Mineral Nutrition of Mungbeans

R.W. Bell

School of Biological and Environmental Sciences, Murdoch University, Murdoch, W.A. 6150

Abstract

Despite relatively low seed yields, or perhaps because of them, there are few reports from Australia of responses by mungbean to fertilizers or soil amendments. Reports from elsewhere that fertilizer treatments in experimental plots have increased seed yields by up to 830 kg ha^{-1} *in green gram and 1170 kg* ha^{-1} *in black gram suggest that fertilizers or soil amendments have the potential to markedly increase mungbean yields. However, the full benefits of improved mineral nutrition are unlikely to be realized unless the yield potential is also increased by improved cultural conditions and genetic potential. Field trials, pot trials, plant symptoms and plant analysis have all been used for the diagnosis of nutrient disorders in mungbean but further work is needed to develop standards for macronutrient deficiency diagnosis. Moreover, there are few soil or plant analysis standards available to predict the occurrence of nutrient disorders or fertilizer requirements in farmers' mungbean crops. In addition to nutrient disorders that limit seed dry matter in mungbean, those that limit symbiotic* N_2 *fixation (deficiencies of Mo, Co, Ca, Fe, and possibly P and Cu, and toxicity of Al) or seed quality (B) require special attention.*

Introduction

Mungbeans are a relatively new crop in Australia (Lawn and Russell 1979) but one with substantial potential for expansion in the subtropics and tropics (Weston *et al.* 1981). Their current yields in Australia (500 - 600 kg ha^{-1}) are lower than those of most other tropical food legumes (e.g. 1,400 to 1,800 kg ha^{-1} - soybean; 1,200 to 1,500 kg ha^{-1} - peanut: ABARE 1988) and much lower than those obtained in farmers' demonstration plots (1,500-2,000 kg ha^{-1}; Singh 1988) or experimental plots (3,000 kg ha^{-1}; Lawn and Ahn 1985). Mineral nutrient constraints are one of the factors which may be contributing to the large gap between farmers' seed yields and those possible under experimental conditions. Mineral nutrient deficiencies or toxicities may also depress mungbean production by depressing seed quality for germination. In addition, by depressing symbiotic nitrogen fixation in mungbean crops, mineral deficiencies or toxicities may depress nitrogen (N) supply to subsequent crops.

Relatively little is known about the nutrient requirements of mungbeans, and curiously rather more is known about their requirements for micronutrients than for macronutrients (e.g. see Bell *et al.* 1990). Previous reviewers have attributed the paucity of information about nutrient requirements of mungbean to their relatively low yield potential and hence to their low demand for nutrients for grain (Rachie and Roberts 1974; Lawn and Russell 1978; Lawn and Ahn 1985). For example, seed of a typical Australian mungbean crop yielding 500 kg ha^{-1} may remove (in kg ha^{-1}): 20-21 N, 1.3-2.4 phosphorus (P); 6-7 potassium (K); 0.5-0.7 calcium (Ca); 0.8-1.2 magnesium (Mg) and 1 sulphur (S) (Table 1). Even allowing for nutrients required to produce the roots and remainder of the shoots, the requirements for nutrients are still relatively low and may be met on most soils, even those with low levels of available nutrients. Nevertheless, if soil nutrient supply is low enough, mungbean seed yield will be depressed even when yield potential is low. For example, in some experimental plots in northeast Thailand, black gram produced 1210 kg seed ha^{-1} when treated with complete nutrients but virtually no seed when boron (B) was omitted (Table 2). The severity of the B deficiency, its prevalence and the sensitivity of current cultivars to B deficiency may account for the failure of farmers to plant much black or green gram in northeast Thailand, and yet a small amount of B fertilizer may be all that is needed to correct the problem. That fertilizers or soil amendments have the potential more generally to markedly increase mungbean yields is suggested by reports that in experimental plots in several countries mineral constraints have depressed green gram seed yields by 150 to 830 kg ha^{-1} and those of black gram by 170 to 1170 kg ha^{-1} (Table 2).

In this paper, I will examine the internal and external nutrient requirements of mungbean, the standards available for the diagnosis and prognosis of mineral disorders, the edaphic limits to mungbean production with particular reference to Australia, the treatment of mineral disorders in mungbean and finally outline future nutrition research needs for the Australian mungbean industry.

