Journal of Agricultural Science, Cambridge (1999), **132**, 273–280. *Printed in the United Kingdom*

Sugarbeet (*Beta vulgaris*) response to residual soil N under Mediterranean agronomic practices

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(*Revised MS received 21 September 1998*)

SUMMARY

Autumn-sown sugarbeet (*Beta vulgaris* L.) responses (sugar yield, plant N-uptake and juice quality) were studied in relation to the residual NO_3^--N in a soil of southwestern Spain which, for the previous five years (1989–93), had received high N rates, in accordance with conventional fertilization schedules used by farmers in the area. Three different combinations of fertilizers, supplying equal amounts of N, were used during the fertilization period (1989–93): a mineral fertilization treatment (MF, a complex 15N-15P_2O_5-15K_2O) and two organo-mineral fertilization treatments (an olive mill wastewater sludge compost, AC, and a depotassified concentrated beet vinasse, V). All these treatments also received a top-dressing with urea (46% N). A control treatment (C), without fertilization was included for comparison.

During the major part of the beet growing season, the presence of almost four times as much mineral N in the 0–100 cm soil layer of previously fertilized plots (AC, V and MF) than in the unfertilized one (C), led to a significant increase ($P < 0{\cdot}05$) in total fresh weight yield and N-uptake, but also to a significant decrease ($P < 0{\cdot}05$) in sugar content and beet processing quality. The time course of NO_3^--N concentration in sugarbeet petioles and the evolution of the nutritional state of leaf-blades gave advance information about the final response of the crop to the different fertilization treatments. Besides N, Na was the element which, due to the repeated and high fertilization rates applied, had a major effect in reducing the technological quality of the sugarbeet.

INTRODUCTION

To maintain soil fertility and achieve large crop yields, high fertilization rates are being used in many conventional schemes, especially in intensive agriculture, supplying greater amounts of nutrients than plants actually require. This philosophy of fertilization is frequently orientated towards fertilizing the soil rather than the crop (Olson *et al.* 1987), since no attention is paid to residual mineral nutrients in the soil at the time of drilling, to the available nutrients derived from the breakdown of soil organic matter and organic manures when the crop is growing, or to the nutrients added with the irrigation water, often polluted by the intensive use of fertilizer mentioned above (Bogardi & Kuzelka 1991). This practice is commonplace under Mediterranean irrigated conditions where increasing fertilization rates since 1960 (necessary, according to farmers, to ensure maximum crop yields) are resulting in a progressive decline in the quality of the groundwater in the area, with concentrations of nitrate > 150 mg l^{-1} (ITGE 1998). For instance, the average rate applied on irrigated land in the Carmona plain (southern Spain) during the early 1980s was *c.* 2200 kg N ha^{-1} per year (IGME 1985).

In sugarbeet (*Beta vulgaris* L.), the fertilization rate for an optimum economic yield is usually considerably less than the rate required for the maximum growth of roots plus tops (Ulrich & Hills 1990; Draycott 1993; Allison *et al.* 1996). Maximum sucrose accumulation in the roots requires a reduction in the amount of N supplied to the crop just prior to harvest to avoid vigorous top growth. An over-abundant uptake of N at this stage would decrease sugar percentage and increase the presence of 'harmful-N' compounds, which make sugar extraction difficult (Draycott 1993). Optimizing the use of N through a better understanding of the crop's requirement is an important goal to obtain roots of high quality, to guarantee the highest net income for the farmers and to minimize the pollution of the groundwater by nitrate leaching (Ulrich & Hills 1990; Draycott 1993).

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Many comprehensive studies have emphasized the importance of residual mineral N for irrigated sugarbeet (Neeteson & Zwetsloot 1989; Pocock *et al.* 1990; Allison *et al.* 1996). However, this information is still very scarce under the conventional Mediterranean management practices, where the soil N pool is being enhanced by the routinely large fertilizer rates applied, as mentioned above (IGME 1985; IGTE 1998) and recently reported by Ramos *et al.* (1995), Fernández *et al.* (1996), Murillo *et al.* (1997) and López-Bellido *et al.* (1997).

