S. HALL JA 1229

ICRISAT

Plant and Soil **150**: 213-222, 1993.
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PLSO 9709

Crop residue application increases nitrogen fixation and dry matter production in groundnut (*Arachis hypogaea* L.) grown on an acid sandy soil in Niger, West Africa*

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Received 27 July 1992. Accepted in revised form 21 December 1992

Key words: acetylene reduction assay (ARA), acid soil, *Arachis hypogaea*, molybdenum availability, nodules, symbiotic N_2 fixation

Abstract

Field experiments were conducted during the rainy seasons of 1989, 1990 and 1991 on an acid sandy soil in Niger, West Africa, to assess the effect of millet straw application (+CR) on growth and N_2 fixation of groundnut (*Arachis hypogaea* L.).

Three years of +CR (4 t ha^{-1} yr^{-1}) increased symbiotic N_2 fixation, total dry matter production (haulm plus pods) by 83% and total nitrogen (N) accumulation by 100%. Concentration of N in the shoot dry matter and total N in the soil were only slightly affected by the +CR treatment.

Crop residue application increased the concentration of potassium (K) and molybdenum (Mo) and decreased the concentrations of aluminium (Al) and manganese (Mn) distinctly, both in the plant (shoot and nodule dry matter) and in the soil.

The increase in dry matter production and N uptake was mainly due to improved N_2 fixation reflected by enhanced formation and growth of nodules as well as nitrogenase activity. This was attributed to improved chemical soil conditions, particularly to the higher availability of Mo and the lowered content of available Al and Mn.

Although with the application of 4 t CR ha^{-1}, 60 kg K were supplied, increased growth could not be attributed to the additional supply of K.

Introduction

West Africa is the largest groundnut (*Arachis hypogaea* L.) producing region of the continent contributing about 54% of the total groundnut production of Africa (Anon., 1987). Although groundnut is one of the most important food and cash crops, in recent years groundnut production in West Africa has declined drastically (FAO, 1991).

A major problem in groundnut production in the semiarid areas of West Africa in general, and Niger in particular, is the low native fertility of the acid sandy soils, due mainly to the high concentrations of aluminum (Al) and manganese (Mn) and low concentrations of available phosphorus (P) and especially molybdenum (Mo) (Hafner et al., 1992). Legumes such as groundnut have a relatively high Mo requirement for the *Rhizobium* symbiosis, since Mo is a key component of the enzyme nitrogenase. Molybdenum deficiency in soils low in N is consequently associated with poor plant growth.

Remedying these unfavourable soil conditions

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*ICRISAT Journal Article No. 1229.

by mineral fertilization and liming is often not feasible in Niger for economic reasons because groundnut production is in the hand of small-scale farmers.

Organic matter plays a key role in maintaining the fertility of acid soils in West Africa (Bationo and Mokwunye, 1991; Gichuru, 1991). In the Sahelian zone of Niger the supply of crop residues as millet straw (stover of pearl millet, *Pennisetum glaucum* (L.) R.Br.) is a suitable alternative for stabilizing and increasing millet yields (Bationo et al., 1987). The overall objective of this study was to test whether the application of crop residues as millet straw is also a suitable input for increasing groundnut production. The main emphasis was put on the effects of crop residues on symbiotic N_2 fixation.

Material and methods

Experiments were conducted in 1989, 1990 and 1991 at the ICRISAT Sahelian Center (ISC) located at Sadoré, 45 km southeast of Niamey, Niger, West Africa (13° 15′ N latitude, 2° 18′ E longitude). Mean annual rainfall is 560 mm with a 25% probability of receiving less than 441 mm, and 36°C average daily maximum temperature on a yearly basis.

The soil at the experimental site is derived from eolian sand deposits, and classified as sandy Psammentic Paleustalf: sandy, siliceous, isohyperthermic (West et al., 1984). Further details of the chemical soil properties are shown in Table 1.

The fields of the experimental site had not been cultivated before. The natural vegetation was removed manually prior to the beginning of the experimental period 1989.

In Experiment I over a three year period the overall effect of crop residue application was studied and in 1991 additional treatments were imposed for evaluating the role of mineral nutrients (Experiment II) and the increase in soil pH by liming (Experiment III) on the growth of groundnut.

