EFFECTS OF STOCK PLANT AGE AND FERTILISER APPLICATION AT PLANTING ON GROWTH AND FORM OF CLONAL *ACACIA* HYBRID

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BON PV & HARWOOD CE. 2016. Effects of stock plant age and fertiliser application at planting on growth and form of clonal *Acacia* hybrid. Some *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) plantations in Vietnam are prone to heavy branching and poor stem form. The age of the stock plants used to produce cuttings for clonal propagation and/or high rates of fertiliser application at planting have been suggested as causal factors. Their effects on growth, stem form and branch size of three *Acacia* hybrid clones were examined in south Vietnam. Experimental treatments were: (1) fertiliser: F-0 (no fertiliser) and F-H (high fertiliser, i.e. a mix of superphosphate and NPK (nitrogen–phosphorus–potassium) fertiliser in the planting hole at rates equivalent to 16, 45 and 8 g tree^{-1} of N, P and K respectively) and (2) planting stock raised from cuttings taken from stock plants aged 1 and 4 years. Stock plant age had no effect on growth and form traits, nor were there differences between clones. Fertiliser increased growth during the first three years, but by age 4 years, had no significant effect on stem diameter or stand volume. The high dose of fertiliser at planting significantly increased the proportions of trees requiring singling and form pruning, the diameter of the largest branch in the 1–2 m stem height interval, and the severity of stem bending and breakage. High doses of fertiliser at planting should be avoided for *Acacia* hybrid plantations.

Keywords: Branch size, pruning, singling, stem straightness, stem breakage

INTRODUCTION

Clonal plantations of the hybrid between *Acacia mangium* and *A. auriculiformis* (termed *Acacia* hybrid here) now total over 500,000 ha in Vietnam (Nambiar et al. 2015). They are grown primarily to produce pulpwood on short (4 to 7 years) rotations. Some growers extend the rotation to 7 years or more to obtain a proportion of the harvest as small sawlogs, which fetch two to three times the price of pulpwood once log diameter exceeds 18 cm.

Commercial planting stock of *Acacia* hybrid is produced in clonal nurseries by rooting stem cuttings from gardens of stock plants established from plantlets raised in tissue culture (Kha et al. 2012). Repeated shoot harvesting maintains the height of the stock plants at about 0.8 m. Plants raised from cuttings lack strong apical dominance and usually develop multiple stems at ground level. Multiple-stemming increases stocking and, thus, reduces stem diameter at harvest and the potential of a stand to yield sawlogs. To avoid this, saplings are singled to leave a single leader at 4–6 months when they are 1–1.5 m tall. Some growers follow this up with form pruning (Beadle et al. 2007) when trees are 3–4 m tall, removing any competing leaders emerging from the main stem to reduce the incidence of forking and improve stem straightness. In commercial forestry, straight stem is an important management goal and factors which may induce stem deformation, heavy branching and stem breakage are to be avoided.

Several management practices affect crown and branch development and stem form in young *Acacia* hybrid plantations. Among these are choice of genetic material (clones), age and physiological condition of stock plants, dose and application method of fertiliser and initial plantation stocking density. In this study, we examined effects of the first three variables.

The first *Acacia* hybrid clones selected for commercial planting in Vietnam did not differ significantly in branching traits in initial trials (Kha 2001). However, Hai et al. (2008) reported genetic differences in stem straightness and branch thickness (branch diameter relative to stem diameter) among 130 clones of *A. auriculiformis* in three clone trials in Vietnam, showing that genotype can affect stem and branch form in tropical *Acacia* species. Vietnamese government guidelines recommend that *Acacia* hybrid stock plants should be replaced after 3 years, and there are anecdotal accounts that use of planting stock from cuttings taken from older stock plants can result in poor stem and branch form.

In Vietnam, 0.1–0.2 kg of NPK (nitrogen–phosphorus–potassium) fertiliser per tree (16:16:8 formulation), equivalent to 16–32 g P per tree, is commonly applied at planting (Kha 2001, Beadle et al. 2013b, Nambiar et al. 2015), and some growers also apply composted animal manure. However, many small growers may apply lower doses of fertiliser or none at all. Higher rates of fertilisers containing N, P, K and trace elements (up to 45 g P/tree at planting) have been applied in experiments investigating sawlog production on short rotations (Beadle et al. 2013a) in which stem deformation and heavy branching have been observed. High fertiliser application can lead to increased branch size and deformity of the main stem in other tree species. For example, N and P fertiliser increased the size and longevity of branches in *Eucalyptus nitens* (Wiseman et al. 2006) and N fertiliser increased basal area in *Pinus radiata* plantation by 45%, but also increased the incidence of stem deformity from 12 to 56% (Hopmans et al. 1995).

