Queensland Journal of Agricultural and Animal Sciences Vol. 44 (2), 133-142 (1987)
Published by the Queensland Department of Primary Industries

Effect of applications of nitrogen, copper and zinc on agronomic performance and element uptake by flue-cured tobacco in north Queensland

J. Littlemore[1], K. Ferguson[2] and J. von Nordheim[3]

[1] Department of Primary Industries, PO Box 1054, Mareeba, Q. 4880, Australia.

[2] Department of Primary Industries, GPO Box 46, Brisbane, Q. 4001, Australia.

[3] Department of Primary Industries, PO Box 174, Mareeba, Q. 4880, Australia.

Abstract

Two experiments were conducted with copper and zinc (0 and 4 kg/ha) applied as subtreatments of nitrogen (70, 100, 130 kg/ha).The addition of extra nitrogen increased the dry weight of leaf, roots, tops and suckers, and the whole plant of the tobacco variety ZZ100. Leaf was found to comprise 47% of the total plant dry weight and the ratio was independent of nitrogen rate.

The effect of the highest rate of nitrogen on cured leaf from the varieties ZZ100 and Hicks Q46 was similar, decreasing yield and the dollar return per hectare and increasing the percentage of nondescript leaf produced. No beneficial effect to agronomic performance was recorded with copper and zinc additions in spite of the soil at the experimental site being low in these elements.

Total plant uptake of nitrogen averaged 146, 167 and 186 kg/ha but only 71, 82 and 91 kg/ha of nitrogen was removed in cured leaf. Suggested maintenance dressings of other macro-elements were based on element uptake by leaf at the highest rate of nitrogen applied and were (in kg/ha): phosphorus 15; potassium 240; calcium 100; magnesium 25; and sulphur 16.

The quantities of micro-elements removed in leaf were (in g/ha): copper 10; zinc 75; manganese 630; and iron 429. A study of the amounts of trace elements applied to district crops as contaminants in fertilisers found that a marginal amount of copper and adequate amounts of iron and zinc were being applied.

INTRODUCTION

A great deal of research in recent years has concentrated on the macro-element nutrition of tobacco. There has been no recent investigation of macro- or micro-element uptake by flue-cured tobacco locally, nor has there been much research into the relationship between micro-element addition and yield and leaf quality of tobacco internationally.

McMurtry (1941) first reported the characteristic symptoms produced in tobacco by deficiency of micro-elements, and several researchers have since investigated micro-element applications. Their results are conflicting. Swanback (1950) and Thompson and Askew (1956) applied copper sulphate at rates of 80.6 and 56 kg/ha respectively and obtained positive yield responses, whereas Bacon *et al.* (1950) found a yield reduction at the rate of 6.7 kg/ha.

In 1982, a farm survey of 50 tobacco growers in the Mareeba–Dimbulah area was undertaken. Cultural practices and the chemical status of both cured leaf and soil were recorded. One observation was that some farms exhibited low soil concentrations of DTPA extractable copper ($<$0.10 to 0.15 mg/kg) and zinc (0.77 to 0.96 mg/kg). Similar results for tobacco soils have been reported in Canada by Elliot (1967) and locally by P. E. Tonello and E. J. Gilbert (pers. comm. 1981). The concentrations of copper and zinc in surveyed leaf were also low being less than 1 mg/kg and 9.2 mg/kg respectively.

Another observation from the survey was the apparent excessive use of nitrogenous fertilisers. The average district application in 1982 was 117 kgN/ha (SD=26.5) with some farmers applying in excess of 160 kgN/ha.

Because of these observations, two trials were conducted to determine the interactions between copper and zinc with applied nitrogen on agronomic performance and element uptake by flue-cured tobacco. The effect of treatment on cured leaf yield and quality could only be recorded in the first trial; extensive hail and wind damage precluded the collection of such data in the second trial.

