CSIRO

A desktop study to predict the fertiliser requirements of cashew trees in Northern Australia

Noel J. Grundon

CSIRO Land and Water, Atherton
Technical Report 32/01, December 2001

CSIRO LAND and WATER

A desktop study to predict the fertiliser requirements of cashew trees in Northern Australia

Noel J. Grundon

CSIRO Land and Water, Atherton
Technical Report 32/01, December 2001

A desktop study to predict the fertiliser requirements of cashew trees in Northern Australia

Noel J. Grundon

CSIRO Land and Water, Tropical Forest Research Centre
PO Box 780, Atherton, QLD 4883.

Table of Contents

List of Tables

1. Introduction

A number of feasibility studies (Wait and Jamieson 1984, 1985; Cann et al. 1987) have suggested that cashew nut production could provide a new opportunity for sustainable agricultural development of light textured soils in northern Australia because:

- World demand for cashew kernels is increasing steadily (Duncan 1992; NOMISMA 1994).
- There is a continuing domestic demand that requires annual imports valued at $25 M to $35M (Agtrans Research 1996).
- Cashew trees (*Anacardium occidentale* L.) prefer a seasonally wet/dry tropical climate and well drained soils (Ohler 1979).
- There are large areas of well-drained light-textured soils in tropical northern Australia with sufficient water resources for irrigated agriculture.
- Recent Australian advances in cashew breeding have provided high-yielding hybrids that produce kernels of superior quality to that readily available on world markets (Chacko *et al.* 1990; Chacko 1994).

As a result, entrepreneurial investors have established about 300 ha of cashews in two commercial plantations and smaller trial plantings in North Queensland (Dimbulah) and the Northern Territory (Wildman River, La Belle Downs, Katherine, Melville Island) (Agtrans Research 1996).

Economic models indicate that yields of nut-in-shell (NIS) between 2.8 t ha^{-1} and 5.0 t ha^{-1} (equivalent to 14 kg NIS $tree^{-1}$ to 25 kg NIS $tree^{-1}$ at 200 trees ha^{-1}) would be required for the highly mechanised Australian industry to be economically viable (Cann *et al.* 1987; Oliver *et al.* 1992; Agtrans Research 1996; Hinton 1998). Average NIS yields from commercial plantations in the major cashew-producing countries (Brazil, India, Thailand, Tanzania) are commonly less than 1.0 t ha^{-1} when cashew trees are grown under rainfed conditions with little or no inputs of fertilisers (Ohler 1979; Lima 1988; Ghosh 1993). However, research data from Australia (Chacko 1994), India (Nalini and Santhakumari 1991; Manoj *et al.* 1993), and Tanzania (Conticini and Partel 1983) indicate that when cashew trees are fertilised and irrigated, individual trees are capable of yielding 23 kg NIS $tree^{-1}$ to 36 kg NIS $tree^{-1}$, equivalent to 4.6 t ha^{-1} to 7.2 t ha^{-1} at 200 trees ha^{-1}.

Because no information was available to the infant Australian cashew industry on the fertiliser requirements for irrigated cashew trees growing in Australian soils, the rates and types of fertilisers applied were based initially on overseas data and intuitive guesses. In the light of new data from recent Australian studies (Richards 1990, 1992, 1993a, 1993b; Robinson and Kesavan 1994; O'Farrell *et al.* 1996), the suitability of the rates and types of fertilisers currently applied in commercial cashew plantations in Australia can be questioned. In 1996, the CSIRO Cashew Multi-Divisional Project was established to, amongst other things, provide a framework for the development of fertiliser management practices for an economically viable and environmentally sustainable cashew industry in northern Australia. To establish a baseline of the likely nutrient requirements of cashew trees and the amounts of nutrients removed in harvested product, a desktop study was completed using data from the literature to predict:

1. The amounts of nutrients required for the growth of whole cashew trees; and
2. The off-take of nutrients in kernel, shell and cashew 'apple' from an economically viable Australian cashew plantation, ie one producing 10 kg NIS $tree^{-1}$ to 20 kg NIS $tree^{-1}$ from mature trees.

This report presents the outcomes of the desktop study; a brief summary has been presented previously (Grundon 1998).

2. Methods

2.1 Nutrients required for tree growth

Although cashew trees are precocious and can be expected to commence producing nuts in their second year of in-field growth, they do not reach their mature size until they are usually between 6- and 8-years old (Ohler 1979). Therefore this study was limited to trees up to 8-years old, and the amounts of nutrient elements required for each year of growth were estimated from the dry matter produced by the whole tree during a given year and the concentration of nutrients in the whole tree for the same year. Cashew trees have a two-phase pattern of annual growth – Phase 1 being solely vegetative, and Phase 2 being reproductive with limited vegetative growth (Ohler 1979). For this study, each year's growth was deemed to finish at the end of Phase 2.

For many commercially valuable species, the published literature provides reliable data on dry matter yields of whole plants. Unfortunately, such information is not readily available for whole cashew trees, and only three sources could be found that listed whole tree dry matter yields:

1. Falade (1978) listed dry matter yields of whole 7-month old seedlings supplied with different rates of N, P, K, Ca, Mg and S that ranged from deficiency to toxicity. The highest dry matter yield recorded in each of the 6 studies was very similar, the range being 13.16 g plant^{-1} to 15.82 g plant^{-1}.

2. Reddy and Reddy (1987) reported that the dry weight of four 96-month old cashew trees ranged from 14.05 kg tree^{-1} to 22.39 kg tree^{-1}.

3. Richards (1990, 1992, 1993c) presented whole plant dry matter yields for 6-, 12-, 40-, 46-, and 70-month old trees, the values being about 0.10 kg tree^{-1}, 0.43 kg tree^{-1}, 90 kg tree^{-1}, 114 kg tree^{-1}, and 344 kg tree^{-1} respectively.