This paper deals with the study of the residual NO_3^--N in a soil of southwestern Spain treated for 5 years with different fertilizers at the conventional rate used in the zone, and the effect that this residual N has on the yield and quality of the subsequent sugarbeet crop.

MATERIALS AND METHODS

The experiment was conducted in the Guadalquivir river valley of southwestern Spain (37·2 °N, 6·1 °W), at the Research Station of the Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS–CSIC). The climate is Mediterranean with > 80% of the mean annual rainfall of 550 mm (1971–92) falling between October and May. The mean annual daily temperature is *c.* 17 °C, with maximum and minimum temperatures in July (33·5 °C) and January (5·2 °C), respectively.

The soil of this region, classified by the Soil Survey Staff (1990) as Typic Xerofluvent, is derived from the accumulation of a mixture of alluvium and marine sediments. It is a fertile sandy clay loam soil, the main properties of which are recorded in Table 1. Nitrogen and organic matter (OM) contents of this soil are low, whilst, following Cope & Evans (1985), P and K contents would be rated as high and very high, respectively, according to the CEC value of this soil.

From 1989 to 1993, three fertilizer treatments in four randomized blocks were set up in experimental plots of 16 m² each, with 1 m distance between plots. Fertilizer treatments were: MF, mineral fertilizer with a complex 15 N-15 P_2O_5-15 K_2O; AC, organo-mineral fertilization with an olive mill wastewater ('alpechin' in Spanish) sludge compost (Table 2); and V, organo-mineral fertilization with a concentrated depotassified beet vinasse (desugared beet molasses) (Table 2).

Table 2. *Properties of olive mill wastewater sludge compost* (*AC*) *and concentrated depotassified beet vinasse* (*V*) (*all values are given as percentage of dry matter*)

Properties	AC*	V
pH (water 1:5)	7·32	5
Dry matter	82	54
OM	21	40
Kjeldahl-N	0·61	3·3
P (P_2O_5)	0·44	0·02
K (K_2O)	2·41	3·5
Ca	9·32	0·3
Mg	0·60	1·0
Na	0·26	2·0
Origin	Fertilizantes Orgánicos Montaño S.A.	Ebro-Agrícolas S.A.

* The values given for AC compost are the average of three composts used throughout the 5 years of the fertilization period.

Mineral and organo-mineral fertilizers were applied during land preparation by ploughing for barley and maize. These treatments also received a top-dressing with urea (46% N). The total amounts of MF, AC and V applied during the whole 5 years were 2650, 93000 and 15500 kg ha^{-1}, respectively. The total amount of urea applied during the 5 years was 1875 kg ha^{-1} for MF and 1800 kg ha^{-1} for AC and V. The total amount of N applied was equivalent to 1329 kg N ha^{-1} for the MF treatment, 1293 kg N ha^{-1} for the AC treatment and 1332 kg N ha^{-1} for the V treatment. A control treatment (C), with no fertilization, was used for comparison.

During the fertilization period, barley (first year) and irrigated maize (the four subsequent years) were cropped. In the sixth experimental year, starting in November 1993, sugarbeet was sown. Average population density was 112000 plants ha^{-1} without fertilization to study the residual effect of the previous fertilization schedules on the N uptake, sugar yield, and juice quality of sugarbeet.

Soil cores (three replicates per plot) were taken periodically (November–June) from each treatment at 0–20 and 20–40 cm depth with a spiral auger

Table 1. *Soil characteristics of the experimental plot* (*Guadalquivir river valley*, *SW Spain*)

pH	7·95	Na_{ex} (mmol$_c$ kg^{-1})	12·5
$CaCO_3$ (%)	28·2	K_{ex} (mmol$_c$ kg^{-1})	12·4
OM (%)	1·35	Ca_{ex} (mmol$_c$ kg^{-1})	57·6
Kjeldhal-N (mg kg^{-1})	760	Mg_{ex} (mmol$_c$ kg^{-1})	35·2
Available-P (mg kg^{-1})	21·8	Sand (%)	50·3
Available-K (mg kg^{-1})	396	Clay (%)	22·8
CEC (mmol$_c$ kg^{-1})	119	Silt (%)	26·9

