GUIDE TO FERTILISERS: COMPOSITION AND CALCULATIONS

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Prepared by: B K Daly[1] and J L Wainiqolo[2]

Landcare Research New Zealand Ltd
Private Bag 11052
Palmerston North
New Zealand

[2]Fiji Agricultural Chemistry Laboratory
Koronivia Research Station
Ministry of Agriculture, Fisheries, Forests and ALTA.
P O Box 77, Nausori, Fiji Islands
Tel: (679)477044; Fax (679)400262

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Ministry of Agriculture, Fisheries, Forests and ALTA.
Research Division
Fiji Agricultural Chemistry Laboratory

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1 INTRODUCTION

The purpose of this manual is to help MAFFA extension officers, and others, assist farmers to decide what type and amount of fertilisers to use for a crop after having a soil fertility assessment test carried out at the Fiji Agricultural Chemistry Laboratory.

This is instead of using a standard recommendation which does not take into account existing levels of soil nutrients. A fertiliser recommendation derived using the approach described in this manual should give better crop yields and/or avoid wasting fertiliser by applying unnecessary nutrients.

At the simplest level where the only information available is the soil fertility assessment, the fertiliser strategy can be worked out by modifying the standard recommendation based on the soil fertility assessment. In contrast where information such as previous yields, fertiliser additions and soil fertility reports are available in the farmers file held by the extension officer, the strategy can be derived by amending what was added last year after considering such factors as increasing or declining yield and soil fertility. In this way the 'ideal' fertiliser strategy for a particular soil and crop can be approached by 'fine-tuning'.

2 FERTILISERS

2.1 What is a fertiliser?

A fertiliser is any material containing plant nutrients that can be added to soil. Usually the manufactured inorganic materials such as superphosphate, urea and muriate of potash are what people think of as fertilisers, but organic materials such as animal manures, sugar mill wastes, poultry shed waste and composted vegetation also contain and release plant nutrients and so are also considered to be fertilisers.

2.2 Why are they needed?

Fertiliser use is becoming more common in Fiji agriculture as farmers move from traditional subsistence methods which use a long fallow period, to cash cropping with short or no fallow period. Most Fiji soils are old and with Fiji's position in the humid tropics the soils are well leached, thus tend to be low in available plant nutrients. In the traditional style of agriculture with a long fallow period, deep rooting plants collect nutrients from deep less weathered soil layers, the organic matter level rises and there is little loss of nutrients from the system. When the forest is cut and burned to prepare a new planting area, most of the accumulated nutrients are released from the ash into the soil for the benefit of the planted crop. This system was generally sustainable where after one or two years cropping the patch of ground was allowed to go back into bush fallow for many years.

In common with most of the agricultural systems in the tropics fallow periods have become shorter, while higher yielding and thus higher nutrient demanding crops are being used. Therefore with greater removal of nutrients and little or no return through fallow periods, the shortage of nutrients must be made up with added fertilisers.

2.3 How are they used?

When considering fertiliser use three questions need to be answered:

- What nutrients are needed?
- How much of each?
- How should the nutrients be applied?

A soil test allows us to answer the first question except for Nitrogen for which no satisfactory soil test exists. For this element it is probably best to use the standard recommendation which has been derived from field trials. The accuracy of this recommendation can be checked by monitoring the plant nutrition by sampling and analysing the correct plant part at the appropriate stage of growth (see Daly & Wainiqolo, 1993). It is worth repeating that if a very short or no fallow is used then the nutrients, including N, which are removed by the crop must be replaced by fertiliser.

The second question concerning how much fertiliser will be answered in detail in the following section.

The third question concerning mode and timing of application is best answered by extension officers or agronomists with specialist knowledge of particular crops. However a number of basic principles need to borne in mind concerning the relative mobility of the various major nutrient elements and whether or not they are held by the soil against leaching.

Nitrogen is the most mobile element of the three major nutrients (N, P & K) and as such most care must be taken in the timing and mode of application of fertiliser N. The soil has no mechanism for retaining added N against leaching. It is important that when N is added the plant is actively growing and ready to use the N. Otherwise most of the added N can be lost by leaching into the ground water by one heavy rainfall event.