As can be seen from these data, there is a wide variation in dry matter production reported for trees of similar age. Probable reasons for this are:

1. *Different genotypes of the datum plants:* Wild cashew trees have two distinct growth genotypes, tall and dwarf, and commercial cashew trees have been derived from selections within each genotype and from hybrids between these genotypes (Ohler 1979). Therefore, reports of dry matter production could be expected to differ greatly if the material used had different genetic backgrounds. In this context, the data of Richards (1990, 1992, 1993c) are more appropriate for the present study because they were derived from semi-dwarf genotypes similar to those grown currently in Australian plantations.

2. *Different management systems of the datum trees:* Most overseas cashew trees are grown under rain-fed conditions with little or no fertiliser additions while the Australian cashew industry is based on adequate irrigation and fertiliser management. The data of Richards (1990, 1992, 1993c) were derived using Australian cultural practices and are therefore more appropriate for the present study.

However, Richards (1990, 1992, 1993c) does not provide dry matter yields on an annual growth cycle basis and to obtain dry matter yields for 12-, 24-, 36-, 48-, 60-, 72-, 84-, and 96-month old whole trees it was necessary to interpolate and extrapolate from his data. This was done by calculating mean Relative Growth Rates (RGR) from the sequential yield data provided by Richards, and then estimating the dry matter yields of whole cashew trees at the end of each annual growth cycle. The dry matter yield data used in this study are listed in Table 1.

To cover the range of published data on nutrient concentrations in whole cashew trees, three sources were used (Table 2). The nutrient contents of whole cashew trees at the end of each annual growth cycle, and the nutrient uptake during each growth cycle, were calculated from the data in Tables 1 and 2.

Table 1. Mean Relative Growth Rates (RGR) for whole cashew trees calculated from the data of Richards (1990) and estimated dry matter yields of whole cashew trees.

Time interval for RGR calculation (months)	RGR (kg kg^{-1} $month^{-1}$)	Age of tree (months)	Estimated dry matter weight of whole tree (kg)
6 – 12	0.2401	12	0.43
12 - 40	0.0978	24	4.24
40 - 46	0.0404	36	42
46 - 70	0.0459*	48	125
		60	217
		72	377
		84	654
		96	1135
*Note: an RGR of 0.0459 kg kg^{-1} $month^{-1}$ was used to extrapolate beyond 70-months of age			

Table 2. Nutrient concentrations in whole cashew trees used to estimate nutrient contents in the present study.

Element	Source		
	Falade (1978): From Table 3; data for whole plant from the second highest treatment	Reddy and Reddy (1987): Calculated from Table 2; data for whole trees	From Richards (1993c): Mean of data for 40- to 70-month old whole trees
N (%)	1.48	0.160	0.625
P (%)	0.31	0.008	0.103
K (%)	1.19	0.063	0.370
Ca (%)	0.26		
Mg (%)	0.13		
S (%)	0.29		

2.2 Off-take of nutrient elements in harvested product

Nutrient off-take was estimated by calculating the nutrient element contents of cashew ‘apples’, kernels[1] and shells using target yields of NIS for trees of various age and nutrient concentrations listed in the literature. Target yields for trees up to 96-months old were taken from the economic study by Oliver *et al.* (1992). These target yields of NIS were partitioned into yields of kernel and shell using a shelling percentage (ie weight of kernel as a percentage of total nut weight) of 30.5%, this value being the average shelling percentage of 18 cultivars tested by Beena Bhaskar (1992). Because the published data on nutrient concentrations were expressed on a dry weight (or dry matter) basis, the yields of kernel and shell at field-dry-moisture content were converted to dry matter yields using dry-matter percentages of 68.2% for the kernel and 50.2% for the shell (from Table 22 of Ohler 1979). The yield of fresh cashew ‘apple’ was estimated by multiplying the target NIS yields at field-dry-moisture content by 11.6, this being the ratio of the mean weight of fresh ‘apple’ of 18 cultivars (74.3 g) to the mean weight of NIS at field-dry-moisture content of the same cultivars (6.38 g) (Table 8 of Beena Bhaskar 1992). Yields of fresh ‘apple’ were converted to dry-matter yields of ‘apple’ using a dry-matter percentage of 12.2% (from Table 22 of Ohler 1979). The target yields of NIS, ‘apples’, kernel, and shell used in this study are shown in Table 3. There are limited data of the concentrations of nutrient elements in ‘apple’, shell and kernel (ie kernel plus testa), and to encompass the range of concentrations reported,

[1] In this study, references to ‘kernel’ means ‘kernel plus testa’.

four sources were used (Table 4). Off-takes of nutrient elements were estimated from the data in Table 3 and Table 4.

Table 3. Target yields of Nut-In-Shell (NIS), kernel, shell, and cashew 'apple' for trees of various age.

Age of tree (months)	12	24	36	48	60	72	84	96
Target yield of NIS at field-dry moisture content (kg tree^{-1})	0	3.00	6.00	8.00	12.00	14.00	16.00	20.00
Target yield of kernel at field-dry moisture content (kg tree^{-1})	0	0.92	1.83	2.44	3.66	4.27	4.88	6.10
Target yield of shell at field-dry moisture content (kg tree^{-1})	0	2.09	4.17	5.56	8.34	9.73	11.12	13.90
Target yield of fresh 'apple' (kg tree^{-1})	0	34.80	69.60	92.80	139.20	162.40	185.60	232.00
Target yield of kernel; dry matter basis (kg tree^{-1})	0	0.62	1.25	1.66	2.50	2.91	3.33	4.16
Target yield of shell; dry matter basis (kg tree^{-1})	0	1.05	2.09	2.79	4.19	4.88	5.58	6.98
Target yield of 'apple'; dry matter basis (kg tree^{-1})	0	4.25	8.49	11.32	16.98	19.81	22.64	28.30

Table 4. Nutrient element concentrations in kernel, shell, and cashew 'apple' used to estimate off-take of nutrients in the present study (Kernel refers to kernel plus testa).

