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The Effects of Different Cutting Heights, Mulching and Burning on the Control of Bellyache bush (*Jatropha gossypifolia L.*) Applicable in East Timor

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature : --

Date :

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Abstract

Since bellyache bush invaded to East Timor it has significantly reduced crop and animal production and consequential loss of income from farm enterprises. Methods of control of bellyache bush chosen should be appropriate to the poor economic position of the farmers. An integrated method of controlling bellyache bush involving slashing combined with mulching and or burning is low cost and is widely used by the Timorese farmers. Although these practices are commonly used to control weeds, there are still many problems that appear in the field during and after weed control. For instance, rapid regeneration of cut stems and production of less fuel than mixed stands to support burning management.

Therefore, the objective of this study is to investigate mechanical control such as cutting stems at different heights and cutting stems at different heights in combination with mulch, hand-pulling and mulching of small plants and mulching of seedlings. This study also investigates bellyache bush properties as a fuel for burning management in the late dry season to control its infestations.

Mechanical control of bellyache bush plants was undertaken south of Darwin at Acacia ($12^0$45'S, $131^0$09'E) which has an annual average rainfall of 1588.1 mm and Channel Island (12º33'S, 130º51'E) which has annual rainfall of 1713.9 mm. This study was conducted from January 2007 to February 2008. All bellyache bush plants were cut off at different heights according to treatment 0cm (ground level), 10cm, 20cm, 30cm, 40cm and uncut plants considered as a control.

The results indicated that all cutting treatments achieved 100% mortality under low canopy cover, irrespective of season. While, under high canopy cover bellyache bush plants only achieved 100% mortality if cut at 0cm and 10cm height. Stems cut at 20cm, 30cm and 40cm heights re-sprouted in the dry season. Hand-pulling completely killed small plants while mulching did not. Mulching achieved a partial kill of seedlings however it stimulated seedling emergence in the wet season, irrespective of site.

The use of bellyache bush as a fuel for burning management was studied. The study was undertaken at Channel Island, Acacia and Katherine (14º22'S, 132º09'E). The latter has a mean annual rainfall of 875 mm. All bellyache bush plants in the plot were cut in May. Five 1m x 1m quadrat samples were selected within a 10m x 10m plot to measure wet weight and dry weight for the curing rate calculation. In addition, 15 of the cut stems were randomly selected to measure re-sprouting. From five randomly selected 25cm x 25 cm quadrat samples were taken to calculate the weight of fine fuel (less than 6mm in diameter), medium (6mm-25mm) and coarse (greater than 25mm). Heat yield of fuel combustion of this material was calculated by using a bomb calorimeter (As 10-38.5 leco 350 calorimeters).

The results indicated that cut stems of bellyache bush from a low canopy cover site had 7 percent moisture content while stems from a high canopy cover site had a 66 percent moisture content by the end of the dry season. The proportion of these stems in the site with low canopy cover re-sprouted significantly less than those in the high canopy cover site. The fuel load at bellyache bush monoculture had less fine, medium and coarse fuel compared with tropical savanna fuel. However, results from this study indicated that it had a similar heat yield of combustion to other plants in the tropical savanna.

A study of the use of fire as a control tool for bellyache bush was undertaken at Acacia and Katherine from May 2007 to February 2008. This study was carried out on established plants of bellyache bush. The experiment was undertaken in three 10m X 10m plots at each of the two sites. The experiment consisted of three treatments namely: cutting stems at 30 cm and followed by burning, uncut plants plus burning and unburnt plants considered as a control. Each of 20 pieces of bellyache bush stems were randomly selected for fine 0-6 mm, medium 6-25 mm and coarse 25 mm fuel. All these pieces were weighed before and after fire to calculate fuel consumption. Fire intensity was calculated by using Byram's fire intensity equation. Fifteen soil temperature sensors were buried under uncut plants before burning. After burning all soil temperature sensors were dug out the temperature read and used to calculate fire temperature. Plant mortality was calculated by counting live bellyache bush plants before and after fire. Seed germination and seed recruitment was calculated by counting all seedlings within five 1m x 1m randomly chosen quadrats.

The results show that fire consumed all bellyache bush stems in the late dry season burning. Fire intensity of bellyache bush fuels was quite low compared to other tropical savanna fuel. Soil temperatures ranged between 54.17^0C to 126.13^0C. All bellyache bush plants were completely killed by the fire treatment, but fire stimulated seedling emergence in the following wet season.

It was concluded from the results of the experiments that mechanical control slashing system may provide a suitable fuel for the burning management if cut early in the dry season. By late in the dry season bellyache bush plants cut early in the dry season have a low moisture content are completely cured and able to support fire spread of adequate intensity to destroy the plants.

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List of Symbols and Abbreviations

'	Minutes
<	less than
>	greater than
°	degrees
%	percent
˚C	degree Celsius
ANOVA	analysis of variance
C	control
BB	bellyache bush plants
EP	established plants
cm	centimetre (s)
E	East
et al.	et alia
FAO	Food and Agriculture Organisation
Fig.	Figure
g	gram (s)
h	hour(s)
H	heat yield of the fuel (kJ/kg)
ha	hectare
i.e.	that is
I	fire intensity (kW/m)
kg	kilogram(s)
kJ	kilojoules
kW	kilowatts
kW/m	kilowatts per metre
m	metre(s)
m^2	square metre(s)
min	minute

mm	millimetre
NS	not significant
NSW	New South Wales
NT	Northern Territory
QLD	Queensland
r	rate of fire spread (m/sec).
s	south
SA	South Australia
T	tonnes
t/ha	tonnes per hectare
TL	Timor Leste
U.K.	United Kingdom
UNTL	East Timor National University
U.S.A.	United States of America
w	fuel consumption (kg/m^2)
WA	Western Australia

Chapter 1 - General Introduction

The intervention of the invasive shrub bellyache bush (*Jatropha gossypifolia* L.) into the agricultural land and grassland of East Timor went unheralded sometime before the 1912 (Metzner, 1977; Parsons and Cuthbertson, 1992; Pit and Miller, 1991). It is reported to have been introduced to East Timor either as a garden ornamental or as a medicinal plant by the Portuguese government before 1912 (Metzner, 1977). The lack of weed knowledge and effective quarantine measures at that time meant that the East Timor was exposed to invasion by a range of exotic and noxious pests and weeds, including bellyache bush. It has significant adverse implications for the sustainable agricultural production and livelihoods of local Timorese near-subsistence farming communities.

The plant grows freely in agricultural land and grassland and produces thousands of established plants, small plants and seedlings every year (Metzner, 1977). The detrimental impact of bellyache bush in these specific areas soon became evident with some farmers being forced to abandon their land and shift to new land for their agricultural activities. Bellyache bush is a highly invasive perennial shrub that thrives in open land areas used for the agricultural production. It grows rapidly and produces a dense mass of leaf matter that gradually out shades out other competition.

Bellyache bush is now a dominant plant species over extensive areas of East Timor. In many villages up to 60% or more of the arable land is now covered by bellyache bush, which is able to thrive over a wide range of soil types and altitudes (Wilson, 1995). While it is still early in the process of the bellyache bush infestation in some parts of East Timor, there are clear indications of potentially substantial adverse impacts on the economy and livelihoods of local Timorese farming communities.

The presence of bellyache bush also has a major impact on animal production in East Timor. In 1912, the Portuguese government in East Timor began introducing Bali cattle onto the island to promote commercial livestock production (Metzner, 1977). The animals proved highly adaptable to the island’s seasonal drought conditions and their capacity to produce consistent annual calving rates. During the twenty-five years of the Indonesian occupation in East Timor, the numbers of livestock exported increased to serve markets in Indonesia, particularly in Java (Kantor Statistik Propinsi, 1996). For the majority of rural Timorese communities, cattle represent the primary store of a family’s wealth. In addition, cattle are a vital and necessary part of the intricate social relationships which link households to one another in complex ties of interdependency. All major ritual events, for example, including marriages, funerals, and collective rituals of the clan, require cattle for feasting and generating the social capital that ensures continuing mutual cooperation and obligation (McWilliam, 1995). The rearing and management of cattle and the conduct and fortunes of the household economy of rural East Timor are therefore closely interrelated. However, the immediate impact of the rapid spread of bellyache bush has been the significant loss of available feed stocks for free grazing herds of cattle and buffalo. Bellyache bush is unpalatable and even very toxic (Kingsbury, 1964). Heavy shading of the plants and the expansion of bellyache bush is in direct proportion to the decline stock feed across the rangelands of East Timor.

The presence of bellyache bush in farming systems can also reduce crop yields through competition with crops for moisture, light and nutrients (Miller, 1982). Heavy infestations of bellyache bush can cause complete crop failures and in some cases the land cannot be used for crop production (Chandhokar, 1978). Sweet potato, cassava, pumpkin, taro and maize are grown as monsoon crops and can be severely affected during the monsoon season when the conditions are also ideal for abundant growth of bellyache bush. Crops are very sensitive to bellyache bush competition, especially in their early stages of development and often result in failed harvest (Labradal *et. al*, 1994).

Despite bellyache bush being a major problem in East Timor there is a lack of research into this weed, particularly for control methods suitable to East Timorese farmers. Therefore, the objective of this study was to investigate mechanical and burning methods to control bellyache bush infestations. Mechanical control such as slash and burn systems have been adopted in East Timor for a long period. Regular slashing, burning and hand weeding are the most common and cheapest methods to control bellyache bush infestations in East Timor. However, there are still many problems encountered by using these methods such as controlling re-sprouting from mechanical control and post-fire emergence after burning. The plants produce new growth immediately after the first rains and maintain dense cover during the wet season. The merit of these traditional methods is that they can reduce the plant's rate of spread and control mature plants in the short term. To achieve a satisfactory control of bellyache bush, the combination of several methods into an integrated management strategy needs to be considered.

Plate 1.1. Land invaded by bellyache bush plants in West of Dili, East Timor.

Sources: Colin Wilson, 2002.

Chapter 2 - Review of Literature

2.1 Description of Bellyache Bush

In Australia and America, *Jatropha gossypifolia L.* is most commonly known as bellyache bush (Everist, 1974; Deghan, 1982; Parsons and Cuthbertson, 2001). Bellyache bush is a major weed of the family *Euphorbiaceae*. It is known by many names throughout the world such as cotton-leaf physic nut, castor been (Queensland) (Kleinschmidt and Johnson, 1987), red physic nut (Burkill, 1994), cotton leaved Jatropha, purging nut, Spanish physic nut tree, American purging nut, wild cassava (BoDD, 2004) red pig-nut flower (Africa), Damar merah (Indonesia) and castor oil plant (Csurhes, 1999). The taxonomy and nomenclature of bellyache bush is shown below (The PLANTS Database, 1996).

Kingdom	: Plantae
Subkingdom	: Tracheobionta
Division	: Magnoliophyta
Class	: Magnoliopsida
Subclass	: Rosidae
Order	: Euphorbiales
Family	: Euphorbiaceae
Genus	: *Jatropha* L.
Species	:*gossypifolia*

Bellyache bush is a sub-tropical perennial shrub typically 2.5 m tall and up to 4 m in areas close to watercourse (Jeffrey, 1998; Parsons and Cuthbertson, 2001; Bebawi and Campbell, 2002a; Vitelli and Madigan, 2004). It demonstrates huge leaf, flower and stem diversity in the wet season. The stems are quite soft and bulky, and roughly hairy and produce a watery sap when cut (Parsons and Cuthbertson, 2001). Each plant can produce one to two or more stems (Csurhes, 1999; Parsons and Cuthbertson, 2001). Young stems are usually green but turn bright crimson red at flowering and grey at maturity.

Its leaves have three to five deep lobes with either purple or glossy green coloration (Pitt and Miller, 1991) with leaf colour dependent on biotype and leaf maturity (Pitt and Miller, 1991; Burkill, 1994; Persons and Cuthbertson, 2001; Bebawi *et al*., 2005b). The leaf cutting edges are palmately 3 to 5 lobes, usually 45-90 x 50-130 mm in size (Bebawi and Campbell, 2002a).

The lamina of bellyache bush is glabrous and the leaf boundary is denticulate with venations finishing in stipitate glandular hairs. In the green biotypes the leaves venation is white but under shade situation it is red (Bebawi *et al*, 2007).

The flowers are red with yellow centres and produced in clusters on branched stalks in the upper leaf axils. Flowers are monoecious with both female and male flowers are on the same inflorescence with approximately 2-8 females and 27-54 males per inflorescence (Reddi and Reddi, 1983). Fruits are round (12 x 10 mm) and comprise of three lobes (locules) per capsule. Capsules are dehiscent and each contains three seeds that are approximately 8 mm in length (Wheeler, 1992). It is globose, pedicellate, generally bright green and woody at maturity before turning pale green when ripe (Berg, 1975; Deghan and Webster, 1979; Burkill, 1994; Parrotta, 2001).

Bellyache bush seeds have caruncle which attracts ants, soft, slippery and glossy. The caruncle is a pale, spongy outgrowth rich in lipids, protein, and carbohydrates (Bebawi and Campbell, 2004).

2.1.1 The history of the spread of bellyache bush

Bellyache bush originates from tropical America, most likely from an area encompassing the Caribbean and Mexico to South Brazil and Paraguay (Kingsbury, 1964). From this region it has spread widely to the other parts of the world (Kingsbury, 1964). It is commonly reported that bellyache bush was introduced by Europeans people to the other parts of the world as a garden ornamental and a medicinal plant (Parsons and Cuthbertson, 1992; Csurhes and Edwards, 1998; Swarbrick, 1997; Das and Das, 1994).

Although there is no published information regarding the first introduction of bellyache bush in East Timor, it has been listed as a weed in 1990's and has formed extensive, dense growth in almost all pasture areas of the Northern Coastal Zone (Wilson, 1995; Waterhouse, 1998). The plant has subsequently become naturalised in dry climates and has invaded native habitats at between the 400 and 1200 mm average annual rainfall zone (Wilson, 1995). According to Wilson (1995) and Waterhouse (1998), bellyache bush has become East Timor's worst weed second only to siam weed (*Chromolaena odorata*).

Since bellyache bush invaded East Timor, it has adversely affected crops, pasture and animal production. Bellyache bush competes with crops for light, water and nutrients. All parts of bellyache bush are unpalatable and toxic to livestock (MAFF, 2001). The leaves, seeds and stems contain purgative oil and pyrrolizidine alkaloids which are very poisonous to most herbivorous animals (Kingsbury, 1964). Therefore, when animals feed on some parts of the bellyache bush it can cause gastro-enteritis and even death (Kingsbury, 1964). Bellyache bush seed contains 40% of pinheon oil. The oil contains small amounts of an irritant curcanoleic acid, which is related to ricinoleic acid and crotonoleic acid, the principle active ingredients of bellyache bush and castor oil (Joubert *et al*., 1984). Other toxins contained in bellyache bush are hydrocyanic acid, an alkaloid, and a glycoside which produce cardiovascular and respiratory depression in animals feeding on bellyache bush (Anon, 1996; Pit and Miller, 1991). Toxalbumins are the largest chemical structures contained in bellyache bush. They are complex protein molecules of high toxicity. They resemble bacterial toxins in structure and physiological effects. Phytotoxins are highly irritating to animals (Kingsbury, 1964). It seems that the presence of bellyache bush in East Timor is likely to cause animal losses. In Queensland, in 1998 312 animal deaths in the Dalrymple shire of north Queensland were attributed to the consumption of bellyache bush (Jeffrey, 1998).

Many grassland savannas in Australia and East Timor which are used to grow pastures have been invaded by dense stands of bellyache bush. The plant's shallow root system precludes growth of other plants under its canopy (McGiffen, 1997). Pure stands of bellyache bush prevent the growth of pasture species. As a consequence, it reduces the overall productivity of land used to graze cattle, buffalo, goats and ponies.

The leaves, seeds and stems contain growth inhibitors, which have been found to be allelopathic to crops. Phenolics, alkaloids and amino acids produced by bellyache bush are the main allelochemicals which are very toxic for crop growth (Labrada *et al*, 1994). Besides the allelopathic effects it competes heavily with crops for moisture, light and nutrients (Anon, 1996; Bebawi *et al*., 2002a; Pit and Miller, 1991). Heavy infestations of bellyache bush can cause complete crop failures and in some cases the land cannot be used for crop production (Chandhokan, 1978).

Bellyache bush is grown as an ornamental plant and is often found in gardens and public areas and are easily accessible. The plants are particularly attractive to children and therefore can pose some risk to human safety, especially if the fruits are eaten. Whilst bellyache bush is not usually eaten by animals, however during drought when there is an acute shortage of grass animals may be forced to consume the plants (Swarbrick, 1997)

Although excessive consumption may cause problems, the roots, stems, leaves, seeds and fruits of the plant have been widely used in traditional folk medicine in many parts of West Africa and Asia including West Timor and East Timor. The seeds have been used as a purgative, antihelminthic and abortifacient as well as for treating ascites, gout, paralysis and skin diseases (Kingsbury, 1964). The seed oil of the plant has been used as an ingredient in the treatment of rheumatic conditions, itch and parasitic skin diseases as well as in the treatment of fever (Ogbobe and Akano, 1993; Taylor *et at*., 1983).

2.1.2 Biology and ecology of the spread of bellyache bush

2.1.3 Habitat

Bellyache bush is a tropical weed that grows well in regions with a pronounced dry season (Dehgan and Webster, 1979). It can persist in coastal and monsoonal areas where the average annual rainfall is between 400 and 1200 mm per annum. The annual rainfall is a very important factor to which the biota of the region has had to adapt (Ridpath and Corbett, 1983). However, bellyache bush is most prevalent in drier areas with an average annual rainfall of 600 to 700 mm. Tothill and Mott (1983) commented that bellyache bush grows extensively in tropical savanna, an area where the natural vegetation is predominantly open woodland and grassland, traversed by meandering creeks and rivers. It also grows in the banks of watercourses which are associated with sandy loam soils (Dehgan, 1982). Bellyache bush disperses into disturbed areas such as channel or overgrazed land (Bebawi *et al*., 2007). Its potential range includes the whole tropical savannas (Thorp and Lynch, 2000, in Bebawi *et al*., 2007).

2.1.4 Dispersal

Bellyache bush can be dispersed by both biotic and abiotic means, but predominantly it is disseminated by human and animal movement, particularly in the mud on the hooves of cattle and buffalos (Smith, 1995; Das and Das, 1994). Dispersal of bellyache bush seeds can also occur via water. When the water flows to the rivers it facilitates pod dispersal over long distances (Ashley, 1995; Henning, 1996). In addition, bellyache bush seeds are also susceptible to dispersal by ants. Ants generally disperse bellyache bush seeds for their structural building materials and for food (Bebawi and Campbell, 2002a). Bellyache bush seeds are dispersed as ant food because of attached food bodies called elaiosomes (caruncles) that are rich in lipid (Ogbobe and Akano, 1993). Ants drag seeds bearing elaiosomes to their nests to feed the larvae and remaining parts of the seed accumulate in their refuse piles or middens outside the nests (Beattie, 1985). Seed dispersal may provide the plant with escape from predation (Reddi and Reddi, 1983), escape from competition (Berg, 1975), and enhanced germination (Culver and Beattie, 1980; Horvitz, 1981).

2.1.5 Phenology

Bellyache bush looses most of its leaves during the dry season. Those that remain are generally quite small and concentrated at the apices of stems (Bebawi and Campbell, 2005b). The plants are either in full leaf or almost leaf-less and the transition between the two stages is fairly rapid (Bebawi and Campbell, 2005b). An average of 17 and 20 leaves per stems have been recorded during the wet season (November-April) on plants growing within sub-riparian and riparian habits, respectively (Bebawi *et al.*, 2005b). On an average there is one leaf per stem in the dry season (June-August). However, along watercourses bellyache bush plants may retain most of their leaves levels all year (Liogier, 1990; Howard, 1989; Bukill, 1994; Parrotta, 2001).

Bellyache bush flowers during the wet season, but in some areas it can also flower during the dry season. In addition, it seems that bellyache bush flower production also depends on moisture availability. Moreover, temperature is also an important influence on timing and duration of flowering (Bebawi *et al.*, 2005b; Wheeler, 1992).

2.1.6 Reproduction

Under favorable conditions bellyache bush can reach reproductive maturity very quickly. The time to first flowering averages 74 days in cleared areas, 294 days in rocky sites, and 454 days in grazed pastures (Bebawi *et al.*, 2005b). Once bellyache bush plants reach reproductive maturity, they have definite pattern of flowering within inflorescences. More female than male flowers mature on the first day, with female flowering slowing a declining trend thereafter over a five day period (Reddi and Reddi, 1983). In contrast, the number of male flowers gradually increases by the twelfth day, after which their frequency gradually decrease (Reddi and Reddi, 1983; Deghan and Webster, 1979).

