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EFFECT OF SOWING DEPTH ON NODULATION, NITROGEN FIXATION, ROOT AND HYPOCOTYL GROWTH, AND YIELD IN GROUNDNUT (*ARACHIS HYPOGAEA*)

By P T C. NAMBIAR *and* B SRINIVASA RAO

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru PO, Andhra Pradesh 502 324, India

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SUMMARY

Hypocotyl length in groundnut is a function of sowing depth In field experiments deep sowing increased the mass of hypocotyl but decreased that of roots, pods and haulm Few nodules were formed on the hypocotyls of plants from shallow sown seeds (4–5 cm deep) More hypocotyl nodules occurred on Virginia types when deep sown but the number and activity of nodules on the roots decreased Nodules on the hypocotyl appeared later and fixed less nitrogen than root nodules Although hypocotyl nodules fixed nitrogen during the later stages of plant growth, this activity could not compensate for the loss in nitrogenase activity due to deeper sowing. Deeper sowing also resulted in decreased pod yields

P T C. Nambiar y B Srinivasa Rao *El efecto de la profundidad de siembra sobre la nodulación, fijación de nitrogeno, crecimiento de raiz e hipocotil, y rendimiento en el cacahuete,* Arachis hypogaea

RESUMEN

El largo del hipocotil en el cacahuete es una funcion de la profundidad de siembra. En experimentos de campo, la siembra profunda aumento las masa de hipocotil pero disminuyó aquel de raices, vainas y hojarasca. Se formaron pocos nódulos en los hipocotiles de plantas de semillas sembradas a poca profundidad (4–5 cm) Se produjeron más nódulos de hipocotil en los tipos Virginia cuando fueron sembrados a mayor profundidad, pero disminuyeron la cantidad y actividad de nódulos en las raices Los nódulos en el hipocotil aparecieron más tarde y fijaron menos nitrogeno que los nodulos en las raices Aunque los nodulos en los hipocotiles fijaron nitrogeno durante las etapas posteriores de crecimiento de la planta, esta actividad no pudo compensar la pérdida de actividad nitrogenasa debida a la siembra profunda. La siembra profunda también dio como resultado menores rendimientos de vaina

The sub species of *Arachis hypogaea* vary in their ability to nodulate in the hypocotyl region (Nambiar *et al*, 1982b) Some genotypes of the longer duration sub-species *hypogaea* (Virginia types) nodulate profusely on the hypocotyl, while those of the shorter duration *fastigiata* (Valencia and Spanish types) rarely nodulate in this region Since hypocotyl nodules are formed late in the life of the Virginia types, during the pod-filling stage, it has been suggested that this character could be of use in a breeding programme to increase biological nitrogen fixation, by extending the duration of nitrogen fixation (Nambiar *et al.*, 1982a)

The growth and length of the hypocotyl is a function of sowing depth (Bouffil, 1947, cited by Gregory *et al.*, 1951). Many farmers in southern India use a bullock-drawn seeder, which places the seed 8–12 cm deep. This paper

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examines the relation between sowing depth, hypocotyl and root nodulation, and nitrogen fixation in groundnut. Observations on the effect of sowing depth and pod and haulm yields are also reported.

MATERIALS AND METHODS

Four experiments were conducted on Alfisol fields at the ICRISAT Centre, Patancheru (18° N, 78° E). Fertilizer in the form of single superphosphate (40 kg P_2O_5 ha^{-1}) 10-15 days before sowing, and gypsum (400 kg ha^{-1}) at flowering was applied to all plots. The plants were grown in rows 75 cm apart, with a plant-to-plant spacing of 15 cm in all experiments except the 1984 rainy-season experiment, when the crop was grown on 1.5 m beds in four rows 30 cm apart with a spacing of 10 cm within the row. The seeds were treated with thiram (3 g kg^{-1} seed). They were sown in furrows opened at the desired sowing depth, except during the 1980-81 post-rainy season when they were either hand sown 4-6 cm deep or sown 8-10 cm deep using the traditional bullock-drawn implement. The sowing rate corresponded to twice the intended population in each experiment and the stands were later thinned to the re-

Table 1. *Effect of sowing depth on nodule number plant^{-1} at 75, 102 and 137 DAS during the 1980-81 post-rainy season for different groundnut cultivars*