Element	Concentration; dry weight basis		
	Apple	Kernel	Shell
Source	Table 2; Mohapatra *et al.* (1973)		
N (%)	0.616	2.793	0.343
P (%)	0.085	0.410	0.005
K (%)	0.390	0.455	0.175
Source	Table 2; Nair *et al.* (1972); 1963-64 data		
N (%)	1.21		
P (%)	0.25		
K (%)	1.38		
Source	Table 9; Beena Bhaskar (1992)		
N (%)	2.87	4.52	2.07
P (%)	0.09	0.23	0.03
K (%)	2.07	0.79	0.54
Ca (%)	0.15	0.34	0.12
Mg (%)	0.09	0.06	0.05
S (%)	0.09	0.16	0.03
Fe (mg kg^{-1})	248	207	180
Mn (mg kg^{-1})	27.5	25.1	34.2
Zn (mg kg^{-1})	33.3	57.9	21.4
Cu (mg kg^{-1})	13.5	23.3	4.7
Source	Table 4; Richards (1993c)		
N (%)	0.91	3.20	0.50
P (%)	0.14	0.53	0.04
K (%)	0.91	0.75	0.60
Ca (%)	0.10	0.10	0.10
Mg (%)	0.10	0.28	0.10

3. Results and Discussion

3.1 Estimated nutrient contents in whole cashew trees

The nutrient concentration of a given element in whole cashew trees differed greatly between the sources used in this study (Table 2). For example, the P concentrations had about a 39-fold range, from 0.31% (Falade 1978) to 0.008% (Reddy and Reddy 1987), and for N there was about a 9-fold range from 1.48% (Falade 1978) to 0.16% (Reddy and Reddy 1987). As a result, there were great differences between the estimated nutrient contents for any given element at the end of each year's growth (Table 5), and the estimated annual uptake of nutrient elements needed to attain these contents (Table 6). The means of these estimates are presented in Table 7.

Table 5. Estimated contents of nutrient elements in whole cashew trees at the end of each annual cycle of growth for trees up to 96-months of age.

Age of tree (months)	Dry weight at end of growth cycle (kg)	Nutrients contents using concentrations from Falade (1978)					
		N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})	Ca (g tree^{-1})	Mg (g tree^{-1})	S (g tree^{-1})
12	0.43	6.4	1.3	5.1	1.2	0.56	1.3
24	4.24	63	13	50	11	5.51	12
36	42	622	130	500	109	55	122
48	125	1850	388	1488	325	163	363
60	217	3212	673	2582	564	282	629
72	377	5580	1169	4486	980	490	1093
84	654	9679	2027	7783	1700	850	1897
96	1134	16783	3515	13495	2948	1474	3289

Nutrients contents using concentrations from Reddy and Reddy (1987)				
Age of tree (months)	Dry weight (kg)	N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})
12	0.43	0.69	0.03	0.27
24	4.24	6.8	0.34	2.7
36	42	67	3.4	26
48	125	200	10	79
60	217	347	17	137
72	377	603	30	238
84	654	1046	52	412
96	1134	1814	91	714

Nutrients contents using concentrations from Richards (1993c)				
Age of tree (months)	Dry weight (kg)	N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})
12	0.43	2.7	0.44	1.6
24	4.24	27	4.4	15.7
36	42	263	43	155
48	125	781	129	463
60	217	1356	224	803
72	377	2356	388	1395
84	654	4088	674	2420
96	1134	7088	1168	4196

Table 6. Estimated annual nutrient uptake by whole cashew trees during each growth cycle for trees up to 96-months of age.

Age of tree (months)	Dry weight increase (kg)	Nutrient uptakes using concentrations from Falade (1978)					
		N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})	Ca (g tree^{-1})	Mg (g tree^{-1})	S (g tree^{-1})
12	0.43	6.4	1.3	5.1	1.1	0.56	1.3
24	3.81	56	12	45	9.9	5.0	11
36	38	559	117	449	98	49	110
48	83	1228	257	988	216	108	241
60	92	1362	285	1095	239	120	267
72	160	2368	496	1904	416	208	464
84	277	4100	859	3296	720	360	803
96	480	7104	1488	5712	1248	624	1392

Nutrient uptakes using concentrations from Reddy and Reddy (1987)				
Age of tree (months)	Dry weight increase (kg)	N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})
12	0.43	0.69	0.03	0.27
24	3.81	6.1	0.30	2.4
36	38	60	3.0	24
48	83	133	6.6	52
60	92	147	7.4	58
72	160	256	13	101
84	277	443	22	175
96	480	768	38	302

Nutrient uptakes using concentrations from Richards (1993c)				
Age of tree (months)	Dry weight increase (kg)	N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})
12	0.43	2.7	0.44	1.6
24	3.8	24	3.9	14
36	38	236	39	140
48	83	519	85	307
60	92	575	95	340
72	160	1000	165	592
84	277	1731	285	1025
96	480	3000	494	1776

The mean nutrient contents (Table 7) show that large quantities of nutrient elements are present within the biomass of whole cashew trees, and that substantial quantities of nutrient elements are required on an annual basis to provide for continued growth of the structure (ie trunk, branches, leaves, roots) of the tree. For example, when the tree is 12-months old, the dry weight of the whole tree was estimated at 0.43 kg, and it contained about 3.3 g N, 0.6 g P, 2.3 g K, 1.1 g Ca, 0.56 g Mg and 1.3 g S. By the time the trees are mature by about 96-months of age, the tree was estimated to contain about 1,134 kg dry matter, 8.6 kg N, 1.6 kg P, 6.1 kg K, 2.9 kg Ca, 1.5 kg Mg and 3.3 kg S (Table 7).

In Australian plantations where semi-dwarf genotypes are grown, annual pruning of the tree is minimal until it reaches a size where its growth restricts access to machinery (Grundon *et al.* 1999). With a row spacing of 8 m, this occurs at about 72-months of age, but at wider row spacings of 10 m to 14 m, pruning may not take place on an annual basis until after about 96-months of age. With a narrow row spacing of 8 m, the tree could be expected to produce annually about the same amount of dry matter as that produced during the sixth or seventh growth cycle, ie between 160 kg and 270 kg dry matter (Table 7). To produce about 277 kg dry matter, the tree would need to take up about 2.1 kg N, 0.4 kg P, 1.5 kg K, 0.7 kg Ca, 0.4 kg Mg and 0.8 kg S (Table 7). These estimates agree well with those measured by Richards (1993c) who reported that the annual uptake required by Australian cashew trees of 70-months of age were 2.1 kg N, 0.45 kg P, 1.32 kg K, 0.54 kg Ca and 0.57 kg Mg in order to maintain the structure of the tree.