Experiment I was established in 1989. The fields were treated with Carbofuran (10 kg active ingredient ha^{-1}) before sowing, in order to decrease microvariability partly attributable to nematode infestation. Seeds of groundnut (*Arachis hypogaea* L.) cv 55–437, derived from plants grown on the ICRISAT Sahelian Center, were treated with Thiram (3 g kg^{-1} seed) just before sowing. Seeds were not inoculated with *Rhizobium*, because of the sufficient occurrence of native N_2 fixing bacteria in the soil. The seeds were sown manually at 50 × 12 cm spacing, on plots 18 × 6 m in size. The experiment was arranged in a randomized complete block design with 6 replications. The treatments were: (i) Control (no crop residues), and (ii) crop residue

Table 1. Chemical properties of the soil[a] in different depths (cm) as affected by millet straw (+CR) (1989–1991) or lime (+Lime) (1991) amendments

Treatment	pH ($CaCl_2$)	Org. C (%)	N (%)	C:N	Mo (avail.) ($\mu g\ kg^{-1}$)	P (Bray 1)	Mn (active)	Ca	Mg	K	Al	ECEC[b] ($meq\ mg^{-1}$)
						($mg\ kg^{-1}$)			(exchangeable)			
Control												
0–10	4.25	0.19	0.025	7.6	11	3.4	19.9	66.4	13.0	17.9	14.4	6.44
10–30	4.06	0.18	0.015	12.0	2	1.5	31.0	34.0	8.5	17.2	36.7	6.93
+CR												
0–10	4.70	0.20	0.029	6.9	19	5.8	18.3	101.6	26.0	41.8	3.0	8.80
10–30	4.28	0.18	0.019	9.5	2	2.3	19.9	44.8	12.0	32.2	22.4	6.55
+Lime												
0–10	5.18	0.19	0.024	7.9	9	9.6	15.3	148.5	13.5	19.2	7.4	9.81
10–30	4.15	0.18	0.020	9.0	1	7.5	28.5	53.5	9.0	19.4	33.3	7.61

[a] Soil samples were taken at flowering (30 DAP) in 1991.

[b] Effective cation exchange capacity was calculated by summation of exchangeable bases and exchange acidity.

application (+CR: 4 t ha^{-1}) as millet straw (stalks and leaves of pearl millet; *Pennisetum glaucum* (L.) R.Br.), containing in kg t^{-1}: 7.5 N, 0.5 P, 15 K and in g t^{-1}: 0.13 Mo.

The crop residues were applied in 1989 after clearing the fallow area and for the cropping periods 1990 and 1991 at the end of the previous cropping season. With the exception of 10 kg N as calcium ammonium nitrate (CAN), applied immediately after germination to all treatments, no other fertilizers were used.

Experiment II was established on plots (18 × 6 m), where P was fertilized additionally since 1989 (16 kg ha^{-1} P as single superphosphate; SSP) prior to planting, in order to correct P deficiency in the plants. In 1991 these plots were splitted to three sub-plots with a plot size of 6 × 6 m. In this experiment particular emphasis was put on the role of potassium (K) and nitrogen (N) in the growth enhancement effects by crop residue application. Accordingly, K and N were supplied as mineral fertilizers at levels equivalent to those applied with the crop residues (4 t ha^{-1}), i.e. 60 kg K and 30 kg N. The treatment were (i) Control (+P), (ii) +K (+P), (iii) +K +N (+P), (iv) +CR (+P). Prior to planting 60 kg ha^{-1} K as KCl were applied to the plots with K treatment, and to the N treatment 30 kg N ha^{-1} (including the basal N dose of 10 kg N ha^{-1}) as CAN, in splits at 10 days intervals, beginning with germination.

As crop residue application slightly increased the soil pH (CaCl$_2$) in 0–10 cm depth from 4.25 to 4.70 after 3 years (Experiment I) an additional experiment with lime treatment (+Lime) was imposed in 1991 on plots of the control (−CR) treatment (Experiment I) after dividing to subplots with a plot size of 6 × 6 m. Treatments in Experiment III were: (i) Control, (ii) +CR, (iii) +Lime. Except the basal N dressing (10 kg N ha^{-1}) no further mineral fertilizers were used. Lime was applied as 400 kg ha^{-1} CaCO$_3$ prior to planting. With this level a soil pH increase to 5.0 was envisaged based on the determination of the pH buffering capacity of the soil.

