Mineral Nutrient Requirements for White Clover Seed Production

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ABSTRACT

Worldwide about 9000 tonnes of white clover (*Trifolium repens* L.) seed, sufficient to sow up to 3 million ha, is produced annually. The paper describes mineral nutrient effects on seed yield. Ca, P, N, K, S, B, and Mo responses reported are based on trials in New Zealand and SW China. The detrimental effect of both high levels of N, P and K causing excessive vegetative growth and reduced seed yields, and severe mineral deficiencies resulting in poor vegetative growth and/or low seed yields are discussed. Rhizobia bacteria should be adhered to the seed, for inoculation and N fixation in sites which have not had a history of white clover usage.

Additional index words: **soil nutrients, minerals, calcium, lime, phosphorus, potassium, nitrogen, sulphur, boron, molybdenum, rhizobia, *Trifolium repens*.**

INTRODUCTION

White clover (*Trifolium repens* L.) is an important legume species in areas ranging from the subarctic to the mediterranean and subtropics. Plant material from many of these diverse environments is represented in the 232 bred cultivars and ecotype selections (Caradus, 1986) developed to reduce limitations within the worlds distinctly differing agricultural land-use patterns. This worldwide importance of white clover is shown in the annual production of some 9000 tonnes of seed, sufficient to sow up to 3 million hectares (Table 1). Even though 60% of this seed is produced in the Canterbury region (43°-45° S) of New Zealand, commercial production on a varying scale is now being carried out in many regions; from the high altitude monsoonal subtropical areas (Himalayas and SW China, 25° N) to the cooler Scandinavian climes (60° N), on a wide range of soils types, with variations in soil mineral nutrient content within countries and between regions.

TABLE 1.
Annual white clover seed production.

	tonnes
New Zealand (1980/87)	5590
EEC (Denmark) (1986)	1390
Australia (1986/87)	930
Argentina (1985/86)	700
USA/other nations	500
Estimated annual total	**9000***

* Value US $30 million

ENVIRONMENT

Mineral nutrition is an important aspect of the plant environment that has a marked influence on white clover growth and seed yield. There are five major and two minor elements that tend to dominate the nutritional limitations to white clover seed yield worldwide. These elements are calcium (Ca), phosphorus (P), nitrogen (N), potassium (K), sulphur (S), boron (B) and molybdenum (Mo).

To produce high seed yields, the key to success is in maintaining a 'controlled' plant response to elements to ensure the best compromise between leaf size and inflorescence density, consistent with efficient harvesting of the cultivar grown (Clifford, 1985, 1987). Application of nutrients (in relation to both type and amounts) must be compatible with both moisture availability for uptake and the temperature for expression at that site. The following section details our experiences with white clover seed crops in New Zealand and in SW China at a site where severe mineral deficiencies occurred (Syers *et al.*, 1986). Soil nutrient levels quoted have been obtained using New Zealand Ministry of Agriculture tests (Cornforth and Sinclair, 1984).

Calcium: Calcium is applied as lime (predominantly calcium carbonate) and this element's major role is in amending soil acidity (pH). Other effects are in (i) reduced Al^{+++} toxicity; (ii) the improved utilization of phosphatic fertilizers; (iii) enhanced micro-organism and earthworm activity; (iv) increased molybdenum availability; (v) enhanced N mineralization of organic N, and (vi) assisting in the survival of clover nodule bacteria (During, 1967).

In New Zealand seed yields of 1000 kg ha^{-1} have

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been achieved at pH 5.5 (Clifford, unpublished data). However, once pH rises above 6.0, particularly in association with surplus P, excessive vegetative growth occurs which tends to diminish seed yield potential. The recommended soil acidity level range is pH 5.5-6.0.