The experiment reported here tested the effects of stock plant age and a high rate of fertiliser application at planting on the development of branch and stem form in young *Acacia* hybrid plantations.

MATERIALS AND METHODS

Site and plantation establishment

The study was conducted at the Nghia Trung Research Station of the Vietnamese Academy of Forest Sciences, Binh Phuoc Province, South Vietnam (11° 61' N, 107° 10' E, 270 m elevation). Records from nearby meteorological stations indicate a mean annual temperature of approximately 27 °C and a mean annual rainfall of 2450 mm, with a pronounced dry season from December to May. The soil is clay loam derived from basalt parent material. Soil sampled at an experimental site 100 m from the trial (Beadle et al. 2013a) had the following properties in the 0–10 cm soil layer: clay 21%, silt 58%, sand 21%, pH H_2O 4.34, organic C 3.94%, total N 0.22%, Bray-1 extractable P 2.32 ppm and cation exchange capacity for Ca and K 0.072 and 0.205 cmol kg^{-1} respectively.

The experimental site, which had a slope of about 10°, was previously under degraded natural vegetation following timber harvesting from the native forest. This had been cleared by bulldozer several years previously but then left fallow, and bamboo and low scrub had regenerated. The regrowth vegetation was cut, and slash was retained and aligned between the planting rows, leaving 10 clear planting rows along the slope contours, spaced 3 m apart. Tree spacing along the planting rows was 3 m, giving a plantation spacing of 3 m × 3 m, equivalent to a planting density of 1111 stems ha^{-1}. Planting hole size was 40 cm × 40 cm × 40 cm. The experiment was planted in July 2011.

Experimental design and treatments

The treatments were (i) two at-planting fertiliser treatments and (ii) two stock types, tested on three *Acacia* hybrid clones. The fertiliser treatments were F-0 (no fertiliser) and F-H (100 g NPK (16:16:8) plus 403 g per tree superphosphate; total nutrients equivalent to 16 g N, 45 g P and 8 g K per tree). Fertiliser was spread at the bottom of the planting hole and then backfilled with soil before planting, in accordance with local practice. Three commercially planted clones (BV10, BV32 and BV33) were supplied by the Vietnamese Academy of Forest Sciences Regional Centre at Trang Bom, Dong Nai Province. Stock was raised from tip cuttings prepared from young shoots harvested from stock plants of two ages: young (1-year) and old (4-years). Cuttings were rooted in a misting chamber and then grown in the nursery to a height of 30 cm at planting. The trial was laid out in randomised split-plot factorial design with four replicates. The main plots (net 48 trees, 8 × 6) tested the fertiliser treatments, while the subplots (net 24 trees, 8 × 3) tested the stock-type treatments (Figure 1). Clones were represented by 8-tree line plots (net sub-subplots) within each subplot. Net main plots were each separated by two additional buffer rows. A single perimeter row in which trees received treatments applied in adjacent plots surrounded the experiment.

Stand management

At planting and for 4 weeks thereafter termites were controlled by applying insecticide. After 1 month, dead seedlings were replaced with corresponding stock. Weeds were controlled manually during the first 6 months and subsequently by glyphosate herbicide applied twice per year at a rate of 4 L ha^{-1} (equivalent to 1.92 kg ha^{-1} active ingredient), together with a wetting agent at 0.1 L ha^{-1}.

Singling (cutting of competing leaders at ground level) and form pruning (to remove competing leaders emerging from the main stem, above ground level) were undertaken where necessary 4 months after planting, and again at 8 months after planting.

Measurements and assessments

At age 4 months, before singling, each tree was photographed at a standard distance. A black screen with a scale was placed as background to improve visibility of the crown (Figures 2a, c). Height and crown width of each tree were subsequently estimated from digital photographs and the ratio of height to crown width calculated for each tree. The number of phyllodes that had expanded to at least 50% of mature phyllode length on each tree at 4 months was counted and the tree was assigned to one of four categories: 1, 2, 3 and 4, with 1–10, 11–50, 51–100 and >100 expanded phyllodes respectively. The numbers of branches removed from each tree by singling and form pruning were recorded during both pruning operations.

