NITROGEN AVAILABILITY TO SUGAR BEET IN DEEP LAYERS OF THE SOIL

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ABSTRACT

The dynamic of nitrogen in the soil is one of the most complex among the main nutrients. Therefore, it is still very difficult to establish the optimal quantity of nitrogen needed by cultivated plants. This element influences greatly the sugar beet crop: its shortage limits sugar production, while excess causes a lowering of processing quality. The matter is problematic because there is a fine line between shortage and excess. Moreover, excessive use of nitrogen fertilisers causes pollution of ground and surface water. To establish with sufficient accuracy the amount of applied nitrogen, it is necessary to know exactly the quantity of the element available in the whole profile of soil explored by the root system. In several countries, sugar beet root system was observed to be capable of reaching a depth of 2.50-3.00 metres. Thirty-two soil profiles were sampled during 3 years in areas of intense sugar beet cultivation in northern Italy. Soil samples were taken from fields where variety tests were in progress, thus ensuring data regarding the climate and yield, all of which are necessary for the correlation of the different sets of data. Twelve soil samples per soil profile were taken every 0.25 m, down to a depth of 3.00 m. To detect the moment when the crop begins the nitrogen uptake at a given depth, a test was set up with ^{15}N injected into the soil at 2.00, 2.50 and 3.00 m from the surface. About 30% of the profiles displayed relatively high concentration of available nitrogen in the deep layers. This means that the nitrogen fertilization based on analysis of samples collected at insufficient deep can lead to underestimate the availability of nitrogen in the soil.

ABRÉGÉ - L'ABSORPTION, PAR LA BETTERAVE SUCRIÈRE, DE L'AZOTE DES COUCHES PROFONDES DU SOL

La dynamique de l'azote dans le sol est l'une des plus complexes parmi celles des principaux nutriments. Il est encore très difficile de déterminer la quantité optimale d'azote nécessaire pour cultiver les plantes. Cet élément influence largement la culture de la betterave sucrière; une quantité insuffisante limite la production de sucre, tandis que les excès conduisent à une baisse de la qualité. La question est problématique parce qu'il n'y a pas de marge entre la carence et l'excès. De plus, l'utilisation excessive de fertilisants azotés pollue le sol et les

eaux de surface. Pour établir avec suffisamment de précision la quantité d'azote à appliquer, il est nécessaire de savoir exactement la quantité de cet élément disponible dans l'ensemble des profils de sol explorés par le système racinaire. Dans plusieurs pays, le système racinaire de la betterave a été étudié, il est capable d'atteindre une profondeur de 2.50 à 3.00 mètres de profondeur. Au nord de l'Italie, dans des régions de culture intensive de la betterave sucrière, trente-deux profils de sol furent échantillonnés pendant trois ans. Les prélèvements furent effectués dans des champs d'essais variétaux, ce qui permettait d'avoir des données climatiques et de rendement lesquelles étaient nécessaires pour la corrélation des différentes sources de données. 12 échantillons de profil de sol furent prélevés tous les 25 cm jusqu'à une profondeur de 3.00 m. Pour détecter la profondeur où la plante commence à absorber l'azote, un test avec de l'azote 15 injecté dans le sol à 2.00, 2.50 et 3.00 m. de la surface fut réalisé. Environ 30% des profils montrent une relativement haute concentration d'Azote disponible dans les couches profondes. Ceci signifie que la fertilisation azotée basée sur l'analyse d'échantillons collectés à une profondeur insuffisante peut conduire à une sous estimation de la disponibilité en azote du sol.