MATERIALS AND METHODS

Location

The field experiment was conducted at Southedge Tobacco Research Station (16°58′S; 145°21′E) on a red earth of granitic origin, locally known as Morganbury loamy sand (Gn 2.14, Northcote 1974). Some soil chemical attributes (0 to 0.15 m) were: pH (1:5 H_2O) 5.8; organic carbon (Walkley and Black 1934) 0.6%; exchangeable cations (N NH_4Cl pH 7.0) K 0.19, Ca 1.21, Mg 0.44 meq/100 g; and DTPA extractable copper, zinc, iron and manganese (Lindsay and Norvell 1978) 0.13, 0.6, 10 and 12 mg/kg respectively.

Design and cultural data

Experiment 1 (1983) was a split plot design with three rates of nitrogen (70, 100, 130 kg/ha) as main plots and copper and zinc addition (4 kg/ha) as sub-plots. Each treatment was replicated three times. In Experiment 1, plots were unintentionally planted with two varieties Hicks Q46 and ZZ100. Because of their distinct features, particularly the erect leaf character and the accelerated ripening pattern of ZZ100, the varieties were permanently labelled in the plots and their harvested leaf kept separate. Experiment 2 (1984) was conducted on the same site with the same fertiliser treatments and randomisation but with only one variety, ZZ100. A basal rate of 70 kg N/ha was applied to plots in each experiment as a commercial NPK mixture (9.7:5:28.8). The balance of the two higher nitrogen treatments was added as an aqueous solution of ammonium nitrate in furrows to either side of the plots. The trace elements were applied as aqueous solutions of copper sulphate and zinc sulphate to the soil surface prior to transplanting. The size of main- and sub-plots was 0.021 and 0.005 ha respectively, and plant density was 19 207 per hectare in each experiment. Normal cultural operations were followed. Maleic hydrazide was used for sucker control at the rate of 16 L/ha.

Experimental techniques

In both experiments, three plants of the variety ZZ100 were selected from each plot at budding on the basis of conformity with plot development. These plants were used to assess the effect of treatment on dry matter production and on element uptake. Over successive harvests, leaves were removed from these plants in a manner which simulated the harvest pattern for the remainder of the plot. The inflorescence (top), suckers and leaves of each plant were kept separate during the harvest period. At the end of the trials, the plants were carefully removed with as much root system intact as possible, thoroughly washed to remove all soil and divided into stems and roots. All plant material (leaf, roots, stem and tops plus was suckers) was dried at 65°C, weighed and ground to pass through a 0.8 mm sieve.

Total and saleable cured leaf weights were recorded in Experiment 1. Leaf quality was assessed by an officer of the Tobacco Leaf Marketing Board and a grade assigned.

The reserve price for each treatment was determined as the weighted average price of assigned grades from the 1984 Grade and Price Schedule. Yield and leaf quality assessment could not be made in 1984 (Experiment 2) because of wind and hail damage. At the time damage occurred, approximately one-third of the leaf from each plot had been harvested. The three plants set aside in each plot for dry matter and whole plant chemical analysis were also severely damaged. By careful reconstruction of plants with leaves collected off the ground, 69% of the plants were recovered. Many of these plants still had up to four leaves missing. Dry weights of missing leaves were interpolated by averaging weights of leaves immediately above and below the missing leaf.

Composite soil samples were taken at three depths (0 to 0.15, 0.15 to 0.30 and 0.30 to 0.60 m) from each treatment at three sampling times. Sampling times were: prior to planting (August 1983); soon after Experiment 1 had finished (January 1984). The final soil sampling (May 1986) for Experiment 2 was conducted 18 months after the trial was completed to gain insight into copper and zinc mobility.

Analytical methods

Following micro-Kjeldahl digestion, the four plant parts were analysed for nitrogen, phosphorus and potassium by autoanalyser (Varley 1966). Calcium and magnesium were determined in the same digests using normal spectroscopy techniques. The trace elements copper, zinc, iron and manganese were determined by atomic absorption spectroscopy following the nitric–perchloric acid wet ashing procedure of Johnson and Ulrich (1959). Sulphur analyses (AOAC 1960) were conducted only on plant material from plots which did not receive copper and zinc additions in Experiment 1.