	75 DAS		102 DAS		137 DAS	
	Sowing depth (cm)					
	5	10	5	10	5	10
			Roots			
MH 2	212	103	274	134		
Gangapuri	291	217	641	353		
NC Ac 529	243	212	350	301	377	386
NC Ac 770	264	184	319	274	331	328
M 13	350	185	846	250		
NC Ac 10	295	261	700	467		
Kadiri 71-1	273	226	674	470	684	655
MK 374	328	194	930	483	887	602
SE ±	20.2		54.2		60.6	
			Hypocotyls†			
MH 2	1.1 (0.7)	2.1 (4)	1.6 (2)	3.6 (14)		
Gangapuri	1.0 (0.5)	2.2 (5)	2.4 (6)	3.7 (16)		
NC Ac 529	0.9 (0.3)	1.2 (1)	1.9 (3)	2.8 (8)	3.3 (11)	3.4 (11)
NC Ac 770	1.2 (1.0)	1.8 (3)	2.3 (5)	3.8 (14)	3.7 (14)	5.0 (25)
M 13	2.4 (6)	2.3 (6)	2.7 (7)	4.3 (28)		
NC Ac 10	1.3 (1.6)	3.6 (13)	3.1 (10)	10.0 (101)		
Kadiri 71-1	1.8 (3.0)	3.8 (14)	4.3 (20)	11.0 (121)	7.2 (52)	15.7 (249)
MK 374	1.3 (1)	3.7 (15)	4.9 (24)	12.9 (170)	8.1 (68)	17.1 (295)
SE ±	0.35		0.70		0.61	

Blank spaces indicate plots harvested before sampling.
† Data analysed after square root ($\sqrt{Y + 0.5}$) transformation with original values in parentheses.

quired populations, any gaps being filled as required. Since native *Rhizobium* populations in these fields were adequate for good nodulation (10^2-10^4 cells g^{-1} dry soil), the plots were not inoculated with *Rhizobium*. The crop was regularly protected by sprays against insect pests and late leaf spot disease (caused by *Phaeoisariopsis personata*). Other details of the experiments are given below.

Post-rainy season 1980-81

Eight genotypes, MH 2, Gangapuri (Valencia type), NC Ac 529 and Nc Ac 770 (Spanish), M 13, NC Ac 10, Kadiri 71-1 and MK 374 (Virginia), were sown at depths of 5 or 10 cm in a split plot design with sowing depth as the main plots and genotype as the sub-plots, replicated four times. Each plot consisted of two rows 4 m long. The crop was sown on 4 December 1980 and irrigated to field capacity (15 cm) at seven day intervals. The plants were sampled at 75, 102 and 137 days after sowing (DAS) for observations on nodulation and nitrogen fixation. Genotypes MH 2, Gangapuri and NC Ac 10 matured and were harvested 110 DAS. Genotype M 13 germinated poorly and did not produce enough plants for sampling at 137 DAS.

Table 2. *Effect of sowing depth on root and hypocotyl nodule number plant^{-1} at 44 and 70 DAS during the 1981 rainy season for different groundnut cultivars*

	44 DAS			70 DAS		
	Sowing depth (cm)					
	3-4	7-8	10-13	3-4	7-8	10-13
			Roots			
MH 2	133	195	93	201	186	129
Gangapuri	176	159	126	292	316	186
NC Ac 529	158	155	119	184	193	141
NC Ac 770	136	148	116	203	221	135
M 13	261	253	207	395	404	311
NC Ac 10	183	242	136	291	396	267
Kadiri 71-1	210	150	126	358	278	177
MK 374	212	211	148	317	244	207
SE ±		20.7			34.1	
			Hypocotyls†			
MH 2	1.1 (0.8)	1.4 (1.9)	1.0 (0.6)	2.3 (5)	3.0 (8)	3.1 (9)
Gangapuri	1.5 (1.7)	1.2 (1.0)	1.6 (2.2)	2.4 (6)	2.9 (8)	3.8 (15)
NC Ac 529	2.0 (4.5)	1.2 (1.6)	0.8 (0.1)	1.7 (3)	2.1 (4)	2.3 (5)
NC Ac 770	0.8 (0.2)	0.9 (0.4)	1.0 (0.9)	2.9 (8)	2.1 (4)	2.5 (6)
M 13	0.9 (0.3)	1.7 (2.5)	1.2 (1.2)	3.4 (11)	4.3 (19)	7.7 (61)
NC Ac 10	1.1 (0.9)	1.9 (3.9)	2.6 (6.6)	4.5 (21)	5.4 (30)	7.0 (49)
Kadiri 71-1	1.7 (2.8)	2.7 (7.4)	4.4 (19)	4.9 (24)	6.2 (38)	9.8 (95)
MK 374	1.1 (0.9)	2.9 (8.4)	3.9 (16)	3.6 (13)	5.9 (34)	7.0 (55)
SE ±		0.31			0.51	