Should wider row spacings of 10 m or 14 m be used, the trees would be larger and would produce annually about the same amount of dry matter as that produced during the eighth cycle of growth, ie about 480 kg dry matter, and the annual uptake of nutrient elements would need to be about 3.6 kg N, 0.7 kg P, 2.6 kg K, 1.3 kg Ca, 0.6 kg Mg and 1.4 kg S (Table 7).

Table 7. Mean estimates of the contents of nutrient elements in whole cashew trees at the end of each annual growth cycle, and mean estimates of the uptake of nutrient elements by whole cashew trees within each annual growth cycle for trees up to 96-months of age.

Age of tree (months)	Dry weight (kg)	Contents of nutrient elements in whole cashew trees (g tree^{-1})					
		N	P	K	Ca	Mg	S
12	0.43	3.3	0.60	2.3	1.1	0.56	1.3
24	4.24	32	6.0	23	11	5.5	12
36	42	317	59	227	109	55	122
48	125	944	175	676	325	163	363
60	217	1638	305	1174	564	282	629
72	377	2846	529	2040	980	490	1093
84	654	4938	918	3538	1700	850	1897
96	1134	8562	1591	6135	2948	1474	3289
Age of tree (months)	Dry weight increase (kg)	Uptake of nutrient elements by whole cashew trees (g tree^{-1})					
		N	P	K	Ca	Mg	S
12	0.43	3.3	0.60	2.3	1.1	0.56	1.3
24	3.8	29	5.4	21	9.9	5.0	11
36	38	285	53	204	98	49	110
48	83	627	116	449	216	108	241
60	92	695	129	498	239	120	267
72	160	1208	225	866	416	208	464
84	277	2091	389	1499	720	360	803
96	480	3624	674	2597	1248	624	1392

3.2 Estimated off-take of nutrient elements in harvested products

The nutrient concentration for a given element in the harvested products, ie NIS (kernel plus testa plus shell) and cashew 'apple', differed greatly between the sources used in this study (Table 4). For example, the N concentration in the 'apple' ranged from 0.616% (Mohapatra *et al.* 1973) to 2.87% (Beena Bhaskar 1992), a 4.7-fold difference. As a result, there were great differences between the estimated nutrient contents for any given element (Table 8). The means of these estimates are presented in Table 9.

The amounts of nutrient elements removed from the plantation in saleable product will depend on the product harvested and method used to harvest the product. In those countries where the cashew 'apple' is sold as a fresh 'fruit', the crop is hand-harvested and both the 'apple' and the nut are removed from the plantation (Ohler 1979). In these instances, the off-take of nutrient elements would be estimated by the total values listed in Table 9.

Table 8. Estimated off-take of nutrient elements in kernel, shell and cashew ‘apple’ for various target yields.

Age of tree (months)		24	36	48	60	72	84	96
Target yield of NIS at field-dry moisture (kg tree^{-1})		3.00	6.00	8.00	12.00	14.00	16.00	20.00
Target yield of kernel; dry matter basis (kg tree^{-1})		0.62	1.25	1.66	2.50	2.91	3.33	4.16
Target yield of shell; dry matter basis (kg tree^{-1})		1.05	2.09	2.79	4.19	4.88	5.58	6.98
Target yield of 'apple'; dry matter basis (kg tree^{-1})		4.25	8.49	11.32	16.98	19.81	22.64	28.30
Nutrient off-take using nutrient concentrations of Nair *et al.* (1972)								
N (g tree^{-1})	'Apple'	51.37	102.74	136.69	205.49	239.37	273.98	342.49
P (g tree^{-1})	'Apple'	10.61	21.23	28.30	42.46	49.53	56.61	70.76
K (g tree^{-1})	'Apple'	58.59	117.18	156.24	234.36	273.42	312.48	390.60
Nutrient off-take using nutrient concentrations of Mohapatra *et al.* (1973)								
N (g tree^{-1})	Kernel	17.43	34.86	46.48	69.72	81.34	92.96	116.19
	Shell	3.59	7.18	9.57	14.36	16.75	19.15	23.93
	'Apple'	26.15	52.31	69.74	104.61	122.05	139.48	174.35
	Total	47.17	94.34	125.79	188.69	220.14	251.58	314.48
P (g tree^{-1})	Kernel	2.56	5.12	6.82	10.23	11.94	13.65	17.06
	Shell	0.05	0.10	0.14	0.21	0.24	0.28	0.35
	'Apple'	3.61	7.22	9.62	14.44	16.84	19.25	24.06
	Total	6.25	12.44	16.59	24.88	28.94	33.18	41.55
K (g tree^{-1})	Kernel	2.84	5.68	7.57	11.36	13.25	15.14	18.93
	Shell	1.83	3.66	4.88	7.33	8.55	9.77	12.21
	'Apple'	16.56	33.12	44.15	66.23	77.27	88.31	110.39
	Total	21.23	42.46	56.61	84.92	99.07	113.22	141.53
Nutrient off-take using nutrient concentrations of Beena Bhaskar (1992)								
N (g tree^{-1})	Kernel	28.21	56.41	75.22	112.82	131.63	150.43	188.04
	Shell	21.67	43.33	57.78	86.66	101.11	115.55	144.44
	'Apple'	121.85	243.70	324.93	487.39	568.63	649.86	812.32
	Total	171.72	343.44	457.92	686.88	801.36	915.85	1144.81
P (g tree^{-1})	Kernel	1.44	2.87	3.83	5.74	6.70	7.65	9.57
	Shell	0.31	0.63	0.84	1.26	1.47	1.67	2.09
	'Apple'	3.82	7.64	10.19	15.28	17.83	20.38	25.47
	Total	5.57	11.14	14.85	22.28	25.99	29.71	37.14
K (g tree^{-1})	Kernel	4.93	9.86	13.15	19.72	23.01	26.29	32.87
	Shell	5.65	11.30	15.07	22.61	26.38	30.14	37.68
	'Apple'	87.88	175.77	234.36	351.54	410.12	468.71	585.89
	Total	98.47	196.93	262.58	393.86	459.51	525.15	656.44
Ca (g tree^{-1})	Kernel	2.12	4.24	5.66	8.49	9.90	11.32	14.14
	Shell	1.26	2.51	3.35	5.02	5.86	6.70	8.37
	'Apple'	6.37	12.74	16.98	25.47	29.72	33.96	42.46
	Total	9.75	19.49	25.99	38.98	45.48	51.98	64.97
Mg (g tree^{-1})	Kernel	0.37	0.75	1.00	1.50	1.75	2.00	2.50
	Shell	0.52	1.05	1.40	2.09	2.44	2.79	3.49
	'Apple'	3.82	7.64	10.19	15.28	17.83	20.38	25.47
	Total	4.72	9.44	12.58	18.88	22.02	25.17	31.46