KURFASSUNG - DIE AUFNAHME VON STICKSTOFF DURCH ZUCKERRÜBEN AUS TIEFEN BODENSCHICHTEN

Die Kreislauf des Stickstoffs im Boden ist der komplizierteste unter den verschiedenen Nährstoffen, weshalb es nach wie vor schwierig ist, die optimal benötigte Stickstoffmenge zu bestimmen. Stickstoff beeinflusst stark das Rübenwachstum: zuwenig führt zu niedrigerer Zuckerproduktion, zuviel verschlechtert die Zuckerqualität und –ausbeute. Der Unterschied zwischen zuviel und zu wenig ist haarfein. Darüber hinaus verursachen zu hohe Stickstoffgaben eine Verunreinigung von Grund- und Oberflächenwasser. Um mit genügender Präzision die richtige Stickstoffgabe bestimmen zu können, ist es notwendig, die Menge des Stickstoffs im Gesamtprofil des Bodens zu bestimmen, der von den Wurzeln der Rübe durchdrungen wird. In verschiedenen Ländern wurde festgestellt, dass die Rübenwurzeln Tiefen bis zu 2.50-3.00 Metern erreichen können. In Norditalien wurden über drei Jahre 32 Bodenprofile mit intensivem Zuckerrübenanbau geprobt. Die Proben wurden von Feldern entnommen, auf denen Sortenversuchen durchgeführte wurden, um sicher zu stellen dass alle Informationen bezüglich Klima und Ertrag für eine Korrelationsanalyse zur Verfügung stehen. Je Bodenprofil wurden 12 Proben aus Tiefen über 0.25 bis hin zu 3.00 Metern entnommen. Über 30% der Profile zeigten eine relativ hohe Konzentration an verfügbarem Stickstoff in tiefen Bodenschichten. Dies bedeutet, dass Stickstoffanalysen, die auf nur oberflächlich entnommenen Proben basieren, den im Boden verfügbaren Stickstoffs unterschätzen.

INTRODUCTION

Farming techniques must be refined to satisfy needs to improve effectiveness and limit the environmental damage caused by cultivation methods (Powers & Schepers, 1989; Cakmak, 2002). Fertilisers that respond better to the current requirements can only be obtained through a better understanding of the relationship between soil and roots (Vance, 2001). Several aspects of this relationship have recently been clarified thanks to progress made in experimental techniques and to studies of the morpho-physiology and the genetics of root development (Lynch, 1995; Scheres *et al.*, 1996; Zhang & Forde, 2000). Nevertheless, with all its theoretical and practical implications, this subject remains extraordinarily complex (Sequi & Vittori Antisari, 1989).

Yield and processing quality of the sugar beet (*Beta vulgaris* subsp. *vulgaris* L. Sugar Beet Group) depend largely on the availability of adequate levels of nutritive elements, in particular nitrogen (Draycott, 1993). The effects on the crop of a shortage or excess of this element are well known (Hills &Ulrich, 1971; Draycott, 1972). Higher than necessary levels reduce sugar content and processing quality. Economic damage is caused by the consequent reduction in price of the roots and the difficulties arising during the industrial process (Hills & Ulrich, 1971).

Estimating the most appropriate amount of nitrogen to distribute on crops (Boon & Vanstallen, 1983, Lindén & Nouno, 1983; Neeteson, 1989) is complicated by the presence in the soil of the element in different forms and in variable quantities (Draycott *et al.*, 1983; Martin Olmedo *et al.*, 1999; Christenson & Butt, 2000; Shock *et al.*, 2000). The main causes of the high variability are: 1) crop rotation; 2) weather, 3) water availability, 3) soil characteristics and its content of organic matter. Indeed, this last factor can free an unpredictable amount of N mineral during the crop development.

To evaluate both the crop's requirements with sufficient accuracy and the dose of nitrogen to be distributed, it is necessary to estimate residual fertility as well as the quantity of the element that will be available following the mineralisation of the organic matter (Blumenthal, 2003). In addition, is necessary to know the other essential parameters concerning the active part, i.e. the root system, whose morphology, development and depth are depending on local conditions. Several authors have referred about the high levels of variability in root parameters, reporting depths of 2.5 m (Girard, 1885), 2.1 m (Andrews, 1927), and 1 m (Kutschera, 1960). More recent studies carried out by Märländer & Windt, 1996, and by Winter, 1998, report depths of 2.8 and 2.74 m (9 ft) respectively. Therefore, the depth of samples taken for analysis has gradually increased: from 0.3 – 0.45 – 0.60 m (Neeteson & Smilde, 1983), at 1.2 m (Soper & Huang, 1963; Hills & Ulrich, 1976), at 1.5 m (Reuss & Rao, 1971), at 1.82 m (6 ft) recently recommended by Blumenthal, 2003. Where soil is homogeneous in the vertical sense, Ludwick *et al.*, 1977, and Reuss and Rao, 1971, recommend taking more superficial samples to reduce costs. The increase in the depths of sample-taking is further justified by experiments made by Peterson *et al.*, 1977, which demonstrated the capacity of beet to uptake ^{15}N labelled fertiliser down to a depth of 2.40 m.