Table 3. *Soil nitrate content (mg NO_3^--N kg^{-1} dry soil) in the subplots at different depths and sampling dates (days from sowing)*

	Sampling dates							
Treatments*	−13	17	49	79	112	148	203	Mean
				0–20 cm				
C	3·1	9·7	3·7	7·9	6·9	1·6	3·7	5·2
AC	3·9	12·9	7·2	9·4	4·8	1·9	8·1	6·9
V	3·8	11·8	4·6	8·8	6·7	1·6	9·4	6·7
MF	5·0	11·6	3·7	19·7	8·9	1·9	9·7	7·4
S.E. (9 D.F.)	0·83	1·67	1·83	2·25	3·11	0·58	3·96	0·73 (81 D.F.)
				20–40 cm				
C	8·7	9·5	7·9	8·6	7·3	1·9	2·6	6·6
AC	20·1	27·5	18·3	15·4	12·5	3·5	3·2	14·4
V	15·9	11·6	11·8	10·3	13·2	2·5	2·9	9·7
MF	19·7	14·0	11·1	8·9	9·1	2·9	2·9	9·8
S.E. (9 D.F.)	5·15	6·13	5·39	2·18	3·15	0·79	0·88	1·17 (81 D.F.)
				40–100 cm				
C	—	4·9	6·8	7·1	6·7	2·6	3·2	5·2
AC	—	28·5	30·9	24·7	24·2	20·4	4·4	22·2
V	—	27·7	27·6	24·7	29·9	16·8	4·2	21·8
MF	—	22·9	23·5	26·8	22·3	28·0	5·1	21·4
S.E. (9 D.F.)	—	9·97	5·78	8·87	7·68	7·47	1·74	1·88 (69 D.F.)

* See text for details.

(2·5 cm diameter) and at 40–100 cm depth with an Edelman type auger (5 cm diameter). The moist soil was analysed shortly after sampling for NO_3^--N using selective electrode methodology (Davies *et al.* 1972). Soil moisture (measured gravimetrically) was used to calculate the NO_3^--N concentration on a dry soil basis. Results were presented as kg NO_3^--N ha^{-1} according to the bulk density values of the soil at 0–20 cm (1·35 g cm^{-3}), 20–40 cm (1·52 g cm^{-3}) and 40–100 cm depth (1·65 g cm^{-3}).

The nutritional status of the sugarbeet plants during the growing season was monitored by analysis of the youngest fully developed leaves. Twenty-five complete leaves per treatment were collected at 98, 129 and 162 days after sowing. Leaf samples were placed in paper bags and taken to the laboratory for processing within a few hours. Leaves were quickly washed in a bath containing a phosphate-free detergent, followed by two successive rinses in distilled water. The petioles were then separated from the leaf blades to create two leaf samples per treatment. Each sample was cut into small pieces and dried overnight in an oven at 70 °C. After drying, the samples were ground to pass 40 mesh screen and stored in plastic vials. Petiole samples were used for the determination of NO_3^--N concentration by the potentiometric method (Baker & Smith 1969). Blade samples were also used to determine the concentration of other essential nutrients (P, K, Na, Ca and Mg).

At harvest (200 days after sowing), 16 representative plants per treatment were collected for analysis. Nitrogen concentration in the above-ground parts and in the roots was determined by Kjeldahl digestion. Phosphorus, K, Na, Ca and Mg contents were measured in blades and roots according to Jones *et al.* (1991) following dry ashing and ash solution by treatment with hot HCl. Sodium and K were determined by flame emission spectrometry, Ca and Mg by atomic absorption spectrometry and P by colorimetric determination using the phosphovanado-molybdic complex.

Total yield, sugar content and the concentration of impurities α-amino N, Na and K contents in the beet were determined by the laboratory of Ebro-Agricolas using standard methods (Last *et al.* 1976).

