

## THE EVALUATION OF NITROGEN PLANT NUTRITION BY CULTAN METHOD UNDER CONDITIONS OF CZECH REPUBLIC - A REVIEW

K. KUBESOVA, J. BALIK, O. SEDLAR, L. PEKLOVA, O. KOZLOVSKY and Z. PEKLOVA  
*Czech University of Life Sciences Prague, Department of Agro-Environmental Chemistry and Plant Nutrition, Faculty of Agrobiology, Food and Natural Resources, Prague, Czech Republic*

### Abstract

K. KUBESOVA, J. BALIK, O. SEDLAR, L. PEKLOVA, O. KOZLOVSKY and Z. PEKLOVA, 2013. The evaluation of nitrogen plant nutrition by CULTAN method under conditions of Czech Republic - a review. *Bulg. J. Agric. Sci.*, 19: 625-634

Fertilization of a range of agricultural crops by CULTAN method has been carried out with success for several years in Germany. In the Czech Republic, nitrogenous plant nutrition by this method is still being tested, only by some basic field crops in the frame of several field experiments at stations with various soil climatic conditions.

CULTAN method (Controlled Uptake Long Term Ammonium Nutrition) is based on long-term nutrition of plants by ammonium form of nitrogen. Fertilizer applied by a special injection machine (GFI 3A, Maschinen und Antriebstechnik GmbH Güstrow, Germany) creates points in the soil with a high concentration of ammonium, so called depot. The result is stabilization of the nitrogen source in the soil, therefore reduction of its loss by leaching and consequential contamination of the water sources. The acceptance of ammonium by a plant is conditioned by its immediate implementation into the organic compounds directly in the roots. Phytotoxicity of loose ammonium in the root cells leads to directed acceptance of nitrogen and its right use by the plant. Development of a bigger root system results in a higher production of aboveground matter in later phases of vegetation and, consequently, also in bigger crops of the main product. Another advantage of placing the fertilizer into depots is lesser influence of antagonism of ammonium to accept other cations by the plant. In this review, we are going to look at the principles of this method, phytohormonal system and reception of nutrients by plants fertilized through CULTAN method. Another part of the review is dedicated to the technology of fertilization through CULTAN method and to conclude, we are going to summarize up-to-date results achieved with plants fertilized by this method in various soil climatic conditions in the Czech Republic.

*Key words:* CULTAN depot, yield, ammonium injection, winter wheat, spring barley, oilseed rape, maize

### Introduction

Nitrogen is an element, which most determines plant production in the world as a whole. Nitrogenous fertilizers are used the most around the world (Stevenson 1982; Malhi et al., 2001). The principal characteristic of current farming on agricultural land is optimization of inputs and outputs. The aim is to secure purposeful use of nutrients by the grown plant and minimize its losses from the soil. The effectiveness of nitrogen on plants depends on soil conditions, climatic factors and agrotechnology, type of plant and the way of applying the fertilizer (Ledgard, 2001). In general, the effectiveness of nitrogen from fertilizers is lower than 50 % in tropical climate (Baligar and Bennett, 1986) and 70 % in moderate climate of North America (Malhi and Nyborg, 1991, 1992). Balík (1982,

1986) states that plants grown in the Czech Republic receive less than 50 % from the fertilizer. Strip and local application of nitrogen can lead to an increase in effectiveness of the applied nitrogenous fertilizer (Pang et al. 1973; Malhi and Nyborg, 1984). The localization of nitrogenous fertilizer into a strip or a point eliminates losses by volatility already in the depth of 5 cm in the soil (Fenn and Miyamoto, 1986). By lowering the losses of nitrogen through local application is possible to achieve the same yield at lower doses of nitrogen (Malhi and Nyborg, 1992).

Nitrogen is a part of important organic matters, such as proteins, nucleic acids, chlorophyll, enzymes (Mengel and Kirkby, 2001).

Application of a nitrogenous fertilizer increases the yield of biomass and the concentration of proteins in plants. It also affects the content of amino acids in plants and their nutrition value (Kozlovský, 2011). If the plant is insufficiently supplied by nitrogen, the content of nitrogenous matters in the plant is reduced. The insufficiency is reflected on a slower growth. The plants are weak, shrunken and they have light-green or even yellow leaves. Plants suffering from a lack of nitrogen ripe earlier and provide smaller and lower-quality crops (Torma, 2005; Vaněk et al., 2007). Sulphur added into a nitrogenous fertilizer increased, its effectiveness (Salvaggioti, 2007). Along with a lower number of atmospheric inputs of sulphur (Daemmgen et al., 1997) comes about its deficit in most soils (Duynsived et al., 1993; Bloem et al., 1997). Sulphur plays a crucial role in plant metabolism and its deficit is reflected on the quality of crops (McGrath and Zhao, 1996). By winter wheat, winter oilseed rape and maize, also nitrogenous fertilizers with sulphur were used, as the uptake of sulphur correlates with the uptake of nitrogen (Jez et al., 2008; Malhi et al., 2007).

### Cultan Method Principles

Conventional methods of supplying plants by nitrogen are based on applying nitrogenous fertilizers and dividing the nitrogen dose accordingly during the growth. Fertilizing by CULTAN method is essentially different from all conventional ways, which cannot enable the plant to make use of a bigger one-off dose of nitrogen effectively.

The principle of CULTAN method lies in placing nitrogenous fertilizers containing ammonium cation near the root system so that the necessary nitrogen is offered to the plant in an accessible, yet little mobile, form in the soil (Weimar, 2003). The base of CULTAN method (Controlled Uptake Long Term Ammonium Nutrition) is long-term nutrition of plants by an ammonium form of nitrogen. The fertilizer applied by a special injection machine (GFI 3A, Maschinen und Antriebstechnik GmbH Güstrow, Germany, Figure 1) creates points in the soil with a high concentration of ammonium ion, so called depots (Boelcke, 2000). Ammonium depots created this way are thanks to toxic characteristics of ammonium in the soil stable against nitrifying processes (Sommer, 2003). Positive ammonium ion relates to negative clay particles and organic matters (Kücke and Scherer, 2006). Therefore, it is possible to reduce nitrogenous fertilization to one total unit of nitrogen per vegetation (Boelcke, 2003). Nitrate nitrogen disperses in the soil more easily than ammonium one. The cause is that both nitrate and microorganisms, but the nitrate one is also subject to losses through denitrification and leaching (Malhi et al., 2001), can immobilize ammonium nitrogen. Ammonium is a paradoxical nutritional ion, even though it is the most widespread source of nitrogen and need not be

reduced through reception by a plant. However, most plants, if not all, grown on ammonium nutrition by nitrogen respond to it toxically (Vines and Wedding, 1960; Fangmeier et al., 1994; Gerandas et al., 1997). Atkinson (1985), Boxman et al. (1991), Wang and Below (1996) described as one symptom of toxicity through nutrition by ammonium form of nitrogen shortened roots. Yet by some plants the opposite effect on the root system was detected, the roots spread and strengthened (Gigon and Rorison, 1972).

