As reported for Slovenian Prekmurje region based on 5,057 mineral nitrogen (Nmin) analyses of field soil from 2006 to 2009, the Nmin content (nitrate and ammonium N) was below 50 kg ha^{-1} N in 53% of the samples. In 16% of samples it was 50-100 kg ha^{-1} N, 17% of samples contained 100-200 kg/ha N, and 14% contained more than the 200 kg ha^{-1} N. In winter the content of Nmin was less than 50 kg Nmin ha^{-1}. In summer months higher values of Nmin were measured in maize (130 kg Nmin ha^{-1}), and lower values in cereals (just 15 kg Nmin ha^{-1}). The main problem was that some farmers did not follow economical and environmental targets; they followed only the rules sufficient for subsidies.

If we compare the data from Nitrate directive reports it is only possible to indirectly conclude the influence of agricultural management on water quality; it is impossible to establish conclusions regarding these two parameters for main cash crops.

In general the EU Commission’s report for the period 2004-2007 reveals that 15% of groundwater monitoring stations in the EU-27 found nitrate levels above the limit of 50 mg of nitrates per liter. For Bulgaria, Cyprus, Estonia and Hungary, 91% of monitoring sites found steady or decreasing levels. Austria, Denmark, Finland, Germany, Ireland, Lithuania, Luxembourg, Malta, the Netherlands and Slovenia decided to provide the same level of protection to their whole territory, rather than designate nitrate-vulnerable zones.

Member States had to establish codes of good practice for farmers, to be implemented on a voluntary basis throughout their territory, and develop specific action programs for compulsory implementation by farmers located in nitrate-vulnerable zones (2013 Nitrate directive report). Possibilities, like Soil and Water Assessment Tool (SWAT) for nitrogen (Neitsh et al., 2002; Pohlert et al., 2007) assessment, until now, was not studied in Slovenia in the case of nitrogen (just phosphorus) and it needs a long time for implementation. However, the SWAT model is very promising, because it includes many factors, like algorithms for decomposition, growth of nitrifying bacteria, nitrification, nitrificatory as well as denitrificatory N-emissions, N-uptake by plants and N transport due to water fluxes.

When we follow coordination of the Rural development program 2014 - 2020 in Slovenia, we did not find any positive coordination between agricultural and N environmental measures at the first stage. According to our suggestion Nmin analyses were taken into account as a production measure.

CONCLUSION

Differences and limitations of decision support tools of the nitrogen fertilization system with respect to the implementation of economical and environmental constraints depend upon relationships of findings and knowledge at all levels from scientists to advisers, governmental administration and farmers.

Soil analyses for the amount of NO_3-N (and NH_4-N) at the start of the growing period or at the stage of cereals for N top dressing and the recommended amount of N to target value is a widespread approach in the USA and the EU. Among countries there exists a big variation, and sometimes relationships with water protection is very scarce. The use of nitrate plant sap tests, chlorophyll meter readings or remote sensing is an additional (not main) adjustment of the N fertilizer application. In both soil and plant analyses there exist differences due to soil and plant characteristics, climatic circumstances and potential mineralization, immobilization, N losses, etc.

According to the situation in Slovenia and the known situation in some EU countries, we can conclude that in some countries the environmental priorities of main cash crops (wheat and maize) production management did not follow available findings, and their application at the field level are very scarce. The use of appropriate models is scarce or out of functions, and must be developed and/or adapted. The main problem for using official models is lack of data, such as cost covers.

Because of discrepancies, the minimal N management standards due to production costs and negative environmental impacts must be regulated and supported around the world by the FAO and/or OECD.

According to UK experiences, special tools like SWAT and licenses for advisers for N management must be developed in Slovenia and also in less developed countries.

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