The ratio of male to female flowers is an average of 11:1 (Reddi and Reddi, 1983; Wild, 2003). Males prefer to flower on the short days compared to female which flowers in long day periods (Deghan, 1983). Female flowers produce nearly 1.6 times more nectar then male flowers (Reddi and Reddi, 1983). Bellyache bush nectar consists of glucose, sucrose, fructose amino acids and proteins (Reddi and Reddi, 1983). The nectar is attractive to insects, which is essential for normal seed set (Reddi and Reddi, 1983; Wild, 2003). Pollination may occur through self pollinating or can be through insects (Deghan and Webster, 1979).

Many insect species have been observed foraging on the nectar of bellyache bush in Queensland (Reddi and Reddi, 1983). Most insects are beneficial to bellyache bush due they perform vital roles such as pollination and dispersal.

2.1.6.1 Seed production and dispersal

Seed production of bellyache bush is generally prolific being particularly supported by suitable factors such as environmental conditions, plant biotype, plant density and the location of seeds produced. Adult plants normally produce 2000 to 12000 seeds per hectare (Bebawi and Campbell, 2002d). For dense infestations of bellyache bush growing in a relatively dry location it is four seeds m^{-2} during the dry season compared to 343 seed m^{-2} in the wet season (Vogler and Keir, 2005). Plants produce fewer seeds at high density with more than 40 plants m^{2} causing seed production per plant to decline (Bebawi *et al*., 2005b).

2.1.6.2 Seed germination

Fresh bellyache bush seeds exhibit high viability, but low germinability. Fresh intact seed collected in North Queensland was 88% viable but only 10% of these were readily germinable (Bebawi and Campbell, 2004). A similar study in Puerto Rico found only 4% of fresh seeds is able to germinate (Ellis *et al*., 1985). Seed type, seed weight, geographical location, temperature, control technique, and ants affect the germinability of bellyache bush seed (Liogier, 1990; Bebawi and Campbell, 2004). Seeds commence germination at the start of the wet season (Ashley, 1995) but can also germinate at any times of the year if environmental conditions are favorable.

Ants play a significant role in the germination of bellyache bush seeds (Bebawi and Campbell, 2004). Results show that 98% of ant-discarded seeds were viable and readily germinable at 100%, compared to intact seeds with 88% viability and only 8% germination (Bebawi and Campbell, 2004). The caruncles were not present in seeds that were dispersed by ants.

Optimal germination temperatures for intact bellyache bush seeds occur between 24 and 31^{0}C. Germination generally commences five days after the imposition of favorable environmental conditions and reaches a maximum between days 11 and 12 (Bebawi *et al*., 2007). Burial depth and litter cover also affect germination and viability following fire (Bebawi and Campbell, 2002c).

Germination and viability of bellyache bush seeds were negatively correlated with peak fire temperature, which was affected by litter cover (Bebawi and Campbell, 2002c). No viable seeds remained under litter cover, but more than 80% of seeds placed on bare ground (2 cm depths) remained viable (Bebawi and Campbell, 2002c). Fire reduced germination and viability of bellyache bush seeds within capsules by 31% and 35% respectively when compared with unburnt seeds (Bebawi and Campbell, 2002d).

2.1.6.3 Seed longevity

Bellyache bush seeds can remain viable in the soil for several years with 3% of ant-dispersed seeds (seed without a caruncle) found to be viable even after 4 years in the soil under natural rainfall conditions (Bebawi and Campbell, 2002c). Conversely, no intact seeds (seeds with a caruncle) exhumed after four years remained viable under natural rainfall conditions. Seedling emergence was still observed after four years at a rocky site away from a watercourse; however, no emergence occurred after three years at a heavy clay soil site within the same period (Bebawi *et al*., 2007). The differences in seed bank depletion were attributed to differences in soil moisture conditions between the two sites.

2.1.6.4 Seedling establishment and mortality

Seedling densities of bellyache bush can be very high under favorable environmental conditions. On an average 247, 126, and 90 seedlings m^{-2} were measured within sub-riparian and riparian infestation of bellyache bush (Bebawi *et al*., 2007). Higher seedling densities were recorded under dense canopies of bellyache bush (300-400 seedlings m^{-2}) (Vogler and Keir, 2005).

Removal of bellyache bush infestations can stimulate massive recruitment of seedlings through increased light for ungerminated seeds (Bebawi and Campbell, 2002a; Bebawi and Campbell, 2002c; Vitteli and Madigan, 2002; Bebawi *et al*., 2004). For instance, bellyache bush spraying with foliar herbicides resulted in increase in the seedling density from 5 plants m^{-2} to 400 plants m^2 (Vitteli and Madigan, 2002). Similarly, for each plant killed by foliar spraying, slashing, and burning as part of integrated research experiment there was an additional 20, 97 and 69 seedlings which emerged in the same location, respectively (Bebawi *et al*., 2004). Treatments that caused the greatest soil disturbance appeared most conductive for seedling recruitment.

High seedling mortality normally occurs if rainfall is limited and in high competition with other plants (Bebawi and Campbell, 2002d; Vitteli and Madigan, 2002). For instance, seedling density in burnt plots reached a peak of 390 seedlings m^{-2} in December and declined to 30 seedlings in the late dry season. However, in unburnt plots seedling density peaked at 200 m^{-2} before declining to 5 m^{-2} in the late dry season (Bebawi and Campbell, 2002c). Even though mortality of seedlings is very high in the dry season, recruitment for re-infestation in treated sites and expansion of infestations occurs in the absence of follow up control treatments. Once seedlings reach about 20 cm in size they are very hardy and will generally tolerate extreme environmental conditions (Bebawi and Campbell, 2002d; Vitteli and Madigan, 2002).

2.2. The impact of bellyache bush in East Timor

2.2.1. Economic and social impact

The economy of East Timor deteriorated during the struggle against the Indonesian occupation and has not yet recovered in the few years since independence (Wilson, 1995). The population of East Timor is less than one million of which 80% are farmers with their livelihood dependent on the farm (Da Costa *et al.*, 2002). Crop and animal production are the main sources of income, however, the increasing presence of bellyache bush has become a significant obstacle to farmers in their attempt to increase their production because the weed is unpalatable and toxic to livestock (MAFF, 2001). The toxins are thought to be caused by high amounts of toxabulbumin and pyrrolizidine alkaloids contained in the plant which if consumed can cause gastro-enteritis and even death (Kingsbury, 1964).

Bellyache bush can also reduce crop yields through competition with crops for moisture, light and nutrients (Miller, 1982). Heavy infestations of bellyache bush can cause complete crop failures and in some cases the land cannot be used for crop production the following year (Chandhokar, 1978). Sweet potato, cassava, pumpkin, taro and maize are grown as monsoon crops and can be severely affected during the monsoon season when the conditions are also ideal for abundant growth of bellyache bush. These crops are very sensitive to weed competition, especially in their early stages of development and the end result is often reduced yields (Labrada *et al*, 1994; Jeffrey, 1998).

Based on literature presented above, it seems that the presence of bellyache bush has become a significant constraint to economic growth in East Timor as the majority of the population are farmers heavily dependent on animal and crop production. The losses in farm production caused by the bellyache bush weed will have a significant impact on the economic income and social aspects of many East Timorese (Wilson, 1995).

2.2.2. Environmental impact

According to Smith (1995), the biggest concern with the infestation of bellyache bush in riparian habitats is that it directly competes with native plants in the early stages of development. Bellyache bush replaces native colonizers and prevents subsequent invasion by secondary species of native shrubs and trees (Wilson, 1997). Parrots, possums, bats and macropods seem incapable of utilizing the plant in any way (Anon, 1996; Pit and Miller, 1991) and based on its effect on livestock; it is highly likely to be also toxic to native animals. Furthermore, bellyache bush obscures fence lines (Webb, 1948) hindering mustering (Smith, 1995). Therefore, it is likely that extensive thickets of the bellyache bush could degrade wildlife habitat and reduce biodiversity in East Timor.

2.3 Integrated management of bellyache bush in East Timor

2.3.1 Preventative strategies

Preventative strategies are the most important method of preventing the introduction of weeds from one country to another country (Hughes and Madden, 2002). However, in East Timor this has proved difficult due to previous conflict and political decisions. Since Portuguese military was invaded into East Timor in 1556 (Metzner, 1977), many Portuguese people introduced bellyache bush as garden ornamental and medicinal plant. Also, vehicles and machinery used by various military organisations probably contributed to the spread of weeds into East Timor in recent times.

When the weeds are spread by natural agents it is difficult to control, but at least some steps can be taken to reduce and control weed spread caused by human movement. For instance, all seeds which are introduced to East Timor must be certified free of weed seeds (MAFF, 2001) and all vehicles and machinery must be cleaned before entering East Timor. Efforts can also be made to control weed seeds in feed and bedding. This is important as many bellyache bush seeds can pass through the animal's digestive tract intact and still remain viable (Smith, 1995).

2.3.2 Physical strategies

One of the most common methods of controlling bellyache bush is by the slashing and clearing system. This is the cheapest method and is used widely in East Timor, particularly in the sloping farm areas (Metzner, 1977). Farmers use a machete to slash the stems then dig out the roots using a hoe. The disadvantage of this practice is that it is only feasible for small areas and causes rapid regeneration unless followed by other methods that act to suppress the seedlings (Labrada *et al*, 1994). The merit of this method is that the hand tools required are locally made and easily available to farmers.

Another physical control used in East Timor is the slashing and burning system. This involves slashing using a machete then allowing the cut plants to dry before burning the vegetation and subsequently planting crops in the ashes. Where there is insufficient vegetation for an efficient burn, the slashed vegetation is left to decompose and is cultivated into the soil after a long fallow (Jeffrey, 1998). This method has been used by farmers for centuries to improve soil fertility and manage pests.

In Australia, Bebawi and Campbell (2002b) found cutting stems at 0 cm height completely killed bellyache bush plants compared with cutting treatments at 10cm, 20cm, and 40 cm height. The majority of plants cut in the dry season at 10, 20, and 40 cm height were able to regenerate, whilst plants cut during the wet season could only regenerate after being cut at 20 and 40 cm.

Thus bellyache bush plants are more likely to regenerate when cut during the wet season rather than the dry season (Bebawi and Campbell, 2002b).

Burning is an effective control technique against bellyache bush where there is sufficient fuel to carry a fire (Bebawi and Campbell, 2002c). In a two year study, burning killed 76% of plants in the first year and 92% in the second year with air temperatures reaching up to 640^{0}C at ground level. Small plants and seedlings were more susceptible to fire than established plants (Bebawi and Campbell, 2002c).

Although bellyache bush plants can be controlled by burning, a large proportion of the seed bank is still able to survive resulting in large scale recruitment (Bebawi and Campbell, 2002d). For example, 540 seedlings m^{-2} emerged from burnt plots compared with 190 seedlings m^{-2} in control plots. Seedling density in burnt plots averaged 37 seedlings m^{-2} over two years, compared with four seedlings m^2 in control plots (Bebawi and Campbell, 2002d). Therefore, using fire as a control technique could exacerbate the bellyache bush problem if follow up treatments are not undertaken. Furthermore, fire can only be used effectively for weed control when there is enough fuel available to burn (Vitteli, 2000). In drier areas, burns can only occur following several years of above average rainfall that enables plan biomass to reach adequate levels for burning. There are also substantial costs incurred by the farmers when using fire as animals will need to be excluded during and after burning.

The use of heavy machinery in suitable terrain, such as a roller, consistently controls established plants, small plants and seedlings (Bebawi and Campbell, 2002b).

2.3.3 Cultural strategies.

Bellyache bush is seldom found on land that is well and regularly cultivated for fodder. Ashley (1995) suggested that improved management of pasture areas is an important factor in smothering and suppressing bellyache bush.

Mulching is another method which is often used to control weeds effectively and has been recognized as a beneficial practice in both agronomic and forestry systems (Haywood, 1999). The function of mulches is to change the microclimate surrounding the plant, including temperature, light intensity, relative humidity, vapour pressure deficit, CO_2 concentration and wind (Bellot *et al*., 2002). Mulching reduces the growth of weed stems (Van Lenteren, 1992; Burger *et al*., 1996; Mayhead and Boothman, 1997).

Preliminary results from a field investigation on the impact of grazing on bellyache bush population densities suggest that bellyache bush grows best in areas void of pasture (Bebawi et al., 2007). Where there is a grass cover, its seedling recruitment is reduced and plants grow more slowly.

2.3.4 Biological control

Biological control is defined as the use of natural agents such as insects, nematodes, fungi and viruses for the control of weeds (Harley and Forno, 1992). Biological control is considered to be the most effective weed management method (Tomley, 2003) as once the biological agent is established and feeding on the bellyache bush plants, they will continue to attack the weeds month after month and year after year. The merit of biological control is it could be integrated with other methods to control weeds (Van Lenteren *et al*., 1992). After agents are released herbicides can still be used in the field, if desired, provided it is not harmful to the agent.

Bellyache bush has been a target for biological control in Australia since 1996 (Wilson, 1997). Over 170 locations in nine countries (Mexico, Venezuela, Dominican Republic, Puerto Rico, Nicaragua, Netherlands Anttiles, Guatemala, Trinidad and Cuba) were investigated for potential agents and more than 1000 specimens were collected and their suitability determined. *Pachycoris kluggi Burmeister* (Scutelleridae) was the most damaging herbivore of plantations of *Jatropha curcas* in Nicaragua, but unfortunately it did not develop on *J. gossypifolia* Preliminary studies on the rust fungus, *Phakopsora jatrophicola* Cummis are promising but limited funds in East Timor have prevented further host testing.

Until recently, only the seed feeding jewel bug *Agonosoma trilineatum* has been approved for release in Australia for the control of bellyache bush. The potential impact of jewel bugs on the bellyache bush has been quantified in greenhouse experiments (Bebawi *et al*. 2005a).

The leaf mining moth (*Epicephalo sp*) and the castor oil looper (*Achaea janat* L.) cause minor defoliation of bellyache bush. The tenebrionids beetles, *Lyphia australis* Blackburn and *Platycotylus nilidulus* Macleay and the nilidulid beetles *Carpophilus marginellus* Motschulsky and *C. obsoletus* Erichson have been observed attacking the stems in the Northern Territory (Wilson, 1997).

Soil borne fungus (*Scytalidium dimidiatum*) can cause stem end rot of bellyache bush stems in North Queensland. It is a very common soil-borne fungus associated with a wide range of hosts such as crop species and eucalypts (Tomley, 2003). However overall there is as yet no effective biological control agent that can replace other control methods.

2.3.5 Chemical control

Chemical control is another option to use to eradicate bellyache bush infestations. Repeated herbicide application is very successful in killing seedlings and preventing flowering and seed production (Vitelli, 1998). A study conducted by Tropical Weeds Research Centre (TWRC) found that 90-100% of mortality was achieved when herbicides were used to control bellyache bush (Biological Branch Annual Report, 1988). The following herbicides have been used to control bellyache bush plants: metsulfuron methyl (Brushoff®), imazaphyr (Arsenal®), glyphosate, 2, 4-D (ethyl ester, amine, acid and DP acid), fluroxypyr (Starane®) and picloram or triclopyr (Grazon®). Brushoff® and Starane® are registered for bellyache bush control in the crop and grassland areas (Jeffrey, 1998). In addition, Access®, Garlon®, Af Rubber vine (2, 4-D) spray® and Starane are use as basal-bark or cut-stump application. Finally, Velpar®, Graslan®, Simazine®, Oust®, and Atrazine® are used as root-absorbed herbicides.

There are, however, some herbicides which do not appear to give satisfactory control in the field. For instance, experiments conducted by Northern Territory Department of Primary Industries and Fisheries on three rates of metsulfuron methyl (50, 75 and 100 g active ingredient/ha) and three rates of glyphosate mixed with simazine (1.5 + 2.0, 1.5 +4 .0 and 3.0 + 4.0 kg active ingredient/ha) applied by helicopter showed these chemicals did not affect the dense growths of bellyache bush after 12 months of application. It seems that the chemicals should be used separately rather than mixed together (Pitt and Smith, 1990). Information given by authorities at the TWRC is that metsulfuron methyl can kill 100% of bellyache bush (Biological Branch Annual Report, 1988).

2.4. Conclusion and research objectives

Only limited research has been undertaken on determining bellyache bush control options that could be adopted by farmers in East Timor. Economically the country is very poor and cannot adopt expensive methods such as chemical and biological control is not yet proven. In order to use chemicals, farmers need to buy both the chemical and appropriate equipment for application. For biological control money is needed for research and to establish appropriate laboratory facilities to test the agents before release.

One of the most widely used methods of controlling bellyache bush is the use of mechanical and burning control. Slashing in combination with burning is the cheapest method and it is used widely in East Timor (Metzner, 1977). Farmers only need a simply machete to slash bellyache bush stems and then follow up by burning (Lavabre, 1991). This practice is commonly used for land cultivation in sloping areas like East Timor. The merit of this method is that all types of hand tools are available for the farmers and these are made locally rather than imported.

Although these practices are commonly used in East Timor to control weeds, there are still many problems that appear in the field during and after control. For instance, the slashing system is only feasible for small areas and in addition it may not significantly reduce regeneration from the cut stems. Another problem is that bellyache bush monoculture is very hard to burn due to high moisture content of stems and low fuel load. Moreover, burning stimulates post-fire seedling emergence which may re-establish again in the wet season.

Therefore the objective of this study is to:

1. Investigate different cutting heights and different cutting heights in combination with mulch on the control of established bellyache bush plants.
2. To examine the effectiveness of hand-pulling and mulching on the control of small plants and mulching on the control of seedlings.
3. To determine bellyache bush properties as a fuel and the efficacy of fire as a tool for bellyache bush control.

Chapter 3 – Experiment I. Mechanical Control

3.1. Introduction

In East Timor, the most common practices used to control bellyache bush infestations are mechanical controls such as cutting, hand-pulling and mulching. It is the only option for landholders in recent years due in part to the deterioration of the national economy since independence. As a result many farmers do not have money to buy herbicides such as metsulfuron-methyl and fluroxypyr that are registered for control of bellyache bush in Australia. These herbicides are very expensive and not available locally.

Mechanical control is considered the cheapest and most common method used by farmers in East Timor (Metzner, 1977). Farmers use a simple machete, which can be made locally, to cut the stems of bellyache bush plants. This method is typically used in undulating areas that are unsuitable for the operation of large machinery. Although mechanical control is the most common technique used in East Timor, it is not without its disadvantages. For instance, the cutting and hand-pulling system is only feasible for small areas because of time and labour constraints. An additional disadvantage of cutting is that there is rapid regeneration from cut stems unless the methods is combined with treatments (Labradal *et al*, 1994) such as digging out the roots with a hoe or burning the regenerating bellyache bush. However these methods are time-consuming and require a high amount of labor.

An alternative mechanical technique to the labor intensive cutting method is mulching. In the recent years many farmers in East Timor are using mulch to control weed infestations. Mulch is considered a cheap method and easily applied by the landholders to control weed infestations without the need for any specific training of farmers (Wilson, 1995). However, the use of mulch can lower the evaporation of moisture from soil by the sun and wind (Watson, 1957). It keeps residual water in the soil which encourages bellyache bush plant growth (Adams, 1997). On the other hand, excessive water in the soil may cause small plants and seedlings to rot (Okigbo, 1965, 1969; Lal, 1975; Dayanand *et al.*, 1977; Lal *et al.*, 1978; Lee *et al.*, 1978). Several forms of mulch have been used to suppress weeds in many parts of the tropics such as China, Vietnam, Thailand and Indonesia (Watson, 1957; Lawson and Lal, 1979).

To optimize mechanical control of bellyache bush farmers need to cut the plants in the wet season to prevent flower and seed development in the dry season thereby reducing seed production and the subsequent increase in the number of new seedlings in the following wet season (Dehgan and Webster, 1979). Cutting bellyache bush plants in the wet season increases the curing time of felled stems and improves the efficiency of a burn in the late dry season (See Chapter 4 for further information). Cutting bellyache bush plants in the wet season and allowing them to cure until the late dry season can achieve 100% plant mortality if they have been cut close to ground level (Bebawi and Campbell, 2002b).

Cutting close to the ground may control established plants of bellyache bush but small plants and seedlings may establish in large numbers in the next wet season (Bebawi and Campbell, 2002b). It is common that there are three different stratum of bellyache bush plants growing together at one place; established plants, small plants and seedlings. Therefore the use of cutting, hand-pulling and mulching needs to be integrated to control these three strata of an infestation.