In comparison with conventional methods, where the nitrogen offer to the plant is regulated, the CULTAN method introduces a so-called ammonium depot, which means that the reception of the ammonium cation from the depot by the plant is regulated by itself throughout the whole vegetation (Sommer and Mertz, 1974) (Figure 2).

The ammonium ion as a nitrogenous source for plants differs from nitrates and urea in many aspects when it is used by fertilization as a concentrated depot into the soil. Provided this way of fertilizing is used, plants grow actively towards the source of the ammonium nitrogen and it is being enhanced through metabolism of organic compounds of nitrogen (Sommer, 2005).

Through CULTAN method, only a part of the root system participates in the reception of the ammonium nitrogen from the edge of the dep. From here, the roots receive the ammonium nitrogen only if they are sufficiently supplied with saccharides from the aboveground part of the plant. Thus, the plants can implement the received nitrogen into the metabolism of the nitrogenous compounds. Those roots, which receive the ammonium nitrogen from the dep, thicken and spread sideways, supported by saccharides in the aboveground part of the plant and their organization in the plant changes accord-



Fig. 1. GFI 3A, Maschinen und Antriebstechnik GmbH Güstrow, Germany (Kozlovský, 2011)

ing to the growth phase of the plant. As a rule, they grow from free space in the soil towards the dep (Sommer, 2005). Chemical changes in plants fertilized by ammonium nitrogen are related mostly to the limited reception of cations, such as potassium, calcium and magnesium, contrary to plants fertilized by nitrate nitrogen (Kirkby, 1968; van Beusichem et al., 1988; Gloser and Gloser, 2000). According to Sommer et al. (1987), CULTAN plants should show no antagonistic behaviour of cations. The reason is that by CULTAN system maximally 5 % of the whole root system is involved in antagonism. This ratio is in comparison with the total reception of cations by plants quite negligible. Rosselt (1990), Balík et al. (2007) even claim that when the plants were fertilized by CULTAN method, there was a higher reception of potassium and calcium compared to plants fertilized by nitrates.

By using CULTAN method, the intensity of nitrogen reception is controlled by phytotoxicity of ammonium (Sommer and Rossig, 1978). According to Schumacher (2009), the efficiency of nitrogen from the fertilizer is by injection CULTAN method up to 90 %.

For CULTAN fertilization, the ammonium can be received by the plant only on the edge surface of the dep, due to its phytotoxicity. There it must be immediately implemented into the metabolism of nitrogenous compounds. After receiving the ammonium into this metabolism, there must be a sufficient uptake of saccharides in the root points from the aboveground part of the plant (Weimar and Sommer, 1990). For this reason, the reception of nitrogen by CULTAN method depends on an equal proportion to the synthesis of saccharides and related weather conditions. The optimal yield is very stable by correctly applied CULTAN fertilization (Weimar and Walg, 2003).

The received ammonium in the roots is at once bound to amino acids, which can be moved from roots and the bottom

part of the stem direct to the growing parts, which consequently leads to a greater development of the root system. The production of cytokinins in the root points increases, whereas the number of the auxins and gibberellins in the shoot decreases (Sommer, 1991; Marschner, 1995; Sommer and Scherer, 2007). Thanks to this phenomenon the root system by CULTAN method continues to develop. It is possible to say that by supplying nitrogen through CULTAN method in contrast to the conventional ones the reception of nutrients improves.

During a dry period, plants fertilized by CULTAN method show a much higher resistance to drought than plants with nitrogen like nitrates or urea. A bigger root system, a more intensive growth of roots in the direction of the sinking water level, differences in thickness of the cell walls and lower transpiration are all likely to improve the reception of nitrogen and its use (Sommer and Kreusel, 1992). Sommer (2005) further claims that the plants enhance the ammonium form of nitrogen from the marginal zones of the dep, while only a part of their root system participates in receiving the ammonium part and a bigger part ensures the reception of nutrients and water. The whole stem is filled with assimilates like storage until the time of anthesis. During anthesis these stored assimilates in the upper part of the stem quickly move to the reproductive organs and assimilating leaves where they are stored again. Assimilates in the bottom part of the stem remain available for the roots to preserve their function. Contrary to plants supplied with nitrogen in the form of nitrates, the period of storing assimilates in cobs prolongs thanks to the preserved function of the roots. Due to this behavior, the ammonium from CULTAN application is understood as a dominant fertilizer for roots (Sommer, 2005; Sommer and Scherer, 2007). According to Neuberg et al. (2008) nutrition of plants by ammonium form results in an increased content of free amino acids in the aboveground biomass. Neuberg et