In Experiment II and III factors such as field layout, field preparations and sowing were the same as described in Experiment I.

For studying the time course of dry matter production in 1989 and 1990, plants from 6 m^2 area were harvested at 20 days after planting (DAP) (before flowering), 35–40 DAP (flowering), 60 DAP (early pegging), 75 DAP (pegging) and 90 DAP (crop maturity). In 1991 plants (6 m^2) were harvested only at flowering, early pegging and at crop maturity. At each harvest plants were divided into shoots, roots and pods. Dry matter was determined after drying to constant weight at 60 °C.

Symbiotic N$_2$ fixation rate was assessed by the acetylene reduction assay (ARA) in Experiment II (1991) at 10 day intervals, beginning 30 DAP until 70 DAP. Between 10^{30} and 14^{00} h five plants from each replicate and treatment were sampled at random by digging with a fork and the root system (0–30 cm) gently shaken free of soil. After removal of the shoot the root system of each plant was placed in an one-litre jar. Immediately after the jar was sealed, 60 mL air was removed and an equivalent amount of acetylene introduced to establish a 6% (v/v) acetylene-air atmosphere (Hansen et al., 1987). The whole procedure was performed under shaded conditions. A 20 mL gas sample was taken twice, first after 5 min and then after another 5 min of incubation, and stored in pre-evacuated serum bottles (Heat-space bottles, Perkin-Elmer). Within 24 h after the ARA test ethylene was measured with a gas chromatograph (Pye Unicam GCV) equipped with a flame ionization detector.

For each root system the number of nodules were counted and their dry weight recorded after drying to constant weight at 60 °C. The concentration of N in shoots and seeds were determined using a Macro-N-Analyzer (Heraeus). For the other mineral elements plant dry matter was ashed at 450 °C, overnight and the resultant ash dissolved in 1:30 (v/v) HNO$_3$. Magnesium, Zn, Cu, Mn, Al were determined by atomic absorption spectrophotometry (Philips Pu 9400 X), K and Ca by flame photometry (Eppendorf, Elex 6361). P and Mo colorimetrically by using the vanado-molybdate method for P (Gericke and Kurmies, 1952) and the thiocyanate procedure for Mo as described by Schwedt and Dunemann (1983). For analysis of Mo plant material (shoots, seeds and nodules) from six replications were pooled.

At flowering soil samples were taken from 0–10 and 10–30 cm depths. Soils from six replications were pooled. Soils were air dried and sieved (< 2 mm) prior to analyses. Soil pH was measured in 0.01 *M* $CaCl_2$. Available P was extracted using the Bray I procedure and P measured by the molybdate-blue method as described by Olsen and Sommers (1982). For exchangeable Al soil was extracted with 1 *N* KCl as described by McLean (1982). The concentration of Al was measured by atomic absorption spectrophotometry (Philips Pu 9400 X). Soil was extracted with 1 N NH_4OAC and the exchangeable cations were determined by flame photometry (Ca, Na and K) and by atomic absorption spectrophotometry (Mg), respectively. Manganese was determined as 'active Mn' using the method of Schachtschabel (1957). Available Mo was extracted with 0.275 *M* ammonium oxalate (Haley and Melsted, 1957) and determined as described above. Total N was determined using a Macro-N-Analyzer (Heraeus). Organic carbon was calculated according to loss of ignition, which was determined gravimetrically after ashing dry soil at 500°C overnight.

Results

The effect of crop residue application on total dry matter of groundnut (haulm plus pods) is shown in Figure 1. The addition of crop residues (+CR) increased total dry matter over the years. In the first year (1989) +CR had no significant effect on total dry matter but increased it by 49% in 1990 and 83% in 1991.

In 1990 and 1991 there was a greater increase in haulm yield by +CR than pod yield, with the increased haulm yield in 1991 being 133% and pod yield 83% (Table 2).