Table 8 (Continued).

Age of tree (months)		24	36	48	60	72	84	96
Target yield of NIS at field-dry moisture (kg $tree^{-1}$)		3.00	6.00	8.00	12.00	14.00	16.00	20.00
Target yield of kernel; dry matter basis (kg $tree^{-1}$)		0.62	1.25	1.66	2.50	2.91	3.33	4.16
Target yield of shell; dry matter basis (kg $tree^{-1}$)		1.05	2.09	2.79	4.19	4.88	5.58	6.98
Target yield of 'apple'; dry matter basis (kg $tree^{-1}$)		4.25	8.49	11.32	16.98	19.81	22.64	28.30
Nutrient off-take using nutrient concentrations of Beena Bhaskar (1992)								
S (g $tree^{-1}$)	Kernel	1.00	2.00	2.66	3.99	4.66	5.33	6.66
	Shell	0.31	0.63	0.84	1.26	1.47	1.67	2.09
	'Apple'	3.82	7.64	10.19	15.28	17.83	20.38	25.47
	Total	5.13	10.27	13.69	20.53	23.96	27.38	34.22
Fe (g $tree^{-1}$)	Kernel	0.13	0.26	0.34	0.52	0.60	0.69	0.86
	Shell	0.19	0.38	0.50	0.75	0.88	1.00	1.26
	'Apple'	1.05	2.11	2.81	4.21	4.91	5.62	7.02
	Total	1.37	2.74	3.65	5.48	6.40	7.31	9.14
Mn (mg $tree^{-1}$)	Kernel	15.66	31.33	41.77	62.65	73.09	83.54	104.42
	Shell	35.80	71.59	95.46	143.18	167.05	190.91	238.64
	'Apple'	116.75	233.51	311.34	467.02	544.85	622.69	778.36
	Total	168.21	336.43	448.57	672.85	785.00	897.14	1121.42
Zn (mg $tree^{-1}$)	Kernel	36.13	72.26	96.35	144.53	168.61	192.70	240.88
	Shell	22.40	44.80	59.73	89.59	104.53	119.46	149.32
	'Apple'	141.38	282.76	377.01	565.51	659.77	754.02	942.52
	Total	199.91	399.82	533.09	799.63	932.91	1066.18	1332.72
Cu (mg $tree^{-1}$)	Kernel	14.54	29.08	38.77	58.16	67.85	77.55	96.93
	Shell	4.92	9.84	13.12	19.68	22.96	26.24	32.80
	'Apple'	57.32	114.63	152.84	229.26	267.47	305.68	382.10
	Total	76.77	153.55	204.73	307.10	358.28	409.47	511.83
Nutrient off-take using nutrient concentrations of Richards (1993c)								
N (g $tree^{-1}$)	Kernel	19.97	39.94	53.25	79.88	93.19	106.50	133.13
	Shell	5.23	10.47	13.96	20.93	24.42	27.91	34.89
	'Apple'	38.63	77.27	103.03	154.54	180.30	206.05	257.57
	Total	63.84	127.67	170.23	255.35	297.91	340.47	425.58
P (g $tree^{-1}$)	Kernel	3.31	6.61	8.82	13.23	15.43	17.64	22.05
	Shell	0.42	0.84	1.12	1.67	1.95	2.23	2.79
	'Apple'	5.94	11.89	15.85	23.78	27.74	31.70	39.63
	Total	9.67	19.34	25.79	38.68	45.13	51.57	64.47
K (g $tree^{-1}$)	Kernel	4.68	9.36	12.48	18.72	21.84	24.96	31.20
	Shell	6.28	12.56	16.75	25.12	29.31	33.49	41.87
	'Apple'	38.63	77.27	103.03	154.54	180.30	206.05	257.57
	Total	49.60	99.19	132.25	198.38	231.44	264.51	330.63
Ca (g $tree^{-1}$)	Kernel	0.62	1.25	1.66	2.50	2.91	3.33	4.16
	Shell	1.05	2.09	2.79	4.19	4.88	5.58	6.98
	'Apple'	4.25	8.49	11.32	16.98	19.81	22.64	28.30
	Total	5.92	11.83	15.78	23.67	27.61	31.55	39.44
Mg (g $tree^{-1}$)	Kernel	1.75	3.49	4.66	6.99	8.15	9.32	11.65
	Shell	1.05	2.09	2.79	4.19	4.88	5.58	6.98
	'Apple'	4.25	8.49	11.32	16.98	19.81	22.64	28.30
	Total	7.04	14.08	18.77	28.16	32.85	37.54	46.93

Table 9. Mean estimates of the off-take of nutrient elements in harvested products for various target yields.