† Data analysed after square root ($\sqrt{Y+0.5}$) transformation with original values in parentheses.

Rainy season, 1981

The same eight genotypes were sown at depths of 3-4, 7-8 or 10-13 cm. The experimental design was the same as in the 1980-81 season. Each plot consisted of two rows 8 m long. The crop was sown on 23 June, and relied for water on rainfall. The plants were sampled at 44 and 70 DAS for observations on nodulation and nitrogen fixation.

Post-rainy season, 1981-82

The three Virginia genotypes (NC Ac 10, MK 374 and Kadiri 71-1) were sown 3-4 cm or 8-12 cm deep. A factorial design was used with four replications. Each plot was three rows wide by 5 m long and the harvested area was 11.25 m^2. The crop was sown on 10 December 1981 and regularly irrigated. Observations were recorded at harvest on 21 April 1982.

Rainy season, 1984

Two Indian-released cultivars, J 11 (Spanish) and Robut 33-1 (Virginia), were sown 5 or 10 cm deep. The experimental design was a split plot with

Table 3. *Effect of sowing depth on nodule mass (mg $plant^{-1}$) of roots and hypocotyls during the 1980-81 post-rainy season for different groundnut cultivars*

	75 DAS		102 DAS		137 DAS	
	Sowing depth (cm)					
	5	10	5	10	5	10
			Roots			
MH 2	116	76	164	101		
Gangapuri	294	204	635	396		
NC Ac 529	245	221	367	392	444	531
NC Ac 770	187	134	263	249	274	275
M 13	206	121	694	170		
NC Ac 10	233	229	654	497		
Kadiri 71-1	234	178	687	487	759	551
MK 374	252	168	856	443	917	622
SE ±	16.1		54.6		61.3	
			Hypocotyls†			
MH 2	0.9 (0.5)	2.3 (5.8)	1.7 (3)	3.4 (12)		
Gangapuri	–	2.1 (5.7)	2.6 (7)	4.8 (31)		
NC Ac 529	–	0.9 (0.5)	2.3 (5)	3.3 (11)	4.1 (17)	4.6 (21)
NC Ac 770	0.9 (0.2)	1.5 (1.7)	2.4 (5)	4.6 (21)	3.9 (16)	6.0 (37)
M 13	2.1 (4.6)	1.6 (3.3)	2.9 (8)	4.3 (30)		
NC Ac 10	1.4 (2)	3.3 (10.8)	3.5 (12)	11.8 (140)		
Kadiri 71-1	1.5 (2.2)	3.9 (15.0)	5.7 (34)	12.8 (167)	8.7 (76)	16.9 (289)
MK 374	1.0 (0.8)	3.4 (13.6)	6.3 (40)	14.4 (208)	8.4 (72)	19.5 (388)
SE ±	0.47		0.90		0.80	

Blank spaces indicate plots harvested before sampling.

† Data analysed after square root ($\sqrt{Y + 0.5}$) transformation with original values in parentheses. A dash is used when no hypocotyl nodules were detected.

genotypes as the main plots and sowing depth as the sub-plots, with six replications. The crop was sown on 29 June and harvested on 31 October. Each plot was four rows wide by 4 m long and the harvested area was 4.5 m^2.