Nitrogen (N) uptake influenced dry matter production. Crop residue application increasingly enhanced N uptake of the shoots and seeds over the years (Table 3), and total N uptake in

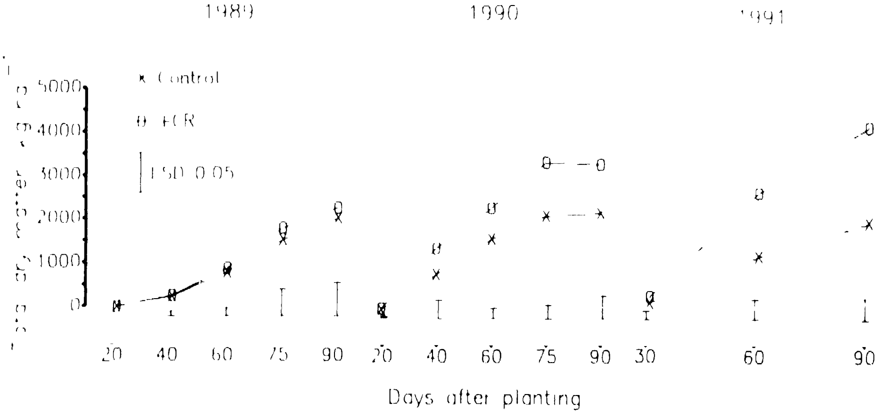

Fig. 1 Total dry matter yield (haulm plus pods) of groundnut as affected by the application of crop residues (+CR). Vertical *bars* represent LSD 0.05, calculated by the Student Newman Keuls Test (Sadore, rainy season 1989, 1990 and 1991)

Table 2 Effect of crop residue application (+CR) on pod and haulm dry matter (kg ha^{-1}) of groundnut at maturity (90 DAP) (Sadore, rainy season 1989, 1990 and 1991)

Treatments	Pod dry matter			Haulm dry matter		
	1989	1990	1991	1989	1990	1991
Control	1134	1360	1038	941	967	1003
+CR[1]	1269	1790	1905	1044	1671	2336
SE	87	95	159	76	116	240
CV (%)	25.2	21.2	37.8	26.9	30.7	50.3

[1] 4 t millet straw ha^{-1}

Table 3. Effect of crop residue application (+CR) on N accumulated in shoots and seeds of groundnut at final harvest. (Sadore, rainy season 1989, 1990 and 1991)

Treatments	N uptake (kg ha^{-1})								
	Shoots			Seeds			Total[b]		
	1989	1990	1991	1989	1990	1991	1989	1990	1991
Control	19	17	16	35	48	36	54	65	52
+CR[a]	22	32	41	46	65	67	68	97	108
SE	1.6	2.9	5.2	2.8	4.1	6.0	4.1	6.6	9.9
CV (%)	27.8	32.9	63.9	24.5	20.3	40.7	23.3	22.8	43.5

[a] 4 t millet straw ha^{-1}.
[b] excluding roots, nodules and shells.

1990 increased by 50% and in 1991 by more than 100%.

Despite the enhancement effect of +CR on dry matter production and total N uptake the N concentrations in the shoot dry matter at flowering (30 DAP) were still at the lower margin of the sufficiency range (Bergmann, 1988) (Fig. 2). Crop residue application decreased the N concentration in the shoot dry matter slightly in 1989 and a slight increase occurred in 1991.

At flowering K concentration in the shoot dry matter of the control was in the deficiency range (Bergmann, 1988) during the three cropping seasons (Fig. 2). With +CR the K concentration in the shoot dry matter was increased to the adequate range already in the second season (1990). In 1991 +CR increased the K concentration in the shoot dry matter by nearly 50% compared to the control (Fig. 2). The higher K concentration in the shoot dry matter of groundnut was presumably caused by the additional K supply from 4 t millet straw, containing 60 kg K ha^{-1}. At flowering P concentration in the shoot dry matter was generally below the sufficiency range (Bergmann, 1988) and reached the sufficiency range only in the third year of +CR (Fig. 2). The concentrations of Ca, Mg, and Zn in the shoot dry matter at the beginning of pod filling (60 days after planting) were in the adequate range (Table 4) and not influenced by CR application. The concentrations of both Mn and Al in the shoot dry matter were very high and Mn may have reached already the toxic range. Although +CR decreased the concentrations of Mn and Al distinctly, they remained at high levels (Table 4).