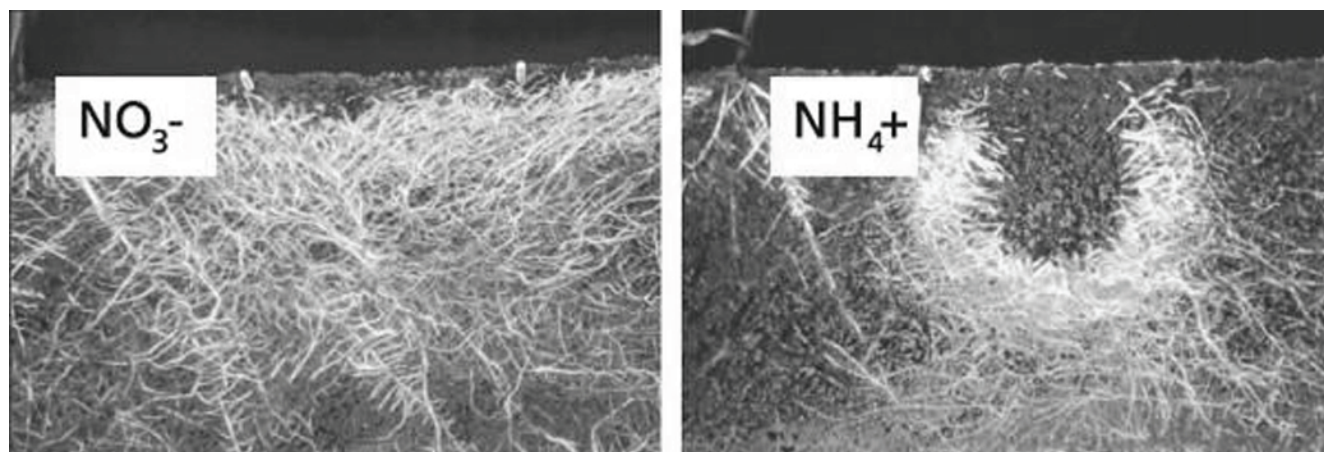


Fig. 2. The distribution of roots in the conventional method ( $\text{NO}_3^-$ ) and in the method CULTAN-depot ( $\text{NH}_4^+$ ) (Sommer, 2005)



al. (2010) states a higher content of free proline and asparagine by plants fertilized by CULTAN method.

Some of the most suitable fertilizers for CULTAN method by cereals are ammoniac waters, ammonium sulphate, ammonium sulphate with urea, and ammonium nitrate with urea (Balík et al., 2008). By blending singular forms of nitrogen, the total share of the ammonium form in the fertilizer should not go below 20% (Sommer and Scherer, 2007).

Moreover, after applying a fertilizer through CULTAN method, there are fewer nitrates in the soil and there are not so many losses or nitrogen caused by leaching and contamination of water sources (Walter, 2003).

### Technologies of Fertilization through Cultan Method

Sommer (2005) describes two significant technologies of fertilization by CULTAN method, and these are aboveground and injection depots. By CULTAN method, it is possible to fertilize the sown seeds, or directly the growing plants.

#### *Aboveground deps*

By this technology, it is possible to fertilize at little technical costs into the growing cultures by a hose. The basic preconditions for use of this method are: the solutions of fertilizers sink into the soil through application; the pH value of the soil is lower than 7.0; and the soil does not contain any free calcium carbonates in order to prevent the loss of ammonium. The aboveground depots are used most frequently in stony soils and by application of liquid organic fertilizers (Sommer, 2005).

#### *Injection depots*

For placing the CULTAN solution into the injection depot serve so called grouting wheels, which are hung on the frame

of the injection machine at the distance of 25 to 30 cm. To these wheels are fixed spikes 5 to 10 cm long, which inject the CULTAN solution into the soil at the distance of 15 to 20 cm. It is not possible to use such forms of nitrogen, by which the ammonium might be volatile because of high pH value of the soil (Sommer, 2005). The longer the distance, the lower efficiency of the fertilizer is. However, provided the distance is shorter, the plant may be damaged by toxicity of the ammonium (Balík et al., 2008).

### Crops Fertilized by Cultan Method

Continuous experiments have been done since 2007, in which the influence of CULTAN fertilization on the yield of the main and secondary product is compared, specifically by winter wheat, spring barley, winter oilseed rape and maize. The experiments were focusing also on the quality of the product, content of nitrogen, dynamics of the creation of aboveground biomass and damage through diseases and pests.

The experiments were carried out at various soil-climatic sites: Čáslav, Hněvčeves, Humpolec and Ivanovice na Hané (Table 1). The CULTAN method fertilization was done by a injection machine (GFI 3A, Maschinen und Antriebstechnik GmbH Güstrow, Germany), while the total dose of nitrogen was applied at once. Each applying wheel consists of 12 spikes, through which the liquid fertilizer is applied into the soil in the depth of 5 cm.

#### **Winter wheat**

The system of fertilization of field trial of winter wheat is mentioned under the text (Table 2). In 2007, a lower yield from the CULTAN variant was observed at all stations, partly caused by the spring spell of drought. The highest yield of grain by both conventional and CULTAN variants was observed in 2008. The CULTAN variants reached a lower yield

**Table 1**  
**Characteristics of experimental sites (Kozlovský, 2011)**

Site	Čáslav	Hněvčeves	Humpolec	Ivanovice na H.
Altitude, m	240	265	525	225
Precipitaton, mm	555	597	667	548
Average temperature per year, °C	8.9	8.1	6.5	9.2
Soil suborders	gray soil	haplic luvisol	cambisol	chernozem
Soil type	loam	clay loam	sandy loam	loam
pH (CaCl <sub>2</sub> )	6.6	6.3	6.6	7.3
Ca (mg.kg <sup>-1</sup> ), Mehlich III	2763	2 522	2 217	4 458
Mg(mg.kg <sup>-1</sup> ), Mehlich III	193	185	183	287
K (mg.kg <sup>-1</sup> ), Mehlich III	276	291	197	390
P (mg.kg <sup>-1</sup> ), Mehlich III	173	89	120	142

than the conventional variants in that year. In 2007 as well as 2008, CULTAN fertilization was carried out based on the recommendation of Sommer (2005) at the end of the tillering period (BBCH 29).

In 2009 and 2010 the application by CULTAN method was delayed till the beginning of the spring (BBCH 22) to achieve more favourable moisture conditions (Kozlovský, 2011). Although the weather conditions in 2009 were similar to 2007, the postponed application caused a higher yield of the grain at all stations. In the following year the grain yield of winter wheat was by conventional and CULTAN variants comparable. According to Sommer (2005) and Weber (2008), the use of CULTAN method in Germany brought about a higher yield of wheat grain.