Stem and branch form were assessed using two criteria, namely, branch diameter and stem kink score. On each tree, the diameter of the largest branch in the height interval 1–2 m was measured 5 cm from the branch collar using dial-gauge callipers at 24 and 36 months. Stem kink was assessed at 36 months on a four-point score as follows: (1) nil, (2) slight kinks, (3) larger kinks but stem deviation stays within the stem centre line and (4) stem deviation beyond

10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10
10	10	32	33	32	33	10	10	10	10	32	33	33	32	10	10

4-year-old hedges	1-year-old hedges	1-year-old hedges	4-year-old hedges
Main plot (fertiliser treatment) P 0		Main plot (fertiliser treatment): P 50	

(Direction of slope contours) ⟶

Figure 1 Layout of the trial; net main plots (fertiliser treatments) had 48 trees (8 rows × 6 columns) and were separated by two buffer columns, net subplots (hedge plant treatments) had 24 trees (8 rows × 3 columns); sub-subplots were 8 trees of a single clone (BV10, BV32 or BV33) the stem centre line (Beadle et al. 2007). At 24 months, following several storms, main stems of some trees were broken, and this was scored as binary trait, i.e. 0 (stem unbroken) and 1 (stem broken).

Stem diameter at breast height (dbh) and tree height were measured at several intervals. Wood volume over bark, down to a small-end diameter of 4 cm, was estimated for each individual tree from dbh at 48 months, using the allometric relationship:

$$V = 0.0002 \times dbh^{2.4174}$$

where V = volume in m^3 and dbh = in cm. This equation was derived from measurements on 35 *Acacia* hybrid trees with dbh ranging from 8 to 23 cm, grown in plantations in central and southern Vietnam, and accounted for 98.6% of the variance in volume in the sample trees (personal observation). Stand volume in each main plot was then calculated by summing individual volumes of all surviving trees and expressed on per ha basis.

Statistical analysis

Individual-tree data were analysed with treatment effects in factorial combination and a nested blocking structure (replicate/plot/subplot/clone sub-subplot) using the ANOVA directive in Genstat release 12. The effect of fertiliser on volume ha^{-1} was also analysed using ANOVA, but using plot data and replicate as the sole blocking factor. Residuals were distributed normally and transformations were not required. The effects of stock plant age and fertiliser treatments on survival to 4 years, the proportions of trees which required pruning and singling and which had broken stems at age 24 months were tested using Fisher's exact test.

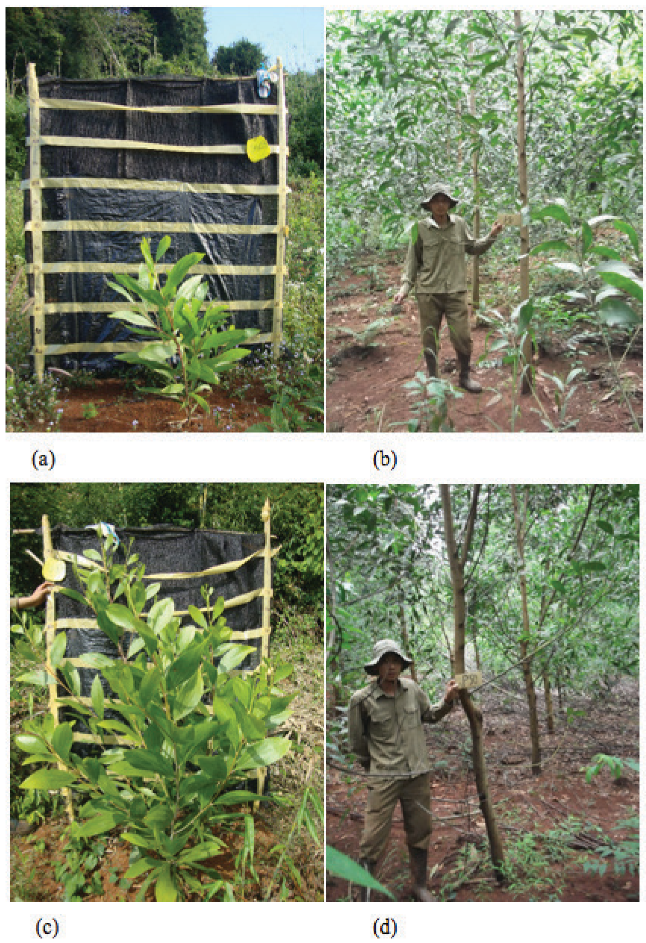

Figure 2 (a) Typical tree in F-0 (no fertiliser) plot at age 4 months, (b) tree row in F-0 at 24 months, (c) typical tree in F-H (high fertiliser) plot at age 4 months and (d) tree row in F-H plot at 24 months

RESULTS

Mortality due to termite attack in the first month was less than 2%. At 4 months, fertilised trees were significantly ($p < 0.05$) taller (1.3 m) than unfertilised trees (0.8 m) (Table 1). The height to crown width ratio was not affected by fertiliser.