Observations

At each sampling, five randomly selected plants from each treatment were dug from the field, the tops cut off, and most of the adhering soil removed by shaking. The roots and hypocotyls were separated. The nitrogenase activity of the root nodules and hypocotyl nodules, if any, was measured by acetylene reduction as described by Nambiar and Dart (1983). Hypocotyl and root nodules were manually separated and dried at 80°C for 24 h. Observations of nodulation and nitrogen fixation only were recorded during the 1980–81 post-rainy season and the 1981 rainy season. During the 1981–82 post-rainy and the 1984 rainy seasons only pod and haulm yields were recorded. The pods were manually separated from all the plants, air dried to around 8–10% moisture content, cleaned and weighed. The total fresh weight of the haulm was recorded immediately after harvest, and its dry mass calculated from 1 kg subsamples dried at 80°C for 48 h.

Table 4. *Effect of sowing depth on the nodule mass (mg plant^{-1}) of roots and hypocotyls at 44 and 70 DAS during the 1981 rainy season for different groundnut cultivars*

	44 DAS			70 DAS		
	Sowing depth (cm)					
	3–4	7–8	10–13	3–4	7–8	10–13
			Roots			
Gangapuri	241	209	176	417	395	235
NC Ac 529	234	204	182	334	301	265
NC Ac 770	144	153	129	212	261	157
M 13	273	264	233	434	503	348
NC Ac 10	208	268	176	391	551	371
Kadiri 71-1	246	226	185	538	404	251
MK 374	197	262	186	386	317	313
SE ±		25.5			32.6	
			Hypocotyls†			
MH 2	0.9 (0.4)	1.1 (1.1)	0.8 (0.3)	2.1 (5)	3.0 (10)	3.6 (14)
Gangapuri	1.4 (2.1)	1.0 (0.6)	1.2 (1.2)	2.4 (7)	3.7 (14)	5.3 (30)
NC Ac 529	2.1 (7.5)	1.5 (3.4)	–	2.1 (4)	2.6 (8)	2.8 (8)
NC Ac 770	0.8 (0.1)	0.9 (0.4)	0.9 (0.4)	3.0 (10)	2.0 (4)	2.9 (8)
M 13	0.8 (0.3)	1.5 (2.2)	0.9 (0.4)	3.9 (16)	4.6 (23)	10.2 (109)
NC Ac 10	1.1 (1.2)	1.6 (3.0)	2.6 (6.6)	5.6 (34)	6.5 (42)	9.5 (90)
Kadiri 71-1	1.3 (1.3)	2.4 (6.3)	4.9 (24.3)	7.0 (49)	7.9 (63)	13.1 (175)
MK 374	1.0 (0.5)	2.7 (7.1)	4.5 (23.2)	3.4 (12)	6.6 (45)	8.3 (79)
SE ±		0.86			0.79	

† Data analysed after square root ($\sqrt{Y+0.5}$) transformation with original values in parentheses. A dash is used when no hypocotyl nodules were detected.

RESULTS

Nodule numbers, mass and time of appearance

Root nodule numbers and mass increased with plant age in all genotypes, but were less when seeds were sown deeper than 5 cm (Tables 1, 2, 3 and 4). During the 1980–81 post-rainy season, at 75 and 102 DAS, plants from seeds sown 10 cm deep had 30–42% fewer root nodules than those from seeds sown 5 cm deep. But by 137 DAS, plants from seeds sown 10 cm deep had formed more hypocotyl nodules than those from the shallow sown seeds. However, genotypes varied in hypocotyl nodulation; the Valencia genotypes, MH 2 and Gangapuri, and Spanish genotypes, NC Ac 529 and NC Ac 770, had few hypocotyl nodules. In contrast, Virginia genotypes such as Kadiri 71-1 formed more nodules on the hypocotyl. Very few hypocotyl nodules were observed at 75 DAS during the post-rainy season and most of the hypocotyl nodules developed during the later stages of plant growth; for example, the genotype Kadiri 71-1 sown 10 cm deep had 14 hypocotyl nodules per plant at 75 DAS, 121 at 102 DAS and more than double this number (249) at 137 DAS. During the 1981

Table 5. *Effect of sowing depth on nitrogenase activity (µmoles ethylene plant^{-1} hour^{-1}) of nodules on roots and hypocotyls during the 1980–81 post-rainy season for different groundnut cultivars*