The timing of application by CULTAN method had a strong influence on the length of the stem as well. By application at the end of the sprouting period was observed a shortened stem under Czech conditions, which corresponds with the experience from Germany (Kücke, 2003; Sommer, 2005). Yet the application by CULTAN method at the beginning of the spring lead to a longer stem by the winter wheat. Thus, it is not possible to confirm the influence of CULTAN method on the length of the stem in Czech conditions. No mechanic and chemical damage of the growth was observed during the application of CULTAN fertilizers, which could affect the number of plants per square meter.

The use of sulphur in nutrition of wheat had a positive effect by AS+CAN variant, for this variant had the highest number of cobs per square meter in total (Kozlovský et al., 2008). A positive effect of using a nitrogenous fertilizer with added sulphur on the yield of wheat grain was observed in Germany (Weber et al., 2008).

The content of potassium in wheat seed was slightly higher by the CULTAN variant. An increased dose of the same fertilizer had no influence on the reception of other elements. By CULTAN variants, there was a higher transfer from stem to grain, which confirms the findings of Sommer (2005).

As regards the quality indicators, the following ones were observed: content of N-matters, content of gluten, sediment index, content of starch, volume weight. A lower content of N-matters was observed by CULTAN variants. The increase of the nitrogen dose from 150 kg/ha to 200 kg/ha resulted in a slight increase of the number of N-matters by all variants. In addition, this parameter was affected by the timing of the application, the spring term seems to be more positive (Kozlovský, 2011).

Almost at all times, there was a lower content of gluten by CULTAN variants. A higher content of gluten was a consequence of CULTAN UAS fertilization. The values of the sediment index were lower by CULTAN method, just like the content of N-matters and gluten.

A higher dose of nitrogen and the application of the fertilizer with sulphur had a positive effect on this parameter, especially by CULTAN variants (Kozlovský, 2011).

The starch content in the wheat grain was higher by CULTAN variants. In addition, this parameter was influenced by timing of the application. Early in the spring there was a smaller difference in the content of starch between conventional and CULTAN variants. No evident difference was observed during the experiment in the bulk density figures and in the number of descent depending on the variant (Kozlovský, 2011). CULTAN method reached lower values in a lot of parameters, but the differences proved to be statistically insignificant. Therefore, it is possible to conclude that the CULTAN method is a suitable alternative for nutrition of winter wheat. The results also implied that before making the step of recommending it for use in common agricultural practice, it is necessary to carry on with its detailed examination (Kozlovský et al., 2009).

### Spring barley

The experiment with spring barley, Jersey variant, was set up at three sites: Hněvčeves, Humpolec and Ivanovice na Hané. One-off fertilization by CULTAN method was com-

**Table 2**  
**System of fertilization of field trial of winter wheat (Kozlovský, 2011)**

Treatment	BBCH 22	BBCH 22 (29)	BBCH 33	BBCH 52	Total N (kg) dosage per ha
conventional 1	43 kg CAN		87 kg CAN	20 kg CAN	150
CULTAN 1		150 kg UAN			150
conventional 2	60 kg CAN		90 kg CAN	50 kg CAN	200
CULTAN 2		200 kg UAN			200
conventional 3	43 kg AS		87 kg CAN	20 kg CAN	150
CULTAN 3		150 kg UAS			150

CAN – Calcium Ammonium Nitrate (27 % N); UAN – Urea Ammonium Nitrate (30 % N); AS – Ammonium Sulphate (20.5 % N, 24 % S); UAS – Urea Ammonium Sulphate (19 % N, 5 % S)

pared with conventional fertilization in individual doses on the surface of the soil (Table 3). Both types of fertilization were performed in two intensities 80 kg/ha and 130 kg/ha. The positive influence of CULTAN method on the content of dry matter proved in BBCH 45 phase in 2007 at Hněvčeves site and in 2008 at Humpolec site, by both doses of nitrogenous fertilizer, and in 2009 at Humpolec station, by intensity 80 kg/ha. In BBCH 51 phase, the content of dry matter was higher almost in half the cases by CULTAN variant (Sedlář et al., 2011a). By nitrogen dose 80 kg/ha the harvest index by CULTAN variants was comparable or higher than by conventional variants. An increase in nitrogen dose to 130 kg/ha led to a decrease in harvest index (Sedlář et al., 2011a). Influence of CULTAN method on shortening the stem of spring barley was observed in the experiment. The increase in nitrogen dose to 130 kg/ha resulted in prolonging the stem by conventionally fertilized variants. By conventional methods, it is recommended to use growth regulators in order to achieve a lower lodgings. By CULTAN method, this measure is not necessary (Kücke, 2003).

A higher grain yield of spring barley by intensity 80 kg/ha was observed by CULTAN variants at Humpolec site in 2009. On applying 130 kg/ha a higher grain yield was observed at Hněvčeves site in 2009, in Humpolec in 2008 and 2009 and in Ivanovice na Hané in 2007 and 2008. Statistically evident higher values of grain yield were achieved by conventional variants only at Ivanovice na Hané station in 2009, by application of 130 kg/ha (Sedlář et al., 2010). Sommer (2005) explains the higher grain yield by using CULTAN method by a longer period of grain filling. Adding sulphur into the fertilizer did not lead to an increase in grain yield. A tendency towards lower protein content in grain was observed by CULTAN variants, which is convenient especially during a short vegetation period, as confirmed in 2007.

On the other hand, a longer vegetation period by CULTAN variants can lead to a decrease in nitrogenous matters in grain, under the limit of malt quality. CULTAN fertiliza-

tion had a positive effect on thousand-grain weight. A higher thousand-grain weight (TGW) was observed in 2007 by CULTAN variants only by 130 kg/ha, in 2008 statistically higher TGW by CULTAN variants appeared by 80 kg/ha (Sedlář et al., 2009). It is possible to explain through the fact that plants suffering from a lack of nitrogen at the beginning of the tillering period create less tillers (Longnecker, 1993), thus the lower intensity of tillering leads to the creation of yield in the main stem and that is why CULTAN variants make grain with a higher value of TGW (thousand grain weight) (Sedlář et al., 2011b). Plants fertilized by CULTAN method differ from conventionally fertilized ones by a shorter length of the stem, a higher content of dry matter in later development phases, a higher harvest index, a lower risk of lodging, and a higher grain yield (Sedlář et al., 2011a). The positive effect of CULTAN method on yield and quality of the spring barley proved especially at less fertile sites (Sedlář et al., 2011b).

