EVALUATING UREA FERTILIZER FORMULATIONS FOR OIL PALM SEEDLINGS USING THE ^{15}N ISOTOPE DILUTION TECHNIQUE

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ABSTRACT

High N volatilization severely limits the use of urea in oil palm cultivation. Urea-based compound formulations incorporating K, Ca and/or Mg have the potential for enhancing urea-N utilization, but information on their efficacy is scanty. Compound and bulk blended urea–based NPK and a bulk blend of gypsum urea were evaluated for oil palm at the main nursery stage on an ultisol (Rengam series). The normal recommended N rate and half of it were used for the urea NPK fertilizers, and only the normal rate for the gypsum urea blend. Nitrogen uptake and utilization from the fertilizers were quantified by the ^{15}N isotope dilution technique. Dry matter yield was not significantly different between the fertilizer treatments irrespective of the rates applied. Percent N utilization was markedly greater at half the normal rate of application (60% versus 33%-38%). Much higher N concentration, uptake and N utilization efficiency (%NUE) were obtained with gypsum urea, probably because the Ca^{2+} added by this material minimized the volatilization of urea-N. Thus, gypsum urea has greater potential than the compound and bulk blended urea-based NPK fertilizers as a source of N for oil palm seedlings.

Keywords: bulk blend fertilizer, compound fertilizer, gypsum urea, ^{15}N isotope dilution technique, nitrogen use efficiency, oil palm.

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INTRODUCTION

Planting robust oil palm seedlings is a prerequisite for the establishment of a successful planting with early fruiting and high yields at maturity. Vigorous seedlings require the provision of adequate moisture and plant nutrients, chiefly N, at the nursery stage. Growth is severely restricted by N deficiency; therefore, an effective fertilization regime should be implemented to satisfy plant requirements.

Although urea is a cheaper source of N (per unit nutrient) because of its high N concentration, its use has not been as widespread as ammonium sulphate in Malaysia because of high N losses mainly through volatilization. This is accentuated in the humid conditions maintained in oil palm nurseries (Bouwmeester *et al*., 1983; Foster *et al*., 1988). On the other hand, ammonium sulphate increases soil acidity, which has deleterious effects on plant growth (Brady and Weil, 1999). Therefore, there is need to develop methods for improving the N use efficiency of urea by reducing its volatilization losses. Various methods, including the application of urea with K^+, Ca^{2+}, Mg^{2+} and NH_4^+ salts, have been reported to reduce N losses significantly (Fenn *et al*., 1981; Foster and Zin, 1985; Popp, 1988). This corresponds with the need for balanced fertilization of, at least, the main macronutrients (N, P, K and Mg) for optimal chlorophyll formation and continuous growth (Hartley, 1977; Turner and Gillbanks, 1974). These are applied in the form of granular compound fertilizers, and the most common ones are N-P-K-

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MgO (15-15-6-4) and N-P-K-MgO + micronutrients (12-12-17-2 + micronutrients) (Mutert *et al*., 1999). In many cases, the formulation 15-15-6-4 is usually applied in the first four months of nursery establishment, and the proportion of K is increased (12-12-17-2) in subsequent applications (Turner and Gillbanks, 1974). However, the use of urea-based compound fertilizers in oil palm nurseries is not common, and information on their utilization efficiencies scanty. Therefore, the primary objective of this study was to evaluate the efficacy of urea-based fertilizer formulations for oil palm seedlings at the main nursery stage. A compound fertilizer and bulk blends of straight fertilizers were compared.

MATERIALS AND METHODS

The experiment was carried out in Ladang Dua of the Faculty of Agriculture, Universiti Putra Malaysia. Topsoil (0-15 cm) of the Rengam series (Typic Kandiudult, fine, kaolinitic, isohyperthermic) collected from Johor was used. The soil properties are presented in *Table 1*. The composition of the urea-based compound fertilizer used was 15:15:15 ($N:P_2O_5:K_2O$). One tonne of this compound fertilizer contains 285 kg urea, 117 kg DAP, 290 kg phosphate rock and 250 kg KCl. The corresponding bulk blend fertilizer also had the same ratio of straight fertilizers. The urea component was replaced with gypsum urea in the gypsum urea bulk blend treatment, T5 (*Table 2*). The straight fertilizers were urea (46%N), muriate of potash (MOP), and diammonium phosphate (DAP). These were applied once a month for six months (*Table 2*) according to the recommended rates given in the field handbook for oil palm nursery management (Rankine and Fairhurst, 1999).