	75 DAS		102 DAS		137 DAS	
	Sowing depth (cm)					
	5	10	5	10	5	10
			Roots			
MH 2	14	10	17	11		
Gangapuri	53	38	113	81		
NC Ac 529	41	46	77	76	29	28
NC Ac 770	34	19	53	47	15	14
M 13	33	26	148	32		
NC Ac 10	44	62	169	120		
Kadiri 71-1	53	55	194	125	148	52
MK 374	65	41	186	111	145	82
SE ±	7.5		11.2		16.9	
			Hypocotyls†			
MH 2			0.9 (0.2)	1.3 (1)		
Gangapuri			1.0 (0.7)	2.0 (4)		
NC Ac 529			1.0 (0.5)	1.3 (1)	1.1 (0.8)	1.1 (0.8)
NC Ac 770			1.0 (0.5)	1.4 (2)	1.0 (0.6)	1.4 (2)
M 13			1.0 (0.7)	2.0 (5)		
NC Ac 10			1.3 (1)	4.4 (21)		
Kadiri 71-1			2.0 (4)	5.2 (28)	2.7 (7)	6.0 (38)
MK 374			1.8 (3)	6.6 (46)	2.8 (8)	7.4 (55)
SE ±			0.44		0.41	

Blank spaces indicate plots harvested before sampling.
† Data analysed after square root ($\sqrt{Y + 0.5}$) transformation with original values in parentheses. Nitrogenase activity was not detected in the hypocotyls at 75 DAS.

rainy season plants from seeds of most genotypes sown 10–13 cm deep had fewer nodules and a smaller nodule mass per plant than those from shallow sown seeds (Tables 2 and 4).

Nitrogenase activity

Genotypes varied in their nitrogenase activity (Tables 5 and 6). The Valencia genotype MH 2 showed poor nitrogenase activity at both sampling dates in the 1980–81 post-rainy season whereas the Spanish genotypes (NC Ac 529, NC Ac 770) and two of the Virginia types (Kadiri 71-1 and MK 374) showed increased nitrogenase activity at the second sampling date but a decline at 137 DAS. Hypocotyl nodules of three of the Virginia genotypes, NC Ac 10, Kadiri 71-1 and MK 374, showed considerable nitrogenase activity when sampled at 102 DAS. In genotype Kadiri 71-1, hypocotyl nodules of plants from seed sown 10 cm deep accounted for 18 and 42% of the nitrogenase activity per plant at 102 DAS and 137 DAS, respectively (Table 5). Genotypic differences in nitrogenase activity were also observed during the 1981 rainy season (Table 6).

During the 1980–81 post-rainy season the mean nitrogenase activity of eight genotypes at 102 and 137 DAS was reduced by 23–27% when sown 10 cm

Table 6. *Effect of sowing depth on nitrogenase actvity (µmoles ethylene plant^{-1} hour^{-1}) of nodules on roots and hypocotyls during the 1981 rainy season for different groundnut cultivars*

	44 DAS			70 DAS		
	Sowing depth (cm)					
	3–4	7–8	10–13	3–4	7–8	10–13
			Roots			
MH 2	51	46	26	35	19	24
Gangapuri	64	43	48	77	47	18
NC Ac 529	79	64	60	45	48	47
NC Ac 770	49	49	35	46	42	19
M 13	103	97	82	83	65	51
NC Ac 10	86	78	53	82	130	81
Kadiri 71-1	106	84	70	154	96	44
MK 374	90	87	59	114	79	74
SE ±		11.3			13.2	
			Hypocotyls†			
MH 2	–	–	–			1.5 (2)
Gangapuri	–	–	–		1.4 (2)	1.6 (2)
NC Ac 770	–	–	–	1.4 (2)		
M 13	–	–	–	1.5 (2)	1.9 (4)	3.7 (14)
NC Ac 10	–	–	–	2.1 (4)	3.0 (9)	4.5 (21)
Kadiri 71-1	–	–	4.0	2.6 (7)	4.0 (15)	6.5 (44)
MK 374	–	–	–	1.5 (2)	2.8 (8)	4.0 (18)
SE ±					0.33	

Blank spaces indicate plots harvested before sampling.