#### Oilseed rape

The experiment with winter oilseed rape was set up in the autumn of 2006 at stations Hněvčeves, Humpolec and Čáslav. Conventional variants were based on individual doses (first spring fertilization – during the roots regeneration period, second spring fertilization – 14 days after the first application and the third in BBCH 30 phase). The second conventional variant contained a fertilizer with added sulphur. By CULTAN variants, the fertilization was done in early spring during BBCH 26 phase by injection into the soil. The total amount of nitrogen by all variants was 200 kg/ha (Table 4). According to the results of Spiss and Meier (2008) the most suitable for is injection point application in the spring, at the beginning of vegetation.

So far, results have not proved any differences in the aboveground dry matter between the two systems of fertilization. An exception was the year 2008 at Humpolec site, when by both development phases there was a higher content of dry matter at CULTAN UAN variant contrary to the con-

**Table 3**  
**System of fertilization of field trial of spring barley (Sedlář et al., 2011b)**

Treatment	Dosage of added N per ha (fertilizer form)			Total N dosage per ha
	Before sowing	BBCH 28-29	BBCH 29-30	
conventional 1	80 kg (CAN)			80 kg
CULTAN 1			80 kg (UAN)	80 kg
conventional 2	80 kg (CAN)	50 kg (CAN)		130 kg
CULTAN 2			130 kg (UAN)	130 kg
conventional+S	23 kg (AS) + 57 kg (CAN)			80 kg
CULTAN+S			80 kg (UAS)	80 kg

CAN – Calcium Ammonium Nitrate (27 % N); UAN – Urea Ammonium Nitrate (30 % N); AS – Ammonium Sulphate (20.5 % N, 24 % S); UAS – Urea Ammonium Sulphate (19 % N, 5 % S)

ventional CAN variant (Peklová et al., 2011a). These results contradict the findings of Sommer (2005) that plants fertilized by CULTAN gradually show by 10–15% higher content of dry matter than plants receiving nitrate nitrogen. Peklová et al. (2011b) state that the length of winter oilseed rape plants by CULTAN variants was statistically evidently shorter than by conventional variants, which supports the findings of Sommer (2005) that CULTAN plants have a lower shoot than plants fertilized conventionally. During the experiments, a negative effect of CULTAN method on the content of nitrogen in the winter rape straw was observed. In the harvest year 2008 at Hněvčeves site CULTAN UAN variant lowered the content of nitrogen in straw by 36.7% contrary to the conventional CAN. In 2010, an evidently lower content of nitrogen by CULTAN UAN variant was found (Peklová et al., 2011a). The content of nitrogen in the colza seed was lower by CULTAN variants. The conventional variants reached on average by 12.2% higher content of nitrogen than the CULTAN variant (Peklová et al., 2011a).

The conclusion of Spiss and Meier (2008) that in German conditions the CULTAN method reached a higher content of proteins and glucosinolates and a lower oiliness was not confirmed (Peklová et al., 2011a). The CULTAN UAN variant had mostly lower yields than the equivalent CAN variant in all years at all stations, with the exception of Hněvčeves station in 2008 and 2009, when it reached on average by 0.12 t/ha higher yield. CULTAN UAS variant was mostly more efficient than equivalent AS+CAN variant. Only in 2009 at Hněvčeves station this variant proved a higher yield, on aver-

age by 0.30 t/ha than the conventional SA+CAN (Peklová et al., 2010). Peklová et al. (2011a) further states that it was not unambiguously confirmed that the plants could be damaged after running the grouting wheel over them and consequently after affecting by diseases (Felgentreu, 2003). Based on the experiments so far it is not possible to prove a positive effect of CULTAN method on the yield of winter oilseed rape in Czech conditions (Peklová et al., 2011a).

### Maize

The experiment with corn was set up in four sites: Čáslav, Hněvčeves, Humpolec and Ivanovice na Hané. The fertilization system is mentioned in Table 5. The experiment used TEXXUD variant with broadcast of 8200 seeds/ha.

By yield element TGW (thousand-grain weight), no statistically evident differences were found at Čáslav station in 2007. In the same year, on the contrary, the TGW was evidently different at Hněvčeves station by the fourth variant (CULTAN UAN + IN) (Kubešová, 2010).

This variant proved TGW (thousand grain weight) 4.4% lower than the conventional variant. A positive effect of CULTAN method on grain yield was observed at Čáslav station in 2009, where there was evidentially higher yield by the fourth variant CULTAN UAN+ IN, which accords with the findings of Blaylock (1990), who experimenting with corn statistically proved higher yield and a better use of nitrogen by point grouting from applied fertilizer UAN than by surface application. Corresponding experience state also Mengel et al. (1992), Pearson (1994) and Sommer et al. (2002).

**Table 4**  
**System of fertilization of field trial of oilseed rape (Peklová et al., 2010)**

Treatment	BBCH 25	BBCH 30	BBCH 26	BBCH 58	Total N (kg) dosage per ha
conventional 1	57 kg (CAN)	93 kg(CAN)		50 kg (CAN)	200
CULTAN 1			200 kg (UAN)		200
conventional 2	57 kg (AS)	93 kg (CAN)		50 kg (CAN)	200
CULTAN 2			200 kg (UAS)		200

CAN – Calcium Ammonium Nitrate (27% N); UAN – Urea Ammonium Nitrate (30% N); AS – Ammonium Sulphate (20.5% N, 24% S); UAS – Urea Ammonium Sulphate (19% N, 5% S)

**Table 5**  
**Fertilization system of field trial of maize (Kubešová, 2010)**

Treatment	Before sowing	CULTAN (plant height 20 cm)
CAN	140 kg N.ha <sup>-1</sup>	
CULTAN UAN		140 kg N.ha <sup>-1</sup>
CULTAN UAS		140 kg N.ha <sup>-1</sup>
CULTAN UAN + IN*		140 kg N.ha <sup>-1</sup>

CAN: Calcium Ammonium Nitrate, 27% N, UAN: Urea Ammonium Nitrate, 30% N

UAS: Urea Ammonium Sulphate, 24% N, 6% S, UAN + IN\*: Urea Ammonium Nitrate (30% N)+ inhibitors of nitrification



In Humpolec higher values were found by CULTAN variant. However, in Humpolec, all experimental variants had lower yields than at other sites. Contrary to Ivanovice, where in 2010 conventional variant CAN reached the highest yields. In 2007, the highest yield of secondary product was reached at Čáslav sites, by CULTAN UAN variant, by 3.1 % more than by the conventional variant. In the experiment, no statistically evident difference in the content of nitrogen in the whole plant, thus neither in the quality, was observed. Only by the fourth variant, there is a higher content of nitrogen in the whole plant in comparison with the conventional variant. Application of fertilizer with sulphur had no impact on the content of nitrogen in the biomass of corn plants. We can say that by corn the influence of individual fertilization variants is lower than the influence of the station on individual parameters. No damage through diseases was found that would be related to the variant and there was a low occurrence of diseases in general at all stations (Kubešová, 2012).