Age of tree (months)		24	36	48	60	72	84	96
Target yield of NIS at field-dry moisture (kg $tree^{-1}$)		3.00	6.00	8.00	12.00	14.00	16.00	20.00
Target yield of kernel; dry matter basis (kg $tree^{-1}$)		0.62	1.25	1.66	2.50	2.91	3.33	4.16
Target yield of shell; dry matter basis (kg $tree^{-1}$)		1.05	2.09	2.79	4.19	4.88	5.58	6.98
Target yield of 'apple'; dry matter basis (kg $tree^{-1}$)		4.25	8.49	11.32	16.98	19.81	22.64	28.30
N (g $tree^{-1}$)	Kernel	21.87	43.74	58.31	87.47	102.05	116.63	145.79
	Shell	10.16	20.33	27.10	40.65	47.43	54.20	67.75
	'Apple'	59.50	119.00	158.67	238.01	277.68	317.34	396.68
	Total	91.53	183.07	244.09	366.13	427.16	488.18	610.22
P (g $tree^{-1}$)	Kernel	2.43	4.87	6.49	9.73	11.36	12.98	16.22
	Shell	0.26	0.52	0.70	1.05	1.22	1.40	1.74
	'Apple'	6.00	11.99	15.99	23.99	27.99	31.98	39.98
	Total	8.69	17.38	23.18	34.77	40.56	46.36	57.95
K (g $tree^{-1}$)	Kernel	4.15	8.30	11.07	16.60	19.37	22.13	27.67
	Shell	4.59	9.18	12.23	18.35	21.41	24.47	30.59
	'Apple'	50.42	100.83	134.44	201.67	235.28	268.89	336.11
	Total	59.15	118.31	157.74	236.62	276.05	315.49	394.36
Ca (g $tree^{-1}$)	Kernel	1.37	2.75	3.66	5.49	6.41	7.32	9.15
	Shell	1.15	2.30	3.07	4.61	5.37	6.14	7.68
	'Apple'	5.31	10.61	14.15	21.23	24.77	28.30	35.38
	Total	7.83	15.66	20.88	31.32	36.55	41.77	52.21
Mg (g $tree^{-1}$)	Kernel	1.06	2.12	2.83	4.24	4.95	5.66	7.07
	Shell	0.79	1.57	2.09	3.14	3.66	4.19	5.23
	'Apple'	4.03	8.07	10.76	16.13	18.82	21.51	26.89
	Total	5.88	11.76	15.68	23.52	27.44	31.36	39.19
S (g $tree^{-1}$)	Kernel	1.00	2.00	2.66	3.99	4.66	5.33	6.66
	Shell	0.31	0.63	0.84	1.26	1.47	1.67	2.09
	'Apple'	3.82	7.64	10.19	15.28	17.83	20.38	25.47
	Total	5.13	10.27	13.69	20.53	23.96	27.38	34.22
Fe (g $tree^{-1}$)	Kernel	0.13	0.26	0.34	0.52	0.60	0.69	0.86
	Shell	0.19	0.38	0.50	0.75	0.88	1.00	1.26
	'Apple'	1.05	2.11	2.81	4.21	4.91	5.62	7.02
	Total	1.37	2.74	3.65	5.48	6.40	7.31	9.14
Mn (mg $tree^{-1}$)	Kernel	15.66	31.33	41.77	62.65	73.09	83.54	104.42
	Shell	35.80	71.59	95.46	143.18	167.05	190.91	238.64
	'Apple'	116.75	233.51	311.34	467.02	544.85	622.69	778.36
	Total	168.21	336.43	448.57	672.85	785.00	897.14	1121.42
Zn (mg $tree^{-1}$)	Kernel	36.13	72.26	96.35	144.53	168.61	192.70	240.88
	Shell	22.40	44.80	59.73	89.59	104.53	119.46	149.32
	'Apple'	141.38	282.76	377.01	565.51	659.77	754.02	942.52
	Total	199.91	399.82	533.09	799.63	932.91	1066.18	1332.72
Cu (mg $tree^{-1}$)	Kernel	14.54	29.08	38.77	58.16	67.85	77.55	96.93
	Shell	4.92	9.84	13.12	19.68	22.96	26.24	32.80
	'Apple'	57.32	114.63	152.84	229.26	267.47	305.68	382.10
	Total	76.77	153.55	204.73	307.10	358.28	409.47	511.83

In Australian plantations where the crop is mechanically harvested, the 'apple' and attached nut are allowed to fall to the ground before harvesting takes place (Grundon *et al.* 1999). If some time elapses between fall of the 'apple' and attached nut and harvesting, the 'apple' can dry out and become detached from the nut during the mechanical harvesting process. The nutrient elements of these 'apples' would remain in the plantation. 'Apples' that remain attached to the nuts and are picked up during harvesting are removed from the nuts prior to further processing. These 'apples' can be either returned to the plantation or used for other products such as animal stockfeed. Therefore, the off-take of nutrient elements from an Australian plantation will depend not only on the yield of NIS and 'apples' and the concentration of nutrients in them, but also on the proportion of 'apples' removed from the plantation during the harvesting process. Nevertheless, the data in Table 9 give an estimate of the likely ranges of the amounts of nutrients that may be removed from an Australian cashew plantation in harvested product. In this context, the total values listed in Table 9 represent *maximum* estimates of off-take of nutrient elements, and the sum of the data for kernels and shell, ie the NIS, represent *minimum* estimates of off-take of nutrient elements.

3.3 Estimated fertiliser requirements for an Australian cashew plantation

By combining the date in Table 7 and Table 9, an estimate can be obtained of the amounts of nutrient elements required to grow and maintain the structures of a cashew tree, and to produce economically viable yields of NIS in an Australian plantation. Because information in the literature on concentrations of nutrient elements in whole cashew trees was restricted to concentrations of N, P, K, Ca, Mg and S (Table 2), only data for these elements are presented in Table 10.

Table 10. Estimated requirements of N, P, K, Ca, Mg and S to grow and maintain the structure of a cashew tree, and to produce an economically viable yield of NIS in an Australian cashew plantation.