The effects of +CR and of the mineral fertilizer equivalents of K and N on total dry matter

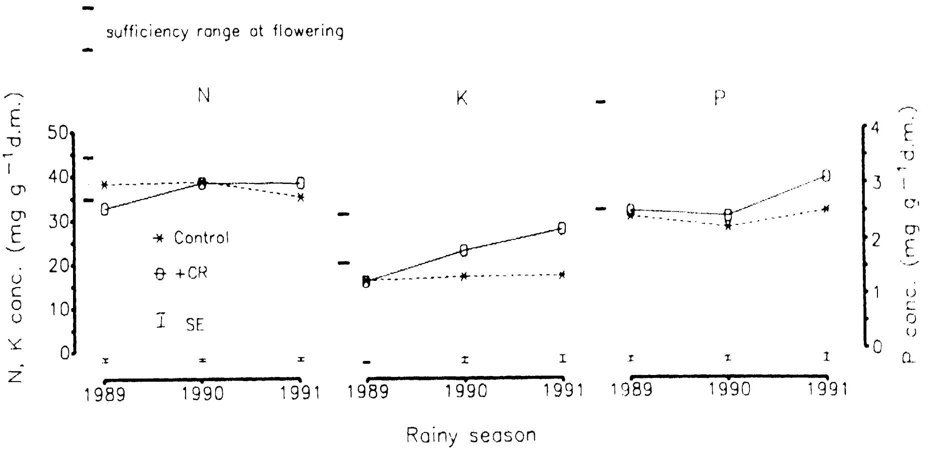

Fig. 2. Effect of crop residue application (+CR) on the concentration of N, P, K in the shoot dry matter of groundnut at flowering in the rainy season 1989, 1990 and 1991. Vertical *bars* represent standard error of means (SE).

Table 4. Mineral element concentration in the shoots of groundnut at early pegging (60 DAP). (Sadoré, rainy season 1990)

	Control	+CR	SE	CV (%)		References
	(mg g^{-1} d.m.)				Sufficiency range	
Ca	12.6	11.5	0.4	9.0	12–17	Small and Ohlrogge, 1973
Mg	6.9	7.1	0.2	7.3	3–8	Small and Ohlrogge, 1973
	(μg g^{-1} d.m.)					
Zn	45	38	2.0	13.4	20–50	Small and Ohlrogge, 1973
Cu	4	4	0.3	23.7	6–15	Small and Ohlrogge, 1973
Mn	868	676	67.0	24.4	100–350	Reuter and Robinson, 1986
					Non-toxic range	
Al	659	465	49.0	24.8	<200	Reuter and Robinson, 1986

production and N uptake are shown in Table 5. Although the K concentration in the shoot dry matter was increased to the sufficiency range (at flowering: 21.5 mg g^{-1} dry matter), mineral K fertilization did not enhance total dry matter production and N uptake (Table 5).

However, application of both, mineral N and K, increased dry matter production and N uptake by plants to a similar extent as +CR. Nevertheless, the origin of N in plants could have differed between the treatments. In the case where mineral fertilizer N was supplied, N presumably originated mainly from the fertilizer, whereas with the +CR, the contribution of N from biological N$_2$ fixation may have been considerable as shown in Figure 3. Application of CR increased nitrogenase activity (ARA) considerably compared to the other two treatments. Although with +CR also 30 kg N were supplied in 4 t ha^{-1} millet straw (+CR) nitrogenase activity (NA), nodule dry weight (plant^{-1}) (Fig. 3) as well as the number of nodules (plant^{-1}) (data not presented) were much higher than when 30 kg N ha^{-1} supplied as CAN. Lime application was less effective than +CR in increasing total dry matter production and total N uptake but performed significantly better than the control (Table 6).

Higher dry matter production and total N uptake with +CR correspond well with lower concentrations of Mn and Al in the shoot dry matter and much higher concentrations of Mo in shoots and nodules (Figs. 4, 5). The lower Mn and Al concentrations in the shoots and the higher Mo concentrations in the shoots and particularly in the nodules (Fig. 5) were in accordance with the treatment effects on the soil chemical properties (Table 1). Although liming increased available P (Bray I) in the soil (Table 1) and concentration of P in the shoots (Fig. 4), dry matter production and N uptake were much less enhanced by liming compared to CR application. This low response to liming is probably caused by the still high concentrations of Mn and Al in the shoots and the low Mo concentration in the shoot and nodule dry matter (Figs. 4, 5).