Potassium (K) is held in the soil by ionic attraction on the surface of clay and organic matter particles. The K^+ ions are exchangeable with other positively charged ions such as H^+ from plant roots or leaching rain water, hence the term cation exchange. This cation exchange limits the mobility of K compared to N but does not completely protect it from leaching. Large excesses of K added as fertiliser will not all be available for following crops; some will be lost by leaching.

In contrast Phosphorus (P) is held very strongly in most soils. P is held by chemical adsorption onto iron and aluminium compounds and is virtually resistant to leaching. However, the adsorption can be so strong that some of the added P will become 'fixed' and will never be available to plants. On balance though the strong adsorption of P by soil is a plus. It means that P fertiliser can be added to soil at the cultivation stage if desired and that much of any excess P fertiliser will be available for subsequent crops. In very strong P fixing soils the loss of P by this route can be minimised by strategies such as side-banding the P near the roots rather than spreading it throughout the soil during cultivation.

3 MODIFYING STANDARD FERTILISER RECOMMENDATIONS BASED ON SOIL FERTILITY TESTS

In order to modify standard fertiliser recommendations based on the results of soil fertility tests, information on fertiliser composition is needed and a number of calculations need to be done. This section contains the information needed and describes how to do the calculations. The section ends with two worked examples using all of the techniques described.

3.1 Fertiliser Composition

Inorganic fertilisers are generally regarded as being of two types; single compound fertilisers usually known as 'straights' and blended fertilisers where a number of different fertilisers are mixed together, usually to give certain proportions of N, P & K. The blends do not always contain all three major nutrients and may contain only two. In contrast some of the straight fertilisers contain more than one nutrient element. For example DAP (diammonium phosphate contains 21% N and 23% P, and superphosphate contains 9% P and 12% S.

Tables 1 gives the elemental compositions of straight fertilisers while table two gives the elemental composition of most of the blended fertilisers available in Fiji.

The composition of a fertiliser is commonly quoted in terms of its NPK rating. Historically this was done in terms of the element percentage for N, but oxide percentage for P and K. Phosphorus was quoted as P_2O_5 and Potassium as K_2O. In most parts of the world this system is no longer used and all three major nutrients are quoted in terms of element percentages (ie. N, P & K and not N, P_2O_5 and K_2O). Unfortunately the older convention is still used in Fiji, mainly for blended fertilisers.

It is important to know which convention is used when carrying out fertiliser calculations as there can be a large difference between the oxide percentage and the elemental percentage. This is particularly true for P where superphosphate is sometimes described as having an NPK rating of 0-20-0. This rating is based on the oxide method of expressing percentages and the real percentage of P in superphosphate is 9%. In the same way the blended fertiliser with an NPK rating of 13-13-21 actually contains 13% N, 5.7% P and 17.4% K.

Tables 1 and 2 give both the old fashioned oxide based NPK ratings and the real elemental percentages of each nutrient.

To convert oxide based percentages to element percentages:

$$\% P_2O_5 \quad x \quad 0.44 \quad = \quad \% P$$

$$\% K_2O \quad x \quad 0.83 \quad = \quad \% K$$

Table 1 Straight Fertilisers

N-P-K Rating*	Material	Formula	N %	P %	K %	Mg %	Ca %	S %
35-0-0	Ammonium Nitrate	NH_4NO_3	35	-	-	-	-	-
21-0-0	Ammonium Sulfate (Sulfate of Ammonia)	$(NH_4)_2SO_4$	21	-	-	-	-	24
21-48-0	Diammonium Phosphate (DAP)	$(NH_4)_2HPO_4$	21	23	-	-	-	-
12-61-0	Monoammonium Phosphate (MAP)	$NH_4H_2PO_4$	12	27	-	-	-	-
0-0-63	Potassium Chloride (Muriate of Potash)	KCl	-	-	52	-	-	-
14-0-47	Potassium Nitrate	KNO_3	14	-	39	-	-	-
0-0-53	Potassium Sulfate	K_2SO_4	-	-	44	-	-	18
16-0-0	Sodium Nitrate	$NaNO_3$	16	-	-	-	-	-
0-20-0	Superphosphate	$Ca(H_2PO_4)_2+CaSO_4$	-	9	-	-	-	12
0-46-0	Triple Superphosphate	$Ca(H_2PO_4)_2$	-	19	-	-	-	-
46-0-0	Urea	$CO(NH_2)_2$	46	-	-	-	-	-