Phosphorus: Phosphates initially assist in establishment through stimulating root growth. Within New Zealand's pastoral economy, the greatest emphasis is on maximising rhizobial nitrogen-fixing activity for the enhancement of grass growth. Under these conditions, with high vegetative growth rates, high soil P levels are common, e.g. Olsen P = 33 ppm, or greater. However, under the 'controlled-growth' regime of a pure seed crop aimed at maximising leaf numbers per unit area, soil Olsen P levels as low as 7 ppm have been found to be adequate, allowing seed yields of over 1000 kg ha^{-1} to be harvested (Clifford and McCartin, 1985). Furthermore, when Olsen P levels increased beyond 7 ppm, seed yields declined due to problems of surplus vegetative growth (Fig. 1; Clifford, 1985). Where a severe P deficiency occurred, added P markedly increased flower density (Table 2).

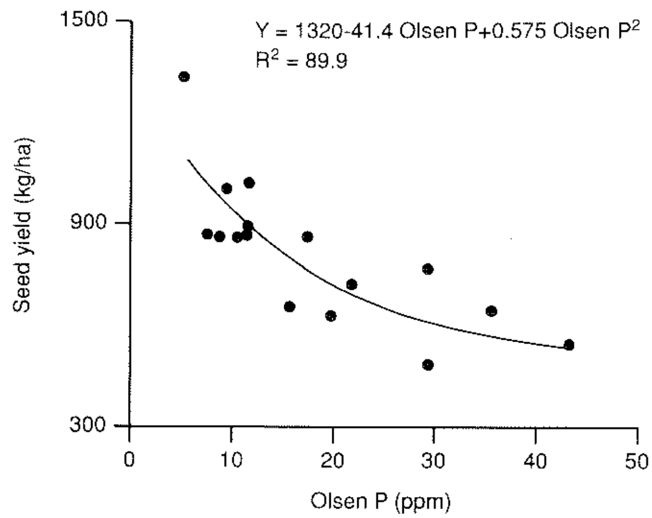
In New Zealand only autumn-applied P is now recommended. Standard practices used to diminish the problem of excessive vegetative growth on seed yield on soils of high inherent P are (i) reduced time from sowing to harvest (autumn sowing rather than spring) and (ii) increased spacing between rows (15 to 30 or 45 cm, depending on cultivar growth habit).

TABLE 2.
Fertiliser replacement trial - white clover 1984 Dushan Model Seed Farm, Guizhou Province[1] Peoples' Republic of China.

Treatment	White clover growth score (10 = max.)	Flowers m^{-2}
No fertilizer	1.6	98
All elements[2]	10	380
- Zn	10	322
- N	6	347
- Mo	7	420
- S	6	395
- K	2	132
- B	8	257
- P	6	285

[1]Latitude 26° N; altitude 1000 m asl; sub-tropical environment.
[2]Replacement trial: all elements applied at non limiting rates (N = urea 200 kg ha^{-1}; P = CaMg Phosphate 18% P_2O_5, 1000 kg ha^{-1}; K = KCl 100 kg ha^{-1}; S = gypsum 40 kg ha^{-1}; Zn = $ZnSO_4$ 5 kg ha^{-1}; B = boric acid 10 kg ha^{-1}; Mo = $NaMoO_4$ 100 g ha^{-1}).

Figure 1
Effect of soil phosphorus on seed yields of commercially grown 'Grasslands Huia' white clover seed crops (from Clifford, 1985).