The statistical analyses were carried out by the ANOVA procedure and paired Student's *t*-test ($P <$ 0·05) using a MINITAB WINDOWS statistical package.

RESULTS AND DISCUSSION

Soil nitrate content has been found to be highly correlated with both sugarbeet root yield and root quality (Pocock *et al.* 1990; Draycott 1993; Allison *et*

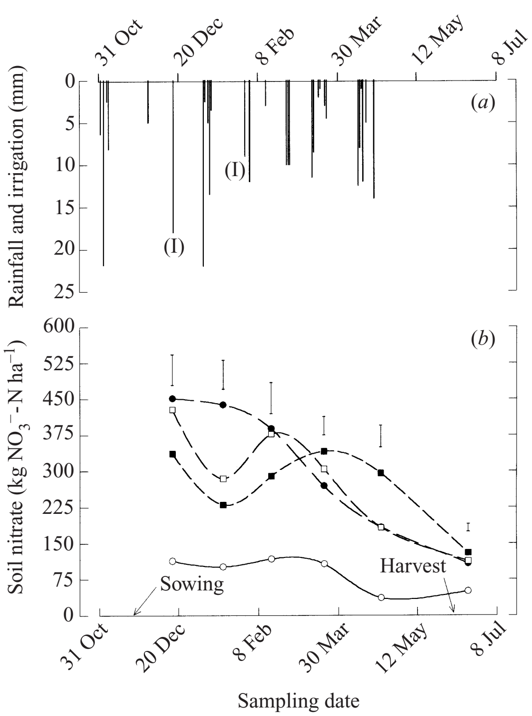

Fig. 1. (*a*) Rainfall and irrigation (irrigation is marked with an I). (*b*) Mean NO_3^--N concentrations in soil of treatments C (○, control), AC (●, 'alpechín' sludge compost), V (□, beet vinasse) and MF (■, mineral fertilization) during the sugarbeet growing period. Vertical bars are S.E. (D.F. = 9).

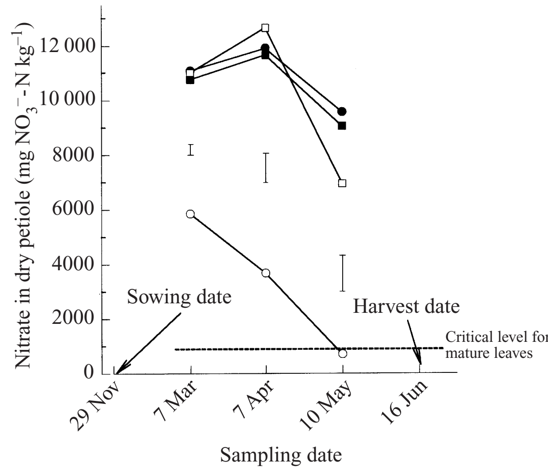

Fig. 2. Variation during the sugarbeet growing period of NO_3^--N concentration in petiole of sugarbeet leaves from treatments C (○, control), AC (●, 'alpechín' sludge compost), V (□, beet vinasse) and MF (■, mineral fertilization). Vertical bars are S.E. (D.F. = 9).

al. 1996). Thus, it is important to know the amount of NO_3^--N in the soil profile prior to sowing, as well as its dynamics during the vegetation period. Sufficient N needs to be provided early in the growing season to develop large storage roots. However, plants should become somewhat deficient in N for at least 4 weeks, and perhaps as long as 10 weeks, before harvest to obtain roots with a large sucrose concentration and small concentrations of α-amino acids and Na^+ and K^+ ions, the presence of which disturb crystallization during sugar refining and thus affect the sugar output (Ulrich & Hills 1990; Draycott 1993).

Nitrate concentrations (mg NO_3^--N kg^{-1}) at different soil depths and times of sampling are shown in Table 3. In general, the desired sampling depth for residual NO_3^--N would be the crop root zone, which for sugarbeet is down to *c.* 140 cm deep in well-drained soils (Hergert 1987). However, the entire root zone may not need to be sampled if there is a strong correlation between N fertilizer requirement and NO_3^--N at shallower depths (Hergert 1987). In the present experiment, the soil layer of 0–100 cm was clearly sufficient to reflect differences in NO_3^--N concentrations between treatments.