The objective of this study is to investigate different cutting heights and different cutting heights in combination with mulch to control established plants of bellyache bush. To investigate the effect of hand-pulling and mulching on small plants and mulching on seedlings of bellyache bush. In addition, the effect of burning on controlling bellyache bush infestations growing as a monoculture was also investigated. The mechanical control measures on established plants, small plants and seedlings were compared with burning of cut and uncut plants as a means of controlling bellyache bush where it occurs in monoculture.

3.2. Materials and Methods

3.2.1. Study site description

This research was conducted from January 2007 to February 2008. The 900 -1000 m² areas at two study sites at Acacia site (12º45’S, 131º09’E) and Channel Island (12º33’S, 130º51’E) south of Darwin were located within a dense infestation of bellyache bush with average density of 90,000 plants/ha. The mean annual rainfall is 1588.1 mm at Acacia and 1713.9 mm at Channel Island with 94% of the rainfall occurring in the wet season between November and March. Average monthly minimum and maximum temperatures at both the sites were 23ºC and 34ºC (Bureau of Meteorology, 2004).

At the Acacia site the soils are a mixture of alluvial sandy loam and clay of moderate fertility with a pH of 6.5 (Fogarty *et al*., 1984). Beneath the canopy of established bellyache bush plants, the vegetation consists of a few grass and herbaceous vegetation, such as feathertop rhodes grass (*Chloris virgata*) and gamba grass (*Andropogan gayanus*) at the edges. The shrub stratum was dominated by 2m bellyache bush with scattered turkey bush (*Calytrix exstipulate*), neem tree (*Azadirachta indica*), *Acacia spp*, *Owenia vernicosa* and emergent to 10m scattered *Eucalyptus miniata* and *E. tetradonta* trees. This vegetation indicates past disturbance of the Acacia site.

The soil at Channel Island varies from sandy loam to sandy clay (Day *et al*. 1979; Fogarty et al. 1984). The herbaceous vegetation was dominated by *Tacca leontopetaloides*, flame weed (*Corchorus sidoides*) and rock fern (*Drynaria quercifolia*). The shrub stratum was dominated by bellyache bush, *Bridelia tomentose*, weeping fig (*Ficus benjamina*), *Owenia reticulate* and *Ardisias*. While a mixture of *Eucalyptus miniata* and Acacia *spp*, river tea tree (*Melaleuca linariifoilia*) and white wood (*Atalaya hemiglauca*) dominated the tree stratum.

Figure 3.1. The location of experimental sites for this study.

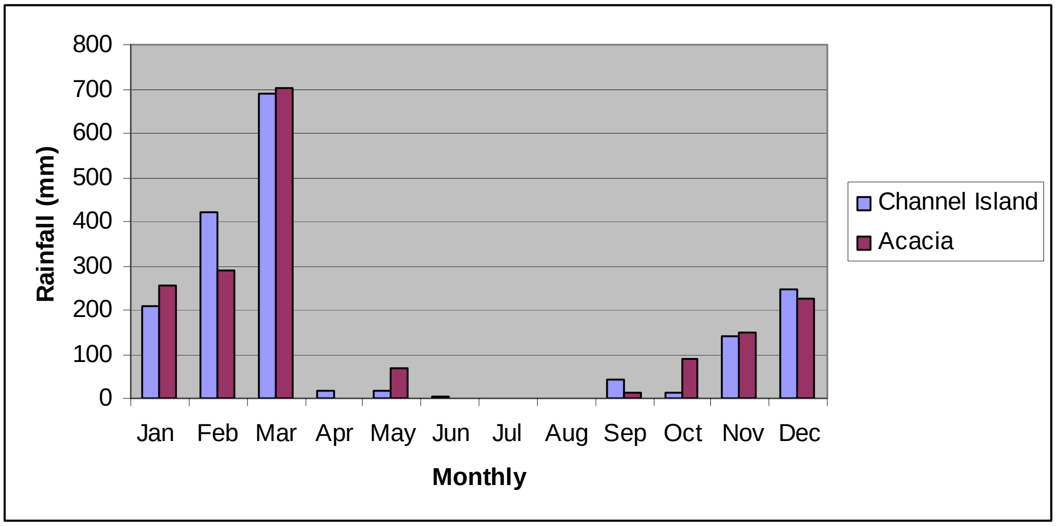


Figure 3.2. Recorded monthly rainfall (mm) at the study sites in 2007. During the wet and dry season there were scattered rainfall events at both sites. For further information regarding weather conditions at the Acacia and Channel Island sites refer to Appendix B, Table 1 and Table 2.

3.2.2 Measurement of canopy density

Canopy density at the two study sites was measured by using a standard densiometer, taking four replicate measurements at each of three experimental plots within the study sites.

3.2.3 Mechanical treatments and experimental design

This experiment was imposed on three different size classes of bellyache bush: established plants, small plants and seedlings. There were four experiments undertaken in three 10m X 10m plots at each of two sites. The treatments in the experiments included:

- Cutting of established plants (>50 cm),
- Cutting in combination with a mulch of established plants (>50 cm),
- Mulching and hand-pulling of small plants (<50 cm and >10 cm), and
- Mulching of seedlings (<10 cm).

3.2.3.1 Cutting of established plants

Fifteen established plants were randomly selected from within each 10m x 10m plot and then cut off according to five different height treatments. The cutting treatments were at heights of 0 cm, 10 cm, 20 cm, 30 cm, and 40 cm. A further 15 plants were left uncut as a control treatment.

Treatments were implemented in a randomised block design. One replicate of each cutting treatment was grouped into each of the 15 clusters (blocks) within each 10m X 10m plot. The locations of plant clusters were chosen using a random numbers table. All plants were cut with secateurs. The location of each plant was marked with tags to facilitate monitoring after cutting. Plant height and total branch number were counted before cutting. Measurements were recorded every six weeks on the number of plants alive, number of new shoots on live plants, height and reproductive status (bud, flowers or fruits present).

3.2.3.2 Cutting and mulching of established plants

There were three treatments for the cutting and mulching consisting of cutting at 0 cm and then covering with straw mulch, cutting at 30 cm and covering with straw mulch and untreated as the control plot. The height and number of branches of all plants in each of three replicate 1m X 1m quadrats were recorded before imposing the treatment. Secateurs were used to cut the plants, before mulch was applied. The straw mulch was applied at 1 kg per 1m X 1m quadrat. The location of each plant was marked with tags to facilitate monitoring after cutting. This rate of mulch application is equivalent to 10 tonnes/ha which is similar to savanna fuel loads and easily manageable in term of logistics and weighing under field conditions. Measurements were recorded every six weeks on the number of plants alive, number of new shoots on live plants, height and reproductive status (bud, flowers or fruits present).

3.2.3.3 Hand pulling and mulching of small plants (< 50 cm and > 10 cm)

There were three treatments applied to small plants: hand pulling, mulching and control. Three replicate 1m X 1m quadrats of each treatment were randomly located within the 10m X 10m plots. However, in some cases 1m X 1m quadrats were chosen from outside 10m X 10m plots because of a lack of small plants in a plot. The height of all small plants within 1m X 1m quadrats were recorded and then located with tags in order to facilitate monitoring after hand pulling and mulching. Control treatment plants were just measured and tagged. Measurements were recorded every six weeks on the number of plants alive, new plants, new shoots, height of the tallest shoots and of the plants.

3.2.3.4 Mulching seedlings (< 10 cm)

There were two treatments for seedlings: mulching and control. Three replicate 1m X 1m quadrats were randomly located within 10m X 10m plots. However, in some circumstances the quadrats 1m X 1m quadrats were chosen from outside of 10m X 10m plots, because of a lack of seedlings. All seedlings within each 1m X 1m were counted and their height measured and marked with tags to facilitate monitoring after mulching. Finally all seedlings except those in control quadrats were covered with straw mulch at a rate of 1 kg per 1m X 1m plot. Measurements were recorded every six weeks on the number of plants alive, new plants and plant height.

3.2.4. Statistic analysis

Only data from February 2008 was analysed to evaluate whether treatments successfully killed individual plants by the next wet season after treatment. Models for the analysis of variance are presented in Table 3.1, where Treatment and Site are fixed factors and Plot is random. Data were check for normality and transformed to Arcsin (square root (proportion alive)). Full results of ANOVA are presented in Appendix A, P values are presented in the text of results. Data in tables and figures is presented as mean ± S.E.

Table 3.1. Model designs for analysis of variance of the four mechanical treatment experiments.

Experiment	**Model for ANOVA**	**Data transformation**
Cutting of established plants	SITE+TREATMENT+SITE*TREATMENT	Arcsin(square root(proportion alive))
Cutting + mulch of established plants	SITE+TREATMENT+PLOT(SITE)+ TREATMENT*SITE+TREATMENT*PLOT	Arcsin(square root(proportion alive))
Small plants	SITE+TREATMENT+PLOT(SITE)+ TREATMENT*SITE+TREATMENT*PLOT	None
Seedlings	SITE+TREATMENT+PLOT(SITE)+ TREATMENT*SITE+TREATMENT*PLOT	Arcsin(square root(proportion alive))

3.3. Results

3.3.1. Canopy cover

ANOVA (Appendix A, Table 1) of canopy cover at wet season and dry season indicated significantly (P = < 0.001) more shade at Channel Island than at Acacia (Table 3.2).

Table 3.2. Canopy cover at the study sites in 2007

Site	Canopy (%) in wet season	Canopy (%) in dry season
Channel Island	88.8 $\pm$ 2.2	63.6 $\pm$ 8.9
Acacia	48.5 $\pm$ 4.7	18.8 $\pm$ 4.9

3.3.2. Cutting treatment of established plants

One month after imposing cutting treatments on one plant at each cutting height in each of 15 clusters, there was a sharp decline in the proportion of plants alive over the wet season at Acacia site. By the onset of the dry season all cutting treatments achieved 100% mortality (Figure 3.3 A). By contrast at Channel Island there was a gradual decline in the proportion of plants alive throughout the wet season (Figure 3.3 B). At Channel Island there were some plants still alive over the following dry season on treatments cut at 20 cm to 40 cm above ground level. There was a significant (Appendix A, Table 2) effect of site (P = < 0.001), treatment (P = < 0.001) and interaction between site and treatment (P = 0.002). The cutting treatments at Acacia and Channel Island achieved 100% mortality at cutting heights 0cm and 10cm by August 2007 while at Channel Island plants cut higher than this survived in the dry season until February 2008 (Figure 3.3A, 3.3 B and 3.4).

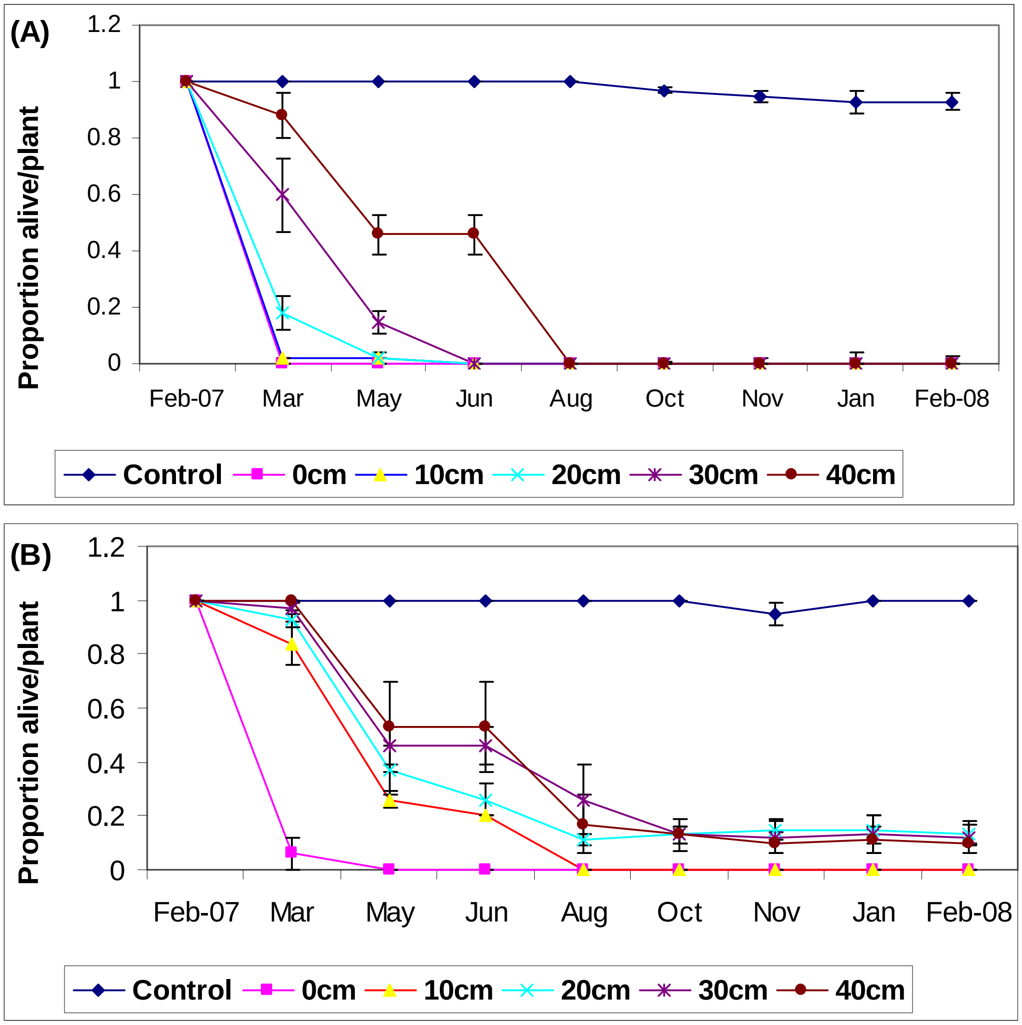


Figure 3.3. Proportion of plants alive in each month following the application of cutting treatments at (A) Acacia and (B) Channel Island.

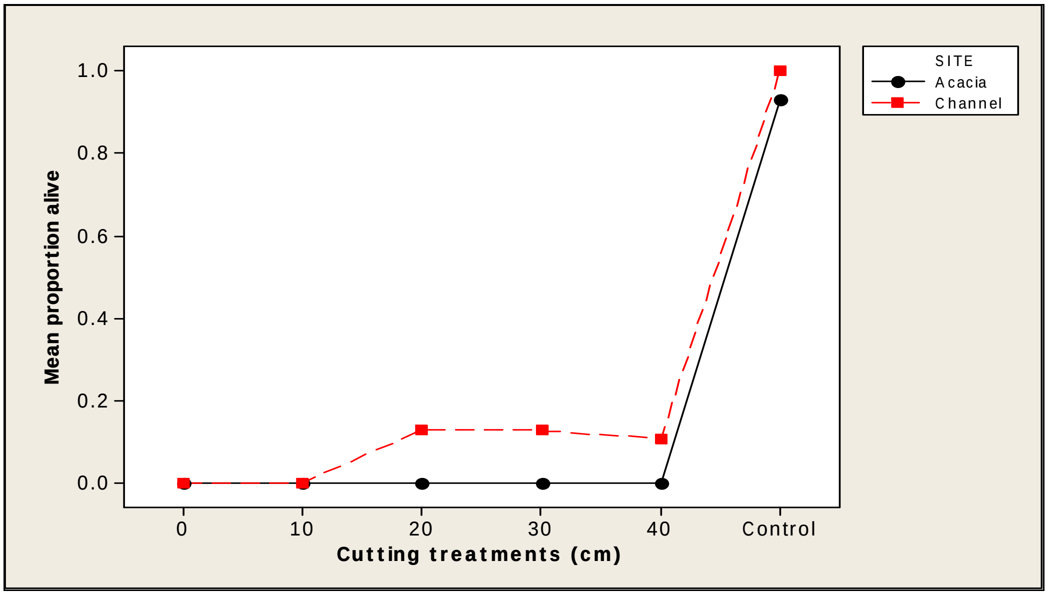
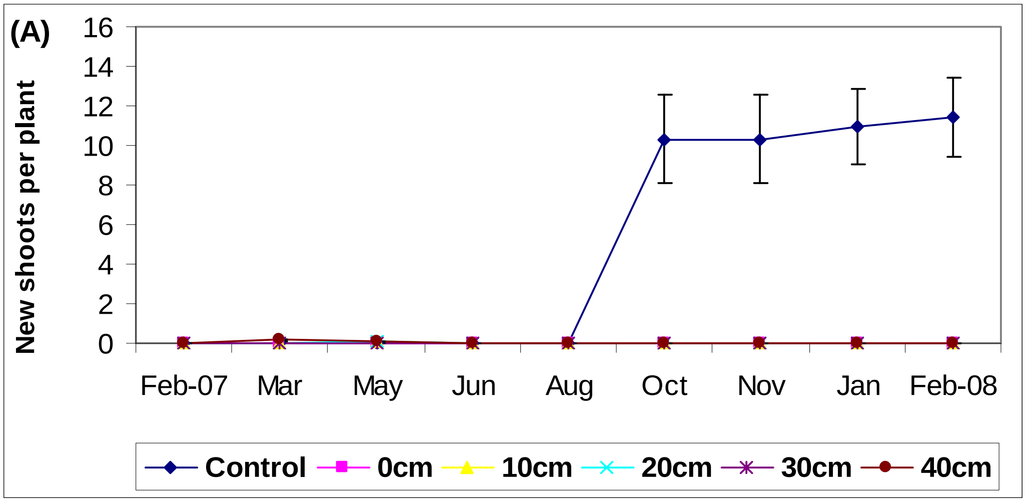


Figure 3.4. Proportion of plants alive at each site in February 2008, at Acacia and Channel Island, for each cutting treatment.

There was some re-sprouting over the wet season at Acacia and Channel Island. However no re-sprouting was found at the Acacia site in the dry season (Figure 3.5 A). By contrast, at Channel Island there were a number of plants alive and re-sprouting in the dry season although numbers gradually declined over time (Figure 3.5 B). There was a significant (Appendix A, Table 3) impact of site on the re-sprouting of established plants (P = 0.025) and treatment (P = < 0.001). The interaction between cutting height and site on re-sprouting of plants is shown in Figure 3.6 where plants were cut at 0 cm and 10 cm did not re-sprout at either site, while the other treatments plants still remained alive until February 2008 at Channel Island (Figure 3.6).



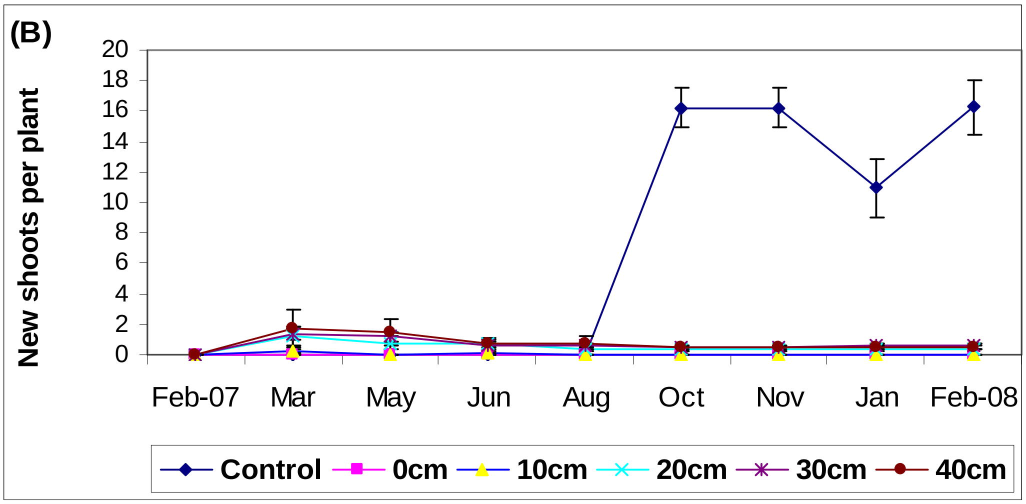


Figure 3.5. Total new shoots each month on established plants following cutting treatment at (A) Acacia and (B) Channel Island.