The soil samples were analysed for DTPA extractable copper and zinc by the method of Lindsay and Norvell (1978). Fertiliser samples were analysed by atomic-absorption spectroscopy for copper, zinc, iron and manganese to determine the amounts of these elements applied to the tobacco crop as an impurity.

RESULTS

Agronomic performance

The addition of extra nitrogen appeared to increase the dry weight of leaf, roots, tops and suckers, and the whole plant in each experiment (Table 1), but these differences were not significant. Because of plant damage, data could not be statistically analysed in Experiment 2. The effect of extra nitrogen on stem dry weight was not clearly defined by the results of the two experiments. In Experiment 1, stem dry weight was significantly reduced by additional nitrogen applications but the results in Experiment 2 suggest the opposite effect.

Extra nitrogen did not have any significant effect on the total and saleable yield of cured leaf of ZZ100 but it did significantly reduce both total and saleable yields of Hicks Q46 (Table 2). The percentage of nondescript leaf was significantly increased ($P<0.05$) by extra nitrogen in Hicks Q46 (Table 2).

The addition of copper and zinc had no significant effect on plant dry weight nor did copper effect the total and saleable yield of cured leaf from either variety in Experiment 1 (Table 2). The addition of zinc significantly depressed total ($P<0.05$) and saleable yield ($P<0.05$) from Hicks Q46 as well as increasing the percentage of cured leaf lost as nondescript ($P<0.05$). However, there was no effect of the addition of zinc on yield from ZZ100 and there was no evidence of an interactive effect on yield with trace elements in either variety.

The addition of extra nitrogen had little effect on the reserve price of cured leaf or on the dollar return per hectare for the variety ZZ100 but the dollar return per hectare was significantly reduced for Hicks Q46 (Table 2). Copper and zinc fertiliser had no beneficial effect on leaf quality from either variety.

Table 1. Effect of treatment on plant dry weight and micro-element uptake by the tobacco variety ZZ100

Treatment applied (kg/ha)	Experiment 1 Weight of plant						Experiment 2 Weight of plant					
	Plant part (g)				Whole per ha		Plant part (g)				Whole Per Ha	
	Leaf	Stem	Root	Top	(g)	(kg)	Leaf	Stem	Root	Top	(g)	(kg)
Nitrogen												
70	228	167	87	14	495	9 507	253	154	98	11	516	9 911
100	237	156	99	24	516	9 911	251	162	105	12	530	10 180
130	250	143	99	49	541	10 391	266	174	104	11	555	10 660
LSD (*P*=0.05)	n.s.	18	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Weight of micro-element						Weight of micro-element					
	Plant part (mg)				Whole per ha		Plant part (mg)				Whole Per Ha	
	Leaf	Stem	Root	Top	(mg)	(kg)	Leaf	Stem	Root	Top	(mg)	(kg)
Copper												
0	0.5	0.9	0.5	0.4	2.3	44	0.5	1.0	0.6	0.1	2.2	42
4	0.9	1.2	0.7	0.5	3.3	63	1.3	1.7	1.0	0.2	4.2	81
LSD (*P*=0.05)	0.2	0.2	0.1	n.s.	0.4	8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zinc												
0	4.4	3.5	1.4	2.5	11.8	227	3.4	6.6	1.7	0.6	12.3	236
4	8.3	4.8	2.0	2.2	17.3	332	8.0	10.3	2.0	0.7	21.0	403
LSD (*P*=0.05)	0.9	0.5	0.4	n.s.	1.9	35	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

n.s. = nsignificant; n.a. = not analysed

Table 2. Effect of treatment on total and saleable yield and leaf quality in Experiment 1