### Mineral Nitrogen in the Soil by Harvest

The content of the ammonium form in the soil was not different between the systems. However, in 2010 CULTAN variants had lower contents of nitrates in subsoil than in the topsoil just like in the previous years, which could indicate less mobility of nitrogen from the dep. The content of the ammonium form in the soil showed no differences, though. Based on the experiment results it is not possible to claim unambiguously that the CULTAN method would be environmentally friendlier in Czech conditions than the surface application of fertilizers. Admittedly, there is a lower content of nitrates in the soil by CULTAN variants than by conventional variants and there is no big move of nitrates in subsoil, but no significant move of nitrates under the topsoil was observed by the conventional variants either. All nitrogen was usually drained by wheat (Kozlovský, 2011).

In the experiment with spring barley, no statistically significant differences in the content of ammonium and nitrate nitrogen in the topsoil and in subsoil were found during the harvest time.

In the experiment with winter oilseed rape in 2009 there was a lower content of mineral nitrogen at Čáslav site both in the topsoil and under topsoil by both CULTAN variants in contrast to the conventional variants. Also at Hněvčevs and Humpolec station there was a lower content of mineral nitrogen under topsoil. A big advantage of CULTAN system is a better use of nitrogen from the applied fertilizer. Therefore, there is also a lower amount of residual nitrogen after harvest (Peklová et al., 2010).

In the experiment with maize there was a tendency by CULTAN variants towards a lower content of mineral nitrogen than by the conventional variant, both in the topsoil and in subsoil, which corresponds with the conclusion of Sommer (2005) that there are lower losses of nitrogen after using the CULTAN method (Kubešová, 2010).

### References

- Atkinson, C. J., 1985. Nitrogen acquisition in four coexisting species from upland acidic grassland. *Physiol. Plant.*, **63**: 375-387.
- Balík, J., 1982. Contribution to nitrogen balance ( $^{15}\text{N}$ ) and its use by plants. Thesis, AU, Prague, 197 pp.
- Balík, J., 1985. The influence of nitrification of inhibitors on the changes of mineral nitrogen in the soil and on the balance of nitrogen from urea  $\text{CO}(\text{15NH}_2)_2$ . *Plant Production*, **31** (9): 913-922.
- Balík, J., J. Lipavský, J. Hlušek, D. Pavlíková and J. Černý, 2007. Modification of plant nutrition by ammonium nitrogen (CULTAN system). Conference Proceedings: Rational Use of Industrial Fertilizers, DAPN CULS, Prague, pp. 39 – 45.
- Balík, J., Pavlíková, D. and O. Kozlovský, 2008a. New technology of plant nutrition by nitrogen CULTAN With us you reach a success Agrofert – Holding Inc., pp. 33-35.
- Beligar, V. C. and O. L. Bennett, 1986. NPK – Fertilizer Efficiency. A situation analysis for the tropics. *Fert. Res.*, **10**: 147-164.
- Blaylock, A. D., 1990. Nitrogen point injection in ridge-till corn. *Soil Science Society America Journal*, pp. 591 – 595.
- Bloem, E. M., S. Haneklaus and E. Schung, 1997. Influence of soil water regime expressed by differences in terrain of sulphur nutritional status and yield of oilseed rape. In: Proc. 9th Int. Plant Coll., pp. 140-144.
- Boelcke, B., 2000. Liquid fertilizers on roots bring first experience with injection of nitrogen fertilizers (Depot. – or CULTAN fertilization). DLZ, 11.
- Boelcke, B., 2003. The effects of nitrogenous injection fertilization on yield and quality about cereals in Mecklenburg-Vorpommern. In: Agricultural research Völknerode, Growing Methods Using Nitrogen Injection (CULTAN) Results, Perspectives, Experience, Collection 245: 47 – 56.
- Boxman, A. W., H. Krabbendam, M. J. S. Bellemakers and J. G. M. Roelofs, 1991. Effects of ammonium and aluminium on the development and nutrition of *Pinus nigra* in hydroculture. *Environ. Pollut.*, **73**: 119-136.
- Deamgen, U., R. Walker, L. Grunhage and H. J. Jager, 1997. The atmospheric sulphur cycle. *Nutr. Ecosystems*, **22**: 75-114.
- Duynsiveld, W. H. M., O. Strebel and J. Boettcher, 1993. Prognosis of ground water quality in an area with water concentration, with models of water transmission. Berlin: Ministry of Environment, texts 93/05 UBA-FB: 90-106.
- Fangmeier, A., A. Hadwiger-Fangmeier, L. van der Eerden and H. J. Jäger, 1994. Effects of atmospheric ammonia on vegetation. A review, *Environ. Pollut.*, **86**: 43-82
- Felegentreu, C., 2003. Firsts results by application of injection fertilization methods by winter colza in Brandenburg. In: Agri-