Table 1. Nutrient concentrations in seed and residue of mungbean and contents of the elements in shoots of a mungbean crop producing 1000 kg seed ha^{-1} and 1500 kg residue ha^{-1}.

Element	Concentration^{A,B}		Content^{C}		
	Seed	Residue (%DM)	Seed	Residue (kg.ha^{-1})	Total
N	4.0 - 4.2	0.6 - 1.6	40 - 42	9 - 24	49 - 66
P	0.26 - 0.48	0.20 - 0.29	3 - 5	3 - 4	6 - 9
K	1.2 - 1.4	2.2 - 3.0	12 - 14	33 - 45	45 - 59
Ca	0.09 - 0.14	1.1 - 1.9	1 - 15	17 - 29	18 - 31
Mg	0.16 - 0.23	0.4 - 0.66	1.5 - 2.5	6 - 10	8 - 13
S	0.19 - 0.20	0.07 - 0.35	2	1 - 5	3 - 7
	-(mg.kg^{-1}DM)-			-(g.ha^{-1})-	
B	6 - 15	30	6 - 15	45	51 - 60
Mo	0.2 - 6	0.05	0.2 - 6	0.1	0.3 - 6

[A] Concentrations of macronutrients from Lawn and Ahn (1985).

[B] Values for B and Mo are critical concentrations for seed and leaves from Bell *et al.* (1990) and Jongruaysap (personal communication).

[C] Content calculated for a crop producing 1,000 kg seed and having a harvest index of 0.4 (Lawn 1979).

Internal Nutrient Requirements

Internal nutrient requirements refer to concentrations of the essential elements required in the plant for growth. They are usually expressed as a critical nutrient concentration and determined from the relationship between growth and nutrient concentration within the plant or a plant part. Limited information exists on the internal nutrient requirements of mungbean for growth, especially those for macronutrients (Table 3).

For mungbean, like other legumes, internal nutrient requirements will depend on soil N supply since legumes have additional requirements for some nutrients when reliant on symbiotic N_2 fixation. When dependent on symbiotic N_2 fixation, legumes require additional Mo, Co and Ca (Robson 1978), and recent reports suggest that additional Fe may also be required (O'Hara *et al.* 1988). For near maximum rates of symbiotic N2 fixation at early flowering, green and black gram require 7000 and 4000 ng Mo g^{-1} DM, respectively in their nodules: by contrast the Mo requirement in the youngest fully expanded leaf (YFEL) was one to two orders of magnitude lower (Table 3). Responses by mungbeans to Co, Ca or Fe have not been reported but based on studies with other legumes, one could expect that a deficiency of each element would be manifest in mungbeans as a N deficiency in shoots reflecting a depressed level of N_2 fixation in nodules.

Table 2. Nutrient constraints limiting seed yield of selected black and green gram crops. Unless otherwise indicated, only significant ($P<0.05$) responses listed. Responses to nitrogen were not considered.

Country	Soil Type	Maximum yield(MY) ($t\ ha^{-1}$)	Nutrient(s) or amendment omitted	Yield Depression		Comments	Reference
				($T\ ha^{-1}$)	% of MY		
			Green Gram				
India		0.88	P	0.21	24	MY-26 kg P ha^{-1}	Kothari
Indonesia	Latosol	1.44	Mg	0.18	13	MY-no added S or lime	Ismunaji et al. (1982)
Malaysia	Ultisol	0.78	Lime	0.31	40		Foster et al. (1980)
	Fluvaquent	0.39	Lime	0.15	39		Foster et al. (1980)
Thailand	Tropaqualf	3.06	B	0.83	27	MY-4 kg borax ha^{-1}	Predisripipat (1988)
	Paleustult	1.15	P	0.24	21	Means of 25 trials	FAO(1985)
			K	0.18	16		
			NPK	0.40	34		
			Black Gram				
Australia	Vertisol	1.48	P	0.39	26	MY-40 kg.P ha^{-1}	Eagleton et al. (1986)
India		1.20	P	0.29	24	MY-18 kg P ha^{-1}	Dhage et al. (1984)
		1.52	P	0.30	20	MY-20 kg P ha^{-1}	Panwar et al. (1977) Mahadkar and Saraf
Thailand	Tropaqualf	1.35	B	0.57	42	MY-10 kg borax ha^{-1}	Rerkasem et al. (1988)
	Tropaqualf	3.27	B	1.04	32	MY-4kg borax ha^{-1}	Predisripipat (1988)
	Paleustult	1.84	B	.95	52	MY-0.25 kg B ha^{-1}	Keerati-Kasikorn (per comm)
	Paleustult	1.21	B	1.08	89	MY-0.5 kg B ha^{-1}	Keerati-Kasikorn (per comm)
	Paleustult	1.07	Mo	0.24	22		Ratanarat (pers comm)
	Paleustult	0.57	Mo	0.17	30		