Treatnent applied (kgha)	Yield kg/ha				Nodescript % total yield		Reserve Price kg		Dollar return per hectare	
	Total		Saleable							
	ZZ100	Q46	ZZ100	Q46	ZZ100	Q46	ZZ100	Q46	ZZ100	Q46
Nitrogen										
70	3 424	4 745	3 277	3 951	5.8	16.6	467	464	15 057	18 335
100	3 813	4 785	3 219	3 772	15.0	21.3	470	433	15 241	16 294
130	3 744	4 366	3 045	3 038	18.6	30.9	474	453	14 435	13 735
LSD (*P*=0.05)	n.s.	357	n.s.	450	n.s.	7.3	n.s.	30	n.s.	1 720
Copper										
0	3 630	4 536	3 161	3 568	12.5	21.7	474	452	15 019	16 101
4	3 691	4 729	3 167	3 607	13.8	24.2	466	448	14 802	16 141
LSD (*P*=0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Zinc										
0	3 628	4 776	3 150	3 797	13.0	20.7	475	454	14 987	17 227
4	3 693	4 489	3 178	3 378	13.3	25.2	466	446	14 834	15 015
LSD (*P*=0.05)	n.s.	239	n.s.	272	n.s.	4.1	n.s.	n.s.	n.s.	1 255

Effect of copper and zinc on plant uptake

The addition of 4 kg/ha of either copper or zinc in Experiment 1 resulted in an approximate doubling of the uptake of each element by leaf whereas much smaller increases were recorded in the other plant parts (Table 1). The cumulative effects of two 4 kg/ha additions of copper or zinc in consecutive years on plant uptake of these elements, can be gauged from the results of Experiment 2. Once again, the greatest change in the pattern of uptake occurred in the leaf where nearly two and one half times the uptake of copper and zinc occurred when compared with the uptake of these elements in the zero treatment.

The amounts of copper and zinc recorded in the whole plant in the zero treatment were similar in each year. At the end of Experiment 2, total plant uptake of copper and zinc had increased from 42 and 236 g/ha to 81 and 403 g/ha respectively.

Macro-element uptake

Uptake of nitrogen, phosphorus, potassium and calcium appeared to increase with increasing rates of applied nitrogen, with the uptake of these elements greater in Experiment 2 (Table 3). However, statistically there were no significant differences found for the plant uptake of these elements. For all rates of nitrogen, leaf accounted for 49% of total nitrogen uptake. Of the total potassium in the plant, leaf removal constituted 63% in Experiment 1 and 72% in Experiment 2. Similarly, calcium removal by leaf amounted to 68% and 74% in Experiments 1 and 2 respectively. Magnesium uptake bore no relationship to the rate of nitrogen applied, nor were there differences in total uptake between experiments. The average removal of magnesium in leaf was 25 kg/ha.

No clear indication of the effect of nitrogen rate on sulphur uptake by the plant was recorded. The greatest uptake, however, was recorded with the highest rate of applied nitrogen. Uptake by the leaf accounted for 70% of the total which was equivalent to a removal of 16 kg S/ha.

Table 3. Effect of three rates of nitrogen on macro-element uptake by the tobacco variety ZZ100 in Experiments 1 and 2