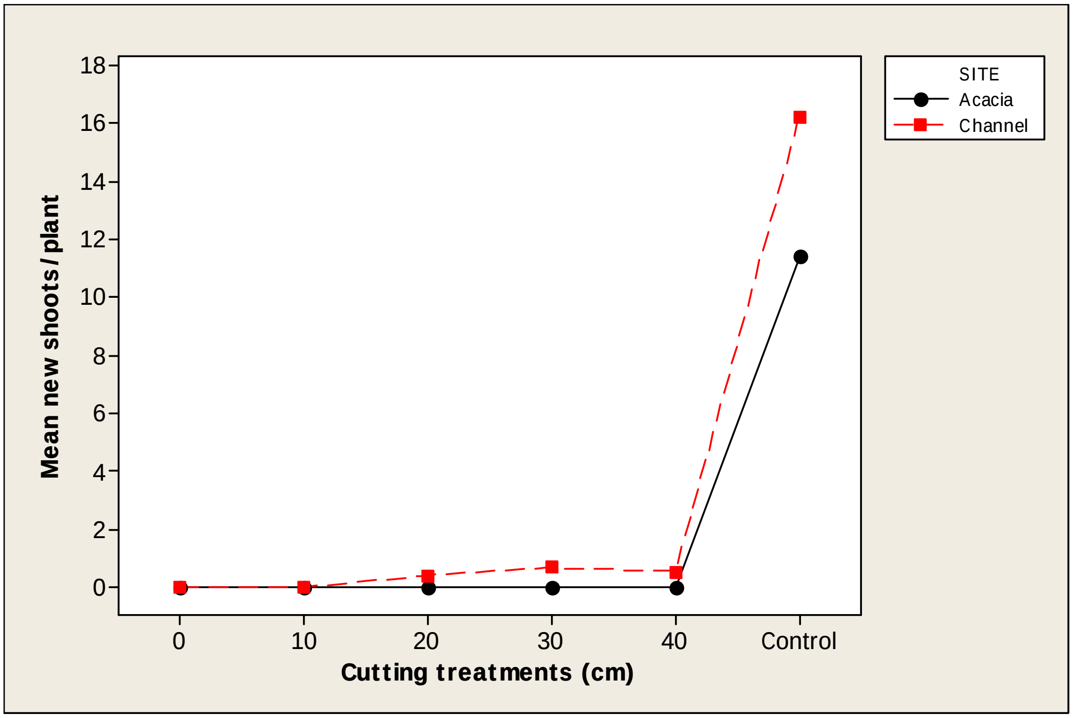


Figure 3.6. Number of new shoots per plant in February 2008, at Acacia and Channel Island, for each cutting treatment.

3.3.3. Cutting in combination with mulching of established plants

Similarly to the results of the cutting treatments, cutting in combination with mulch resulted in a sharp decline in proportion of live plants over the wet season at the Acacia site. All plants cut 0 cm and 30 cm above ground in combination with mulch were killed by the end of the wet (Figure 3.7 A). However, the proportion plants alive at Channel Island gradually declined over the wet season. In addition, at this site some plants cut at 30 cm in combination with mulch remained alive over the dry season (Figure 3.7 B). ANOVA (Appendix A, Table 4) indicated that there was a significant effect of different cutting treatments in combination with mulch of site ($P = < 0.001$), treatment ($P = < 0.001$) and interaction between site and treatment ($P = 0.030$) but not plot ($P = 0.380$), or interaction between treatment and plot ($P = 0.398$). These results show that stems cut at 0 cm and 30 cm in combination with mulch resulted in 100% mortality at Acacia while at Channel Island only those cut at 0 cm in combination with mulch did not sprout. At the latter site plants remained alive on the 30 cm cutting treatment in combination with mulch at the February 2008 observation (Figure 3.8).

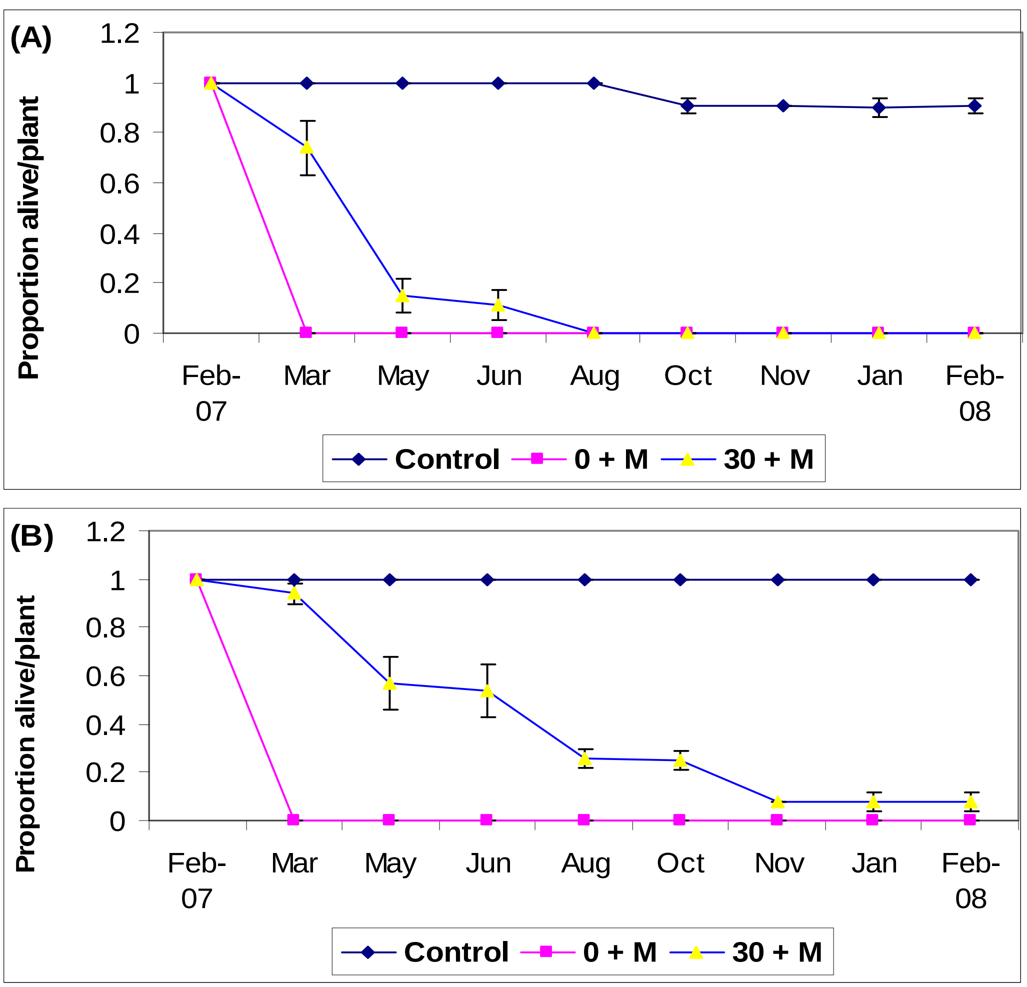


Figure 3.7. Proportion of established plants alive in each month following cutting in combination with mulching treatments at (A) Acacia and (B) Channel Island.

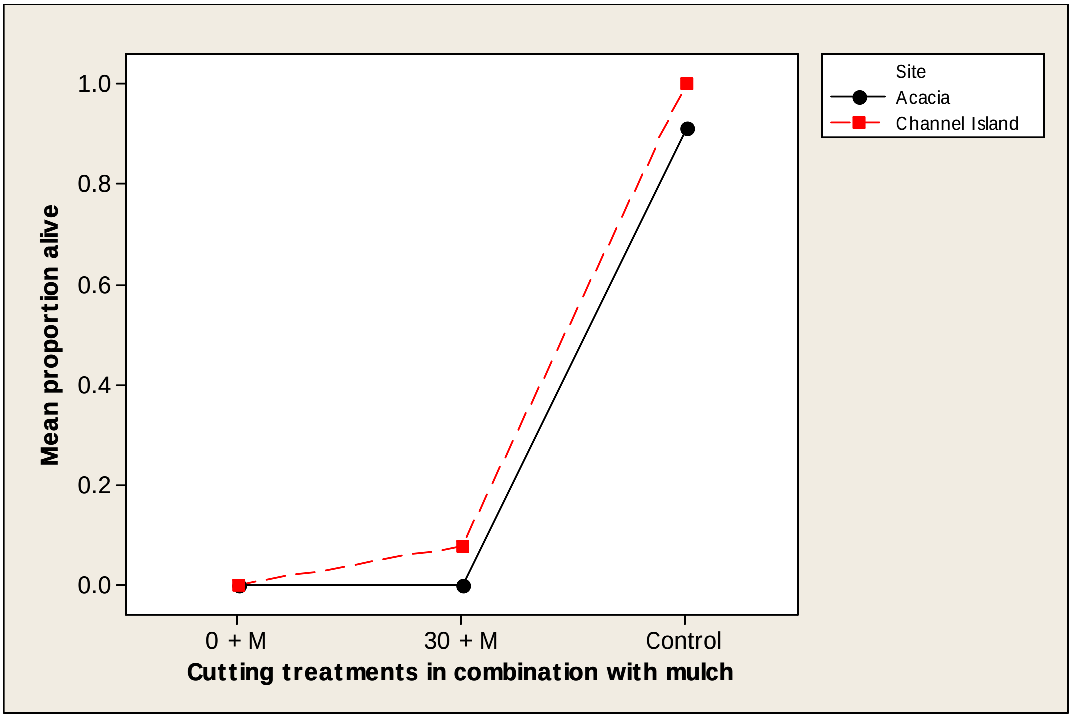


Figure 3.8. Proportion of established plants alive in February 2008, at Acacia and Channel Island, following cutting in combination with mulch treatments.

There was no re-shooting of cut plants in combination with mulch at Acacia due to plants having been killed (Figure 3.9 A). While at Channel Island, where plants were cut at 30 cm in combination with mulch application the number of new shoots per plant moderately increased over the first two months after the cutting. This was followed at this site by a gradual decline in new shoots over the dry season (Figure 3.9 B). There was no significant (Appendix A, Table 5) impact of cutting treatments in combination with mulch on the re-shooting of established plants due to site (P = 0.097) and treatment (P = 0.065). This is due to nil re-sprouting of the stems cut at 0cm and 30cm in combination with mulch at Acacia and 0cm in combination with mulch at Channel Island. While some re-sprouting was still found in the stems cut at 30cm in combination with mulch under the high canopy cover by February 2008 at Channel Island (Figure 3.10).

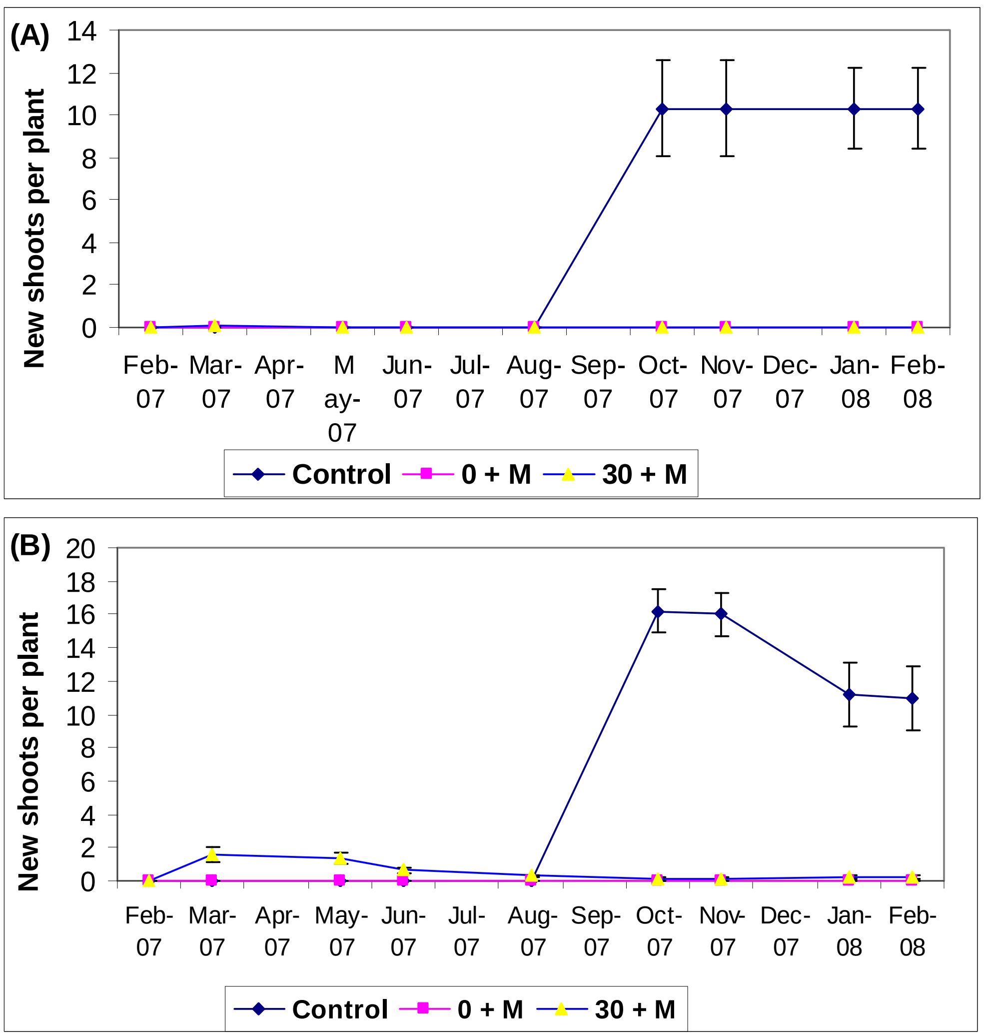


Figure 3.9. Total number of new shoots per plant for established plants in each month following cutting in combination with mulch at (A) Acacia and (B) Channel Island.

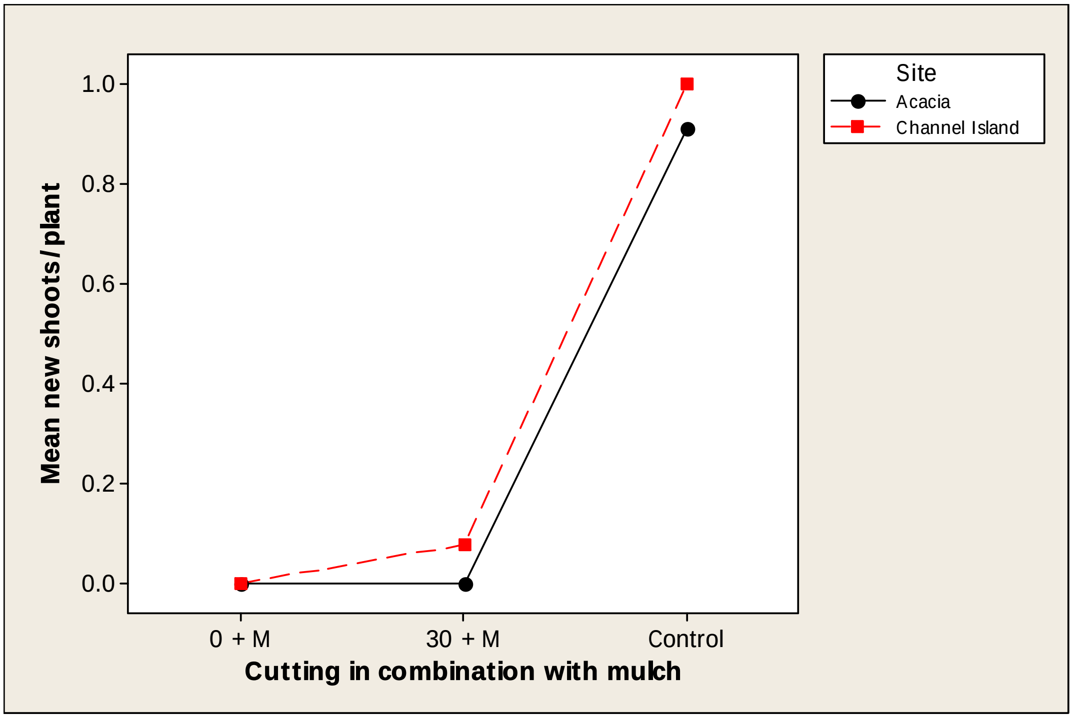


Figure 3.10. Number of new shoots per plant in February 2008, at Acacia and Channel Island, following cutting in combination with mulch.

3.3.4. Hand pulling and mulching treatment of small plants

There was a significant (Appendix A, Table 6) effect of hand-pulling and mulching treatments of small plants between sites (P = < 0.001) and treatment (P = < 0.001) but there was not a significant interaction between treatment and plot (P = 0.279). Hand-pulling completely killed small plants; irrespective of season and site at the both study sites (Figure 3.11). When the small plants were pulled out by the hand in the early wet season, they were immediately killed and did not recover as shown by the 100% mortality recorded in the observation conducted in the following month (Figure 3.12 A) and (Figure 3.12 B).

Mulching treatment reduced the survival of small plants at Acacia and Channel Island. At Acacia there was a sharp decline in the proportion of plants alive after one month in the mulching treatment. After that it remained stable (Figure 3.12 A). However, the use of mulch at Channel Island did not control small plants and the proportion alive remained constant throughout the year (Figure 3.12 B).

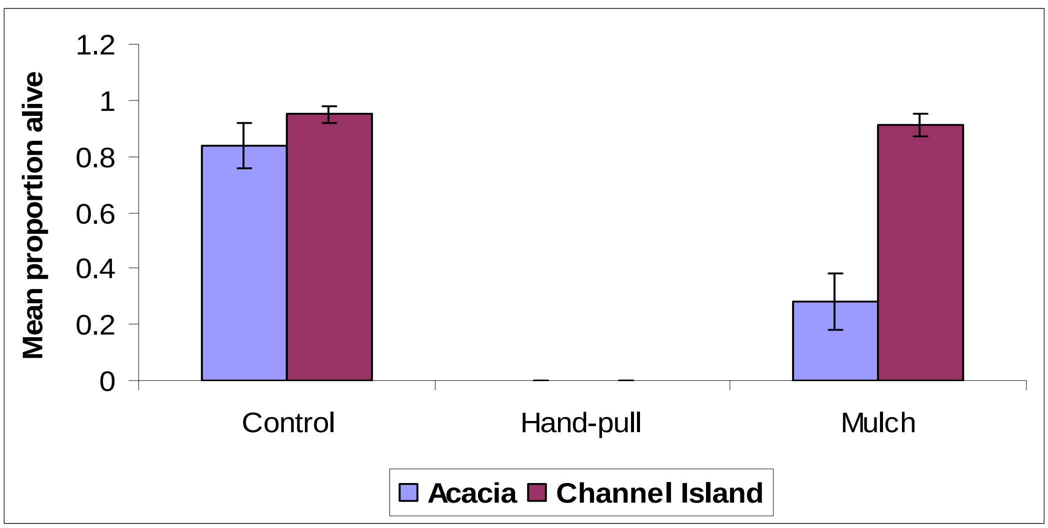


Figure 3.11. Mean proportion of small plants alive on control plots compared to plots where a hand pulling and mulch treatments where applied at Acacia and Channel Island (February 2008).

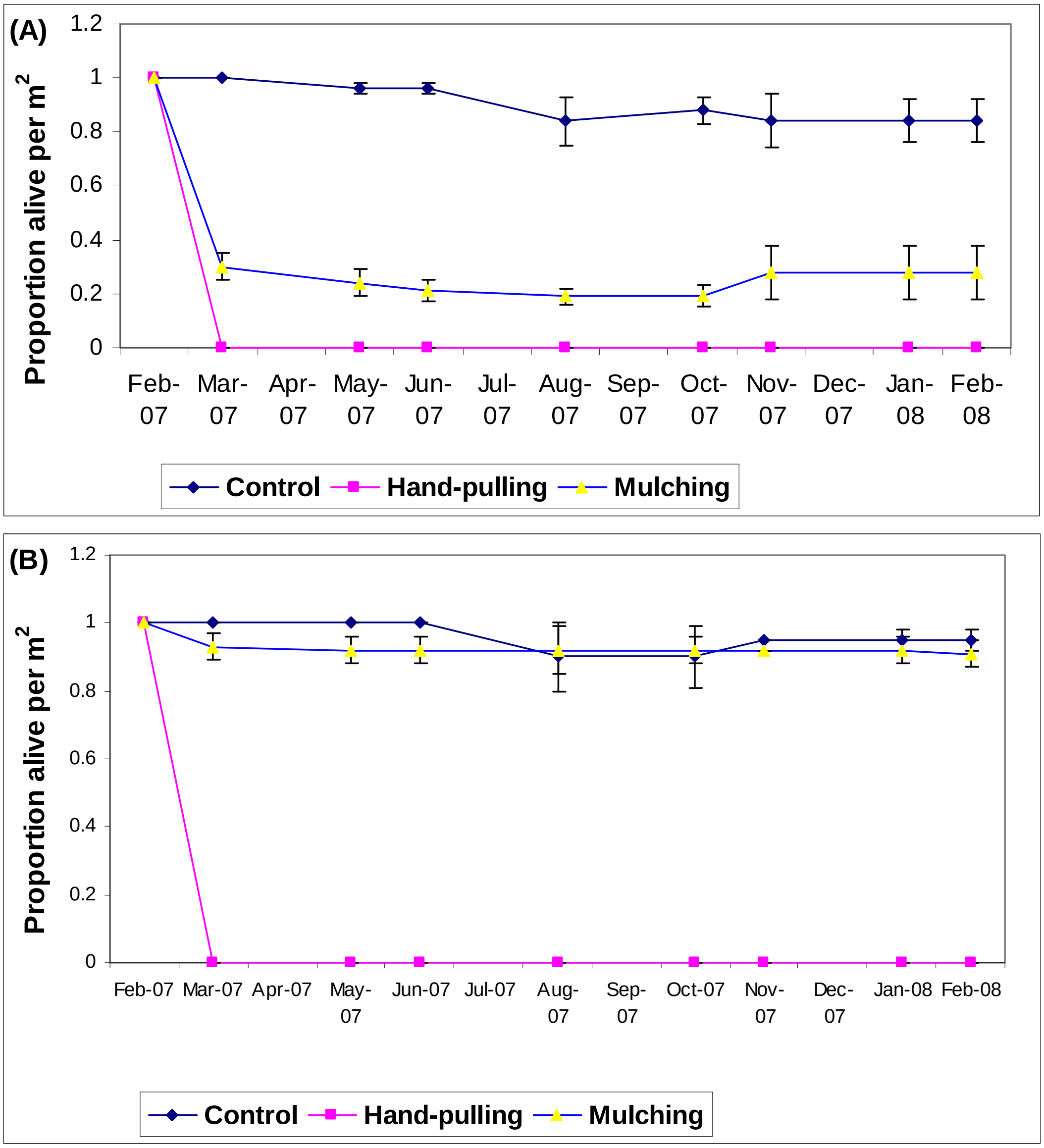


Figure 3.12. Proportion of small plants alive following hand-pulling and mulching treatments in each month at (A) Acacia and (B) Channel Island.