Experimental Procedure

Three-month-old oil palm seedlings were transplanted into black polythene bags containing 25 kg soil. At planting, 50 g of Gafsa phosphate rock were applied in each planting hole. The compound and bulk blended urea fertilizers were surface applied according to the recommendations for oil palm nurseries (*Table 2*). This was replicated eight times and arranged in a completely randomized design. The treatments were compound urea-based NPK and bulk blend urea applied at half and full (normal) recommended rates, gypsum urea bulk blend at the normal rate, and a control. The focus of the study was to compare the efficiencies of compound and bulk blend urea-based NPK fertilizers. Gypsum urea was only added for comparison. The control received P and K at the same rates as the full rate treatments, but N was only applied as the ^{15}N label. Similarly, P and K were augmented in the half N rate treatments to the same levels as the full rate treatments. Boron was also applied in solution form (100 ml of boron solution containing 12.5 mg B ml^{-1}) during each round of fertilizer application. Moreover, MgO was added as kieserite (27% MgO) to all treatments in the last three rounds of fertilizer application (2.7, 2.7 and 0.4 g MgO $plant^{-1}$). The full rate treatments received 90 g fertilizer and the half rate 45 g, which translated to 13.50 g N $plant^{-1}$ and 6.75 g N $plant^{-1}$, respectively. The soil in each polybag was labelled with 2 mg ^{15}N fertilizer (10% a.e.) as $(NH_4)_2SO_4$ solution in the beginning of the trial and prior to every round of fertilizer application (seven times). Weeding and irrigation were carried out manually as and when necessary. The plants were harvested after seven months, and each plant was divided into top (shoot) and roots. Dry weight of the shoots and roots were recorded after oven drying at 70°C to constant weight. Sub-samples were ground (1 mm) and then analysed for total N and ^{15}N (Axmann, 1990; Axmann *et al*., 1990).

TABLE 1. CHEMICAL CHARACTERISTICS OF TOPSOIL (0-15 cm) USED – RENGAM SERIES

Parameter	Value
pH_{water}	4.3
Total N (g kg^{-1})	1.4
Organic C (g kg^{-1})	20.8
Total P (mg kg^{-1})	163.0
Olsen P (mg kg^{-1})	9.2
Cation exchange capacity [cmol(+)kg^{-1}]	6.85
Exchangeable K [cmol(+)kg^{-1}]	0.21
Exchangeable Ca [cmol(+)kg^{-1}]	0.88
Exchangeable Mg [cmol(+)kg^{-1}]	0.14
Exchangeable Al [cmol(+)kg^{-1}]	3.42

TABLE 2. TREATMENTS AND QUANTITIES OF FERTILIZERS USED

Treatment	Description	Total fertilizer applied (g $plant^{-1}$) (∑ monthly applications over 6 months period)
T1	Urea-based NPK at normal rate	10 +10 +15 +15 + 20 + 20 = 90
T2	Urea-based NPK at 0.5 normal rate	5 + 5 + 7.5 + 7.5 + 10 + 10 = 45
T3	Bulk blend urea at normal rate	10 +10 +15 +15 + 20 + 20 = 90
T4	Bulk blend urea at 0.5 normal rate	5 + 5 + 7.5 + 7.5 + 10 + 10 = 45
T5	Gypsum urea bulk blend at normal rate	10 +10 +15 +15 + 20 + 20 = 90
T6	Control with ^{15}N labelled fertilizer only	0.014

Note: MgO was also added at the rate of 2.7, 2.7 and 0.4 g $plant^{-1}$ as kieserite in the last three rounds of fertilizer application.