		Experiment 1 Weight of element						Experiment 2 Weight of element					
Element	Rate of nitrogen bapplied (kg/ha)	In plant parts (g)					In plants per ha (kg)	In plant parts (g)					In plants per ha (kg)
		Leaf	Stem	Roots	Tops	Whole		Leaf	Stem	Roots	Tops	Whole	
Nitrogen	70	3.603	2.255	0.816	0.511	7.185	138	3.903	2.324	1.248	0.516	7.991	153
	100	3.997	2.194	1.007	0.855	8.028	154	4.689	2.657	1.427	0.548	9.321	179
	130	4.388	2.084	1.108	1.606	9.186	176	4.967	2.987	1.587	0.613	10.154	195
LSD (*P*=0.05)		0.729	n.s.	0.239	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Phosphorus	70	0.453	0.343	0.145	0.054	1.000	19	1.058	0.503	0.245	0.085	1.891	36
	100	0.468	0.331	0.164	0.099	1.062	20	1.071	0.537	0.274	0.092	1.974	38
	130	0.477	0.303	0.174	0.193	1.147	22	1.129	0.551	0.267	0.094	2.041	39
LSD (*P*=0.05)		n.s.	0.039	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Potassium	70	8.659	3.644	0.706	0.437	13.446	258	13.321	3.793	0.966	0.422	18.502	355
	100	9.059	3.606	0.866	0.821	14.362	276	13.186	3.855	1.048	0.480	18.569	357
	130	9.101	3.079	0.815	2.092	15.088	290	15.834	4.215	1.065	0.479	21.593	415
LSD (*P*=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Calcium	70	3.698	0.994	0.448	0.098	5.238	101	5.794	1.473	0.512	0.105	7.884	151
	100	3.748	1.086	0.536	0.155	5.526	106	6.223	1.493	0.537	0.117	8.370	161
	130	3.987	1.082	0.559	0.461	6.090	117	6.558	1.623	0.590	0.103	8.874	170
LSD (*P*=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Magnesium	70	1.399	0.371	0.101	0.059	1.929	37	1.296	0.386	0.132	0.069	1.883	36
	100	1.201	0.364	0.110	0.077	1.752	34	1.269	0.374	0.123	0.047	1.813	35
	130	1.235	0.331	0.112	0.188	1.867	36	1.349	0.392	0.114	0.056	1.911	37
LSD (*P*=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sulphur*	70	0.775	0.150	0.137	0.039	1.101	21						
	100	0.703	0.125	0.089	0.044	0.961	19						
	130	0.851	0.229	0.079	0.139	1.298	25						

* Results apply only to those plots which received no copper and zinc addition.

n.s. = not significant, n.a. = not analysed.

Micro-element uptake

Unlike the macro-elements, the greatest uptake of copper and iron occurrred in the stem (40%) and root (40%) respectively (Table 4). Twenty six per cent of the total uptake of copper occurred in leaf, with increased application of nitrogen depressing leaf content in each experiment. Total uptake of copper averaged 56 g/ha with no evidence of a consistent effect of nitrogen rate on plant uptake. The effect of nitrogen rate on iron uptake by the whole plant exhibited conflicting trends, decreasing with higher nitrogen rates in Experiment 1 but increasing in Experiment 2.

Manganese uptake by the whole plant tended to increase with the increased rate of nitrogen applied in Experiment 2 and was greatest at the highest rate of nitrogen in Experiment 1. In no case were differences significant (P=0.05). In general uptake was substantially lower in Experiment 2. When averaged over the experiments, 72% of the manganese uptake was found to occur in leaf. On the other hand, the results for zinc uptake were inconsistent, being higher in leaf in Experiment 1 but higher in stem in Experiment 2. In addition, higher rates of applied nitrogen tended to stimulate plant uptake of zinc in Experiment 1 but this trend was not evident in the results of Experiment 2, nor was it significant (P=0.05) in Experiment 1.

Table 4. Effect of three rates of nitrogen on micro-element uptake by the tobacco variety ZZ100 in Experiments 1 and 2

Element	Rate of nitrogen bapplied (kg/ha)	Experiment 1 Weight of element						Experiment 2 Weight of element					
		In plant parts (g)					In plants per ha (kg)	In plant parts (g)					In plants per ha (kg)
		Leaf	Stem	Roots	Tops	Whole		Leaf	Stem	Roots	Tops	Whole	
Copper*	70	0.8	1.2	0.5	0.3	2.8	54	1.0	1.4	0.8	0.2	3.3	65
	100	0.6	1.0	0.6	0.4	2.6	50	0.9	1.2	0.7	0.1	3.0	56
	130	0.6	0.8	0.7	0.7	2.8	54	0.7	1.3	0.8	0.1	2.9	56
LSD (P=0.05)		0.1	0.2	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zinc*	70	6.0	3.8	1.6	1.3	12.7	244	4.6	9.6	1.6	0.6	16.4	315
	100	6.7	4.3	1.8	1.8	14.6	280	6.9	9.0	2.2	0.8	18.9	363
	130	6.2	4.4	1.7	3.8	16.1	309	6.0	6.5	1.8	0.6	14.9	286
LSD (P=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Iron*	70	21.7	11.9	25.4	1.4	60.4	1 160	18.9	17.4	24.1	5.1	65.1	1 249
	100	22.5	10.6	21.3	1.8	56.2	1 079	23.7	16.5	29.4	2.8	72.4	1 390
	130	22.0	10.2	18.2	3.8	54.2	1 041	25.1	14.1	37.1	2.6	78.9	1 515
LSD (P=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Manganese*	70	37.0	5.2	2.5	10.1	54.8	1 052	22.9	3.9	2.2	1.0	30.0	576
	100	35.7	4.9	2.1	10.0	52.7	1 012	29.1	4.6	2.7	0.9	37.3	716
	130	40.0	5.1	2.2	16.5	63.8	1 225	32.2	5.2	2.9	0.9	41.2	791
LSD (P=0.05)		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