By contrast with Mo, the evidence for additional requirements by legumes for P and Cu is not so clear (Robson 1978). Whilst mungbeans are often grown on low P soils, and responses to P fertilizer are not uncommon (Rachie and Roberts 1974; Table 2), few studies provide any evidence that mungbeans have additional internal requirements for symbiotic N_2 fixation; one exception is the study by Ikombo (1989). In green gram, rates of P supply marginally lower than those required for near maximum growth, depressed N concentrations in shoots and induced N deficiency symptoms suggesting that sub-optimal P supply specifically depressed symbiotic N_2 fixation (Ikombo 1989). The issue of whether mungbeans have additional Cu requirements for symbiotic N_2 fixation can only be resolved by experimentation. In subterranean clover, mild Cu deficiency depresses growth by inducing N deficiency (Snowball *et al.* 1980) but by contrast, in peanut Cu deficiency did not specifically impair N_2 fixation (Nualsri 1977).

For the remaining elements (K, S, Mg, Zn, Mn and B), internal requirements for symbiotic N_2 fixation in legumes are generally similar to, or lower than those for host plant growth (Robson 1978), and are therefore independent of inorganic N supply.

In addition to their nutrient requirements for dry matter production, mungbeans have additional nutrient B requirements for seed quality (Bell *et al.* 1989). In black gram, B concentrations <6 mg B kg^{-1} DM may depress seed quality for sprouting by depressing its germination percentage. That the plants which produced the seed with impaired germination percentage contained adequate B for maximum seed dry matter, suggests that black gram required higher B concentrations for seed quality than for seed dry matter.

In black gram, low B concentrations in seed also depress the percentage of hard seed in plants grown in the glasshouse (Bell *et al.* 1989) and in

Table 3 Critical nutrient concentrations for the diagnosis of deficiencies and toxicities in black and green gram.

Element	Species	Plant Part	Sampling Time[A]	Critical Concn[B]	Source
			Deficiencies		
P	Green gram	YFEL[C]	R1	0.43	Ikombo (1989)
B	Black gram	YFEL	V5	14-17	Bell *et al.* (1990)
		Seed	Maturity	6	Bell *et al.* (1989)
	Green gram	YFEL	V2	16	Bell *et al.* (1990)
Mn	Green gram	YFEL	40 DAS	19	Bansal & Nayyar (1989)
Zn	Green gram	Shoots	42 DAS	19	Gupta & Mittal (1981)
Mo	Black gram	YFEL Nodule	R1-2	35 7000	Jongruaysap
		YFEL Nodule	R5-6	25-30 2500-3000	
	Green gram	YFEL Nodule	R1-2	90-130 3900-4300	McLay (1989)
			Toxicities		
Mn	Green gram	YFEL	22 DAS	800	Aswathappa (1989)
	Black gram	YFEL	22 DAS	277	" "

[A] Sampling times are in days after sowing (DAS) or growth stages after the convention of Fehr *et al.* (1973).
[B] Concentrations in % (P), mg kg^{-1} (B, Mn, Zn) and ng g^{-1} (Mo).
[C] Blade of the youngest fully expanded leaf

the field (Netsangtip personal communication). Since the level of hard seed is closely correlated with resistance to weathering in green gram seed (Imrie *et al.* 1988), these results could be particularly relevant for ensuring high levels of hard seed in green gram on low B soils. Further, they suggest that the B requirement for resistance to weathering of mungbean seed also exceeds that for seed dry matter.