Fertilised trees had many more phyllodes than unfertilised trees, reflected in the significantly higher mean phyllode number score (Table 1). Figures 2a and c illustrate the heavier crowns resulting from the F-H treatment at age 4 months. Stock plant age had no effect on early growth, height to crown width ratio or phyllode number. The height to crown width ratio was significantly ($p < 0.05$) higher for clone BV10 (1.6) than for clones BV 32 and BV 33 (1.3 and 1.4 respectively). Interactions among the treatment factors were not significant for growth and form at 4 months.

Trees receiving fertiliser required more pruning (Table 1). The percentage of F-H trees requiring singling at 4 months, 8 months or at both of these times was 74% for F-H trees and 66% for F-0 trees, while 77% of F-H trees required form pruning compared with only 59% of F-0 trees. These proportions differed significantly. However, the mean number of branches removed per tree did not differ significantly between F-0 and F-H treatments. Stock plant age and clone did not influence the pruning requirement.

Fertiliser increased growth during the first 3 years, but its effect declined over time. At 8 months, the F-H trees were almost twice as tall as F-0 trees, but by age 2 years, there was no difference in height between them (Table 1). The dbh of fertilised trees was significantly higher over 1–3 years but by age 4 years the difference between the F-0 and F-H trees (0.7 cm) was no longer significant. Stock plant age had no effect on growth rates or other attributes (data not

Table 1 Effects of fertilizer at planting on acacia growth and form traits. Fertilizer treatments are F-0 (no fertilizer) and F-H (high rate of fertilizer applied at planting)

Trait	Age (months)	Fertiliser treatment		Significance of difference
		F-0	F-H	
Height	4	0.8	1.3	**
	8	1.6	2.9	**
	12	3.7	5.3	***
	24	8.7	8.7	ns
	36	10.8	10.7	ns
Dbh	12	2.9	5.0	**
	24	8.0	9.2	*
	36	11.0	11.9	*
	48	12.5	13.2	ns
Stand volume (m^3 ha^{-1})	48	96.0	105.0	ns
Survival (%)	48	92	88	ns
Phyllode number score	4	2.0	3.2	**
Singling (% singled)	4, 8	66.0	74.0	*
Form pruning (% pruned)	4, 8	59.0	77.0	***
Number of branches per tree removed in form pruning	4, 8	1.4	2.1	ns
Diameter of largest branch (cm)	24	1.7	2.2	*
1–2 m stem height interval (cm)	36	1.7	2.4	*
Stem kink score	36	2.7	3.3	*
Trees with broken stem (%)	24	6.0	15.0	**

F-0 = no fertilizer, F-H = high rate of fertiliser applied at planting; ns = not significant, * = $0.05 < p < 0.01$, ** = $0.01 < p < 0.001$, *** = $p < 0.001$; dbh = diameter at breast height shown) and the three clones grew at very similar rates. Interactions between treatment factors were not significant, except for that between clone and stock type for dbh at age 36 months ($p < 0.05$).

Overall survival to age 48 months was 90%, with no significant treatment effects. Stand volumes at age 48 months were 104 m^3 ha^{-1} for F-H and 96 m^3 ha^{-1} for F-0, but the difference in stand volume was not significant (Table 1). Fertiliser had significant effect on form traits (Table 1). At age 2 years, dbh of the largest branch in the 1–2 m stem height interval was 1.7 cm for F-0 and 2.2 cm for F-H, and this effect remained significant ($p < 0.05$) at 3 years. Significantly ($p < 0.01$) higher proportion of F-H trees also had broken stems at 2 years and stem kink score of F-H trees was higher ($p < 0.05$) at 3 years than that of F-0 trees (Table 1, Figure 2b, 2d) Hedge plant age and clone had no direct or interactive effects on form traits.

DISCUSSION

In this study hedge plant age had no effect on growth, stem form or branch form although we used hedges one year older than the recommended 3-year working life. The absence of age effect was consistent for the three clones tested, which are widely planted in Vietnam (Kha et al. 2012). This consistent result suggests that the working life for *Acacia* hybrid hedge plants could be extended beyond the current recommended period of 3 years, if needed. However, in addition to hedge age, hedge physiological status, as affected by environment and management, and also the type of cuttings harvested are known to influence the success of rooting and the subsequent performance of rooted cuttings in many tree species (Leakey 2014) and may do so in *Acacia* hybrid.