n.s. = not significant; n.a. = not analysed.

* results from plots receiving no copper or zinc application.

Soil DTPA extractable copper and zinc concentrations

There were significant increases in the DTPA extractable levels of copper and zinc in the soil in response to copper and zinc additions. These increases were confined largely to the top 0.15 m of soil, with increase in the 0.15 to 0.30 m depth 18 months after completion of the second experiment (Table 5). The initial DTPA extractable copper and zinc levels of the experimental site were well below the district average for granitic soils on which 78% of tobacco farms are located.

Table 5. DTPA extractable soil copper and zinc from the site after each experiment with averages from 1982 district survey of the granitic soil type for comparison

Element	Experiment site				District survey (0-0.23 m)†
	Soil depth (m)	Initial	Expt 1	Expt 2*	
Copper	0-0.15	0.13	0.89	1.09	0.30 (0.16)
	0.15-0.30	0.11	0.15	0.54	
	0.30-0.60	n.d.	0.10‡	0.15	
Zinc	0-0.15	0.68	1.19	2.36	1.74 (0.93)
	0.15-0.30	0.40	0.43	1.16	
	0.30-0.60	n.d.	0.12	0.21	

* Sampled 18 months after completion of experiment.

† Results in brackets are standard deviations of the mean.

‡ analytical threshhold.

n.d. = not determined.

Trace element contamination of fertilisers

The commonly used tobacco fertilisers contain levels of copper 3 to 18 mg/kg, zinc 5 to 250 mg/kg, manganese 0.4 to 95 mg/kg and iron 12 to 254 mg/kg (Table 6). The amounts of each element applied per hectare in an average district application of each fertiliser are indicated.

Table 6. Trace element analysis of fertilisers(mg/kg) and approximate application rates per hectare based on fertiliser rates recorded in 1982 district survey

Fertiliser	Copper		Zinc		Iron		Manganese	
	Concentration in fertiliser	Rate/ha (g)	Concentration in fertiliser	Rate/ha (g)	Concentration in fertiliser	Rate/ha (g)	Concentration in fertiliser	Rate/ha (g)
Tobacco 6 Mg*	9	7	231	186	1964	1577	84	67
Tobacco 315, Mg*	3	3	180	178	2540	2510	95	94
Tobacco 10	18	10	246	137	383	213	17	10
Nitram†	6		9		16		0.4	
Sodium Nitrate	13	2	5	1	12	2	0.4	1

* Results courtesy Consolidated Fertilisers, Brisbane.

† Source of additional nitrogen in Experiments 1 and 2.

DISCUSSION

Agronomic performance

In north Queensland flue-cured tobacco, the percentage of total plant dry weight which is leaf (47%) is greater than that (35%) found by Elliot (1967) for Canadian flue-cured tobacco. Some of this difference would be due to improved sucker control since Elliot had reported that suckers and tops comprised 10% of plant dry weight whereas we found them to comprise only 4% of the total. Lower stem (30%) and root (19%) dry weights compared with Canadian stem (33%) and root (22%) suggest that genotypic and phenotypic variation accounted for about half the differences.