3.3.5. Mulching treatment of seedlings

There was a gradual decline in the proportion of seedlings alive after imposing mulching treatments (Figure 3.13 A, B). Seedling mortality following mulching treatment significantly increased during the dry season. However there are differences in seedling mortality achieved at Acacia and Channel Island. Seedling mortality at Acacia is high compared to Channel Island. There was a significant (Appendix A, Table 7) effect of mulching on seedlings mortality of site (P = < 0.001) and treatment (P= < 0.001) but no significant on plot (P = 0.053), interaction between site and treatment (P = 0.226) and interaction between treatment and plot (P = 0.252). At Acacia no seedlings survived the mulch treatment while at Channel Island just under 20% survived by February 2008 (Figure 3.14).

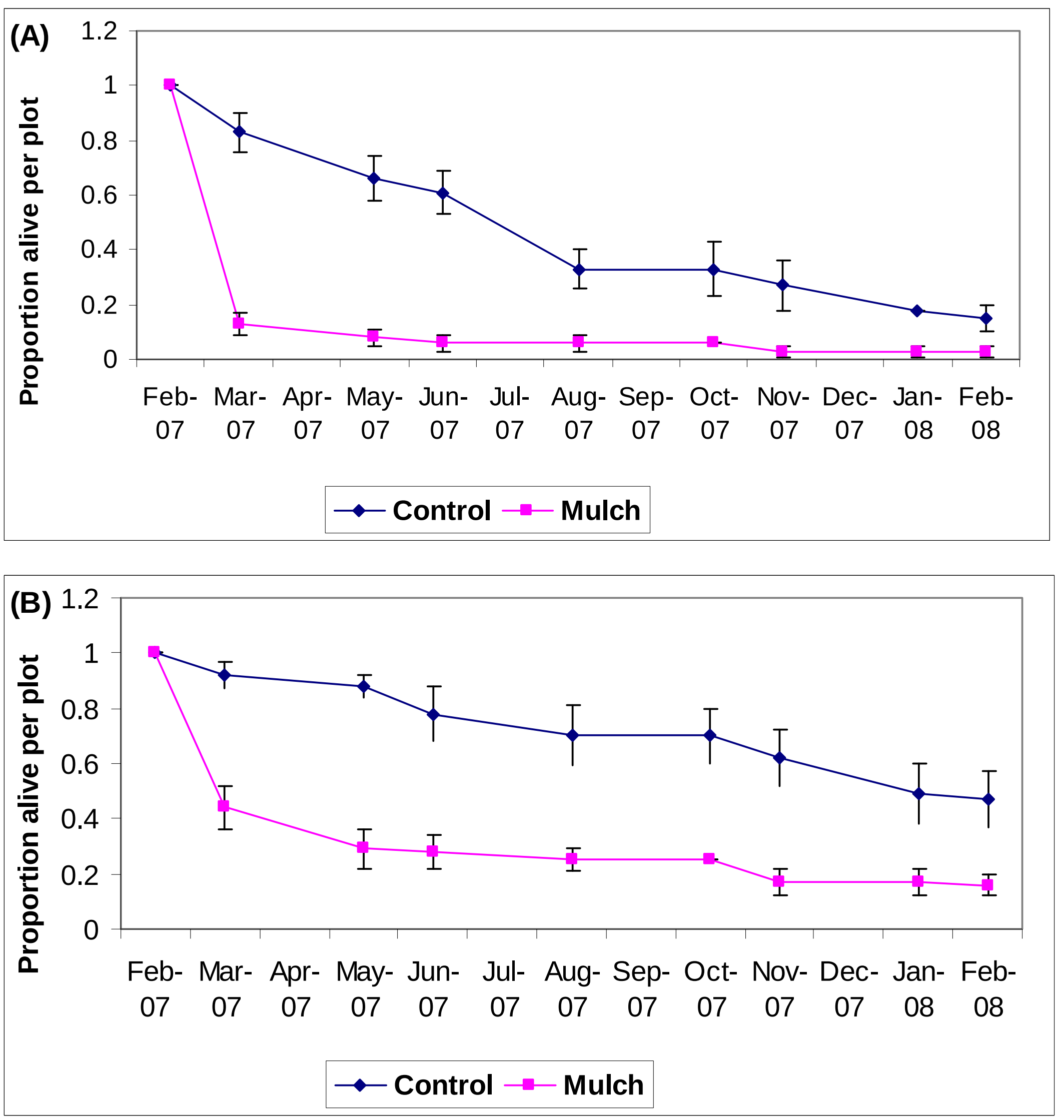


Figure 3.13. Proportion of seedlings alive following mulching treatment at (A) Acacia and (B) Channel Island.

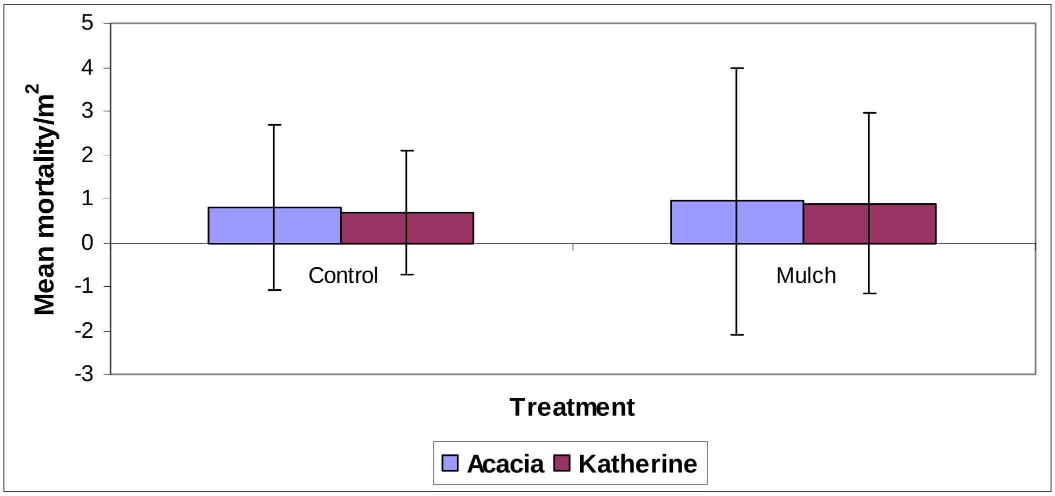


Figure 3.14. Proportion of seedlings alive in February 2008, at Acacia and Channel Island following mulching treatment.

There was no significant (Appendix A, Table 8) effect of site ($P = 0.445$), treatment ($P = 0.124$), or interaction between site and treatment ($P = 0.777$) and interaction between treatment and plot ($P = 0.132$), but there was a significant effect of plot ($P = < 0.001$). The use of mulching generally stimulated the emergence of new seedlings in the early wet season in both sites. This could be due to conditions being improved for germination and seedling emergence under mulch. Within the mulching treatment massive numbers of new seedlings were found compare to uncontrolled (Figure 3.15 A, B).

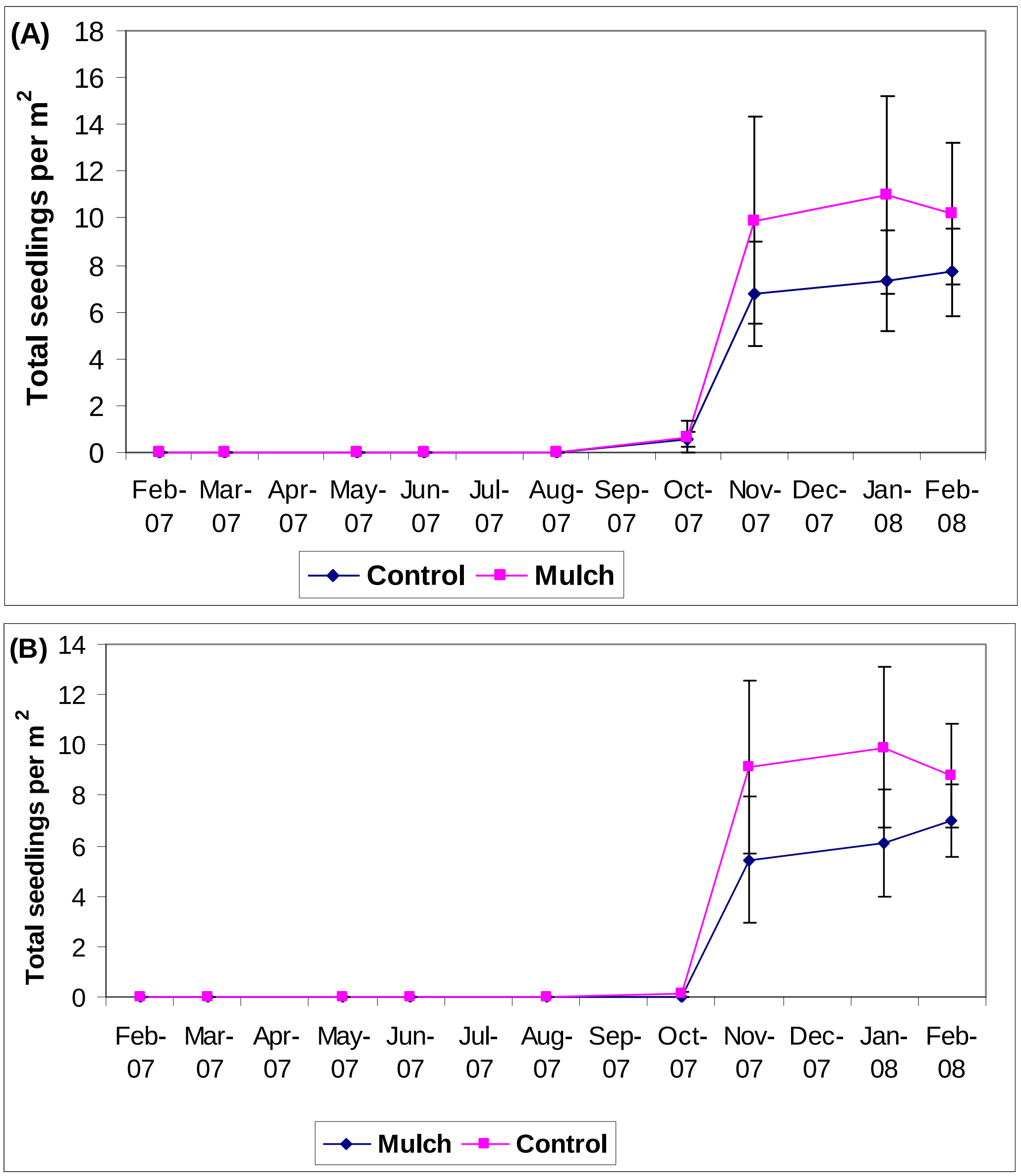


Figure 3.15. Total number of new seedlings each month (m^{-2}) in mulch and control treatments at (A) Acacia and (B) Channel Island.

3.4. Discussion

This study has confirmed the results of previous studies which also found cutting of stems can be used to kill established bellyache bush plants (Bebawi and Campbell, 2002b). However this study also found that mechanical control is only partially successful in killing established plants and is dependent on shade levels and cutting heights. The differences of canopy cover and possibly rainfall at the study sites appear to be the main factors influencing plant mortality as stated by Pyne *et al*. (1996) and Anderson (1985). They argued that cutting plants opened the areas exposure to direct solar radiation which results in higher evaporation lower average soil moisture content and greater amplitude to the soil moisture content cycle which may affected to plant growth compared with plants in adjacent plots under canopy cover. The study also found that under low canopy cover such as at Acacia, the site temperature may be higher, humidity lower and this may cause the release of moisture from soil and cut stems to the free atmosphere which may reduce plant growth. Under these conditions plants may be completely killed in dry season. In addition, under low canopy cover the mean maximum temperature tends to increase which may also contribute to high plant mortality at all cutting heights (Anderson, 1985; Trollope, 1980; Pyne *et al*., 1996). By contrast, where there is high canopy cover such as that at the Channel Island site, radiation may be hindered and wind speed reduced temperature and evaporation lowered, and atmospheric moisture content raised which may promote plant growth (Anderson, 1985; Pyne *et al*., 1996; Goudriaan, 1977; Norman and Campbell, 1983).

Cutting heights of 10 cm or lower killed all bellyache bush plants, irrespective of canopy cover. Cutting below 10 cm could be an option for the landholders treating bellyache bush infestations occurring under higher canopy cover. However, under low canopy cover stems may only need to be cut to 40 cm; which may mean less manual effort for the landholder.

Cutting established plants higher than 20 cm still resulted in 100% mortality under low canopy cover. This is because bellyache bush plants that were cut at 20cm-40cm under low canopy cover may experience high temperature, excessive heat and low humidity (Anderson, 1985; Pyne *et al*., 1996). As a consequence of these inappropriate environmental conditions cut bellyache bush plants may be completely killed (Mohr and Schopfer, 1994). In contrast, mortality of cut stems under high canopy cover was very poor unless cut at ground level (Bebawi and Campbell, 2002b). This could explain the re-shooting and re-growth from cutting treatments above 20 cm under high canopy cover. The marked difference in efficacy between the cutting treatments lower than 10 cm and cutting treatment higher than 20 cm under different canopy cover may be associated with carbohydrate reserves and physiological stress of the cut stems (Kramer and Kozlowski, 1979; Bebawi and Campbell, 2002b; Wilkins, 1984).

Mulching generally did not contribute to the plant mortality of established plants. This is shown in all results obtained in the cutting treatments in combination with mulch are no significant different to the cut only treatments.

Hand-pulling of small plants achieved 100% mortality within one month, irrespective of canopy cover. Although hand-pulling treatment completely killed small plants in the short term, the cost of this method must be considered. Hand-pulling is considered a common practice, effective and widely used to control weed infestations, but it is highly labor intensive, particularly in dense infestation (De Datta and Barker, 1975). Moreover, in some circumstances bellyache bush small plants are very hard to pull in dry soil condition and also depending on plant maturity at the hand-pulling time.

The use of straw mulch 1 kg/m^2 did not effect the kill of small plants at the Acacia and Channel Island sites. This is due to height of small plant being approximately 25-30 cm at the time of application so the mulch applied at $1kg/m^2$ did not cover the plants sufficiently to smoother all the small plants. Furthermore the mulch it may have lowered evaporation from the soil which would have resulted in higher soil water content which would promote growth rather than kill small plants of bellyache bush (Watson, 1957; Lawson and Lal, 1979).

The application of mulch increased the mortality of seedlings present in treated plots. Mohler and Teasdale (1993) also found that mulch smothered and killed seedlings.

By contrast to seedling mortality, the use of straw mulch is likely to promote new seedling emergence in the wet season. The increase of seed germination and new seedlings emerging in the wet season was probably due to ability of mulch to trap heat or moisture in the dry season enhancing the breakdown seed dormancy (Bebawi and Campbell, 2002d). It may also show the capacity of the bellyache bush seeds to germinate and emerge under different canopy cover (Csurhes, 1999; Teasdale, 1999).

Although mechanical control is a practicable method for East Timorese farmers to control bellyache bush infestations, there are still many problems associated with this method. For instance, re-sprouting may occur from some cut stems and or small plants and new seedlings may re-establish stands of this weed. Therefore, the East Timorese farmers need to incorporate good management strategies with other methods to control re-sprouting from cut stems and new seedlings that might be establish again following mechanical control.

3.5. Conclusion

To conclude that mechanical control is partially successful in killing established bellyache bush plants and the success is dependent on shade levels and cutting heights. Under low canopy cover cutting treatments at 0-40 cm completely killed established plants by the end of the dry season. This may be due to higher temperature and lower humidity expected under the lower canopy at Acacia. By contrast, under high canopy cover some plants were still found alive, particularly cutting heights of 20-40 cm. This is due to lower temperature; higher humidity and lower evaporation experienced under high canopy cover which reduces the impact of dry season conditions. Cutting higher than 20 cm may provide a substantial carbohydrate reserve to promote growth under suitable soil moisture temperature and humidity such at Channel Island.

Hand-pulling techniques completely killed small plants within one month but the labor requirement is high, particularly in dense infestation. In addition, in some circumstances bellyache bush small plants cannot be pulled out due to dry soil condition.

The use of straw mulch generally did not contribute to plant mortality of established and small plants of bellyache bush. This is due to the use of straw mulch 1 kg/m^2 being insufficient to cover and smoother established and small plants of bellyache bush. However, the use of straw mulch 1 kg/m significantly reduced seedling surviving in the dry season, irrespective of site. This is due to the use of straw mulch at the rate of 1 kg/m^2 was sufficient to suppress or smother seedling growth. The mulch stimulated new emergence in the wet season which can result in more plants surviving. This treatment would need to be followed with other methods to control reshooting of established plants and new seedlings.

Chapter 4 – Experiment II. Bellyache Bush Properties as a Fuel

4.1. Introduction

The most common practice used in East Timor to control weed infestations is by slashing and burning. The slash and burn system has been used traditionally by the East Timorese farmers for land preparation since 1912 (Metzner, 1977). It is the only option available for landholders in recent years due to financial and resource constrains suffered by farmers. As a result many farmers still use this method to control weeds and to clean land. The system of slash and burn is considered the cheapest method of land preparation for cropping and is used widely by the East Timorese farmers (Metzner, 1977). Farmers use a simple machete to slash weed and other plants in the early dry season in order to provide enough fuel for burning. This method is typically used in undulating areas that are unsuitable for the operation of large machinery.

Although the slash and burn system is the most common technique used in East Timor for weed control and land cultivation, it is not without its disadvantages. For instance, if slashing is carried out close to the start of the wet season bellyache bush will retain high moisture content and provides a less suitable fuel for fire (Metzner, 1977). As a consequence of the difficulty of burning at the start of the wet season many farmers in East Timor abandoned their land and shifted to new places to settle their agricultural activities.

An alternative technique to solve this problem is to identify the properties of bellyache bush for optimal burning management. A slashing and burning system is a method of clearing target vegetation (Metzner, 1977) and the effectiveness of fire depends on the duration and intensity of heat produced and the dryness of the slashed stems (Bowman and Wilson., 1988; Pitt 1998). The drying of the slashed stems (curing) is an essential factor that needs to be taken into consideration when dealing with fire management to control bellyache bush. Curing refers to the degree of drying of the slashed stems and it indicates the moisture content of the fuel, its flammability and thus the potential rate of fire spread. According to Williams *et al.* (2001),\ the grass curing starts as soon as a fuel is greatly accelerated by the sudden onset of the dry season. On the other hand, they also argued that fuel curing can be vary greatly across the landscape according to position in the landscape, canopy cover, plant species, land types weather condition and the season. For instance, grasses such as annual sorghum on sandy soils will cure rapidly than perennial grasses on cracking clay (Williams *et al*, 2001; Dyer *et al*, 2001). The curing of grasses usually takes about one to one and half months to complete. As grasses fuel dries off over the dry season fuel becomes more cured and may produces higher fire intensity (McArthur and Cheney, 1972).

However, there are other factors which need to be taken into consideration during the curing period. For instance, the consistent rainfall during the curing period in the dry season can cause grass fuels to stay green longer and produce fresh growth on the slashed stems, thus reducing the fuel flammability (Australian Fire Authorities Council, 2002). The greenness and re-sprouting on the cut stems in the dry season tends to reduce fuel flammability as a fire season progresses.