* Based on N - P_2O_5 - K_2O

Table 2 Blended Fertilisers available in Fiji

N-P-K Rating *	N %	P %	K %
10-20-10	10	8.8	8.3
13-13-21	13	5.7	17.4
8-14-13	8	6.2	10.8
20-5-8	20	2.2	6.6
16-16-16	16	7.0	13.3
13-13-13	13	5.7	10.8
FSC Blend A	10	20	0
FSC Blend B	15.8	0	12.5
FSC Blend C	16	2.7	10.8
FSC Blend D	13.7	2.3	13.7

* Based on N - P_2O_5 - K_2O

3.2 Calculation of Fertiliser Requirement if No Standard Recommendation is Available to Modify

If a soil fertility report is available but in the absence of any other information such as a standard fertiliser recommendation to modify based on the soil fertility test results, the values in table 3 below could be used with care to formulate a fertiliser recommendation. The values given in the table represent the amounts of nutrients removed by different crops for the given yield levels.

The values are an approximate guide only to the amounts of nutrients required to be added to the soil to maintain yield. This is because they represent minimum amounts required only. Extra N and K are lost through leaching and P is lost through adsorption and conversion to forms unavailable to plants. On the other hand there is some release of nutrients, particularly N, from decomposition of soil organic matter and in younger soils some release of K and possibly P from soil minerals.

Table 3 Major nutrients removed by various crops.

Crop			Yield (T/ha)	Nitrogen kg/ha N	Phosphorus kg/ha P	Potassium kg/ha K
Banana			30	60	7	164
Beans			2.4	155	22	100
Cassava	-	roots	20	125	13	125
Cabbage			70	181	22	141
Citrus			15	100	11	180
Cocoa	-	beans	1	20	5	12
Maize	-	grain	8	115	28	35
	-	stover	6	58	7	140
Peanut			2	100	13	25
Rice	-	paddy	6	100	22	133
Sugar Cane			100	110	39	282
Sweet Potato	-	tuber	25	140	15	140
	-	vines	15	96	13	120
Tomato	-	fruit	75	112	11	202

3.3 Calculating the Elemental Amounts of Nutrients Added per Hectare with a Standard Recommendation based on a Blended Fertiliser

The first step in modifying a standard fertiliser recommendation in response to a soil fertility assessment is to calculate the amounts of each element added by the standard recommendation in terms of kg per hectare of each nutrient in the blended fertiliser.

For example if the recommendation to be modified is 600 kg / ha 13-13-21, what are the individual amounts of N, P & K /ha?

Remember that the 13-13-21 refers to 13% N, 13% P_2O_5 and 21% K_2O.

Multiply the kg/ha of the blended fertiliser by the percentage of each element in the blend divided by 100 to get the kg/ha of element. For P and K it is also necessary to multiply by the factor for converting from oxides to elements (0.44 for P and 0.83 for K).

600	x	13 / 100	=	78 kg N / ha				
600	x	13 / 100	=	78 kg P_2O_5 / ha	x	0.44	=	34 kg P / ha
600	x	21 / 100	=	126 kg K_2O / ha	x	0.83	=	105 kg K / ha

3.4 Calculating the Amount of Straight Fertiliser Needed From kg of Element per Hectare

Once the kg / ha of each of the elements has been worked out and decisions made about increasing, decreasing or eliminating each, then the kg / ha of each element to be added needs to be converted into kg of fertiliser / ha.