- cultural research Völknerode, Growing methods using nitrogen injection (CULTAN) Results, Perspectives, Experience, Collection 245: 55-60.
- Fenn, L. B. and S. Miyamoto**, 1981. Ammonia loss and associated reactions of urea in calcareous soils. *Soil Sci. Soc. Am. J.*, **45**: 537-540.
- Gerendás, J., Z. Zhu, R. Bendixen, R. G. Ratcliffe and B. Sattelmacher**, 1997. Physiological and Biochemical Processes Related to Ammonium Toxicity in Higher Plants. *Plant Nutrition, Bodenkd* **160**: 239-251.
- Gigon, A. and I. H. Rorison**, 1972. The response of some ecologically distinct plant species to nitrate and to ammonium-nitrogen. *J. Ecol.*, **60**: 93-102.
- Gloser, V. and J. Gloser**, 2000. Nitrogen and base cation uptake in seed-lings of *Acer pseudoplatanus* and *Calamagrostis villosa* exposed in an acidified environment. *Plant Soil*, **226**: 71-77.
- Jez, J. et al.**, 2008. Sulphur: A missing Link between Soils, Crops and Nutrition. Madison, WI: American Society of Agronomy: Crop Science Society of America: Soil Science Society of America: 323 pp.
- Kirkby, E. A.**, 1968. Influence of ammonium and nitrate nutrition on the cation-anion balance and nitrogen and carbohydrate metabolism of white mustard plants grown in dilute Nutrient Solutions. *Soil Science*, **105**: 133-141.
- Kozlovský, O., J. Balík, M. Kos, J. Černý and V. Nedvěd**, 2008. The influence of CULTAN method on grain yield and yield parameters of winter wheat. Conference Proceedings: Rational use of industrial fertilizers, DAPN CULS, Prague, pp. 115-119.
- Kozlovský, O., J. Balík, J. Černý, M. Kulhánek, M. Kos and M. Prašilová**, 2009. Influence of nitrogen fertilizer injection (CULTAN) on yield, yield components formation and quality of winter wheat grain. *Plant, Soil and Environment*, **12**: 536-543.
- Kozlovský, O.**, 2011. Verification of a new CULTAN system of plant nutrition by nitrogen by winter wheat. Thesis ČZU, 104 pp.
- Kubešová, K.**, 2010. Verification of a new CULTAN system of plant nutrition by nitrogen on yield and quality of corn. Thesis, 66 pp.
- Kubešová, K., J. Balík, J. Černý, L. Peklová, O. Sedlář and M. Kos**, 2012. Effect of CULTAN Method on Yield Formation and Yield of Maize in 2011, Conference Proceedings: Rational use of industrial fertilizers, DAPN CULS, Prague, pp. 131 – 135.
- Kücke, M.**, 2003. Yield and grain quality of winter wheat and winter rye after nitrogenous grouting fertilization – results of field experiments. In: Agricultural research Völknerode, Growing methods using nitrogen injection (CULTAN) Results, Perspectives, Experience, Collection 245: 69 – 80.
- Kücke, M. and H. W. Scherer**, 2006. Injection fertilization in Germany. RKL Rendsburg, pp. 397-429.
- Ledgard, S. F.**, 2001. Nitrogen cycling in low input legume-based agriculture with emphasis on legume/grass pastures. *Plant and Soil*, **228**: 43-59.
- Longnecker, N., E. J. M. Kirby and A. Robson**, 1993. Leaf emergence, tiller growth and apical development of nitrogen-deficient spring wheat. *Crop Science*, pp. 154-160.
- Malhi, S. S., C. Grant, A. Johnston and K. Gill**, 2001. Nitrogen fertilization management for no – till cereal production in the Canadian Great Plains: a review. *Soil and Tillage Research*, **60**: 101-122.
- Malhi, S. S., Y. Gan and J. P. Raney**, 2007. Yield, seed quality, and sulphur uptake of Brassica oil seed in response to sulphur fertilization. *Agron J.*, **99**: 570-577.
- Malhi, S. S. and M. Nyborg**, 1984: Inhibiting nitrification and increasing the efficiency of fall-applied urea by placing in bands with the urea. *Plant Soil*, **77**: 193-206.
- Malhi, S. S. and M. Nyborg**, 1991. Recovery of <sup>15</sup>N-labeled urea: influence of zeti tillage, and time and method of application. *Fert. Res.*, **28**: 263-269.
- Malhi, S. S. and M. Nyborg**, 1992. Placement of urea fertilizer under zero and conventional tillage for barley. *Soil Tillage Research*, **23**: 193-197.
- Marschner, H.**, 1995. *Mineral Nutrition of Higher Plants*, 2nd edn. Academic Press, London, 420 pp.
- McGrath, S. P. and F. J. Zhao**, 1996. Sulphur uptake, yield responses and the interactions between nitrogen and sulphur in winter oilseed rape (*Brassica napus* L.). *Jour. Agric. Sci.*, **126**: 53-62.
- Mengel, D. B., D. W. Nelson and D. M. Huber**, 1992. Placement of nitrogen fertilizers for no-till and conventional till corn. *Agronom. J.*, **74**: 515-518.
- Mengel, K. and E. A. Kirkby**, 2001. Principles of Plant Nutrition. *Kluwer Academic Publishers*, Dordrecht, 849 pp.
- Mengel, K., B. Hutsch and Y. Kane**, 2006. Nitrogen fertilizer application rates on cereal crop according to available mineral and organic soil nitrogen. *Europe. J. Agronomy*, **24**: 343-348.
- Neuberg, M., M. Pavlík, J. Balík, R. Kaliszová and D. Pavlíková**, 2008. The effect of nitrogenous fertilization on the content of free amino acids. Conference Proceedings: Rational Use of Industrial Fertilizers, DAPN CULS, Prague, pp. 143-146.
- Neuberg, M., D. Pavlíková, M. Pavlík and J. Balík**, 2010. The effect of nitrogen nutrition on proline and asparagines. *Plant, Soil and Environment*, **56**: 305-311.
- Pang, P. C., R. A. Hedlin and C. M. Cho**, 1973. Transformation and movement of band applied urea, ammonium sulphate and ammonium hydroxide during incubation in several Manitoba soils. *Canadian J. Soil Sci.*, **53**: 331-334.
- Pearson, C. H.**, 1994. Plant response to the management of fluid and solid N fertilizers applied to furrow – irrigated corn. *Fer. Res.*, **37**: 51-58.
- Peklová, L., J. Balík, J. Černý, O. Kozlovský, O. Sedlář and M. Kos**, 2010. The use of CULTAN method in the growing system of winter colza. Conference Proceedings: Rational Use of Industrial Fertilizers, DAPN CULS, Prague, pp. 105-109.
- Peklová, L., J. Balík, O. Kozlovský, O. Sedlář and K. Kubešová**, 2011a. The yield and quality of winter oilseed rape in the system of nitrogen fertilizer injection (CULTAN). Proceedings of International Conference Soil, Plant and Food Interactions, Faculty of Agronomy, Mendel University in Brno, 60 pp.
- Peklová, L., O. Kozlovský, O. Sedlář and M. Kos**, 2011b. The formation of dry matter and nitrogen content in straw and winter colza seeds after fertilization by CULTAN method. Confer-