External Nutrient Requirements

For mungbean production, external nutrient requirements concern both the concentrations of nutrients required in soils, and the amounts of fertilizers required for growth. The latter concern is of more immediate interest to mungbean producers, but the accurate prediction of fertilizer requirements will generally involve the development of soil tests in conjunction with fertilizer rate experiments. Unfortunately, few of the experiments which examined mungbean response to fertilizers have measured nutrient concentrations in the soil. As a consequenece, too few of the results can be confidently extrapolated beyond a limited set of circumstances. A useful model for future experiments on the external nutrient requirements of mungbeans is a study of the P requirements of soybean which related fertilizer P rates and bicarbonate-extractable P levels in the soil to grain yield in three successive years (Garside and Fulton 1986).

Numerous studies have reported responses of mungbeans to P fertilizer: optimum rates of P fertilizer generally range from 9 to 20 kg P ha^{-1} (e.g. Rachie and Roberts 1974; Lawn and Ahn 1985). In the Northern Territory, 225 kg superphosphate ha^{-1} (20 kg P ha^{-1}) is recommended on previously fertilized land but on virgin land the recommendation is for 350 - 400 kg superphosphate ha^{-1} (32-36 kg P ha^{-1}; Putland *et al.* 1982). Even higher rates of P fertilizer (44 kg P ha^{-1}) have been required on some lateritic soils in India (Lawn and Ahn 1985). By contrast, in central Queensland, no P fertilizer is recommended for dryland mungbean crops on soils fallowed for less than 12 months, and only 10 kg P ha^{-1} is recommended if a severe P deficiency exists (Daniels 1990). Preliminary evidence suggests that root infection by vesicular-arbuscular mycorrhiza may be important for supplying P requirements by green gram on Vertisols in central Queensland, especially after a short fallow (Hibberd, personal communication).

The marked variation in P fertilizer rate required or recommended for mungbeans illustrates firstly the importance of soil types and previous fertilization in determining P requirements, and secondly the need to relate the recommendations to a soil test value. One of the few attempts to do so is contained in a brief report by Eagleton *et al.* (1986) which indicates that on the alkaline Cununurra clay (Vertisol) in the Ord Irrigation Area, green gram is unlikely to respond to P fertilizer when bicarbonate-extractable P levels exceed 6-10 mg kg^{-1} and that annual applications of 10 kg P ha^{-1} barely maintain available soil P levels at this level.

Reports of responses by mungbean to other macronutrients in the field are scarce. In northeast Thailand, repeated cropping of an Oxic Paleustult induced severe K deficiency symptoms (Keerati-Kasikorn, personal communication). Potassium fertilizer is recommended in conjunction with N and P for mungbean production on Grey and Red Yellow Podzolic soils (Oxic Paleustults) in Thailand: recommended rates range from 35 kg K ha^{-1} on soils yielding >800 kg seed ha^{-1} when unfertilized to 50 kg K ha^{-1} on soils yielding <800kg seed ha^{-1} in unfertilized plots (FAO 1985). In the sub-tropical and tropical areas of Australia, low S levels are relatively common on the red and yellow earths and texture contrast soils (Bruce and Crack 1978). Moreover, Ca deficiency in subsoils may be a relatively common limitation to plant growth in virgin acid soils of tropical Australia (Edwards and Bell 1989). Thus, as mungbean production expands onto a wider range of soils, the need to consider the external requirements for K, Ca and S may be more important.

Zinc deficiency appears to be a relatively common problem for mungbean production in Australia because much of the present crop is grown on alkaline clays. A single soil application of 20-30 kg $ZnSO_4$ ha^{-1} appears to be effective for several years although thorough incorporation in the soil is important for effective correction of the Zn deficiency in the year of application (Daniels 1990). Mild Zn deficiency in a standing crop may be corrected by a foliar application at up to four weeks after emergence of 1 kg $ZnSO_4$ ha^{-1}.

In Thailand, B deficiency is a severe limitation for black gram, depressing seed dry matter on average by 50% (Bell *et al.* 1989; Rerkasem *et al.* 1988). The B deficient soils had hot water soluble B levels of 0.08-0.1 mg B kg^{-1} and ranged in properties from the silty clay loams in northern Thailand (Typic Ochraqualfs) to sand and loamy sands in northeast Thailand (Oxic Paleustults). Black gram and green gram responses to B have been related to soil B levels and critical concentrations have been developed (Table 5).