The calculation is kg of element multiplied by 100 divided by the percentage of the element in the fertiliser.

For example if 60 kg of P is required and TSP (triple superphosphate) is the fertiliser to be used, how much TSP is needed to give 60 kg P? We see from table 2 that TSP contains 19% P so therefore the calculation is:

60 x 100 / 19 = 316 kg of TSP

This would probably be rounded down to 300 kg to give an even number of 50 kg bags per hectare.

For a second example if 80 kg of N is required and Urea is the fertiliser to be used, how much urea is needed to give 80 kg N? Urea contains 46% N so therefore the calculation is:

80 x 100 / 46 = 174 kg of Urea

3.5 Examples of modifying standard fertiliser recommendations based on soil fertility tests

Two fully worked examples are given below complete with a soil fertility report showing the nutrient levels in the soils. The first is a field used for growing ginger and is fairly typical of many ginger growing soils which tend to have more than adequate reserves of K and very low levels of P.

The second example is from a maize growing soil where the soil fertility report indicates that K is needed; an element which is not added by the standard recommendations.

Example 1 - Ginger

A soil fertility report for a soil previously used for ginger, shows P levels are very low and K is high - very high (more than 1,500 kg K / 20 cm ha). Potash is obviously not needed and as the P value is very low in a soil that has been farmed for ginger previously, it likely the standard P recommendation is too low for this soil. As soil testing can not help with N nutrient level it is assumed that the N recommendation is at the correct level. (This can be checked by analysing the foliage - 3rd leaf blade below apex of plant at about 4-6 months of growth for ginger).

The standard recommendation for ginger is 10 T/ha poultry manure, 300 kg/ha urea and 1,000 kg/ha 13-13-21 NPK. The poultry manure is applied pre-planting and half the NPK is applied at planting with the remainder at 3 months. The urea is applied at 100 kg/ha at 2, 4 and 5 months.

NB: 13-13-21 NPK means 13% N, 13% P_2O_5, and 21% K_2O

therefore calculating the elemental amounts (N,P & K) in the standard recommendation:

1,000 kg	=	13/100 x 1,000	=	130 kg N		
	=	13/100 x 1,000	=	130 kg P_2O_5	=	57 kg P (130 x 0.44)
	=	21/100 x 1,000	=	210 kg K_2O	=	174 kg K (210 x 0.83)

As K is not needed the 13-13-21 NPK will be replaced with straight fertilisers for N and P; urea and triple superphosphate are the most easily available.

If we assume Nitrogen level is right - therefore 130 kg of N is needed. Urea contains 46% N:

therefore 130 x 100/46 = 280 kg - say 300 kg Urea for an even number of bags.

Based on the soil test, P should be increased from 57 to say 100 kg. Triple superphosphate (TSP) contains 19% P

therefore 100 x 100/19 = 526 kg - say 500 TSP kg.

The overall fertiliser recommendation per hectare for this crop and this field will be therefore:

10 T poultry manure applied pre-planting.
* 250 kg TSP and 150 kg Urea applied at planting
100 kg Urea at 2 months
* 250 kg TSP and 150 kg Urea at 3 months
100 kg Urea at 4 months
100 kg Urea at 5 months

where * indicates the changes from the standard recommendation.

Using ex-Lautoka fertiliser prices (June, 1994) the 500 kg TSP and 300 kg Urea which replaced the 1,000 kg of NPK, cost $430 compared to $484 for the NPK. This rate of TSP gives nearly double the original P recommendation. If the same amount of P is used as in the original recommendation (300 kg TSP) the cost is $326.

Example 2 - Maize

A soil fertility report for a soil previously used for maize, shows P levels are medium (22 mg/kg, equivalent to 44 kg/ha for a 20 cm layer) and K is low (0.14 me/100g, equivalent to 110 kg K / 20 cm ha).

Standard recommendation for maize is 250 kg/ha superphosphate and 100 kg/ha urea. The superphosphate is applied at planting and the urea is applied at 6 weeks after planting.