† Data analysed after square root ($\sqrt{Y + 0.5}$) transformation with original values in parenthesis. A dash is used when no nitrogenase activity was detected.

deep (Table 5). During the 1981 rainy season, at 44 DAS, plants from seeds sown 10-13 cm deep showed less nitrogenase activity (54 μmoles C_2H_4 plant^{-1} hour^{-1}) than those from seeds sown 3-4 cm deep (78 μmoles C_2H_4 plant^{-1} hour^{-1}). The reduction in root nitrogenase activity due to deeper sowing was not compensated for by hypocotyl nitrogenase activity even in the genotypes Kadiri 71-1 and MK 374 which formed most hypocotyl nodules (Table 5).

Plant growth and yield

During the 1980-81 post-rainy season deeper sowing reduced the root mass (Table 7) and haulm and pod yields (Table 8, data on haulm dry matter not

Table 7. *Effect of sowing depth on root and hypocotyl mass 102 days after sowing during the 1980-81 post-rainy season for different groundnut cultivars*

	Root mass (g plant^{-1})		Hypocotyl mass (g plant^{-1})	
	Sowing depth (cm)			
	5	10	5	10
Gangapuri	1.2	0.5	0.2	0.3
NC Ac 529	0.9	0.8	0.2	0.4
NC Ac 10	1.3	0.1	0.3	0.9
MH 2	0.5	0.2	0.1	0.2
MK 374	1.8	0.9	0.4	0.9
M 13	2.1	0.5	0.4	0.4
NC Ac 770	0.7	0.6	0.2	0.3
Kadiri 71-1	1.4	1.1	0.4	1.1
Mean	1.2	0.7	0.3	0.6
SE ±	0.12		0.06	

Table 8. *Effect of sowing depth on pod yield (kg ha^{-1}) of three groundnut cultivars during the 1981-82 post-rainy season and two cultivars during the 1984 rainy season*

	Sowing depth (cm)	
	3-4	8-12
	1981-82 post-rainy season	
NC Ac 10	1560	1140
MK 374	1880	1430
Kadiri 71-1	1430	900
SE ±	182	
	Sowing depth (cm)	
	4-6	8-10
	1984 rainy season	
Robut 33-1	3200	3400
J 11	2930	2220
SE ±		

presented). During the 1981–82 post-rainy season deeper sowing of the three Virginia genotypes reduced dry matter yields by 13% and pod yields by 28%. During the 1984 rainy season the haulm yield of Robut 33-1 (Virginia) was decreased by 20% and the pod yield by 25% by deeper sowing. The pod yield of cultivar J 11 (Spanish) was also reduced 24% by deeper sowing.

DISCUSSION

Deep sowing decreased pod and haulm yield, the number and mass of nodules, and nitrogenase activity in all the groundnut genotypes tested, but there was some evidence of differences between genotypes. In general, Virginia cultivars formed more nodules and showed more nitrogenase activity than the Spanish and Valencia cultivars. The Virginia forms differ from the Spanish and Valencia forms in growth habit, branching pattern, leaf chlorophyll content, and perhaps in source-sink limitation and energy availability for nitrogen fixation. These factors could influence nitrogen fixation and may explain the differences among the genotypes but this needs further investigation. Virginia genotypes may be better for deep sowing, but the time to maturity also needs to be considered since limitations in rainfall and/or irrigation make this a major concern for many farmers. All genotypes showed less nitrogenase activity when sown more deeply, but the reduction was not so marked in the Virginia types. In the Spanish and Valencia genotypes only a few nodules were formed on the hypocotyl but in the Virginia types, especially Kadiri 71-1, hypocotyl nodules made a significant contribution to nitrogen fixation (Table 6). However, this was not sufficient to compensate for the loss in activity due to deep sowing and when shallow sowing was practised the hypocotyl nodules made only a small contribution to nitrogenase activity. Deeper sowing also reduced root mass (Table 7).

In field surveys we observed that many farmers sow groundnut 8–12 cm deep so as to make use of residual moisture for germination and seedling growth and so help avoid drought stress, although direct evidence for this hypothesis is lacking. Some of the conventional sowing devices also place the seed deeper than is required for good crop establishment, although deep planting protects the seeds from birds and rodents. However, our results indicate that yield losses due to deep planting can be substantial, and that shallow sowing is preferable if the above problems can be solved by alternative methods.

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