External nutrient requirements of mungbeans may differ among species and cultivars, especially in relation to micronutrient deficiencies and toxicities. Such differences among cultivars appear to be due to their differential ability to absorb and utilize nutrients from the soil. Randhawa and Takkar (1976) reported that some black gram cultivars exhibit tolerance to Zn deficiency. Similarly, green gram cv. Uthong 1 was markedly more tolerant of Fe deficiency than cv. Kamphaengsaen 1 in Thailand (Lawn *et al.* 1988). Black gram cv. Uthong 2 was extremely sensitive to B deficiency in Thailand whereas recommended cultivars of green gram, cvs. Uthong 1 and Kamphaengsaen 1 were relatively tolerant of low B soils. Because of the prevalence of low B soils in northern and northeast Thailand, black gram cultivars tolerant of low B soils are urgently needed; from preliminary screening some cultivars have been identified with greater tolerance than the current cultivars (Rerkasem, personal communication).

Table 4 Critical concentrations for the prediction of nutrient deficiencies or toxicities in greem gram or black gram grown in soils, solution culture or in the field.

Element	Species[A]	Growth Medium[B]	Plant Response	Method	Critical value	Source
			Deficiencies			
P	GG	Soil	Shoot DM	Soil solution	9.0 M	Ikombo (1989)
	GG	Soil	Seed DM	Soil solution	5.4 M	Eagleton et al. (1986)
	GG	Field	Seed DM	Bicarbonate	7 mg kg^{-1}	Fist et al. (1987)
	BG	FSC	Shoot DM	Solution	2.0 M	
Zn	GG	Soil	Shoot DM	DTPA+$CaCl_2$	0.5 mg kg^{-1}	Guppta and Mittal (1981)
			Shoot DM	0.1 M HCl	2.2 mg kg^{-1}	
Mn	GG	Soil	Shoot DM	DTPA	2.9 mg kg^{-1}	Bansal and Nayyar (1989)
B	GG	Field	Seed DM	HWSB	0.14 mg kg^{-1}	Bell et al. (1990)
	BG	Field	Seed DM	HWSB	0.1- 0.18 mg g^{-1}	
	BG	Soil	Shoot DM	HWSB	0.53 mg kg^{-1}	Sakal et al. (1985)
Ca	GG	Solution	Sprouting quality	Solution	5000 M	Liptay and Vandierendonck (1987)
			Toxicities			
NaCl	GG	Soil	Shoot DM	Sat. extract	3.5 dS m^{-1}	Keating & Fisher (1985)
	BG	Soil	Shoot DM	Sat. extract	5.0 dS m^{-1}	
Al	GG	Field	Seed DM	Al sat^{n}	5%	Wade et al. (1988)
Mn	GG	FSC	Shoot DM	Solution	1.7 M	Aswathappa (1989)
	BG	FSC	Shoot DM			

[A] GG - green gram; BG - black gram

[B] Soil - soil in pots; FSC - Flowing solution culture

Table 5. Standards for the prognosis of nutrient deficiencies from analysis of leaves of black gram. Values for the youngest fully expanded leaf blades (YFEL) are for samples taken at early flowering and are minimum concentrations of elements found in fieldgrown crops which produced seed dry matter > 1599 kg.ha^{-1}. From Bell *et al.* (1990).

Element	Plant Part	Critical Concentration
N (% DM)	YFEL	3.8
P (% DM)	YFEL	0.30
K (% DM)	YFEL	1.0
S (% DM)	YFEL	0.2
Cu (mg.kg^{-1} DM)	YFEL	4
B (mg.kg^{-1} DM)	YFEL	25-30
Mo (ng.g^{-1} DM)	YFEL	50

Diagnosis and Prognosis of Mineral Disorders

Mineral disorders that might limit mungbean seed production or seed quality must first be correctly identified or accurately predicted before appropriate corrective treatments can be applied. Responses to fertilizers or soil amendments, symptoms, soil analysis and plant analysis have all been used to diagnose or predict nutrient disorders in existing mungbean crops (Tables 2, 3, 4 and 5).