The K figure in the fertility report is low and K will be needed. The standard recommendation does not include K so we need to decide on the amount required. This can be done by looking at the amount removed by a crop of maize (Table 3) to give us a minimum value; 35 kg/ha for the grain and 140 kg/ha for the stover. If the stover is dug in or burned most of the K will be released to the soil for the next crop. However for this year's crop we need about 180 kg/ha and with 110 kg present the requirement is for about 70 kg/ha K. For a following crop of maize the requirement would be closer to 40 - 50 kg K assuming return of most of the stover K.

For P the soil test showed a medium amount of available P and indicated that P fertiliser may not be needed. It is probably desirable to maintain the soil P fertility at this level so as to act as a bank for P. Therefore the amount expected to be removed by the maize crop should be added; this would be about 30 kg/ha, which is the grain P and a portion of the stover P. A problem for the P addition is that the recommendation states Superphosphate and only Triple Superphosphate is available.

As soil testing can not help with N nutrient level it is assumed that the N recommendation is at the correct level. (This can be checked by analysing the foliage - ear leaf of plant at early silking stage).

therefore requirements are:

Nitrogen the same as the standard recommendation = 100 kg/ha Urea

Phosphorus 30 kg/ha P needed (Triple Superphosphate = 19% P to be used)

therefore 30 x 100/19 = 157 kg - say 150 kg/ha TSP

Potassium 70 kg/ha needed (KCl or Muriate of Potash = 52% K is available)

therefore 70 x 100/52 = 135 kg - say 150 kg/ha KCl

The overall fertiliser recommendation per hectare for this crop and this field will be therefore:

- * 150 kg/ha Triple Superphosphate to be applied at planting
- * 150 kg/ha Muriate of Potash to be applied at planting or ½ at planting and the rest with the Urea at 6 weeks after planting
- 100 kg Urea at 6 weeks after planting

where * indicates the changes from the standard recommendation.

As mentioned previously, it should not be necessary to apply as much K for a further crop of maize next year. This should be checked by having another soil fertility assessment carried out before planting the next crop.

3.6 Converting kg / ha recommendations to other units

Often the farmer will not want a fertiliser recommendation in terms of kg / ha because his plot size is smaller than a hectare. Appendix 1 describes in detail how to derive a recommendation for kg fertiliser / plot for a plot of a given size in square metres from kg / ha of element required.

Appendix 2 gives a large number of conversion factors for different units including factors for weight / area conversions. For example to convert kg / ha to kg / square chain multiply by 0.04.

1000 kg / ha x 0.04 = 40 kg / square chain

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Appendix 1 Calculation of fertiliser needed for a given plot size from kg of element / ha

To calculate the kg of fertiliser required for an area of $\boldsymbol{a}$ square metres where the rate is given as $\boldsymbol{x}$ kg of element (N, P, K etc) per hectare two equations are used. The first converts kg of element required per hectare to kg of element required per plot by multiplying by the plot size in square metres and dividing by 10,000, which is the number of square metres in a hectare. The second converts the kg of element per plot to the kg of fertiliser per plot, given the percentage of the element in the fertiliser.

$$y \text{ kg element / plot} = \frac{x \times a}{10{,}000}$$

$$\text{kg fertiliser / plot} = \frac{y \times 100}{p}$$

where:

x	=	kg of element required per ha
a	=	area of plot in square metres (m^2)
y	=	kg of element required per plot
p	=	percentage of element in fertiliser to be used (table 1)

These two equations can be combined:

$$\text{kg of fertiliser / plot} = x \times \frac{a}{10{,}000} \times \frac{100}{p}$$

$$= \frac{x \times a}{100 \times p}$$

Appendix 2 Some Useful Measurements and Equivalents:

It is preferable to work in SI (Systeme International) units eg. metres, hectares, kilograms, but as some farmers still work in Imperial units, the conversions for many of the more commonly used older units are given here together with some useful conversions within the SI system. To convert a number in the units on the left to the units on the right, multiply by the conversion factor given.