The traditional practice of distributing fixed quantities of fertilisers (each year and in every location) is often inadequate for satisfying the real requirements of each field (Hills & Ulrich, 1971). As a response to the evident imprecision of traditional systems for estimating nitrogen requirements, a series of research into the characteristics of the sugar beet's root system in Italian environments was set up in 1993.

MATERIALS AND METHODS

The tests were carried out using minirhizotron tubes and endoscopic equipment (Morselli & Biancardi, 1997; Biancardi *et al.*, 1997). During the experiments, profile samples were taken in the most cultivated Italian areas to evaluate the concentration and distribution of organic matter and nitrogen in the layer explored by the crops' roots.

Profiles were collected from fields of sugar beet at the end of May 2000 and in the middle of June 2001. The 22 farms were selected to represent a sample of Italy's most intensely farmed area. All profiles were located in the centre of variety trials. The availability of agricultural, meteorological and yield data will allow the evaluation of the relationship between root parameters and the characteristics of the soils.

A depth of 3 m was reached by taking samples from each layer of 0.25 m; 12 samples per profile were collected. After freezing and air-drying, the samples were analysed according to the official analysis methods. Levels of organic carbon were calculated using the Walkley and Black method, while total N was measured using the Kjeldahl method. Mineral N was extracted with KCl 2mol (soil/extracting-agent ratio, 1:5). The nitrates ($N\text{-}NO_3$) were reduced to nitrites ($N\text{-}NO_2$) through a cadmium column. The nitrites and the ammonium ion ($N\text{-}NH_4$) were determined using an Autoanalyzer Technicon III ®. Bars in the figures represent the standard errors of the mean.

RESULTS AND DISCUSSION

Figure 1 shows the average root density of the different layers observed in late August in 4 locations and for 4 years. Maximum depth is reached at the beginning of harvesting time, while greatest development (considered as total root length) can be observed in early summer (Morselli & Biancardi, 1997). Root growth is conditioned by several factors and its variability is very high.

A significant location effect was observed in terms of total development, distribution of the roots in the different layers, and maximum depth. Early seeding and emergence tend to increase the aforementioned parameters. The effect of the year on the same soils can lead to differences in growth that are largely attributable to the amount of rain: root growth is lower in rainy years. Similar effects were observed on irrigated plots. The varieties display significant differences in root growth, but the effects of the year interact in ways still unclear (Biancardi *et al.*, 1997).

In the 22 profile samples taken during 2000-2001, 18 displayed relatively normal nutrient distribution, but a great variability from one location to another. In the remaining profiles, accumulations of organic matter were discovered at lower depths which were much greater that in the surface. If these values had been put together with the others they would have affected the average profile valid for the other locations. It was decided therefore to keep separate the two groups profiles. In the normal ones, the concentrations at different depths were expressed as a percentage of the surface layer's content (figure 2) so as to limit variability between the absolute values for each location. The other 4 were recorded separately with the content of the layers expressed as absolute values (figure 3).

As an average across the 18 locations, organic carbon (figure 2 A) decreases until about 2 m whereupon in the lower layers it returns to similar values to those on the surface. The considerable amounts of organic matter can be attribute to the alluvial origins of the soil, which came from ancient deposits of fluvial sedimentation (Filippi & Sbarbati, 1994).