Age of tree	Nutrient requirements based on content of whole tree plus total nutrient off-take in harvested NIS and 'apple' (g tree^{-1})					
(months)	N	P	K	Ca	Mg	S
12	3.3	0.6	2.3	1.1	0.6	1.2
24	120	14	80	17.7	10.8	16
36	468	71	323	114	61	120
48	870	140	607	237	124	254
60	1061	164	734	271	143	287
72	1635	265	1142	453	235	488
84	2580	435	1814	762	391	831
96	4234	732	2991	1300	663	1426

It is tempting to suggest that the data in Table 10 could be used to design a fertiliser strategy for an Australian cashew plantation. However, this is impractical because of the lack of quantitative data on a number of other factors that must be taken into account, including the native fertility of the soils and the amounts of elements recycled in canopy fall-out (leaf litter, flowers and unharvested 'apples'). For example, the published data available on the fertility status of many of the soils that are suitable for growing cashew in northern Australia suggest that they are of low native fertility for the growth of pasture and crop species and would require N, P, K, S and Zn fertilisers to produce economic yields of these plants (Teitzel and Bruce 1971; Jones 1973; Isbell *et al.* 1976; Calder and Day 1982). Hence it is probable that only some nutrient elements would need to be provided in fertilisers for a cashew plantation to be economically viable in these soils. However, there is no quantitative data on the growth and yield response of cashew to soils of different fertility status, making it impossible to estimate the ability of northern Australian soils to provide sufficient nutrient elements to meet the demands listed in Table 10. If it is assumed that the soils provide little nutrients to the tree, then the data in Table 10 represent the *maximum* amounts of nutrient elements that must be provided by fertilisers for an economically viable Australian cashew plantation.

On the other hand, if it is assumed that the soils can provide only sufficient nutrient elements to grow the tree, ie to provide the amounts of nutrients listed in Table 7, then the total off-takes of nutrient elements as listed in Table 9 represent the *minimum* amounts of nutrient elements that would need to be provided through nutrient recycling and/or fertiliser applications to produce the harvested products. If all the ‘apples’ were returned to the plantation, then the off-takes of nutrient elements in NIS (ie in kernels plus testa plus shell) would represent the *absolute minimum estimates* of the amounts of nutrient elements that would need to be provided in fertilisers to replace the amounts of nutrients being removed annually from the plantation; these values are listed in Table 11.

Table 11. Estimated amounts of nutrient elements that would be removed annually in Nut-In-Shell from an economically viable Australian cashew plantation. (*na = not applicable because of no harvest of nuts.)

Age of tree (months)	Nutrient requirements based on off-take in harvested NIS only					
	N (g tree^{-1})	P (g tree^{-1})	K (g tree^{-1})	Ca (g tree^{-1})	Mg (g tree^{-1})	S (g tree^{-1})
12	na*	na	na	na	na	na
24	92	8.7	59	7.8	5.9	5.1
36	183	17	118	16	12	10
48	244	23	158	21	16	14
60	366	35	237	31	24	21
72	427	41	276	37	27	24
84	488	46	315	42	31	27
96	610	58	394	52	39	34
	Fe (g tree^{-1})	Mn (mg tree^{-1})	Zn (mg tree^{-1})	Cu (mg tree^{-1})		
12	na	na	na	na		
24	0.32	52	58	19		
36	0.64	103	117	39		
48	0.85	137	156	52		
60	1.27	206	234	78		
72	1.48	240	273	91		
84	1.69	274	312	104		
96	2.12	343	390	130		

The amounts of nutrient elements recycled in canopy fallout may be sufficient to satisfy the requirements for the production of NIS. For example, the data of Richards (1993c) suggests that 194 g Ca tree^{-1} and 110 g Mg tree^{-1} are recycled over an 18 month period in fallout of old leaves and flowers from 4- to 5-year old trees. These amounts are about 6.3-fold and 4.6-fold the amounts of Ca and Mg respectively in the off-take in NIS for a 60-month old tree (Table 11). Hence except in highly infertile soils, annual dressings of Ca and Mg fertilisers may not be necessary because sufficient of these elements may be recycled from canopy fallout.

On the other hand, there may be insufficient amounts of N, P and K in canopy fallout for the production of NIS. Thus, Richards estimated that the canopy fallout contained 225 g N $tree^{-1}$, 11 g P $tree^{-1}$ and 62 g K $tree^{-1}$, but these are only about 61%, 31% and 26% of the N, P and K off-take in NIS respectively from 60-month old trees (Table 11). Therefore, annual dressings of N, P and K, and possibly S and some or all the micro-elements, may be needed to replace the amounts of these elements removed annually in NIS.

4 Acknowledgments

I wish to acknowledge the leadership of the late Dr Elias Chacko whose efforts lead to the initiation of the CSIRO Cashew Multi-Divisional Project.

Financial support for the cashew project came principally from the CSIRO Tropical Agri-Exports Program, and that support is gratefully acknowledged. Additional funding for the studies reported herein were provided by CSIRO Land and Water and the Potash and Phosphate Institute and that support is acknowledged.

5 References

Agtrans Research, 1996. The Cashew Research and Development Program: Performance and Future Prospects for Industry Development - Background Report, Chapters 1-4. 26p. Report to RIRDC.

Beena Bhaskar, 1992. *Uptake Pattern of Major and Minor Nutrients in Selected Cashew Types*. M.Agr.Sc. Thesis, Kerala Agricultural University. 123p.

Calder, G. J. and Day, K. J., 1982. Fertility studies on four soils of the northern lateritic uplands, Northern Territory. Department of Primary Industry and Fisheries Technical Bulletin No. 48. 57p. (Department of Primary Industry and Fisheries: Darwin, Northern Territory.)

Cann, B., Baker, I., and Kuppelweiser, W., 1987. An economic assessment of cashew production in the Northern Territory Top End. Department of Industries and Development, Australia, Technical Bulletin No. 110. 30p.

Chacko, E. K., 1994. Cashew hybridisation during 1988 - 92 (CSH-36H) and evaluation of progenies planted at four test sites in Northern Australia. *Working Papers of the Seventh Annual Cashew Research and Development Workshop, May 17, 1994, Cairns, North Queensland*. pp. 1-10.

Chacko, E., Baker, I., and Downton, J., 1990. Towards a sustainable cashew industry for Australia. *Agricultural Science (New Series)* **3**: 30-43.

Conticini, L. and Partel, L., 1983. AC4, a cashew clone selected in Tanzania. *Rivista di Agricoltura Subtropicale e Tropicale* **77**, 503-7.

Duncan, I., 1992. World Cashew Market: 1992. 100p. (RIRDC: Canberra, ACT.)