Data Analysis

The %N derived from each fertilizer formulation (%NdfU) was calculated from the following relationships based on the isotope dilution principle (Zaharah *et al.*, 1999):

%NdfU = {1- (^{15}N a.e. urea treated plants/^{15}N plants in control)} × 100 [1]

Therefore, total N derived from urea fertilizer (NdfUg) is given by:

NdfUg = %NdfU × N yield/100 [2]

where N yield = total N uptake in g $plant^{-1}$. Then, the N use efficiency (%NUE) was calculated thus:

%NUE = NdfUg × 100/g N applied [3]

The fertilizer effects on the parameters were established by analysis of variance using the SAS statistical software (SAS, 1990). The means were separated using Duncan's Multiple Range Test (DMRT) at 5%.

RESULTS AND DISCUSSION

There was a significant response to the fertilizer treatments (T1 – T5 versus T6). The effect of the urea fertilizers on dry matter yield was not significantly different irrespective of the rate of application (*Table 3*). Nevertheless, there were considerable differences in the concentrations of N in the shoot and root tissues between the full and half rate treatments. This was anticipated, since dry matter production was similar in the plants that received the normal and lower amounts of N. There was a dilution of N concentration in plants with the lower N treatment. However, the normal rate of N provided by gypsum urea resulted in markedly higher N concentration in the plants than those with the same rate of N from the urea-based NPK (*Table 3*). Similarly, total N taken up by the plants in the gypsum urea treatment was also significantly higher than from the other urea fertilizers. Bulk blend urea gave a similar N concentration as gypsum urea in the top, but

TABLE 3. DRY MATTER YIELD, NITROGEN CONCENTRATION AND UPTAKE BY OIL PALM SEEDLINGS TREATED WITH VARIOUS FORMULATIONS OF UREA FERTILIZERS

Treatment	DM yield (g $plant^{-1}$)	%N	Total N uptake (g $plant^{-1}$)	%NdfU	NdfUg (g $plant^{-1}$)
T1	200.46 a	1.94 b	3.88 ab	84.24 a	3.26 bc
T2	229.45 a	1.53 c	3.46 b	69.28 b	2.40 d
T3	204.81 a	1.99 a	4.03 ab	83.52 a	3.38 ab
T4	236.38 a	1.53 c	3.65 ab	74.36 b	2.71 d
T5	197.88 a	2.16 a	4.25 a	89.32 a	3.96 a
T6	120.31 b	0.86 d	1.02 c	0.00 c	-
			Roots		
T1	47.13 a	1.33 b	0.63 b	84.47 a	0.53 b
T2	42.86 a	1.01 c	0.43 c	75.85 b	0.33 c
T3	36.27 a	1.42 b	0.52 bc	87.92 a	0.47 bc
T4	45.96 a	1.01 c	0.45 c	72.05 b	0.32 c
T5	43.10 a	1.90 a	0.82 a	88.61 a	0.79 a
T6	43.22 a	0.44 d	0.19 d	0.00 c	-

Note: Values in a column with the same letter(s) are not significantly different according to Duncan's Multiple Range Test at P = 0.05%.

significantly lower N concentration in the roots. Also, the bulk blend urea and urea-based NPK gave comparable N uptake values irrespective of the rate of application (*Table 3*).

The superior effect of gypsum urea may be attributed to lower N volatilization. Although this was not actually determined, many studies have established that the presence of cations such as Ca^{2+}, Mg^{2+} and K^+ significantly reduces N loss from urea (Fenn *et al*., 1981; Khanif and Wong, 1988; Popp, 1988). These cations are believed to suppress elevation of the pH that normally promotes the hydrolysis of urea in soils. This effect is much greater with Ca^{2+} than K^+. The bulk blend urea and urea-based NPK fertilizers contain K^+ and NH_4^+ at the cation:urea ratio of about 0.5:1. However, more effective reduction of N loss through volatilization has been observed to occur at cation:urea ratios of 1:1 for univalent cations and 0.5:1 for divalent cations (Popp, 1988). In this study, the Ca^{2+} supplied by the gypsum in the gypsum urea bulk blend increased the proportion of cations in the cation:urea ratio. This could have increased the effectiveness for reducing N loss in this treatment. Hence, the greater uptake of N from the gypsum urea blend compared to the other formulations.