Procedures for the diagnosis of mineral disorders are essential, especially for growers who are new to the industry or when cultivars or soils are being used for the first time for mungbean production. They are therefore important for a new industry or one undergoing rapid expansion. However, the current season's crop production may already be severely depressed by the time a correct diagnosis is made. For producers, it is far more important to prevent mineral disorders by using reliable procedures that predict their likely development. All soil tests and some plant procedures are predictive for nutrient disorders. Predictive tests are developed on the presumption that potential yield is realised, but in practice, factors such as rainfall, pests, diseases etc may influence the actual production in any particular season. As a consequence, predictive tests are inherently more difficult to calibrate and interpret than diagnostic tests. Crop Response

Crop response to a fertilizer or soil amendment treatment is the best method of diagnosing a nutrient disorder in the field. It is the method most valued by producers, and is the standard against which all other procedures must be calibrated. Provided a number of precautions are exercised and good experimental technique is used, response of mungbean crops to application of fertilizer or soil amendment is a positive test for nutrient disorders. Few such studies have been conducted in Australia. By contrast there are more extensive reports of responses by mungbean in South and Southeast Asia to macronutrients, micronutrients, mixed fertilizers or lime (Table 2).

Treatment of control plots so that they achieve their yield potential is the most important of the precautions to take with field experiments to diagnose mineral disorders. Achieving maximum potential involves choosing appropriate cultivars, agronomic practices, effective rhizobia strains, optimum supply of macronutrient and micronutrient fertilizers, and where appropriate, amendments for soil acidity, alkalinity, or sodicity. Lawn (1979) has illustrated the importance of adjusting the plant density according to cultivar and sowing date in order to maximize yield. Choosing appropriate rates of nutrients may be difficult when there is no prior experimental data in an area. A first approximation to the fertilizer requirements can be obtained from those used for comparable crops as is the case in central Queensland where the fertilizer recommendations for soybean are also used for mungbeans (Daniels 1990). In doing so, the researcher should be aware that among species and cultivars large differences exist in sensitivity to deficiencies and toxicities. Thus for example, in the central highlands of Thailand, on Typic Calciustolls (pH 7.9; Parkpian *et al.* 1988), green gram cv. Kamphaengsaen 1 was acutely Fe deficient whereas cv. Uthong 1 was entirely free of Fe deficiency symptoms (Lawn *et al.* 1988). On these soils, research on the response of green gram cv. Kamphaengsaen 1 to macronutrients or other micronutrients besides Fe would prove entirely fruitless.

Fertilizer placement or the method of its application may be as important as the rate in obtaining crop responses. In areas where the surface soil dries intermittently during the growing season due to extended periods without rainfall, placement of fertilizer close to the soil surface may result in poor responses because of the crop's inability to absorb the nutrient from dry soil as was the case for Cu treatment of wheat in Queensland (Grundon 1980) or P treatment of lupins in Western Australia (Jarvis and Bolland 1990). Similarly, crops may show poor responses to surface lime application when the primary constraint to crop growth is sub-soil acidity (e.g. Cregan *et al.* 1989).

Obtaining reliable crop responses to micronutrient deficiencies is more difficult than that with macronutrients, but is possible with appropriate precautions, the main ones being the use of fertilizers free of micronutrient contamination, and in the case of Mo and Ca, the use of seed with low contents of these elements (Bell *et al.* 1990).

Symptoms

Plants suffering nutrient deficiencies or toxicities often exhibit distinctive symptoms which can be used to diagnose the disorder. Descriptions and colour photographs of nutrient deficiencies and toxicities have been published for green gram (Smith *et al.* 1983); in addition descriptions and photographs of B deficiency and toxicity and of Mo deficiency in black gram are available (Bell *et al.* 1990). However, diagnosing nutrient disorders from plant symptoms has its limitations and the reader is referred to Robson and Snowball (1986) for a discussion of them.

Plant Analysis

Plant analysis may be a simple, reliable and rapid method for the diagnosis of nutrient disorders in farmers' mungbean crops provided appropriate diagnostic standards have been developed, appropriate parts of the plant are sampled and precautions are taken to avoid contamination of the samples. Precautions for avoiding contamination of plant samples are particularly important for the diagnosis of micronutrient deficiencies (Bell *et al.* 1990). For the diagnosis of nutrient disorders in mungbean, the blade of the YFEL is the recommended plant part for all elements examined (Table 3). Nodules are also suitable for the diagnosis of Mo deficiency but are not preferred because of the difficulty of reliable sampling. For B deficiency, the YFEL should be sampled to diagnose deficiency in the shoots during crop growth, and the seed analysed to diagnose deficiency for seed germination.