Mean annual increment at 4 years was 25 m^3 ha^{-1}, similar to that reported in commercial *Acacia* hybrid plantations in south-eastern Vietnam (Harwood & Nambiar 2014). Although high fertiliser application at planting increased early height and dbh growth, this response was not sustained to age of 4 years.

Judicious fertiliser application may be needed to sustain growth in *Acacia* plantations, particularly in the second and subsequent rotations. Declines in soil extractable P have been observed in second-rotation plantations of acacias in Indonesia and Vietnam (Hardiyanto & Nambiar 2014, Huong et al. 2015), although both studies noted that currently used measures of soil P availability such as Bray-1 extractable P, may not accurately represent the levels of soil P available to acacias. An experiment in a second-rotation *Acacia* hybrid plantation in central Vietnam tested response to P at planting applied as superphosphate, at rates of 0, 10 and 20 kg elemental P per tree, with another treatment receiving 20 g P and 10 g K as KCl at planting followed by a further 40 g P per tree 1 year after planting. Differences in productivity among these treatments were small but significant ($p < 0.05$) at age 5 years, with the mean annual increments of the zero fertiliser, the10 g P and the 20 + 40 g P + 10 g K treatments being 18.0, 21.0 and 21.9 m^3 ha^{-1} $year^{-1}$ respectively (Harwood et al. 2014). Superphosphate equivalent to 18 g P per tree applied at planting in a third-rotation *A. auriculiformis* experiment in southern Vietnam resulted in small but significant increases in dbh (12.6 compared with 12.2 cm for the unfertilised treatment) and stand volume (186 compared with 169 m^3 ha^{-1}) at 6 years (Huong et al. 2015). In a third-rotation *A. mangium* experiment in Sumatra, Indonesia, 36 g P per tree as superphosphate at planting resulted in slight but non-significant response in dbh over an unfertilised treatment at 3 years (17.4 cm compared with 16.4 cm) (Hardiyanto & Nambiar 2014). Results of all these trials and others in Sumatra (Mendham & Hardiyanto 2011) suggest that on a range of soil types, application of a small dose of P (10–15 g per tree) is sufficient for tropical *Acacia* species in short rotations. Based on this study and the other research reviewed here, there is no reason to resort to high rates of fertiliser application for healthy *Acacia* growth in South-East-Asia.

Higher proportions of fertilised trees required singling and/or form pruning during the first year. Despite these pruning operations, the F-H trees had significantly larger branch diameter at age 2 years and greater severity of stem kinks at age 3 years (Table 1, Figure 2). Both traits would lead to greater incidence of log defects. The F-H trees had heavier crowns, making them more susceptible to stem bending and breakage during storms which occurred during the second year after planting. Higher rates of stem breakage in the F-H treatment during the second and third years after planting and the associated loss of foliage in the broken trees would have contributed to the subsequent decline in growth advantage relative to the F-0 treatment. Wounds associated with these higher rates of stem breakage and with heavy branches in the lower stems of F-H trees (whether pruned or not) could also increase the risk of infection by serious diseases such as stem wilt/canker *Ceratocystis acaciivora* (Tarigan et al. 2011). Poor stem and branch form similar to that in this study have been observed following high fertiliser application in other trials of *Acacia* hybrid in Vietnam (Beadle et al. 2013a), and the results here partly explain these observations.

The adverse effect of the F-H treatment on stem and branch form may have been strengthened by the application method. Applying all the fertiliser at the bottom of the planting hole in one dose results in most of the root system of the young plants being exposed to high concentrations of solutes in the soil–root environment during the first few months after planting. Had such application been in split doses or in bands on the soil surface, effects may have been less pronounced. It is concluded that heavy fertiliser application at planting is undesirable for tropical *Acacia* plantations.

CONCLUSIONS

Growth, stem and branch form of planting stock raised from 1- and 4-year-old hedge plants of three *Acacia* hybrid clones did not differ. A high dose of mineral fertiliser at planting added to the planting holes resulted in an early growth response but no significant increase in dbh or wood volume at age 4 years. However, the high dose of fertiliser at planting resulted in greater pruning requirement and induced poorer stem form, heavier branches and more frequent stem breakage.

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