Nitrate concentrations in soil (Table 3) were generally greater in previously fertilized plots (AC, V and MF) than in the unfertilized plot (C), although differences were significant only at 40–100 cm depth. Considering all sampling times, the average NO_3^--N concentration in the upper layer (0–20 cm) of treatment C was similar to the concentration at 40–100 cm, while for the other treatments average NO_3^--N concentration at 40–100 cm was *c.* three times more than in the upper layer. Allison *et al.* (1996) suggested that ploughing down manures could increase the depth to which nitrate is released from organic manures. Sugarbeet may be viewed as a scavenger crop in terms of its extensive use of soil N in the shallower soil layers (Ulrich & Hills 1990) and this, too, could explain the lack of statistical difference for NO_3^--N concentration between fertilized and unfertilized plots in the top 40 cm layer.

Soil nitrate concentration in the whole profile (0–100 cm), rainfall and irrigation throughout the growing season are presented in Fig. 1. Shortly after sowing, the previously fertilized plots contained almost four times as much NO_3^--N than the unfertilized treatment (C). At this stage, previously fertilized plots already contained more available N than the total uptake (200–250 kg N ha^{-1}) which is considered optimum to obtain a maximum sugar yield under both spring (Draycott 1993) and autumn-sown conditions (López-Bellido *et al.* 1994).

The amount of NO_3^--N in the soil remained large throughout the growing period (Fig. 1), and only after harvest and in treatment C did it decrease to 50–80 kg ha^{-1}. This reduction was probably due to a combination of the uptake of N by sugarbeet plants and the impeded or retarded mineralization during

Table 4. *Nutrient concentration (% DM) in leaf blades of sugarbeet on three occasions during the growing season as affected by fertilizer treatment*

Treatments*	P	K	Na	Ca	Mg
			98 days after sowing		
C	0·33	4·0	4·4	1·0	1·2
AC	0·33	3·5	4·9	0·9	1·2
V	0·32	3·1	5·1	1·0	1·3
MF	0·34	3·3	5·0	0·9	1·2
S.E. (9 D.F.)	0·015	0·27	0·18	0·03	0·07
			129 days after sowing		
C	0·27	2·3	5·5	1·0	1·2
AC	0·23	1·9	6·8	1·0	1·2
V	0·21	1·6	7·7	1·1	1·3
MF	0·19	1·7	7·5	1·1	1·4
S.E. (9 D.F.)	0·027	0·16	0·40	0·07	0·07
			162 days after sowing		
C	0·22	1·9	4·8	1·5	1·3
AC	0·18	1·2	6·8	1·2	1·5
V	0·17	1·3	6·7	1·3	1·5
MF	0·19	1·2	7·3	1·3	1·5
S.E. (9 D.F.)	0·011	0·11	0·78	0·09	0·13
			Recommended ranges (Ulrich & Hills 1990)		
	0·1–0·8	1–6	0·02–3·7	0·4–1·5	0·1–2·5

* See text for details.

the dry period after April. These NO_3^--N contents are still larger than the desirable 30 kg N ha^{-1} content in the 0–60 cm soil layer recommended for late in the vegetation period to ensure good beet quality (Neeteson & Zwetsloot 1989). These authors suggested that more than 70 kg NO_3^--N ha^{-1} would be detrimental to the quality of both sugarbeet and the environment.

Fluctuations in temperature and soil moisture throughout the growing season could have affected mineralization of the organic-N supplied with AC and V, and the release of the NH_4^+-fixed. This could explain the more erratic values of NO_3^--N content in the previously fertilized soils than in the unfertilized treatment (Fig. 1). Similar results were found by Shepherd (1993).