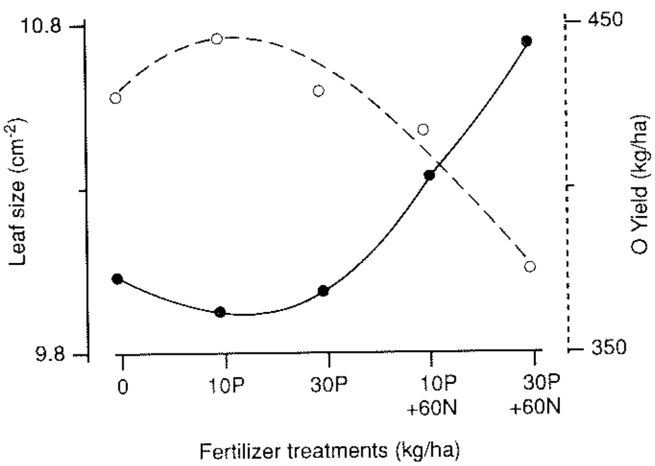


Nitrogen: In most cases nitrogen requirements are more than satisfied by way of the clover roots' symbiotic relationship with nitrogen-fixing bacteria (rhizobia). Therefore, part of the reasoning for keeping soil pH below 6 is to limit the release of additional organically-bound N, through the process of mineralization. This process is enhanced by (i) cultivation; (ii) presence of freely available Ca (high pH) and (iii) high temperatures. Thus, direct drilling of crops has an advantage through limiting the mineralization process. The ploughing in of stubbles on soils of low N status can impose a critical N shortage for establishing clovers. In this situation, the bacteria breaking down the straw have a capacity to out-compete the establishing clover for available N. In sites with low soil N as in China (Table 2) or where low soil N is coupled with moisture stress (Danyach-Deschamps and Wery, 1987), flower numbers and hence seed yields respond to N fertilizer.

N limitations can readily be amended by application of a nitrogenous fertilizer, and if associated with sulphur deficiency, ammonium sulphate (21% N, 24% S) should be used.

The use of fertilizer nitrogen to sustain controlled growth for a desired period, rather than risking over-application of P, is now becoming an accepted practice in specialist crops.

Figure 2
Fertilizer effects on leaf size and seed yield under conditions of adequate soil moisture (each data point = mean of 4 cultivars x 4 replicates) (from Clifford, 1987).



P-N Inter-relationship: Clifford (1987), designed an autumn-sown experiment to highlight the effect of over-supply of P and N (Fig. 2). For a soil of Olsen P = 7 ppm, P was applied at sowing at 0, 10 or 30 kg P ha^{-1}, with and without N at 30 kg N ha^{-1} applied in late autumn, and again in early spring for P treatments only. Leaf size, as a vigour response function of element application, was used to explain variations in seed yield. A lower plant establishment at nil P than other P treatments allowed a similar competition level for soil-available P between nil P and 30 P treatments, resulting in similar leaf sizes and seed yields. In contrast, the better establishment at 10 P lead to greater competition among plants for P in the following spring, thereby producing smaller leaves and high seed yields. This feature highlights the advantage of applying some P at sowing to (i) ensure good establishment and (ii) give greater control over uptake levels in the following spring. The addition of N with P increased leaf size, but to the detriment of seed yield.

Potassium: The soils of the Canterbury Province, New Zealand's major white clover seed production area, are mainly alluvial with relatively high weathering rates. Because of these factors, K has never been a major limitation to seed yield. Sites with exchangeable K of 20 ppm are adequate for producing high yielding crops. Good yields have been obtained from crops with a herbage K content of 1.5% (Clifford and White, 1986); whereas the optimum for vegetative growth was assessed at 2.0-2.4% (Cornforth and Sinclair, 1984). Where K is limiting (Table 2), large responses occur to applied K. However, it is important to ensure that over correction does not occur, as high K levels can limit plant nectar secretion potential, as evidenced in red clover (Sheul, 1957).

Sulphur: Sulphur deficiency is thought to be equally limiting to the metabolism of both plants and nitrogen-fixing rhizobia (During, 1967). However, because this element has a major function in plant protein synthesis, application of mineral N to correct nitrogen-fixing limitations has no effect if a S deficiency occurs. In New Zealand, S deficiency is either inherent (as it is in many soils) or has been induced with cereal cropping and the use of compound or concentrated N-P fertilizers in association with irrigation. A trial on a soil of the latter type, with a soil sulphate sulphur level of only 2 ppm, showed that a spring application of 20 kg S ha^{-1} as either gypsum or normal superphosphate, increased yields by 60% (Table 3). In this trial the importance of S in protein formation is highlighted in both the high proportion of 'seconds' and the low 1000-seed weight, and a 30% reduction in vegetative material, from 4980 to 3800 kg ha^{-1}. Subsequent research has indicated no advantages to added S above soil sulphate levels of 6 ppm (Clifford, unpublished data).