If the fuel moisture content is greater than 20% then it is mostly unable to burn in the dry season (Australian Fire Authorities Council, 2002; McArthur and Cheney, 1972). The higher the moisture content, the more energy required to combust the fuel, and consequently fire may be less intense (Geoffrey *et al.*, 2003). In addition, Johnson (2002) stated that, the greenness and moisture content of fuel affects ignition potential, fire intensity and rate of fire spread. Plant moisture acts as a heat sink and thus influences fire behavior by increasing the specific fire required for the fuel to combust. As plant moisture decreases to 20%, fire intensity and potential ignition increase (Australian Fire Authorities Council, 2002; Johnson, 2002).

The second important thing dealing with fire management is fuel characteristics and fuel texture. Fuel availability and fuel load affects fire intensity (McArthur and Cheney, 1972). Fuel loads can be expressed in different units, for instance tones per hectare, kilogram per hectare, kilograms or grams per square meter (Williams *et al.*, 2001). Most savanna fuels are fine fuels and less than 6 mm in diameter. Annual inputs of fine fuel from grass growth and litter fall between about 2-8 tonnes of dry matter per hectare. Under annual burning, fuel loads generally remain at these levels in both higher rainfall and semi-arid savannas. If country remains unburnt, the fuel loads rise but do not generally increase above the equivalent of a few years' grass growth and leaf fall because the litter breaks down quickly during each wet season (Williams *et al.*, 2001).

The volume of available dead fine and heavy fuels will change with the seasons. Usually the dry season brings about an increase in the total volume of dead litter fuels as trees shed leaf and bark material in response to moisture stress. Also the dry litter bed decomposes or composts more slowly. In time of drought this can amount to an increase of up to 8 tonnes per hectare of dead fine fuel (Stinson and Wright, 1969). .

During the wet season, heavy dead fuels and deep litter beds of fine fuels in forest become saturated. As the dry season commences, these fuels slowly dry out providing increasing quantities of available fuel. These fuels may take one to two months or more of drying weather to fall to minimum moisture contents to support fire (Australian Fire Authorities Council, 2002; McArthur and Cheney, 1972).

The third important factor needing to be considered in the fire management is heat yield during combustion. The measurement is related to the ability of fuel to produce heat, and correlates with factors such as scorch height of vegetation. Total energy released per unit area is more closely related to the completeness of combustion and the post fire state of the site (Byram, 1959).

Although fire is a common tool used to manage weeds in East Timor, it has proven difficult to control bellyache bush due to its high moisture content and dense monoculture habitat. By growing as a monoculture, bellyache bush produces less fine fuel and medium fuel to support management burns than where it occurs in mixed stands where there is more fine and medium fuel. The objective of this study was to determine the properties of cut bellyache bush stems required for successful management of fire. It is expected that stems, if allowed to cure can form a suitable fuel bed for fire management in the late dry season.

4.2. Materials and Methods

4.2.1. Site description

This study was conducted from May to October 2007 at three locations in northern Australia and investigated curing rate, re-sprouting, fuel texture and heat yield combustion of bellyache bush. Channel Island was used for the curing and re-sprouting studies only. Acacia was used for curing, re-sprouting, fuel texture, fuel consumption and heat yield combustion studies. Katherine was used for the fuel texture study.

The Channel Island and Acacia sites are described in Chapter 3. The Katherine site (14º22’S, 132º09’E) had a mean annual rainfall of 875 mm (Figure 4.1), mean annual maximum temperature 34.4ºC, minimum temperature 19.4ºC and mean relative humidity 67%. The soil type at the Katherine site was a sandy loam to sandy clay (Day *et al*., 1979; Fogarty *et al*., 1984). At this site there was almost a monoculture of bellyache bush situated on limestone outcrops that were surrounded by dense mission grass (*Pennisetum sp*) 1.5 m tall, with *Eucalyptus confertiflora, E.tectifica, E.latifoli, and Ficus platipoda* present in small numbers. There were three plots in this study. The first plot was located in the heart of the limestone outcrop on a flat soil sheet surrounded by rock. The second plot was located amongst shallow soil lenses amongst a limestone outcrop. And the third plot was a long narrow plot located between two rocky ridges.

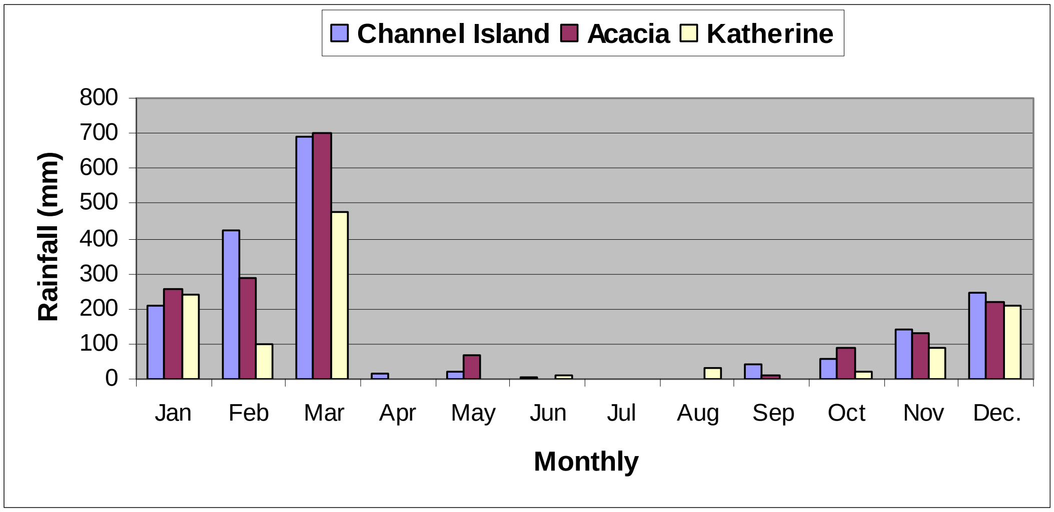


Figure 4.1. Monthly rainfall data at the study sites during 2007.

4.2.2. Measurement of canopy cover

The experiment was undertaken in three randomly selected of 10m x 10m plots at all sites. Canopy cover was measured using a standard densitometer, taking four replicate measurements at each plot within the study sites, as per 3.2.2.

4.2.3. Curing rate of bellyache bush

This measurement was undertaken on plots of cut bellyache bush stems at the Acacia and Channel Island sites. At each site one 10m x 10m was divided into 100 quadrats each measuring 1m x 1m. All bellyache bush in the plot was cut in May, when biomass is maximum after the proceeding wet season. Every four weeks, five 1m x 1m quadrats at each study site were randomly selected and all fuel in the quadrat was collected. These fuel samples were then quickly sealed in plastic bags, and transported to laboratory for wet weight measurement. Samples were then oven-dried in paper bags at 70ºC until the weight was constant to obtain dry weight. The moisture was calculated as a percentage using the dry weight relative to the total wet biomass.

4.2.4. Measuring re-sprouting of cut stems

This measurement was undertaken on the plot of cut bellyache bush stems at Channel Island and the plot of cut bellyache bush stems for the burning experiment at Acacia and Katherine. At each site one 10m x 10m plot was used for this study. In each of these plots 51 previously cut stems of bellyache bush were randomly selected within each of 10m x 10m plots in September

2007. Total length of the each stem and the length from the tip (meristem) at which shoots were appearing and still green were recorded.

4.2.5. Characterising fuel size classes before burning

This measurement was carried out at the Acacia and Katherine sites. At each site three 10m x 10m plots ware used for this study. These plots were subsequently burned in the fire study (Chapter 5). Five 25cm x 25cm quadrats were randomly selected within each of the three plots and all fuel collected and sorted according to texture and weight. Size classes were fine (less than 6mm in diameter), medium (between 6mm-25mm in diameter) and coarse (greater than 25mm in diameter). Samples were placed back in the field after measurements were taken. There was so little grass in the plots that it was not possible to identify it separately.

4.2.6. Heat yield of fuel (J/g)

The samples for this measurement were collected from the Acacia site. Two stems of each size class were randomly selected and then sealed into bags. Samples were then ground and homogenised using a wooding vessel. A 0.8-1g sample was analysed for heat yield by using a bomb calorimeter (AS 1038.5 leco 350 calorimeter). This was done at HRL Technology Pty Ltd, Victoria laboratory, New South Wales.

4.2.7. Statistical Analysis

Data collected for this chapter was of a descriptive nature and therefore did not require statistical analysis such as an ANOVA. Mean and standard error were determined using descriptive statistics in Minitab. However, the proportion of whole stems length alive and number of shoots per stem was analysed to evaluate whether curing was effected by canopy cover. A model for the analysis of variance is one factor, where site is fixed factor and stems are random. Data were checked for normality and transformed to Arcsin (square root (proportion alive). Full results of ANOVA are presented in Appendix A, while P values are presented in the text of results.

4.3 Result

4.3.1. Canopy cover

Canopy cover differed between sites and seasons. There was less canopy cover present during the dry season for all three sites. Channel Island had higher cover than Acacia and Katherine for both seasons (Table 4.1).

4.3.2. Curing rate of bellyache bush stems

Bellyache bush stems had the highest moisture content at the start of the dry season (May) at both sites (Figure 4.2). During the first two months moisture content decreased by only 10 %, however, after the three months moisture content of stems at Acacia site dropped sharply. After five months all stems at Acacia site contained less than 10% moisture content and were well cured. In contrast, the moisture content of cut bellyache bush stems at Channel Island site still remained high (>55%).

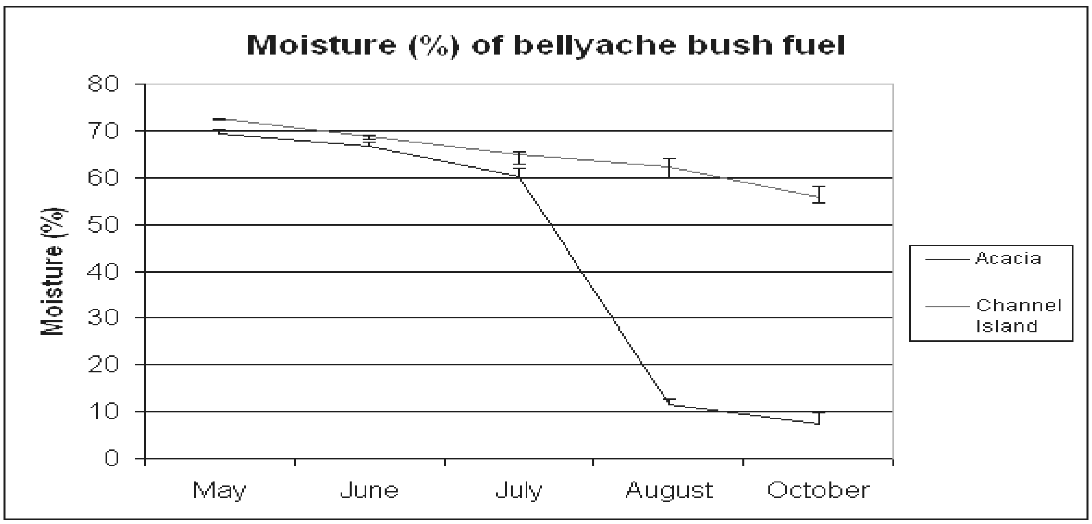


Figure 4.2. Curing of bellyache bush fuel. Moisture (% content) from early dry season to late dry season 2007.

4.3.3. Measuring re-sprouting of cut stems

A considerable number of cut stems were still alive and had re-sprouted at the end of the dry season (P = < 0.001) (Table 4.1). Channel Island had the largest proportion of live stems present (0.76) in addition to the highest number of re-sprouted shoots (7), in comparison to Acacia (0.13 and 3.8) and Katherine (0.15 and 3.3) which has similar results.

Table 4.1. Canopy cover and re-sprouting (mean ± S.E.) of cut stems. The influence of canopy cover on proportion of stems re-sprouting of cut stems while lying on soil surface during the dry season. Stems were cut in May and monitored at October (2007). Values with same letter are not significantly different ($p < 0.5$).

Site	Canopy cover %		Proportion of cut stems alive	Whole stem length for alive stems (cm)	Proportion of whole stem length alive	Number of shoots per stem
	Wet	Dry				
Channel Island	88.8 ± 2.2	63.6 ± 8.9	0.76	198.3 ± 9.8	0.93 ± 0.04 [a]	7.0 ± 0.7 [a]
Acacia	48.5 ± 4.7	18.8 ± 4.9	0.13	183.3 ± 12.7	0.25 ± 0.02 [b]	3.8 ± 0.8 [b]
Katherine	46.2 ± 4.3	14.2 ± 3.3	0.15	247.0 ± 12.2	0.27 ± 0.03 [b]	3.3 ± 0.4 [b]

4.3.4. Characterizing fuel size classes before burning

Fuel load was greater at Acacia (5.95 t/ha) than Katherine (5.40 t/ha) (Figure 4.3). Acacia also had higher amounts of fine and medium sized stems. There were differences of total biomass and land cover types at the both sites. At Acacia bellyache bush grew with some grasses, herbs and other plants. By contrast bellyache bush grew as a monoculture at the Katherine and less fine and medium fuel occurred with greater coarse fuel.

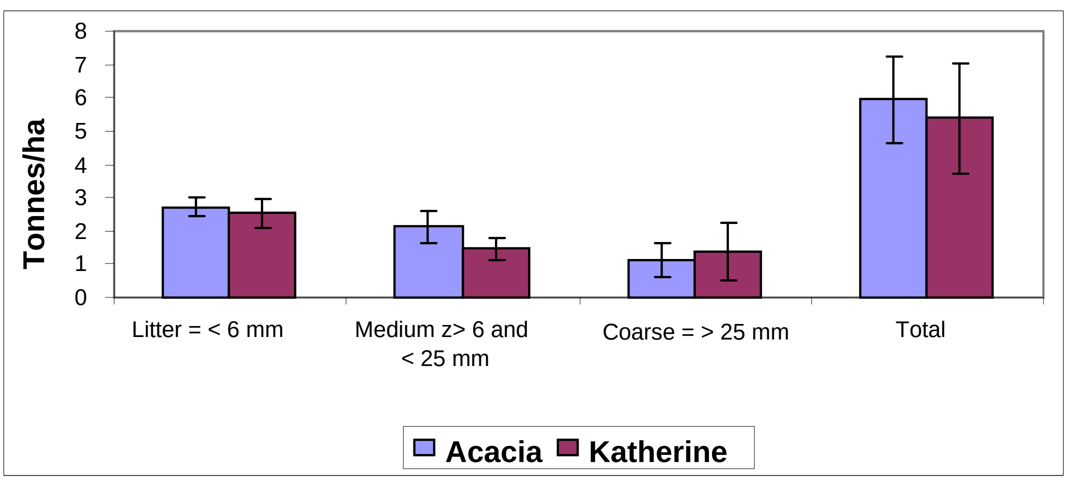


Figure 4.3. Fine fuel (<6 mm), medium (>6 mm and <25 mm) and coarse (>25 mm). Mean (± S.E) of fuel dry weight at the time of experimental fires at Acacia and Katherine in October 2007.

4.3.5. Combustion heat yield of bellyache bush

The average combustion heat yield of bellyache bush stems did not differ between textures 16.8 ± 0.2 j/g (Table 4.2).

Table 4.2. Combustion heat yield of bellyache bush stems analysed in 2007.

Sample Description	Gross Calorific Value kJ/kg
Fine	17,000 ± 400
Medium	17,000 ± 100
Coarse	16,600 ± 300
Average	16,800 ± 200

4.4. Discussion

This study has determined that curing ability and re-sprouting properties of bellyache bush is dependent on environmental conditions and other factors such as canopy cover, weather conditions and season. Low canopy cover and more open areas such as that found at Acacia and Katherine sites are likely to experience more direct heat and radiation during the dry season such as stated by Anderson, 1985; Trollope, 1980 and Pyne *et al*., 1996. This condition may create greater evaporation, releasing more moisture from the stems and increasing curing rate (Anderson, 1985; Arno and Ottmar, 1994; Pyne *et al*., 1996). In addition, the weather conditions such as the mean maximum temperatures tend to increase at Acacia and Katherine in the dry season compare to the minimum air temperatures (Pyne *et al*., 1996). Given this pattern the variation in humidity is very low at Acacia and Katherine sites compare to Channel Island. Therefore, it seems that the meteorological conditions at Acacia and Katherine produce a higher rate of curing compared to Channel Island (Trollope, 1980).

Curing process of bellyache bush cut stems was very slow in the early part the dry season. This is due to highly moisture content of bellyache bush stems (70%) at the time of cutting and subsequent influence of dry season showers in May and June. As a consequence of these factors cut stems of bellyache bush takes two to six months to cure. By contrast, the grasses cure rapidly with the onset of the dry season. It just takes one to one and half months for grasses to completely cure. In forests land the fuel takes one to two months to completely cure (Williams *et al.,* 2001; McArthur and Cheney, 1972; Bowman and Wilson., 1988).

From the results obtained at the curing study plots it indicated that all cut stems from bellyache bush under the low canopy cover site at Acacia cured completely after six months. However, stems cut from bellyache bush under high canopy cover at the Channel Island did not cure. This may be due to the high density canopy cover at that site reducing radiation and wind speed that resulted in lower temperatures and lower evaporation from cut stems (McArthur and Cheney, 1972; Arno and Ottmar, 1994).

Although cutting of all bellyache bush plants in the early dry season and later burning is an alternative on fire management, the effect of dry season showers should be taken into account during the curing period. The consistent dry season showers in May, June, August, September and October in this study may have contributed to the delayed of curing process. As a consequence, it caused bellyache bush fuel to stay green during the dry season (Australian Fire Authorities Council, 2002). The greenness trait is likely to be linked to the high moisture content of the cut bellyache bush stems. The greenness on the bellyache bush cut stems tends to reduce fuel flammability in the late dry season burning as stated by Geoffrey *et al*., 2003; Burrows, 1994; McArthur and Cheney, 1972). Moisture retention of cut bellyache bush stems may mean it is not a suitable fuel for burning at some sites (Geoffrey *et al*., 2003) such at Channel Island site.

The total bellyache bush fuel load at Acacia site was 5.95 t ha^{-1} of dry matter. The fuel at this site consisted of 2.7 t ha^{-1} of fine, 2.1 t ha^{-1} of medium and 1.1 t ha^{-1} of coarse stems. Total bellyache bush fuel at Katherine was 5.4 t ha^{-1} of dry matter which was made up of 2.5 t ha^{-1} of fine, 1.5 t ha^{-1} of medium and 1.4 t ha^{-1} of coarse textured material. From this it can be seen that bellyache bush fuel texture at both study sites is not significantly different from fuels in native savanna. According to Williams *et al.* (2001) most savanna fuels are fine fuels less than 6 mm in diameter and in the range of 2-8 t ha^{-1} of dry matter per hectare.

High available fuel levels and low fuel moisture levels are likely to result in greater fire intensity (Cheney, 1981; Sneeuwjagt and Peet, 1985; Burrows, 1994). Therefore, at Acacia and Katherine higher fire intensity may be expected than could occur at Channel Island. Also, the difference in land habit at both study sites contributed to the large differences in fuel texture and load availability. The fuel texture at Acacia was relatively high in fine and medium component which was likely to cause fire to spread relatively quickly (Burrows, 1994). In contrast, the Katherine site had a larger proportion of coarse textured stems and a lower fuel load that may result in a slower rate of fire spread.

The combustion heat yield of bellyache bush cut stems is similar to that found in other plant materials such as grass and forest fuel in Australia (16,830 kJ/kg) (Luke and McArthur, 1978) and forest fuel in the US (18,640 kJ/kg) Albini (1976). Therefore it can be concluded that bellyache bush has the necessary fuel properties that are required to produce a satisfactory fire if other conditions are favorable.

Although fuel loads differed between Acacia and Katherine, the combination of lengthy curing time, the low moisture content of the cut stems, the mix of the different of fuel sizes at the sites and its availability is likely to result in satisfactory burns at both sites. Delaying burning until late in the dry season when the conditions are hot and the fuel has low moisture will result in fire of sufficient intensity to achieve a high level of fuel consumption.

4.5. Conclusion

Cut stems of bellyache bush monocultures under low canopy cover is more likely to possess fuel properties that support a successful burn. In addition, approximately half of the fuel at the study sites was less than 6 mm in texture, with a load of 2-3 t ha^{-1}, which is an ample amount to support fire during the dry season, especially the late dry season, in northern Australia (Williams *et at*. 2001).

However, bellyache bush cut stems under high canopy cover are not likely to be a suitable fuel for fire if it is still green. Leaf production and re-sprouting of cut stems are indicators to land managers that stems may still be very moist. Cut stems under this condition may be too moist for the burning management.