Plant analysis standards have been developed for the diagnosis of Mn toxicity and deficiencies of most micronutrients in green and black gram but of the macronutrients, standards exist for only P deficiency diagnosis in green gram (Table 3). Whilst for B, critical concentrations in the YFEL were comparable in green and black gram, for Mo the values were markedly different between the two species (Table 3). Thus, in the absence of suitable standards for one of the species, values developed for the other should be used with caution in making a diagnosis. Caution should also be exercised in using the above critical values for diagnosis of disorders (Table 3) at growth stages other than those tabulated. Whilst the critical concentrations in the YFEL for B deficiency diagnosis were constant from early vegetative to early pod set, those for P deficiency diagnosis declined with plant age from 0.69% at 15 days after sowing (DAS) to 0.43% at 40 DAS (Ikombo 1989).

Plant analysis standards for the prognosis of nutrient deficiencies for seed yield in black gram have been proposed by Bell *et al.* (1990). These standards should be regarded as tentative values for black gram; they were developed from studies in Thailand and are the minimum concentrations of elements in the YFEL at early flowering in black gram crops which subsequently produced >1500 kg seed ha^{-1} (Table 5). By contrast with the leaf analysis standards for diagnosis which are expected to be valid for most crops and locations, those for prognosis may vary with seasonal factors which limit the realization of potential seed yield, and soil factors which control the supply of nutrients to the plant after leaf sampling (Craswell *et al.* 1987).

Soil Tests

When soil tests are used to predict fertiliser requirements they are, like predictive plant tests, more difficult to calibrate and interpret than diagnostic tests. However, when properly calibrated and used prior to the planting of a mungbean crop, they have the potential to predict the probability of a disorder and the amount of fertilizer or soil amendment required to correct it (Craswell *et al.* 1987). Unfortunately, few critical concentrations have been established for the prognosis of nutrient disorders in mungbean by soil analysis (Table 4).

As with prognostic plant tests, a number of precautions must be exercised for accurate prognosis of nutrient disorders from soil analysis (Craswell *et al.* 1987). Firstly, critical values are usually related to potential yield rather than actual yield. The farmer can then choose from a range of fertilizer options according to the yield expected, the probability of obtaining it and the costs of fertilizer inputs required. Secondly, soil tests are empirical and are generally useful only if the amount of the nutrient extracted by the test is correlated with crop response. As the ability of the soil test to extract plant available nutrients may vary among soil types, critical values for soil tests may be limited to particular soil types. This may explain why Bell *et al.* (1990) have reported that the critical levels of hot water soluble B in neutral-acid sands and loams of Thailand (0.10-0.18 mg kg^{-1}) were much lower than that reported by Sakal *et al.* (1985) for calcareous loams and clay loams of Bihar province, India (0.53 mg kg^{-1}).

Thirdly, as plant species and cultivars may differ greatly in their capacity to absorb nutrients from the same soil, critical levels for soil tests may be limited to the particular cultivar for which it was developed. This limitation is particularly important on soils where low availability rather than an absolute deficiency of the nutrient limits uptake as is the case with Fe or Zn deficiency in many calcareous soils.

Edaphic Limits for Mungbeans

The growth of mungbeans on a wide range of soils (Lawn and Ahn 1985) probably reflects the fact that they are often grown on an opportunistic basis with low levels of input. Like many crops, however, mungbeans perform best on well-drained loams and sandy loams (Rachie and Roberts 1974). Accordingly, in the Douglas-Daly region of the Northern Territory, good mungbean crops are grown on neutral red earths (Paleustalfs) with sand to clay loam topsoils grading to clay loam to medium clays at depth (Putland *et al.* 1982). By contrast, most of Australia's mungbean crop is grown on heavier textured soils in the Darling Downs and Central Highlands of Queensland and central and northwestern New South Wales (Lawn *et al.* 1988).

Neither green nor black gram are tolerant of waterlogging (Rachie and Roberts 1974) especially prior to emergence although black gram germplasm exhibits some tolerance to waterlogging which may account for its better performance on heavy clay soils (Lawn and Ahn 1985). Among the mungbean cultivars grown commercially in Australia all of the green gram cultivars have poor tolerance of waterlogging whilst black gram cv. Regur exhibits only fair tolerance (Lawn *et al.* 1988). By contrast, Hamblin (1987) listed mungbeans as slightly tolerant of waterlogging and Hodgson *et al.* (1989) reported that green gram cv. Berken was tolerant of waterlogging when subject to 32h cycles of furrow irrigation on a Vertisol at Narrabri, NSW. Different rankings of mungbeans for tolerance to waterlogging may arise from the failure to distinguish between the tolerances of green and black gram or between those of established plants compared to seedlings or pre-emergent plants, and to differences in the duration of the waterlogging event.