Boron: Seed yield responses to B have been reported in a number of legumes (Sherrell, 1983) including white clover (Johnson and Wear, 1967; Spooner and Hunneycutt, 1978). The B requirement for seed production is higher than for vegetative growth (Shorrocks, 1974). Clifford (unpublished) found in the field that white clover seed set was increased from 1.1 to 2.9 seeds per floret when B deficiency was corrected, and this increase was probably associated with increased nectar production (Smith and Johnson, 1969). A minimum foliar B concentration of 20-25 ppm (Cornforth and Sinclair, 1984) is recommended for white clover vegetative growth, and the concentration for seed production may be higher. Application of excessive B will seriously reduce both vegetative growth and seed yield (Sherrell, 1983) and therefore B should only be used if known deficiencies occur.

Molybdenum: The major role of Mo is to ensure efficient nitrogen fixation by the root nodule rhizobia. The main function of Mo in this symbiotic relationship is in

TABLE 3.
Effect of 20 kg sulphur ha^{-1} applied as two fertilizers on seed production in white clover (from Clifford and White, 1986).

	Control	Gypsum (110 kg ha^{-1})	Superphosphate (200 kg ha^{-1})	± SEM
Inflorescences per m^2	739	764	741	45.1
Seed yield (kg ha^{-1})	356	512	550	39.8
1000-seed weight (g)	0.66	0.70	0.71	0.006
'Seconds' (% of total)[1]	14	6	5	0.8

[1]small seed removed during cleaning.

the union with the root to ensure adequate plant carbohydrate transfer for bacterial use. In New Zealand 0.5 to 1.0 ppm Mo in herbage is considered adequate for this requirement. Application rates for deficiency correction are low, being of the order of 150 g ha^{-1} in the form of sodium molybdate. This rates provides 60 g Mo and is sufficient for 5 to 7 years (During, 1967). Response to a foliar application is rapid, and under good conditions may be visibly evident within 10 days (Clifford, pers. comm.). When Mo deficiency has severely limited spring growth, correction has given seed yields of 400 kg ha^{-1} (in comparison with no yield if the problem had not been addressed). Because Mo is needed to sustain plant N requirements, similar results can be gained from the spring application of 10-20 kg N ha^{-1}.

It is of note that the correction of S deficiency will depress Mo levels (Clifford and White, 1986). In this instance, 20 kg S ha^{-1} applied as gypsum or normal superphosphate respectively, depressed Mo levels from 1.29 to 0.73 and 0.58 ppm. Thus a knowledge or Mo levels is desired where correction for S deficiency is contemplated.

Rhizobia: Although a soil micro-organism and not an element, the role of rhizobia in making N available for plant use at a very low cost is an important function of both pastoral and legume seed production systems. Most legume species have specific rhizobia which they host. For many species scientific selection, based on high nitrogen-fixing ability, has produced improved, commercially-available strains. The normal method for soil incorporation of improved strains is by adhering the rhizobia to the seed immediately prior to sowing, either using a peat slurry or one made from skim milk powder. Alternatively, this process may be carried out commercially, with the inoculum being coated on to the seed surface (pelleted seed). Rhizobial mortality is high in the presence of direct sunlight, high temperatures, and acidic fertilizers, e.g. superphosphate. Thus, cultures should be kept refrigerated, in the dark and used only immediately prior to sowing. The inoculated seed should never be mixed with any nitrogenous or acidic fertilizer used as an aid to accurately sowing low rates of seed.

CONCLUSIONS

Mineral nutrients have a major effect on white clover seed production. While deficiencies can be defined and corrected, the management of nutrient interactions, particularly P x N and S x Mo, requires care. The synergistic leaf growth responses to additional water with nutrients such as P, lead to excessive leaf size and poor seed yields, and are particularly difficult to manage.

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