- ence Proceedings: Rational use of industrial fertilizers, DAPN CULS, Prague, pp. 127-131.
- Roselt, J. P.**, 1990. Station examination of nitrogen depots, PK late and complementary leaf fertilization by winter wheat in Rheinland-Pfalz. Dissertation, Rhein Friedrich-Wilhelms-Universität Bonn, 205 pp.
- Salvagiotti, F., J. M. Castallarín, D. J. Miralles and H. M. Pedrol**, 2009. Sulphur fertilization improves nitrogen use efficiency in wheat by increasing nitrogen uptake. *Field Crop Res.*, **113**: 170–177.
- Sedlář, O., O. Kozlovský, J. Černý, M. Kos and J. Balík**, 2009. The formation of grain yield by spring barley through CULTAN method. Collection from conference: Rational use of industrial fertilizers, DAPN CULS, Prague, pp. 129-132.
- Sedlář, O., J. Balík, O. Kozlovský, L. Peklová and D. Roldán**, 2010. The development of spring barley through CULTAN method fertilization. Conference Proceedings: Rational use of industrial fertilizers, DAPN CULS, Prague, pp. 113-116.
- Sedlář, O., O. Kozlovský, L. Peklová and K. Kubešová**, 2011a. Effect of nitrogen injection application on growth progress of spring barley. *Agrochémia*, **2**: 11-14 (Cz).
- Sedlář, O., J. Balík, O. Kozlovský, L. Peklová and K. Kubešová**, 2011b. Impact of nitrogen fertilizer injection on grain yield and yield formation of spring barley (*Hordeum vulgare* L.). *Plant, Soil and Environment*, **57** (12): 547-552.
- Schumacher, H. J.**, 2009. Yield and quality advantages for malt barley, agriculture without plough. **I**: 26-28.
- Sommer, K. and M. Mertz**, 1974. Growth, yield and minerals uptake of plants – effect of ammonium or nitrate. *Agricultural Research*, pp. 8–30.
- Sommer, K. and K. Rossing**, 1978. Influence of nitrification hindrance on the yield by various nitrogen fertilizers and suggestion of classification. *Agricultural Research*, **31**: 291–299.
- Sommer, K.**, 1991. Ammonium-Depot fertilization: foundation, state of development, perspectives. Research report of Faculty of Agriculture, Rhein Friedrich-Wilhelms-Universität, 5.Wiss. Fachtagung, pp. 6-40.
- Sommer, K. and U. Kreusel**, 1992. (Non-public results), Thesis, Bonn
- Sommer, K.**, 2003. Basis of CULTAN method. In: Agricultural research Völknerode, Growing methods using nitrogen injection (CULTAN) Results, Perspectives, Experience, Collection 245: 1-22.
- Sommer, K.**, 2005. CULTAN – Fertilization. *Publishing house Th. Mann*, Gelsenkirchen, 218 pp.
- Sommer, K., H. W. Scherer and A. Kunert**, 2002. CULTAN method by corn. *Magazine for Corn Growers*, **1**: 20-23.
- Sommer, K. and H. W. Scherer**, 2007. Source /sink relationships in plants as depending on ammonium as CULTAN, nitrate or urea as available nitrogen fertilizers. International Symposium Sink-Source Relationships in Plants. Kaliningrad, Russia, pp.1-29.
- Spiess, E. and U. Meier**, 2008. CULTAN fertilization method in practice. *Swiss Land Technology*, **3**: 14-17.
- Stevenson, F. J.**, 1982. Nitrogen in Agricultural Soils. *Madison Wisconsin*, pp. 721-772.
- Torma, S.**, 2005. Nitrogen, irreplaceable element in soil and plants. *Agro*, **1**: 26–28.
- Van Beusichen, M. L., E. A. Kirkby and R. Baas**, 1988. Influence of nitrate and ammonium nutrition and the uptake, assimilation, and distribution of nutrients in *Ricinus communis*. *Plant Physiol.*, **86**: 914-921.
- Vaněk, V. et al.**, 2007. Nutrition and fertilization of field and garden plants. *Sedláček*, 132 pp.
- Vines, H. M. and R. T. Wedding**, 1960. Some effects of ammonia on plant metabolism and a possible mechanism for ammonia toxicity. *Plant Physiol.*, **35**: 820-825.
- Vorsatz, C. and K. Sommer**, 1995. Regulation of clover and grass relationships in green through nitrogen fertilization by CULTAN method. VDLUFA Congress Band, **40**: 969-972.
- Walter, E. E.**, 2003. CULTAN fertilization – further measures for ground water maintenance in water provision. Grünbach group – Agricultural Research Based on Several Years of Experience, *Völknerode*, Collection 245: 103–115.
- Wang, X. T. and F. E. Below**, 1996. Cytokinins in enhanced growth and tilling of wheat induced by mixed nitrogen source. *Crop Sci.*, **36**: 121-126.
- Weber, E. A., W. D. Koller, S. Graeff, W. Hermann, N. Merkt and W. Claupein**, 2008. Impact of different nitrogen fertilizers and an additional sulfur supply on grain yield, quality and the potential of acrylamide formation in winter wheat. *J. Plant Nutrition and Soil*, **171**: 643-655.
- Weimar, S. and K. Sommer**, 1990. Examination of Access to Ammonium-Depots of Corn. VDLUFA, Congress Band, pp. 301–307.
- Weimar, S. and O. Walg**, 2003. required natural provision of nitrogen through CULTAN method. In: Agricultural research Völknerode, Growing methods using nitrogen injection (CULTAN) Results, Perspectives, Experience, Collection 245: 121 – 129.

Received August, 2, 2012; accepted for printing February, 2, 2013.