Mungbeans are reported to be well adapted to alkaline and to saline soils (Rachie and Roberts 1974). However, many cultivars are sensitive to Fe deficiencies on alkaline, calcareous soils (Field and Kameli 1987; Lawn *et al.* 1988; Parkpian *et al.* 1988). Moreover, two recent studies suggest that mungbeans may be less tolerant of saline soils than previously reported (Ashraf and Rasul 1985; Keating and Fisher 1985). In a sandy loam soil treated with increasing levels of NaCl to establish electrical conductivities ranging from 1.3 to 13.8 dS m^{-1}, both green and black gram were more sensitive to salinity than soybean and markedly more so than guar and cowpea (Keating and Fisher 1985). However, the relevance of these results to effects of salinity on seed yield in the field are not clear. Firstly, plants were supplied with inorganic N whereas many legumes, but not all, are more sensitive to salinity when dependent on symbiotically fixed N (Robson 1988). Secondly, the heavy clay soils on which much of Australia's mungbean crop is grown, have moderate to high salt levels at lower depths in the profile rather than at the surface where most of the nodules exist (Keating and Fisher 1985).

The adaptation of mungbeans to acid soils appears to vary with species and cultivars and with the particular mineral constraint associated with soil acidity. By comparison with rice, corn, cowpea, peanut and soybean, green gram was markedly more sensitive to Al toxicity on acid soils in W. Sumatra, Indonesia (Wade *et al.* 1988). In another study on acid soils, decreasing pH to 4.5 (1:1 H_2O) depressed shoot dry matter when plants were reliant on symbiotically fixed N, but when supplied with inorganic N, growth of only some cultivars was depressed (Munns (1986). However, in acid soils where the problem is high levels of manganese (Mn) rather than Al, flowing solution culture studies by Aswathappa (1989) suggest that green gram may be appreciably more tolerant than black gram, cowpeas, soybean and comparable in tolerance to peanut.

Conclusions

Mineral constraints for mungbeans in Australia should be avoided not only because of the lost production from a particular crop, but also because it damages the confidence of new producers in a way that may limit the expansion of the industry. To avoid acute deficiencies it is important to know about the nutrient requirements of mungbean species and cultivars, how they compare with other field crops, and their response to agronomic practices and soil conditions.

Raising yield potential of mungbean crops in Australia by increasing both genetic potential and improving cultural practices will probably increase the frequency of responses to the alleviation of nutrient constraints. Moreover, it will probably change the focus of research and extension from diagnosis of acute disorders which prevent or severely limit growth of mungbeans to the development of management models which allow the prediction of fertilizer rates that will give the most economic returns on investment. Furthermore, the range of treatments applied to a mungbean crop capable of producing 2,000 or more kg seed ha^{-1} will differ from those considered for crops capable of producing only 500 kg ha^{-1}.

In the immediate future, the prevalence of mungbean production on the alkaline clay soils in Queensland and NSW suggests that nutritional research should concentrate on deficiencies of P, Zn and Fe and on salinity. It should include a determination of fertilizer requirements and their residual value, their relationships to soil types, fertilizer history and soil test values. Plant analysis standards should be developed in conjunction with soil tests. Such studies should consider the effect of symbiotic associations of plants with VA mycorrhiza and rhizobium on P, Zn and Fe requirements. They should also consider the magnitude of cultivar differences in ability to tolerate nutrient constraints, particularly those of Fe and Zn deficiencies and salinity. In the longer term, expansion of mungbean production onto a wider diversity of soils will expose mungbeans to a wider range of nutrient constraints more common on sandy soils such as K, S, B, Cu and Mo deficiencies or those associated with acid soil infertility including, deficiencies of Ca or Mn and toxicities of Al or Mn.

Acknowledgements

Much of the research reported was supported by the Australian Centre for International Agricultural Research (ACIAR Project 8329/8603). The author is grateful to colleagues, B. Rerkasem, P. Keerati-Kasikorn, S. Ratanarat and S. Jongruaysap for permission to quote unpublished data.

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