Concentrations of mineral N ($N\text{-}NO_3$ + $N\text{-}NH_4$ + $N\text{-}NO_2$) tend to diminish as a function of depth (figure 2 B). Nevertheless, under the ploughed layer there is a quantity of mineral N that is about twice as high as on the surface layer. $N\text{-}NO_3$ varies in much the same way as mineral N since it is the most important component of concentration in the soil (figure 2 C). Given the minimal levels in the deep layers, it can be presumed that the $N\text{-}NO_3$ formed on the surface and which is surplus to the crop's requirements is leached or denitrified below the examined profile.

As for $N\text{-}NH_4$ (figure 2 D), it increases steadily down to the deepest layer where it reaches a value of about 3 times that found on the surface. This growth should be attributed to the amount of organic matter found at the lower depths. $N\text{-}NH_4$ can not have come from the surface given the low mobility of the soil. It is likely, therefore, that it formed *in loco* through the mineralisation of organic matter. Even though $N\text{-}NH_4$ levels are lower than those of $N\text{-}NO_3$, it is an important source of nitrogen for the roots (Draycott, 1973).

In the average profile, values of $N\text{-}NO_2$ were recorded of about 0.2 mg/kg (unreported data) with a maximum of about 0.5 at around the depth of one metre (Marchetti *et al.*, 2002). At depths between 2 and 3 metres, the anomalous locations contained levels of organic matter about 4 times greater than the surface layers (figure 3 A). Correspondingly, high values of $N\text{-}NH_4$ and mineral N were recorded, while $N\text{-}NO_3$ decreases as depth increases as with the 18 normal samples (figures 3 B, 3 C and 3 D).

CONCLUSIONS

Tests carried out in different locations and experimental conditions allowed to verify some root system traits which are useful for studying the supply of nitrogen in the soil profile explored by the roots. The analyses carried out on deep profiles allow the estimation of the nitrogen distribution in a representative sample of Italian soils intensely farmed with sugar beet. High concentrations of organic matter and mineral nitrogen in lower depths can be correlated with the presence of layers containing high amounts of organic matter. In most cases, significant concentrations of $N\text{-}NO_3$ were found in the deepest layers. In the considered farming areas, the mineral nitrogen in the profile explored by the roots generally exceeds the uptake of the crop. The soil samples taken to calculate the quantity of nitrogen to be distributed to the sugar beet should include the deepest layers explored by the roots.

Fig. 1. Sugar beet root density in September. Mean of 4 locations over a period of 4 years.

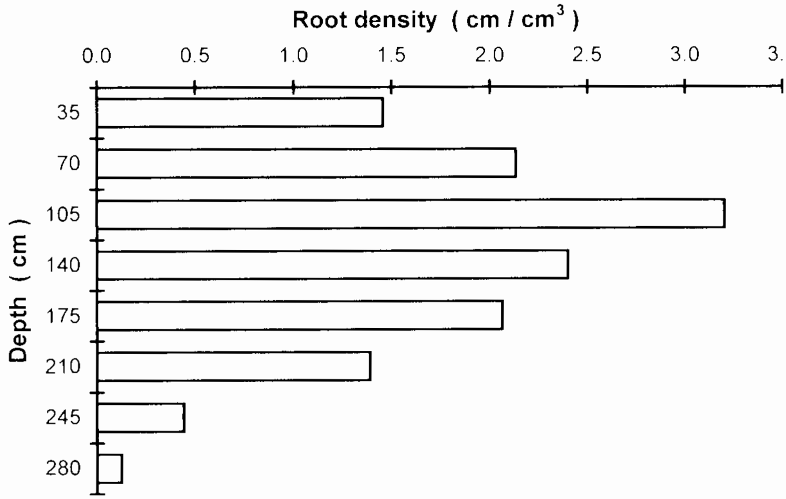


Fig. 2. Organic carbon, N mineral, nitrate and ammonium content along the soil profiles to a depth of 300 cm. The data are expressed as percent ± ES of the surface layers of 18 sampling locations.