From the ^{15}N data, 83%-89% of the total N in the plant tops was derived from the fertilizers when applied at the normal rate. This declined to 69%-74% because of lower N supply when the rate of application was halved. A similar trend was observed in the roots. This reaffirms the problem of N deficiency in this soil and the importance of N fertilization for oil palm seedlings in such situations. High loss of urea-N was expected in this soil with low organic matter and CEC, so the substantial N utilization suggests that the accompanying cations in these formulations minimized the losses (Popp, 1988). On the whole, the gypsum urea bulk blend gave distinctly higher %NUE than the other urea formulations at the normal rate for the same reasons mentioned earlier (*Table 4*).

Uptake of Other Nutrients

The urea-based NPK and urea blend produced similar P, K, Ca and Mg concentrations both in the tops and roots of the plants (*Table 5*). However, the gypsum urea gave distinctly higher Ca and Mg concentrations in the plant tops, and much lower P and K concentrations in both the tops and roots. This was probably partly due to antagonistic effects between the three elements – K, Ca, and Mg - in the plants as their absorption by the roots depended on their relative concentrations in the soil solution. The availability of K^+ is generally dependent on its concentration relative to that of Ca^{2+} and Mg^{2+} (Havlin *et al*., 1999). Thus, K^+ uptake declines as Ca^{2+} and Mg^{2+} increase in the soil solution and *vice versa*.

TABLE 4. TOTAL NITROGEN UPTAKE AND NITROGEN USE EFFICIENCY BY OIL PALM SEEDLINGS TREATED WITH VARIOUS UREA FORMULATIONS

Treatment	Total nitrogen (tops + roots)(g plant^{-1})	Nitrogen use efficiency (NUE) %
T1	4.51 ab	33.41 c
T2	3.89 b	57.63 a
T3	4.55 ab	33.70 c
T4	4.10 b	60.74 a
T5	5.07 a	37.56 b

Note: Values in a column with the same letter(s) are not significantly different according to Duncan's Multiple Range Test at P = 0.05%.

TABLE 5. CONCENTRATIONS OF PHOSPHATE, POTASSIUM, CALCIUM AND MAGNESIUM SEEDLINGS TREATED WITH VARIOUS UREA FORMULATIONS

Treatment	%P	%K	%Ca	%Mg
T1	0.201 a	1.64 a	0.375 b	0.313 b
T2	0.201 a	1.75 a	0.358 b	0.296 b
T3	0.188 ab	1.71 a	0.326 b	0.269 c
T4	0.204 a	1.73 a	0.376 b	0.308 b
T5	0.153 c	0.894 b	0.514 a	0.344 a
		Roots		
T1	0.163 a	1.98 a	0.30 a	0.160 a
T2	0.158 a	1.96 a	0.27 a	0.143 a
T3	0.164 a	2.01 a	0.27 a	0.138 a
T4	0.161 a	1.95 a	0.28 a	0.138 a
T5	0.119 b	0.764 b	0.30 a	0.144 a

Note: Values in a column with the same letter(s) are not significantly different according to Duncan's Multiple Range Test at P = 0.05%.

CONCLUSION

Halving the rate of N application reduced plant N uptake but did not affect dry matter yield. This suggests that the lower rate is optimal for the oil palm seedlings. Nevertheless at the normal rate, gypsum urea bulk blend was the best formulation as it provided more N than the other urea fertilizers and has the potential of being a source of Ca for the palms. The latter is shown by the marked increase in %Ca in plants in the gypsum urea treatment. Due to the promising potential shown by the gypsum urea blend, there is need for further testing of this material to identify suitable methods for its management, for instance identification of the appropriate timing and optimal levels of application.

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