Therefore, the land managers need to cut down a large enough proportion of bellyache bush plants in the early dry season in order to provide enough fuel biomass, reduce canopy cover to allow curing and gives longest time to create fuel curing under hot condition. Maximum temperatures and low humidity during curing period may increase rate of curing in the late dry season.

Chapter 5 – Experiment III. Fire as Control Tool for Bellyache Bush

5.1. Introduction

Fire has been traditionally used to control invading woody plant species in East Timor since 1912 (Metzner, 1977) and elsewhere in the world (Hensel, 1923; West, 1965; Kayll, 1974; Trollope, 1980). Fire has been suggested as a useful tool, either alone or in combination with other methods, for the control of woody weeds (Bebawi and Campbell, 2002c; Miller *et al*., 1981; Miller, 1988). However, East Timorese farmers tend to abandon rather than burn bellyache bush monoculture (personal observations). The aim of this chapter is to evaluate the potential for fire, in combination with cutting, for controlling bellyache bush.

According to Bebawi and Campbell (2002c) and Vitelli and Madigan (2004), the effect of fires on bellyache bush plants depends on the susceptibility of the age structure of the stand. Bebawi and Campbell (2002c) found fire significantly reduced bellyache bush plant density by 76% in the first year after burning. The relative sensitivity to fire was found to be seedlings greater than small plants, and small plants greater than established plants. In addition, West (1965), Hodgkinson and Harrington (1985) and Lonsdale and Miller (1993) found that fire generally kills most woody seedlings, but its effect on adult plants varies. Bebawi and Campbell (2002c) reported that mature bellyache bush plants were quite resistant to fire, the majority of plants re-growing from the base or stems.

Fire causes plant mortality and stem death due to indirect metabolic changes, and also directly causing protein denaturation which can alter lipid mobility or chemical decomposition (Alexandrov, 1964; Levitt, 1972). Burning around the entire circumference of plants may be effective in destroying the vascular cambium and rupturing cell walls, leading to plant death (Hare, 1961; Vaster, 1988; Parish *et al*., 1997). The cambium layer and cell walls are normally destroyed when the cambium and cells are exposed to temperatures of 60˚C or more (Hare, 1961; Fahnestock and Hare, 1964).

High temperatures generated by the heat of the fire may not be experienced in the soil at depths of more than 2 cm. Temperatures above 60^{0}C occur only between the soil surface and depths of 2 cm. Seeds are protected at greater soil depths, therefore post-fire seedling recruitment occurs from depths greater than 2 cm (Bradstock and Auld, 1995). In addition, Bebawi and Campbell (2002d) conducted research on the riparian habitat in the tropics to quantify the effects of late dry season burning on the seed bank of the bellyache bush infestations. They found *"seed viability was nil for seed under litter cover, but > 80% of seeds placed on bare ground or 2 cm below ground remained viable"*.

The impact of fire on plants depends upon fire intensity. Weather conditions during the fire, fuel load and fuel texture are important determinants of fire intensity (Cheney, 1981). Dense stands of bellyache bush that have little or no understorey (Braithwaite *et al*., 1989), do not burn easily. Wildfires have been observed to go out soon after passing from scattered infestations, where there was dry understorey fuel, into dense infestations where fuel was disconnected (Miller, 1982).

Although it has been practicable for the East Timorese farmers to use fire to control weed infestations for a long time, there are also disadvantages of using fire. Burning cannot completely control the weed, because it re-shoots from some stems, and fire at the beginning of the wet season can stimulate seed germination.

Therefore, the East Timorese farmers need to incorporate a range of management strategies to control the seeds that might have survived post-fire treatment. These methods may include cutting down all bellyache bush trees early in May to prevent flowering, fruiting, seeding and seed maturation. In addition, burning should be implemented in the late dry season to generate high fire intensity. The advantages of this combination of treatments are to produce hot fire in order to kill seeds and new re-shooting plants after cutting. If any plants still survive, then farmers could use a second fire, weeding and hand-pulling treatments until all seedlings and surviving plants have been eliminated.

There is a major knowledge gap in the relationship between fire intensity, and subsequent impact on mature bellyache bush plants, and the effect of fire on seedling emergence. The objectives of this study therefore were to investigate the intensity of fire that can result from a fuel bed consisting of mainly cut bellyache bush stems (and relatively little grass) and to investigate the impact of single late dry season fire of known intensity on plant mortality and post-fire seedling emergence.

5.2. Material and Methods

5.2.1 Site description

This experimental fire took place in the late dry season in October 2007 at Acacia and Katherine. The two study sites at Acacia site (12º45’S, 131º09’E) and Katherine (14º22’S, 132º09’E) were located within a dense infestation of bellyache bush, with an average density of 90,000 plants/ha. The Acacia and Katherine sites are described in Chapter 3 and 4, respectively.

The soil type at Katherine site is a sandy loam to sandy clay loam (Day *et al.*, 1979; Fogarty *et al.*, 1984). The monoculture of bellyache bush was situated amongst a limestone outcrop. The outcrop was surrounded by dense mission grass (*Pennisetum sp*) 1.5 m tall, with emergent

Eucalyptus confertiflor, E.latifolia, E.tectifica, and Ficus platipoda scattered among the rocks. There were three plots at Katherine. The first plot was located in the heart of the limestone outcrop on a flat soil sheet surrounded by rock. The second plot was located amongst shallow soil lenses amongst limestone outcrop. And the last was a long thin plot located between two rocky ridges.

5.2.2 Fuel load and consumption.

Fuel loads and fuel texture classes (fine less than 6mm, medium between 6mm-25mm and coarse greater than 25mm) at both sites have been presented in Chapter 4 (Figure 4.3). For fuel consumption, 20 pieces of each fine litter (0-6 mm in diameter), medium litter (6-25 mm in diameter) and coarse litter greater than (25 mm in diameter) were selected from within each plot. The length of each piece varied between 15 and 25 cm. Each piece of litter was numbered individually and weighed immediately before burning.

The labelled pieces of litter were retrieved and reweighed immediately after the fires. The average proportions by weight consumed for the 20 replicate coarse, medium and fine pieces of litter were then used to calculate the average proportion of biomass consumed for each plot for each texture class. This value was then used to calculate fuel consumption (t ha^{-1}).

5.2.3 Fire characteristics

Fire intensity was determined using Byram's fire intensity equation (Byram, 1995), $I = Hwr$, where I is fire intensity (kW/m), H is heat yield of fuel (kJ/kg), w is fuel consumed (kg/m^2) and r is rate of fire spread (m/sec).

Samples (0.1 g) of representative dry fuel of each texture class were sent to HRL Technology Ply Ltd New South Wales for analysis of heat yield using bomb calorimeter (AS 1038.5 leco 350 calorimeter).

Rate of spread was determined using temperature activated time recorders, as described by Moore *et al.* (1994). The timers are essentially thermocouples attached to stop watches. Timers were positioned at three different point sites within each 10m x 10m plot. Thermocouples sense passing of the fire front and when the fire moves over the particular points and the temperature exceeds 200°C a small current is generated, which automatically stops the internal stopwatch. All timers were synchronised before each fire and each one stops as the fire front moves over its location. The differences in these times were used to calculate the rate of fire spread according to the trigonometric triangulation formulae of Simard *et al.*, (1994).

Plate 5.1. Thermocouple timers used at Acacia and Katherine to measure rate of spread during fire.

5.2.4 Measurement of soil temperature

Soil temperature was measured using iButton programmable temperature sensors (Maxim Integrated Products Inc, Sunnyvale, California). These sensors record to a maximum of 125^{o}C, and in this study were programmed to start recording temperatures above 39^{o}C, then buried several hours prior to the experimental fires (Refer to Appendix C Table 1 and 2).

This measurement of soil temperature was undertaken in the three replicate 10m X 10m fire plots at each of two sites. Before the fire was ignited, five established plants were selected randomly within each plot. The iButtons were buried in the soil, beneath the canopy of the five plants, at 1 to 2 cm depth. All iButtons were retrieved from the soil within 1 – 2 hours after the passage of the fire.

5.2.5 Impact of burning on plant survival

Within each of the six 10m x 10m plots, 15 individual established plants were cut 30 cm above the ground and tagged. Another 15 individual plants were tagged and left uncut. Three plots were burnt and three remained unburnt for the control. The location of each plant was marked with metal tags to facilitate monitoring after burning. Plant height and number of branches were recorded before imposing the cutting treatment. In the fire plots, all other bellyache bush stems were cut down and allowed to dry out for several months in order to serve as a fuel. After burning all individual tagged plants were revisited after three weeks (November 2007) and three months (February 2008). Surviving individuals, number of re-sprouts, reproductive status and their heights were recorded during of these visits.

5.2.6. Post fire seed germination and seedling establishment

In order to monitor post-fire seed germination and seedling establishment five 1m x 1m quadrats (within the 10m x 10m plots) were randomly selected before burning. Seedling establishment was measured in November 2007 and February 2008 in both burnt and control plots.

5.2.7. Statistical analysis

Plant survival data did not require analysis due to 100% mortality. Seedling emergence data was analysed using 3-Factor ANOVA. Factors were: Site (n=2, fixed), Treatments (n=2, fixed) and Plot (n=3, random, nested in site). The model for analysis of variance is SITE+TREATMENT+PLOT (SITE) +TREATMENT*SITE+TREATMENT*PLOT. Data were checked for normality. Full results of ANOVA are presented in Appendix A, while P values are presented in the text of results.

5.3. Results

5.3.1. Fuel load and consumption

Fuel loads ranged from 1.5 to 5.9 t/ha at each plot. There were a high proportion of fine fuels (almost 50% by mean) at both Acacia and Katherine sites. The fires supported by these fuels resulted in almost total fuel consumption (Figure 5.1). For fine litter between 86 – 100% of samples were consumed, for medium 79 – 100% and for coarse 76 – 98% of samples were consumed.

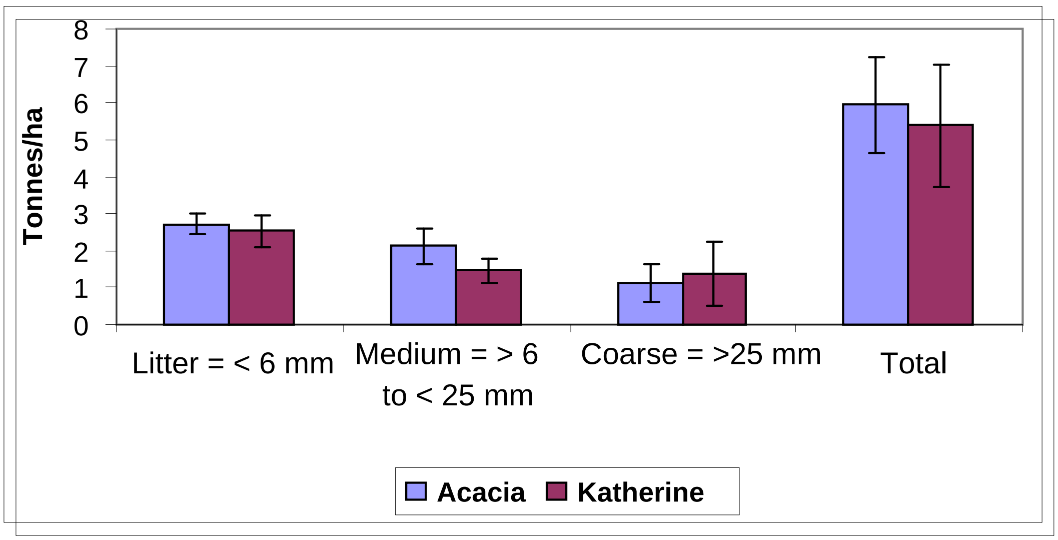


Figure 5.1. Fuel Consumption (tonnes/ha) at Acacia and Katherine after imposing fire treatment.

5.3.2. Fire characteristics

Despite similar fuel loads (Figure 4.3), fire intensity at Katherine was greater than at Acacia site (Table 5.1). Rate of spread was also variable within the sites. Rate of spread at Acacia ranged from 0.0038 - 0.1896 m/sec, while at Katherine ranged from 0.0046 - 0.05932 m/sec (Table 5.1).

Fire intensity varied by one order of magnitude, from a low of 35 kW/m on plot 1 at Acacia, to 1369 kW/m on plot 3 at Acacia.

Table 5.1. Heat of combustion (kJ/kg), fuel consumption (kg/m^2), rate of spread (m/s) and fire intensity (kW/m) at each plot at Acacia and Katherine.

SITE	Plot	H (kJ/kg)	w (kg/m^2)	r (m/s)	I (kW/m)
Acacia	1	16800	0.55	0.0038	35
	2	16800	0.69	0.0314	366
	3	16800	0.43	0.1896	1369
Average for Acacia	All	16800	0.56	0.0749	703
Katherine	1	16800	0.56	0.0046	44
	2	16800	0.55	0.05932	548
	3	16800	0.38	0.0202	128
Average for Katherine	All	16800	0.50	0.02610	240

5.3.3. Soil temperature

Soil temperature recorded during burning varied among the study plots. Maximum soil temperature at Acacia varied from 54^{0}C to 126^{0}C (Figure 5.2). Maximum soil temperature at Katherine varied from 63^{0}C to 126^{0}C (Figure 5.3).

Within the sites there was a range of periods for which temperature remained elevated after the fire (Table 5.2). For example at Acacia temperature remained elevated for between 12.2 minutes to 22.1 minutes after the fire. At Katherine temperature remained elevated for between 3.3 minutes to 22.6 minutes after the fire.

There was no relationship between Byram's fire intensity and maximum temperature change (Table 5.3). No relationship between fuel load, rate of spread and maximum temperature change was found.

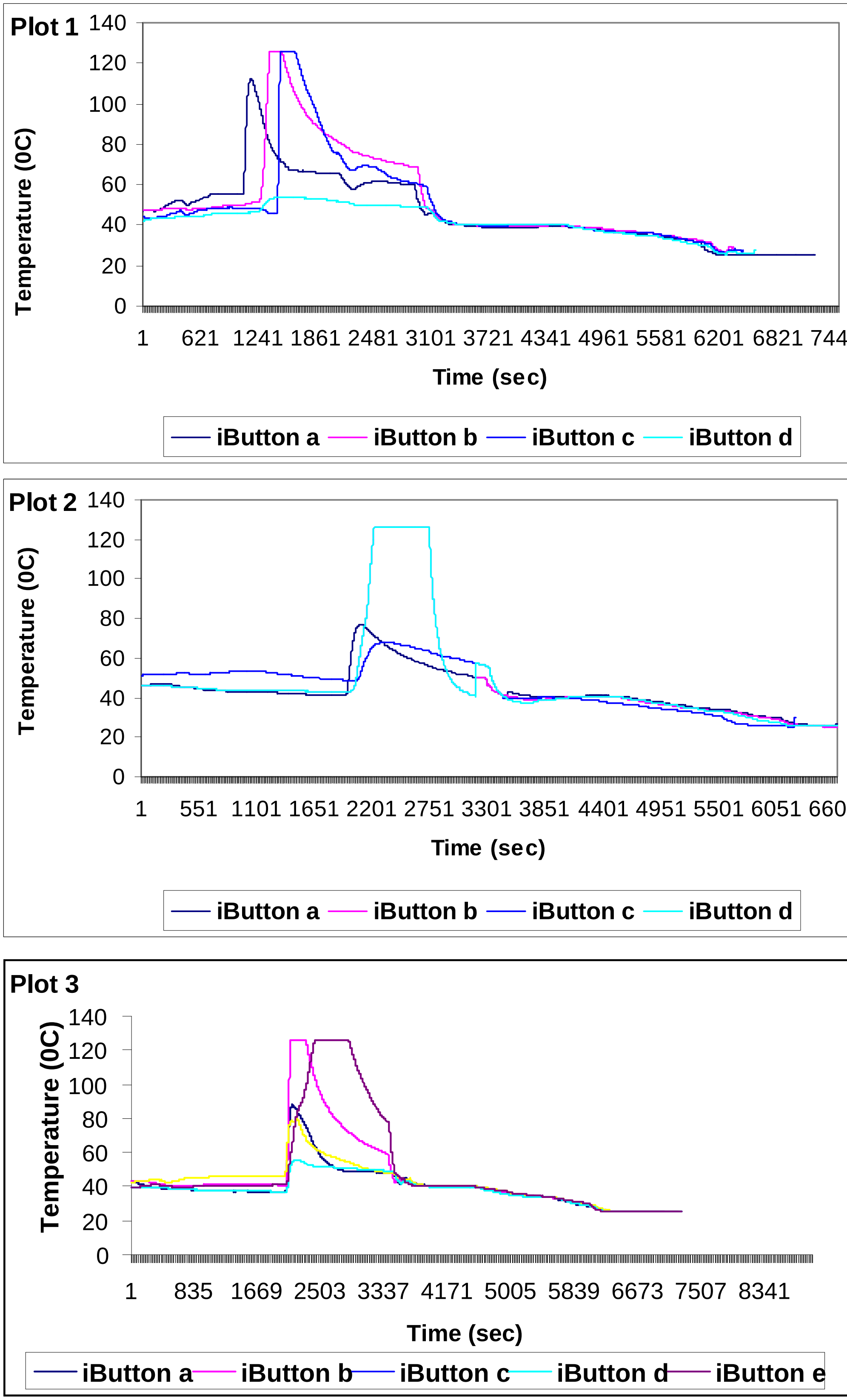


Figure 5.2. Soil temperature - time profiles at Acacia. Note that there were original 5 iButtons at each plot, but some iButtons failed.

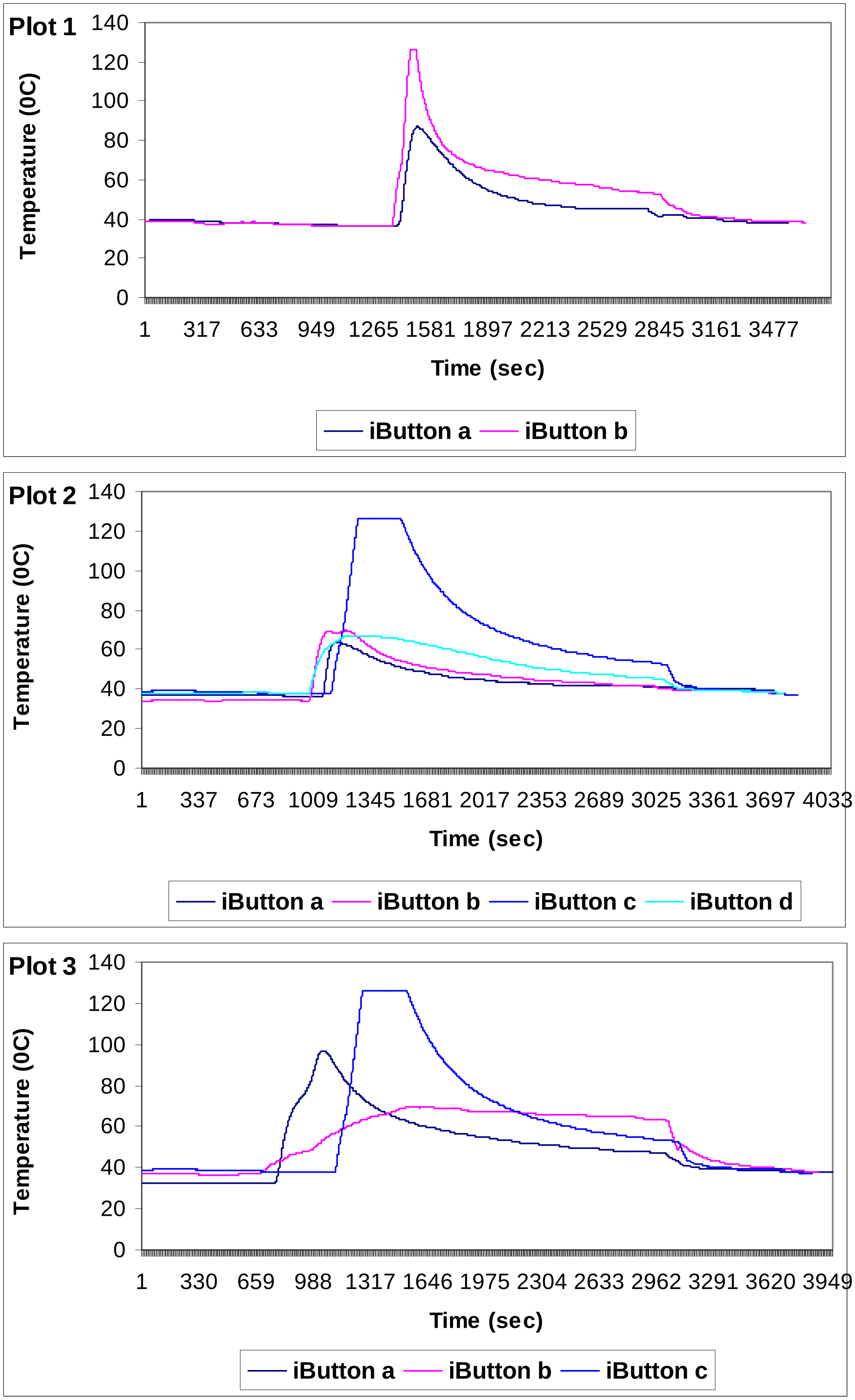


Figure 5.3. Soil temperature – time profiles at Katherine. Originally there were 5 iButtons in each plot but some failed.