The term ‘total yield’ can be misleading because it implies the yield of all leaf from the plant instead of only the yield of cured leaf prior to grading. Leaf dry weight results (variety ZZ100) in Experiment 1 (Table 1) were converted to cured leaf yields by assuming that the cured leaf contained 15% moisture. (Cured tobacco leaf contains 14 to 15% moisture). Thus for rates of 70, 100 and 130 kg N/ha these theoretical yields were 5034, 5233 and 5520 kg/ha respectively. A comparison of these theoretical yields with total yields of cured leaf (Table 2) in the same experiment, same variety, show discrepancies of 1610, 1420 and 1776 kg/ha for the respective rates of applied nitrogen. In real terms, using the reserve price quoted in Table 2 to estimate this tobacco’s value, the discrepancies between theoretical and saleable yields represent losses of $8210, $9470 and $11 730 per hectare respectively for the three rates of nitrogen.

Part of the yield discrepancy may be attributed to the presence of the slower ripening Hicks variety in Experiment 1. In other words, at harvest there was the likelihood of leaf of ZZ100 being left in the field because it was too mature to cure. We tried to minimize this from occurring by scheduling harvesting frequency on the ripening pattern of ZZ100 plants. However, the disparity between the average district yield of saleable leaf from the 1982–83 season (2724 kg/ha) which was based largely on ZZ100 plantings, and the theoretical yields based on dry matter yields in Experiments 1 and 2, support our suggestion that further investigation is warranted.

The relevant point to the discussion is that the highest rate of nitrogen exacerbated the loss of green leaf. It further exacerbated the loss of cured leaf as evidenced by the increased percentage of nondescript leaf, where 18.6% of the total yield of cured leaf was lost at the highest rate of nitrogen (Table 2).

Micro-element in plant and soil

No recorded instances of trace element deficiency in north Queensland tobacco have occurred although low soil levels of DTPA extractable copper and zinc were recorded in the survey of 50 farms in 1982. DTPA extractable copper and zinc in the soil of the experimental site were low (Table 5). No beneficial response in yield or leaf quality was recorded from 4 kg/ha additions of each element (Table 2). Plant uptake of each element in response to these additions was small (Table 1).

There was a significant build-up of DTPA extractable copper and zinc in the soil which was largely confined to the top 0.15 m, although some increase in level of each element was evident in the 0.15 to 0.30 m depth after the end of Experiment 2 through cultivation (Table 5).

Rainfall recorded at the site during the 18 months following completion of Experiment 2 in 1984 was 1974 mm. Approximately one-third of this 1974 fell during January to March 1985, one third during the same period in 1986, and one-third fell over the remaining 12 months. The soil results demonstrate that both copper and zinc are relatively immobile in the soil surface layer even when subjected to fairly intense rainfall, as previously noted by Swanback (1950) and Graham and Nambir (1981).

The quantities of copper and zinc removed in cured leaf were 10 and 75 g/ha respectively (Table 1). An analysis of tobacco fertilisers for trace element impurities and an assessment of the amounts of each element applied per hectare in an average district application of each fertiliser (Table 6) indicate that a marginally acceptable rate of copper and an adequate rate of zinc are being applied to crops. A further 0.14 to 1.4 kg/ha zinc is applied to crops as fungicide sprays.

The DTPA extractable manganese level in soil on some farms in the survey group has been found to be high (150 mg/kg), but the soil at the experimental site was low (12 mg/kg). In these experiments, higher rates of nitrogen appeared to promote manganese uptake primarily in the leaf, but the differences were not significant (P=0.05). Elliot (1967) found manganese uptake to be 840 g/ha in Canadian leaf which was comparable with our average result of 722 g/ha in Experiment 1. However, average uptake by leaf in Experiment 2 was lower (539 g/ha), possibly because of an increased plant uptake of calcium (Table 3). Manganese toxicity is remedied by raising soil pH with lime. Akehurst (1981) and Tso (1972) report that for tobacco, the presence of calcium in the soil and its uptake is antagonistic to the uptake of manganese.