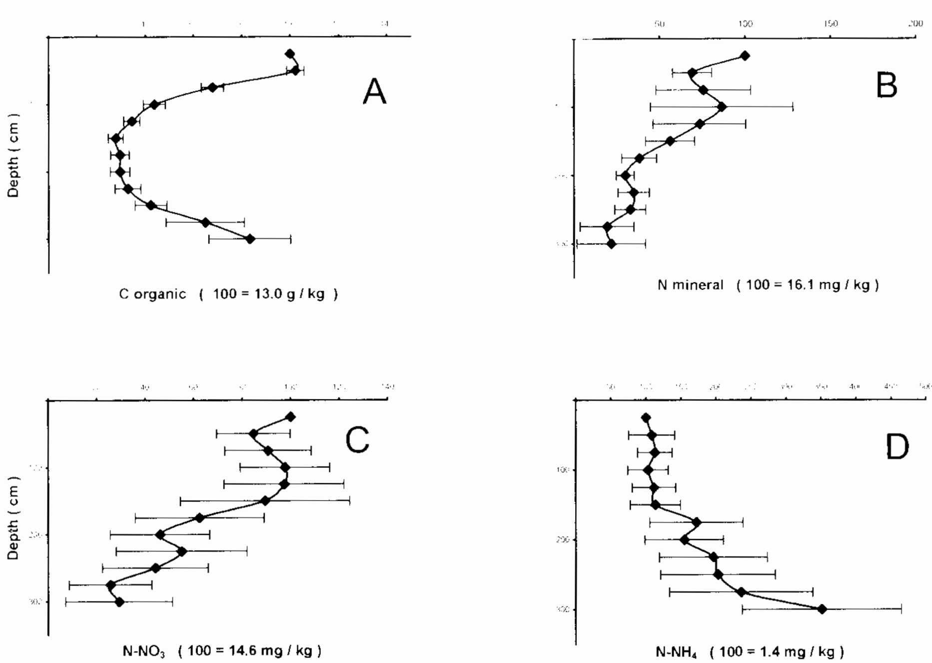
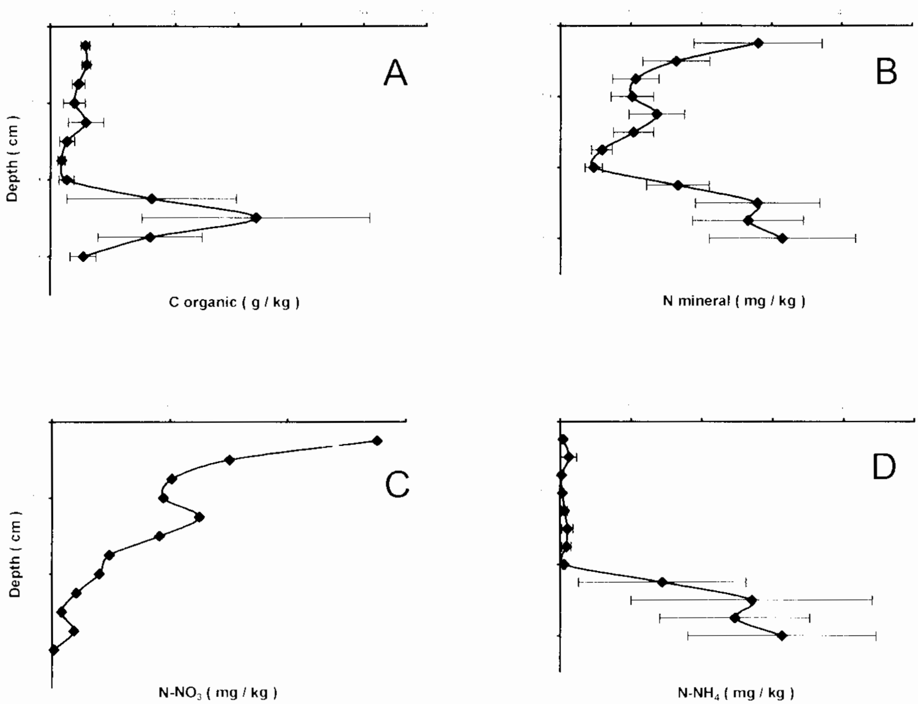


Fig. 3. Organic carbon, N mineral, nitrate and ammonium content along the whole soil profile to a depth of 300 cm. The data are expressed as absolute value ± ES of 4 sampling locations.



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