The application of organic residues for several years normally results in an increase in the N mineralization potential of soils; an increase in the content of easily mineralizable N (Griffin & Laine 1983). In an incubation experiment carried out by Martín-Olmedo *et al.* (1995) with two different soils, it was observed that the application for 3 years of the same 'alpechin'-compost (AC) and beet vinasse (V) as used in the present study led to an increase in the N mineralization potential of 5–10% in AC and 24–35% in V. Results obtained by Vaidyanathan *et al.* (1991) showed that large soil mineral N reserves ($>$ 300 kg NO_3^--N ha^{-1}) were identified in fields receiving different types of organic manures. It is also well established that inorganic N (NO_3^- and NH_4^+) may be immobilized in the soil in organic forms, which are very slowly available to plants, or trapped (NH_4^+) within interlayer spaces of vermiculite, illite and other 2:1 clay minerals (Glendining & Powlson 1991; Breitenbeck & Paramasivam 1995).

Plant response to the residual soil N content throughout the experiment was clear, as reflected by petiole NO_3^--N contents shown in Fig. 2. In general, there was a fall-off in the petiole NO_3^--N content in all four treatments 4 weeks before harvest, but only in the unfertilized treatment (C) did this decline reach a value $<$ 1000 mg NO_3^--N kg^{-1}, the critical content recommended by Ulrich & Hills (1990) as an indicator of the N deficiency desirable to obtain an optimum sugar yield. The average petiole NO_3^--N contents for fertilized treatments (6943–9552 mg NO_3^--N kg^{-1}) at the last sampling data (162 days after sowing), although smaller than at the beginning of the study period, were still much higher than this critical content (Fig. 2). The differences between the fertilized and the unfertilized plots were highly significant at all times.

Table 5. *Response of sugarbeet to previous fertilizer treatments and resulting N uptake*

	Fresh weight yield (t ha^{-1})			N uptake (kg ha^{-1})		
Treatments*	Tops	Roots	Total	Tops	Roots	Total
C	19·7	60·2	79·9	52	82	133
AC	37·6	71·3	108·9	136	140	276
V	39·5	71·8	111·3	149	128	276
MF	48·6	66·4	115·0	214	140	354
S.E. (9 D.F.)	12·6	5·3	18	17	7·0	23·8

* See text for details.

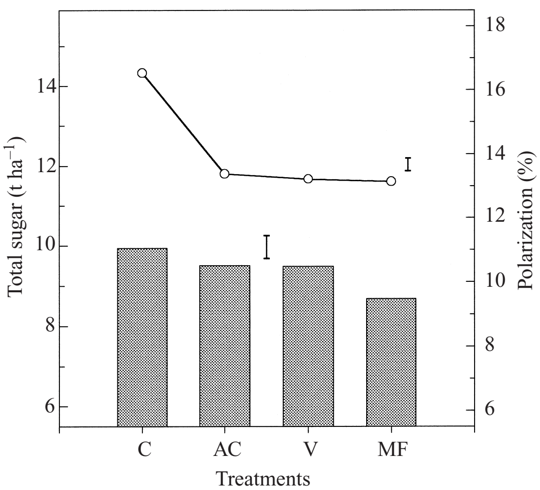

Fig. 3. Total sugar yield (▩) and polarization (○) for the treatments C (control), AC ('Alpechín' sludge compost), V (beet vinasse) and MF (mineral fertilization). Vertical bars are S.E. (D.F. = 9).

Throughout the growing season, Na was the only nutrient whose concentration in the leaf blades of sugarbeet was increased as a consequence of residual fertilizer treatments (Table 4). Phosphorus, K, Ca and Mg concentrations were always within the recommended ranges reported by Ulrich & Hills (1990), only Na exceeded the upper limit. Thus, besides N, Na may be a frequent constraint for cropping sugarbeet under arid and semi-arid conditions, where the element is often abundant and where repeated and excessive fertilization may enhance Na uptake, leading to a detrimental effect on sugarbeet quality, as discussed later.