Although plant uptake of iron in these experiments (1.24 kg/ha) was much lower than that found in Canadian tobacco (3.06 kg/ha) by Elliot (1967), it is not considered to be limiting to agronomic performance. Adequate applications of iron are made to crops in basal fertiliser applications (Table 6). The DTPA extractable iron level in the soil of the experimental site, which was similar to that found for granitic soils in the 1982 district survey, was equivalent to an available iron reserve of 37 kg/ha.

Macro-element uptake

Nitrogen uptake by leaf accounted for 49% of the total uptake and this percentage varied little with applied nitrogen rate (Table 3). The amounts of nitrogen removed in leaf were 71, 82 and 91 kg/ha for the nitrogen rates of 70, 100 and 130 kg/ha. Since there was no net gain to either total or saleable yield at the highest nitrogen rate, we conclude that applications of nitrogen over 90 kg/ha will lead to an eventual net gain of nitrogen in the soil system.

Of the other major cations, the results of Table 3 indicate the amounts of each element which would be suitable as a maintenance dressing, either applied in a base fertiliser or in a base fertiliser-side dressing combination. These maintenance dressings have been based on the nutrients removed by the leaf at the highest nitrogen rate and they are (in kg/ha); phosphorus 15, potassium 240, calcium 100, magnesium 25 and sulphur 16.

ACKNOWLEDGEMENTS

This study was conducted with financial support from the Tobacco Industry Trust Account. Assistance of H. C. Mulder (Biometry Branch, Townsville), M. J. Dwyer, D. C. Wiffen, and D. E. Rowan (Agricultural Chemistry Branch, Mareeba) is gratefully acknowledged.

References

Akehurst, B. C. (1981), In *Tobacco* Longman, London.

AOAC (1960), *Official Methods of Analysis*, Horwitz. (ed.) ninth edition, Association of official Agricultural Chemists, Washington.

Bacon, C. W., Leighty, W. R. and Bullock, J. F. (1950), *Boron, copper, manganese, and zinc requirement tests of tobacco*, United States Department of Agriculture Technical Bulletin No. 1009.

Elliot, J. M. (1967), Chemical composition of various parts of flue-cured tobacco plants, *Lighter* **37**(4), 15–18.

Graham, R. D. and Nambir, S. (1981), Advances in research on copper deficiency of cereals, *Australian Journal of Agricultural Research* **32**, 1009–37.

Johnson, C. M. and Ulrich, A. (1959), *Analytical methods for use in plant analysis*, Bulletin Californian Agricultural Experimental Station, No. 766.

Lindsay, W. L. and Norvell, W. A. (1978), Development of a DTPA soil test, for zinc, iron, manganese and copper. *Soil Science Society of America Journal* **42**, 421–28.

McMurtry, J. E. (1941), Plant nutrient deficiency in tobacco, in G. Hambridge (ed.) *Hunger Signs in Crops*, American Society of Agronomy, and the National Fertilizer Association, Washington D.C. 33.

Northcote, K. H. (1974), *A Factual Key for the Recognition of Australian Soils*, Fourth Edition, Rellim Technical Publications, Glenside, South Australia.

Swanback, T. R. (1950), *Copper in tobacco production*, Connecticut Agricultural Experiment Station, New Haven Bulletin 535, April.

Thompson, R. and Askew, H. O. (1956), A leaf breakdown of tobacco associated with the copper status of the soil, *New Zealand Journal of Science and Technology*, **Q**, 584–99.

Tso, T. C. (1972), Physiology and Biochemistry of Tobacco Plants, in *Tobacco*, Dowden, Hutcheson and Ross, Inc. Stroundsburg, Pa.

Varley, J. A. (1966), Automatic method for the determination of nitrogen, phosphorus and potassium in Plant Material, *Analyst* **91** (1079), 119–26.

Walkley, A. and Black, T. A. (1934), An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method, *Soil Science* **37**, 29–38.

(Accepted for publication 11 June 1986)