Table 5. Effect of crop residues (+CR) and mineral fertilizer (+N as CAN; K as KCl) on total dry matter production, and on N uptake of groundnut. (Sadore, rainy season 1991)

Treatments	Total dry matter (kg ha^{-1})	N uptake (kg ha^{-1})		
		Shoots	Seeds	Total[a]
Control (+P)	2515	24.0	40.2	64.2
+60 kg K ha^{-1} (+P)	2581	32.5	36.9	69.4
+30 kg N ha^{-1} +60 kg K ha^{-1} (+P)	4440	61.2	42.9	104.1
+4 t CR ha^{-1} (+P)[b]	4902	59.3	48.7	108.0
SE	276	4.6	3.3	6.9
CV (%)	37	50.9	38.2	39.9

[a] excluding roots and shells;
[b] third year of +CR.

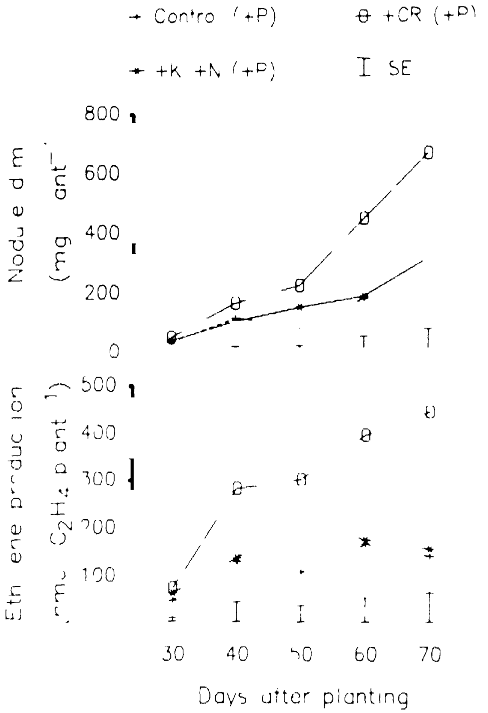

Fig. 3 Nitrogenase activity (ethylene production min plant) and nodule dry matter as affected by the application of crop residues plus P (+CR), mineral K and N plus P (+K +N) and P only (Control). Vertical *bars* represent standard error of means (SE). (Sadore, rainy season 1991)

Discussion

Although groundnut is able to meet its N requirement through N fixation (Dutta et al. 1988, Peoples and Craswell, 1992), the results demonstrate that in our case it was not, and N deficiency was the main factor responsible for poor growth of groundnut on this acid soil in Niger. Generally, in acid soils the legume–*Rhizobium* symbiosis is impaired by low concentrations of available Mo (Burmeister et al. 1988) and P (Cassman et al. 1980) and by high concentrations of H and particularly Al (Chong et al. 1987) inhibiting root infection with *Rhizobium* and nodule initiation even in the presence of sufficient numbers of rhizobia (Whelan and Alexander 1986).

In the unamended sandy soil N fixation of groundnut was low, obviously due particularly to the soil acidity and low availability of Mo. The favourable effects of the application of crop residues on N fixation and dry matter yield, especially shoot growth, and total N uptake suggest that some positive changes in soil conditions occurred. Enhanced shoot growth of groundnut due to improved N supply either via mineral fertilizer N (Lombin et al., 1985) or N fixation (Hafner et al. 1992) is often desired.

Increased N fixation and N uptake in the +CR treatment was mainly the consequence of improved chemical soil conditions. Noteworthy were the increased availability of Mo and P and the decreased concentrations of exchangeable Al and Mn (Table 1 and Fig. 4). Although the concentrations of K in the shoot dry matter (Fig. 2) and also in the soil (Table 1) increased with +CR (nutrient recycling), fertilization with equivalent amounts of mineral K neither enhanced growth of shoots (Table 5) nor nodules (data not represented), suggesting that the pre-existing K was sufficient or that K was not the main limiting factor for plant growth and N fixation.

In contrast, the supply of equivalent amounts of mineral N had a similar effect on dry matter production and N accumulation as +CR (Table

Table 6. Effect of crop residues (+CR) and lime (+Lime) on total dry matter production and on N uptake of groundnut (Sadore, rainy season 1991)

Treatments	Total dry matter (kg ha^{-1})	N uptake (kg ha)		
		Shoots	Seeds	Total
Control	2041	15.9	36.0	51.9
+CR	4241	40.8	66.7	107.5
+Lime	3022	32.6	44.1	76.7
SE	292	3.8	4.9	7.6
CV (%)	40	53.8	42.1	40.7

excluding roots and shells

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Section editor: R O D Dixon