In response to the high residual nitrate content in the soil profile and as can be deduced from the changes in NO_3^--N content in the petioles (Fig. 2), the mean total fresh weight yields for the AC, V and MF treatments were significantly greater than that for treatment C (Table 5). Differences in yields between fertilized and unfertilized treatments were especially due to the top fraction which was 90, 100 and 145% larger in treatments AC, V and MF, respectively, than in treatment C (Table 5). Changes in root yield were not significant (Table 5). This is in accordance with Milford *et al.* (1988), who observed that large amounts of available N and late season N uptake unduly prolonged leaf and shoot development with smaller amounts of the photosynthate being partitioned to roots, resulting in a decrease in the biological and economic yield of sugarbeet. Nitrogen uptakes from fertilized treatments were also statistically greater than in the unfertilized treatment (Table 5). In studies carried out by Pocock *et al.* (1990), located at different sites in the UK and Belgium, it was found that N uptake in the sugarbeet crop increased linearly with the amount of available N.

Residual N decreased sugar percentage (or polarization) by an average of 3·3% (Fig. 3). The maximum sugar concentration was attained with the unfertilized treatment whose polarization value was significantly higher than those for the AC, V, and MF treatments. The high concentration of NO_3^--N found in the soil profile for all treatments in the late vegetation period (Fig. 1), and the late N uptake by plants, could have altered the pattern of development and morphological structure of storage roots, thereby decreasing the concentration of sugar (Mengel & Kirkby 1982). Pocock *et al.* (1990) and Allison *et al.* (1996) reported similar effects.

The sugar yield results in Fig. 3 also show the detrimental effect of previous applications of high rates of fertilizers (AC, V and MF treatments), the MF treatment significantly reduced sugar yield compared with the control. Moreover, the N uptake (in kg) required to produce 1 tonne of sugar – an index for assessing N efficiency (López-Bellido *et al.* 1994) – was between 13·5–16·1 kg N t^{-1} sugar in fertilized plots, which was almost double that corresponding to the unfertilized plot (8·3 kg N t^{-1} sugar), indicating superfluous N uptake in the fertilized plots.

The effect of fertilizer N on the processing quality of sugarbeet is well-known (Draycott 1993). As was

Table 6. *Concentrations of impurities in beet at harvest as affected by the different fertilizer treatments*

Treatments*	α-amino N	Sodium	Potassium
	(mg/100 g beet)		
C	22	46	241
AC	61	135	292
V	64	152	278
MF	67	152	267
S.E. (9 D.F.)	6·4	11·8	5·5

* See text for details.

pointed out by Pocock *et al.* (1990), late-season uptake of N increases soluble-N (mainly as α-amino N and betaine) in harvested beet by increasing the amount of N in the crop at a time when it cannot be fully utilized for growth, resulting in the decrease of the efficiency of sucrose extraction within the factory. In addition, the monovalent cations, Na and K, are also impurities which may be increased by the application of N fertilizer at high rates (Allison *et al.* 1996). The technological quality of the sugarbeet in this experiment was severely impaired by the heavy fertilization rates applied during the previous 5 years (AC, V and MF treatments). The concentrations of α-amino N, Na and K in the root beet were significantly greater in plants from AC, V and MF treatments than in those from the control treatment (C) (Table 6). The previously fertilized treatments had especially high concentrations of Na, which is in agreement with what was observed during the development of the plants (Table 4). The relative increase for K was much smaller (Table 6).

CONCLUSIONS

The results obtained in this study have shown that the routine application of high rates of fertilizers, frequently used by farmers in the Mediterranean area to ensure maximum yields, considerably increases the reserves of soil N. A large part of this N becomes available in the soil profile during the following cropping seasons through the release of fixed ammonium or mineralization processes. Autumn-sown sugarbeet is very much affected by this practice. In the present study, residual N from previous fertilizer treatments led to a superfluous N uptake by sugarbeet, a significant decrease in sugar percentage and an increase in impurities in the beet at harvest. A more sustainable practice with reduction in the conventional fertilization rates and a good index for the prediction of N availability prior to sugarbeet sowing would be recommended to optimize sugar yield and juice quality and to reduce the risk of environmental pollution.

This work was supported by the CICYT of Spain (Project AGR 91-0600). P. Martín-Olmedo is grateful for the grant received from the Ministerio de Educación y Ciencias de España.

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