Length:

Metres (m)	x	39.4	=	Inches (in)
Inches (in)	x	0.0254	=	Metres (m)
Metres (m)	x	3.28	=	Feet (ft)
Feet (ft)	x	0.305	=	Metres (m)
Metres (m)	x	1.09	=	Yards (yd)
Yards (yd)	x	0.91	=	Metres (m)
Chains	x	22	=	Yards (yd)
Chains	x	20.1	=	Metres (m)
Metres (m)	x	0.05	=	Chains

Area:

Square metres (m^2)	x	1.19	=	Square yards (yd^2)
Square Yards (yd^2)	x	0.84	=	Square metres (m^2)
Square Metres (m^2)	x	0.0001	=	Hectares (ha)
Hectares (ha)	x	10,000	=	Square Metres (m^2)
Hectares (ha)	x	2.47	=	Acres
Acres	x	0.405	=	Hectares (ha)
Acres	x	4,840	=	Square Yards (yd^2)
Square Yards (yd^2)	x	0.00021	=	Acres
Acres	x	4,426	=	Square Metres (m^2)
Square Metres (m^2)	x	0.00023	=	Acres
Square Chains	x	0.04	=	Hectares (ha)
Hectares (ha)	x	24.8	=	Square Chains
Square Chains	x	0.1	=	Acres
Acres	x	10	=	Square Chains
Square Chain	x	484	=	Square Yards (yd^2)
Square Yards (yd^2)	x	0.0021	=	Square Chains

Square Chain	x	404	=	Square Metres (m^2)
Square Metres (m^2)	x	0.0025	=	Square Chains

Weight:

Kilograms (kg)	x	1000	=	Grams (g)
Grams (g)	x	0.001	=	Kilograms (g)
Kilograms (kg)	x	2.2	=	Pounds (lb)
Pounds (lb)	x	0.454	=	Kilograms (kg)
Tonnes (metric) (T)	x	1000	=	Kilograms (kg)
Tonnes (metric) (T)	x	2205	=	Pounds (lb)
Pounds (lb)	x	16	=	Ounces (oz)
Ounces (oz)	x	28.3	=	Grams (g)
Hundredweights (cwt)	x	112	=	Pounds (lb)
Hundredweights (cwt)	x	50.8	=	Kilograms (kg)
Kilograms (kg)	x	0.02	=	Hundredweights (cwt)

Volume:

Litres (L)	x	1000	=	Millilitres (mL)
Millilitres (mL)	x	0.001	=	Litres (L)
Litres (L)	x	0.224	=	Gallons (gal)
Gallons (gal)	x	4.546	=	Litres (L)

Weight / Area:

Kilogram/Hectare (kg ha^{-1})	x	0.89	=	Pounds / Acre (lb $acre^{-1}$)
Pounds / Acre (lb $acre^{-1}$)	x	1.12	=	Kilograms / Hectare (kg ha^{-1})
Kilogram/Hectare (kg ha^{-1})	x	0.04	=	Kilograms / Square Chain
Kilogram/Hectare (kg ha^{-1})	x	0.0001	=	Kilograms / Square Metre (kg m^{-2})
Kilogram/Hectare (kg ha^{-1})	x	0.1	=	Grams / Square Metre (g m^{-2})
Cwt/Acre	x	126	=	Kilogram/Hectare (kg ha^{-1})
Cwt/Acre	x	0.126	=	Tonnes/Hectare (T ha^{-1})

Appendix 3 Atomic Weights of Elements Used in Fertiliser Calculations

Element	Symbol	Molecular Weight	Element	Symbol	Molecular Weight
Boron	B	10.8	Manganese	Mn	54.9
Calcium	Ca	40.1	Molybdenum	Mo	95.9
Carbon	C	12.0	Nitrogen	N	14.0
Chlorine	Cl	35.5	Oxygen	O	16.0
Copper	Cu	63.5	Phosphorus	P	31.0
Hydrogen	H	1.0	Potassium	K	39.1
Iron	Fe	55.8	Sulfur	S	32.1
Magnesium	Mg	24.3	Zinc	Zn	65.4