Falade, J. A., 1978. Effects of macronutrients on mineral distribution in cashew (*Anacardium occidentale* L.). *Journal of Science and Food and Agriculture* **29**: 81-86.

Ghosh, S. N., 1993. Effect of eucalyptus (*Eucalyptus teretecornia*) plants as intercrop in the cashew plantation - a case study in West Bengal. *The Cashew* **7**, 17-9

Grundon, N. J., 1988. Fertilising cashews: Validation of fertiliser strategies in North Queensland. RIRDC Publication No. 98/122. 42p. (Rural Industries Research and Development Corporation: Canberra, A.C.T.)

Grundon, N. J., O’Farrell, P., Hinton, A., Kulkarni, V., Leonardi, J., Blaikie, S., Richards, N., Armour, J., Shearer, P., Duncan, I., Hood, S., and Kernot, I., 1999. Cashew Information Kit. Agrilink Series QAL 9806. (Queensland Department of Primary Industries: Brisbane.)

Hinton, A., 1998. Cashew production in North Queensland - estimating profitability. Department of Primary Industries Queensland Information Series QI98039. 21p. (Department of Primary Industries: Brisbane, Qld.)

Isbell, R. F., Jones, R. K., and Gillman, G. P., 1976. Plant nutrition studies on some yellow and red earth soils in northern Cape York Peninsular. 1. Soils and their nutrient status. *Australian Journal of Experimental Agriculture and Animal Husbandry* **16**: 532-541.

Jones, R. K., 1973. Studies on some deep sandy soils in Cape York Peninsular, north Queensland. 2. Plant nutrient status. *Australian Journal of Experimental Agriculture and Animal Husbandry* **13**: 89-97.

Lima, V. d. P. M. S., 1988. *Cashew Tree Culture in Northeast Brazil [a Cultura Do Cajuerio No Nordeste Do Brazil]*. 306p. (Fortaleza: Brazil).

Manoj, P. S., George, T. E., and Krishnan, S., 1993. Evaluation of F1 hybrids of cashew (*Anacardium occidentale* L.). *The Cashew* **7**, 3-4.

Mohapatra, A. R., Vijay Kumar, K. V., and Bhat, N. T., 1973. A study of nutrient removal by the cashew tree. *Indian Cashew Journal* **9**: 19-20.

Nair, P. Sundaresan, George, C. M., and Tajuddin, E., 1972. Studies on foliar and soil application of fertilisers on cashew (*Anacardium occidentale*). *Agricultural Research Journal of Kerala* **10**: 10-13.

Nalini, P. V. and Santhakumari, S., 1991. Study on performance of selected types of cashew at Cashew Research Station Anakkayam, Kerala. *The Cashew* **5**, 3-6.

NOMISMA, 1994. *The World Cashew Economy. 2nd edn.* 218p. (L'Inchiostroblu: Bologna, Italy.)

O'Farrell, P. J., Armour, J. D., and Reid, D. J., 1996. Preliminary results on the effect of nitrogen on the growth and nut yield of cashew cv 9/14 in North Queensland. *Working Papers of the Eighth Cashew Research and Development Workshop August 6, 1996, Kurunda, North Queensland*. pp. 52-9.

Ohler, J. G., 1979. *Cashew.* 260p. (Koninklijk Instituut voor de Tropen: Amsterdam, Netherlands.)

Oliver, M., Ngo, H., and Kuppelweiser, W., 1992. Cashew production in the Northern Territory Top End: an economic evaluation. Northern Territory, Department of Primary Industry and Fisheries Technical Bulletin No. 198. 25p.

Reddy, S. E. and Reddy, K. S., 1987. Partitioning of nitrogen, phosphorus and potassium in cashew (*Anarcadium occidentale* L.) trees. *Indian Cashew Journal* **18**: 17-21.

Richards, N. K., 1990. Summary of cashew research at Wildman River, Northern Territory DPIF. Third Annual Cashew Research and Development Workshop, 21 February 1990, Berrimah Agricultural Research Centre, Darwin, NT. pp 5-7.

Richards, N. K., 1992. Cashew tree nutrition related to biomass accumulation, nutrient composition and nutrient cycling in sandy red earths of Northern Territory, Australia. *Scientia Horticulturae* **52**: 125-142.

Richards, N. K., 1993a. Cashew tree yield, growth and macronutrient status, as influenced by fertilizer applications. Cashew Research in Northern Territory, Australia, 1987-1991. NT, Department of Primary Industry and Fisheries Technical Bulletin No. 202. pp. 1-16. (Department of Primary Industry and Fisheries: Darwin, Northern Territory.)

Richards, N. K., 1993b. Cashew response to water and nutrients in a sandy red earth soil of the Northern Territory. Cashew Research in Northern Territory, Australia, 1987-1991. NT, Department of Primary Industry and Fisheries Technical Bulletin No. 202. pp. 17-38. (Department of Primary Industry and Fisheries: Darwin, Northern Territory.)

Richards, N. K., 1993c. Cashew tree nutrition related to biomass accumulation, nutrient composition and nutrient cycling in sandy red earths. Cashew Research in Northern Territory, Australia, 1987-1991. NT, Department of Primary Industry and Fisheries Technical Bulletin No. 202. pp. 50-65. (Department of Primary Industry and Fisheries: Darwin, Northern Territory.)

Robinson, D. and Kesavan, V., 1994. The effect of N P K nutrition on the early growth and yield of cashew on Cununurra Clay soil. Seventh Annual Cashew Research and Development Workshop, 17 May 1994, Cairns, North Queensland. pp. 32-40.

Teitzel, J. K. and Bruce, R. C., 1971. Fertility status of pasture soils in the wet tropical coast of Queensland. 2. Granitic soils. *Australian Journal of Experimental Agriculture and Animal Husbandry* **11**: 77-84.

Wait, A. J. and Jamieson, G. I., 1984. Cashews - Industry prospects in Queensland. *Farm Note* **AGDEX 246/00**, 3 p.

Wait, A. J. and Jamieson, G. I., 1985. Prospects for a cashew industry in Queensland. *Queensland Agricultural Journal* **111**, 315-6.