Table 5.2. Summary soil temperature – time profiles at Acacia and Katherine.

Site	Plot	Pre-fire temperature (1.00pm)	Max temp	5% below max temp (°C).	Duration at 5% of max (minute)
Acacia	1	45.0	104.7	99.4	15.3
	2	47.3	98.8	93.9	22.2
	3	41.5	94.9	90.2	12.2
	All plots	44.6	99.5	94.5	16.6
Katherine	1	19.4	53.3	50.6	3.3
	2	36.7	81.7	77.6	13.5
	3	36.1	97.5	92.6	22.6
	All plots	30.7	77.5	73.6	13.1

Table 5.3. Summary of fuel load consumption, soil temperature, rate of spread and fire intensity at Acacia and Katherine.

Site	Plot	Fuel load consumption	Soil temperature	Rate of spread	Fire intensity
Acacia	1	5.5 t/ha	104.7 ^{0}C	0.003 m/sec	35 kW/m
	2	6.9 t/ha	98.8 ^{0}C	0.031 m/sec	366 kW/m
	3	4.3 t/ha	94.9 ^{0}C	0.189 m/sec	1369 kW/m
Katherine	1	5.6 t/ha	53.3 ^{0}C	0.005 m/sec	44 kW/m
	2	5.5 t/ha	81.7 ^{0}C	0.0593 m/sec	548 kW/m
	3	3.8 t/ha	97.5 ^{0}C	0.020 m/sec	128 kW/m

5.3.4. Plant mortality

Fire treatments completely killed all established plants, small plants and seedlings at both sites (Table 5.4). In comparison, mortality in control plots for established plants was just 3%, small plants 12% and seedlings 67% at Acacia and 0% of established plants, 10% of small plants and 30% of seedlings at Katherine. There was no recovery of plants post-fire when monitored in February 2008.

Table 5.4. Bellyache bush plant survival after late dry season (October) fire. Plant survival was monitored in November 2007.

Site	**Established plants**		**Small plants**		**Seedlings**	
Treatment	Fire	Control	Fire	Control	Fire	Control
Acacia	0	0.97 ± 0.01	0	0.88 ± 0.05	0	0.33 ± 0.10
Katherine	0	1.000 ± 0	0	0.90 ± 0.09	0	0.70 ± 0.10

5.3.5. Seed germination and seedling establishment

ANOVA of seedling emergence post fire (February 2008) detected no significant effect of site (P = 0.675) or treatment (P= <0.927), but there were significant effects of plot (P = <0.001), the interaction between site and treatment (P= <0.001) and the interaction between treatment and plot (P= 0.008) (Appendix A, Table 10). This was due to seedling emergence being higher in the burnt plots at Acacia, while at Katherine it was higher in the control plots (Figure 5.4). Also, on one burnt plot at Acacia seedling emergence was significantly higher than all other plots in both treatments. In summary, there was no simple relationship detected between burning and seedling emergence.

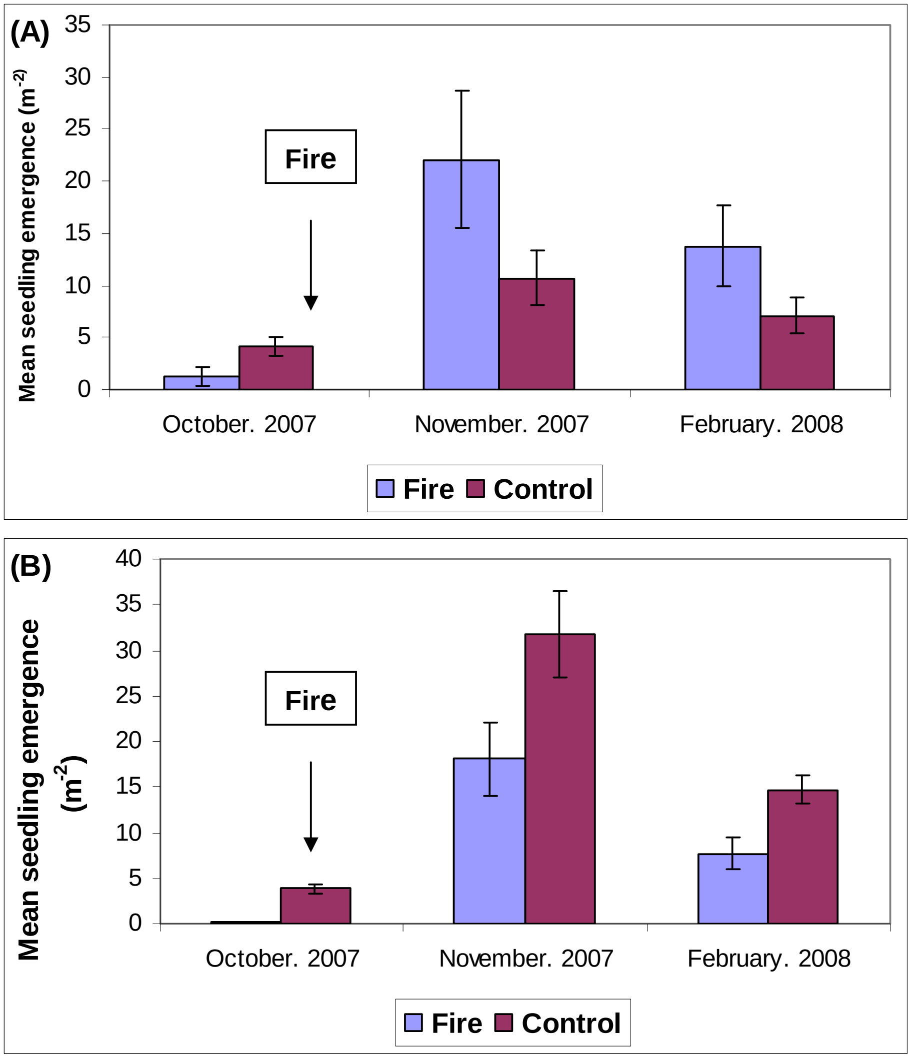


Figure 5.4. Bellyache bush seedling emergence (m^{-2}) before and after fire at (A) Acacia and (B) Katherine. Seedling emergence was monitored before burning in October 2007 and after burning in November 2007 and February (2008).

Plate 5.2. Top picture: The cut stems of bellyache bush monoculture at Acacia before burning in October 2007. Lower picture: Bellyache bush monoculture in the same plot was completely replaced by grass four months after burning, February 2008.

Plate 5.3. Top picture: The cut stems of bellyache bush monoculture at Katherine before burning in October 2007. Lower picture: Bellyache bush monoculture in the same plot was completely replaced by grass four months after burning, February 2008.

5.4. Discussion

All bellyache bush fuels in the treated plots were completely consumed by the experimental fires. This was due to a combination of sufficient curing time, low moisture content of the cut stems, the mix of the different of fuel sizes at the burning plots (particularly the proportion of fine fuels) and its compactness which supported the management fire and the fire weather at the time of burning. During the late dry season, midday temperatures are 35-40^{0}C and mean relative humidities 10-20%. Furthermore, winds, especially midday and afternoon winds are on average faster in the late dry season than in the early dry season (Williams *et al*., 1998). This combination of factors may contribute to the suitable condition for the fire to consume most bellyache bush fuels, even that in large stem size classes.

Although bellyache bush fuel was completely consumed, fire intensity of bellyache bush fuel was low, compared with other studies in the tropical savanna. This may have been due to woody fuels from the cut bellyache bush stem impeding rate of spread compared with grass fuels (Bradstock and Auld, 1995). In addition, the dense stands of bellyache bush, with little or no understorey do not burn easily as stated by Braithwaite *et al.* (1989). Therefore, fire intensity at Acacia and Katherine was only702 kW/m and 240 kW/m respectively. In contrast to this study, fire intensity reported in tropical savanna regions is very high in the late dry season, for instance 7700 k/W/mhas been reported (Williams *et al*., 1998).

Soil temperature recorded during burning varied among the study plots. Maximum soil temperature varied from 54.17^{0}C to 126.13^{0}C. Within a site there was a range of periods for which temperature remained elevated after the fire between 3.3 minutes to 22.6 minutes. There was no relationship established between Byram's fire intensity maximum temperature changes, nor between fuel load, rate of spread and maximum temperature in this study. The results of this study differed from that of Bradstock and Auld (1995). According to Aston and Gill, 1976; Auld, 1986; Hodgkinson and Oxley, 1990; Dimitrako-Poulous and Martin, 1990; Steward *et al*, there are positive relationship between fuel consumption on the ground and soil temperature. Generally, where more fuel was consumed on the ground it significantly influenced soil temperature to increase (Aston and Gill, 1976; Dimitrako-Poulous and Martin, 1990). By contrast in this study, although bellyache bush fuels were completely consumed but soil temperature was low compared to other fires reported in tropical savanna. This is probably due to the texture of woody fuels typical of bellyache bush at the study site having a lower proportion of fine fuel and medium fuel than the sites reported by other authors. In addition, in some plots bellyache bush fuel was patchy which reduces the intensity of the fire and the heat of the fire which results in lower effect on soil temperature (Bradstock and Auld, 1995).

Although fire intensity was generally low at the study plots, established plants, small plants and seedlings were completely killed. The important information revealed in this study was, 100%

plant mortality was achieved where there was 5.95 t/ha of bellyache bush fuel, compared to 9.5 t/ha of fuel load in the study of Bebawi and Campbell (2002c). Although fuel load of bellyache bush monoculture was only 5.95 t/ha, it produced a maximum soil temperature almost 100^0C compared to 93^0C reported by at the Bebawi and Campbell study.

In contrast to the deleterious impact on established plants, small plants and seedlings, fire stimulated post fire seedling emergence at Acacia. Markedly more seedlings emerged in burnt plots than in the unburnt plots. This is may be due to the influence of the fire may not be experienced in the soil at the depths of more than 2 cm. Seeds laid more than 2 cm deep may be protected as stated by Bebawi and Campbell, 2002d) in their study. No viable remained under litter cover, but more than 80% of bellyache bush seeds placed on bare ground or 2 cm below ground remained viable (Bebawi and Campbell, 2002d). As a consequence, more seedling emergence was present in the greater number in the burnt plots compared to the unburnt plots (Bradstock and Auld, 1995).

Statistical analysis in this study indicated seedling emergence was higher in the unburnt plots at Katherine, while at Acacia it was greater in the burnt plots. This may have been due to bellyache bush plants growing as a monoculture at Katherine, with and no grass beneath bellyache bush canopy to compete with seedlings. As a consequence, seedling emergence at unburnt plots was higher than at burnt plots. This finding was similarly to the Vogler and Keir (2005) observation, “Higher seedling densities (300-400 seedlings m^{-2}) were recently recorded under dense canopies of bellyache bush”. In contrast, bellyache bush at Acacia growing mixture with other exotic grass and plants in the burnt and unburnt plots. This unsuitable condition and environment may suppress and smother seedlings, therefore it was less present at Acacia site (Roche *et al*., 1998).

In addition, Bebawi and Campbell (2002d) also reported that fire stimulated seedling emergence in their burnt plots. They recorded density of 368000 seedlings per hectare compared with 2700 seedlings per hectare in this study. Although the density of seedlings reported in the study of Bebawi and Campbell (2002d) was much higher compared to this study, 2700 seedlings per hectare is still may reestablish again. This level of establishment could be more than enough to cause rapid re-infestation of a site.

The reason for the increased seedling emergence of bellyache bush in burnt plots remains to be clarified. Possible contributing factors include direct effects that stimulate seed germination and there are indirect effects that provide a more favorable environment for germination to occur, such as the removal of competition or shading. Direct effects following burning are generally attributed to the exposure of seeds to high temperature (Roche *et al.*, 1998).

In this study it was found that grass establishment dominated in the burnt plots. Bellyache bush monoculture was completely changed to grassland after fire, particularly gamba grass

(*Andropogon gayanus*) and mission grass (*Pennisetum polystachin*). The presence of gamba grass and mission grass in the burnt plots may viewed as a positive or a negative depending on the perspectives. The greater proportion of new gamba grass and mission grass post fire may be viewed as a tool (mulch) in the agricultural sector in East Timor to suppress and smother other weeds includes bellyache bush seedlings. In addition, gamba grass growth builds up fuel biomass which will allow follow up management fires to be used. Moreover, in East Timor grazing can be provided by gamba grass to cattle following the burning of bellyache bush. However, new gamba grass and mission grass may alter all three determinants of savanna function namely: nutrient and water availability and fire regime (Rossiter, 2007). In addition, the presence of new gamba grass and mission grass may become problems with management of new suites of weed species (Rossiter, 2007).

5.5. Conclusion

Bellyache bush is amenable to management by cutting and burning, when it is sufficiently cured by the late dry season, and then completely consumed during burning. The effectiveness of this control method is enhanced by late dry season conditions such as midday temperatures of 35-40^0 C and mean relative humidities 10-20% at the time of burning.

Fire intensity of bellyache bush fires in this study was low compared with other studies in the tropical savanna at Acacia 702 kW/m and Katherine 240 kW/m compared to 7700 kW/m in late dry season burning reported at the Kapalga study site (Williams *et al*., 1998).

Maximum soil temperature does not seem to depend on Byram's fire intensity and rate of spread, possibly due to the completeness of fuel consumption.

Bellyache bush plants as established plants, small plants and seedlings were all susceptible to fire although the soil temperature and fire intensity was low at the study sites. However, fire stimulated post-fire seedling emergence. Significant seedling emergence was found in the burnt plots compared with the controlled plots. Even though the majority of these seedlings died within two months, 2700 seedlings per hectare remained in February, enough to cause re-infestation in following years.

Therefore, managers need to plan for the post burning management of seedling emergence. This could include second and subsequent burning treatments. Further research is needed to determine how long bellyache bush seeds persist in the soil under different canopy cover conditions for extended periods after burning. Such studies will provide a better understanding of the management effort that is needed to prevent re-infestation in low and high canopy cover, after cutting and burning.

Chapter 6 – General Discussion and Recommendations

6.1. Model for bellyache bush management

The common practice to control bellyache bush infestations in East Timor is by using mechanical and burning control. Mechanical control such as cutting and cutting in combination with mulching of established plants, hand pulling and mulching of small plants and mulching of seedlings are traditional methods and are the cheapest to apply. The merits of these control methods are that the land managers do not rely on the chemical, biological and modern machinery. This is due to chemicals being very expensive and farmers need to buy both the chemical and appropriate equipment for application. Money is needed for biological control to establish appropriate laboratory facilities to test the agents before release onto bellyache bush infestations. Biological control trials are underway, but are not yet proven.

Although mechanical and burning controls are considered as the cheapest control methods, there are problems associated with these methods for example they may not achieve a complete kill. Therefore, the objectives of this study were to define the strength and weaknesses of using these control methods. From understanding these strength and weaknesses the managers can build up a better model to control bellyache bush in the future.

The results of this study revealed that, the use of a simple machete to cut bellyache bush plants at 0cm and 10cm height from ground level completely killed established plants irrespective of canopy cover. In addition, under low canopy cover plants were also completely killed by the 20cm, 30cm and 40cm cutting treatments. These higher cutting treatments involve less effort for the land manager than cutting at ground level. The use of straw mulch at 1 kg per m^2 did not alter the kill rate for cut stems. Hand pulling immediately killed all small plants. The use of mulch was significant in killing seedlings in the end of the dry season, although some seedlings persisted.

This study has confirmed that, bellyache bush can be used as a fuel for management fires to control bellyache bush plants. Bellyache bush fuel was completely cured after six months of the imposed cutting treatment and this fuel was able to carry a suitable fire. The fire treatment completely consumed the bellyache bush fuel in the burn. The established plants, small plants and seedlings of bellyache bush were all completely killed by the fire fuelled by cured bellyache bush.

Although mechanical control completely killed established plants where cutting was used under low canopy cover, where hand pulling of small plants and burning on all stratums of bellyache bush, there are still many disadvantages of using these methods. For example, mechanical control is highly laboured intensive and only feasible for small areas. Only cutting stems at 10 cm completely killed established plants, but under shaded conditions cut stems still re-sprout if cut above 10 cm heights.

Bellyache bush fuel had high moisture content (70%), particularly at the time of cutting stems; therefore it needs to be cut early in the dry season (May) to ensure time for the fuel to cure. Some stems under shade still remained green and moist throughout the dry season.

The results of this study shows that fire fuelled by cut bellyache bush only produced low soil temperatures, rate of spread and fire intensity. As a consequence of low soil temperatures, fire did not kill seeds, which Bebawi and Campbell (2002d, 2007) found were buried 2 cm deep in the soil. Therefore post-fire, seedlings emerged in great numbers. The use of fire may not solve this problem for the landholders as seeds can remain viable in the soil for up to 4 years (Bebawi and Campbell, 2002d).

From the findings it seems that cutting in combination with burning could be implemented in agro-environmental conditions in East Timor due to climate similarity to the Northern Territory, particularly at study sites such as Acacia and Katherine (See East Timor's Weather at Appendix B, Table 4). In addition, most land in East Timor includes open areas and experiences more direct heat and radiation during the dry season, therefore allowing fuel curing for the burning implementation.

To obtain best results for the control of bellyache bush the following is a mechanical and burning model based on reproductive and vegetative phenology which will be suggested to landholders to use to control bellyache bush monoculture in the first and second management burns (Figure 6.1).

Figure 6.1. A schedule of bellyache bush phenology and a model for management actions

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec.
Rainfall (Bureau of meteorology 2007)												
Bellyache bush phenology												
Flowering and fruiting (Hussey et al. 1997; Vitelli, 1998).												
Fruit ripening, seed shed and maturing (APB Infone 1994)												
Seedling recruitment (Parson and Cuthbertson, 1992).												
Established plants leaf flush (Personal observation, 2007)												
Established plants leaf defoliation (Personal Observation, 2007).												
Management actions - First Year												
Slash bellyache bush plants												
Curing												
First burning												
Seed emergence after burning												
Management actions - Second Year												
Seed emergence after burning												
BB monoculture replaced by grasses												
Second burning												

Note: First and second burning depends on the curing development and its dryness of cut stems.

6.2. Future research

It has been postulated in this study that cutting established plants before flowering and seed production, followed by burning after cut stems have cured will lead to some depletion of the seed bank by the germination in the next wet season. The question remaining is how the seed bank and seedling emergence will be managed after the removal of established plants by fire.

Therefore, future research will need to address the subsequent management of seed bank persistence, including gaining information on how long bellyache bush seeds persist in the soil under different canopy cover after cutting, hand-pulling, and fire. Possible solutions are managing seedling emergence by either suppressing to prevent establishment or by encouraging seed bank depletion.

Cover may be manipulated to promote or reduce seedling emergence, for example cover crops such as macuna bean or other scrambling crops may be able to be used to return land to productivity while suppressing bellyache bush seedling establishment.

Establishment of other vegetation after fire, for example, grass cover as occurred after burning in this study. The grass may provide a valuable fodder for cattle and small ruminants in East Timor but would need to be managed to prevent overgrazing which frequently results in woody weed invasion.

Further work is required investigating other fire regimes. For example cooler fires (i.e. earlier time of burns, lower fuel loads) may be sufficient to manage bellyache bush infestation.

Finally, the results of this study as well as these proposed studies must be evaluated on the ground in East Timor in collaboration with East Timorese land managers.

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Appendix A

Following are tables outlining the design of analyses of variance used to test for effects of site, treatment and plot on plant mortality, survivorship and new recruitment of established plants, small plants and seedlings.

Table 1: Results of 2-Factor ANOVA of the canopy cover taken at wet and dry season at Acacia and Channel Island (2007/2008).

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	15 693.0	15 693.0	15 693.0	54.79	0.000
Season	1	7176.1	7176.1	7176.1	25.06	0.000
Site x Season	1	79.0	79.0	79.0	0.28	0.603

Table 2. Results of 2-Factor ANOVA of the proportion alive after cutting treatments of established plants from the data collected at February 2008. Factors were: Site (n=2, fixed) and Treatments (n=6, fixed). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	0.38236	0.38236	0.38236	49.87	0.000
Treatment	5	9.48005	9.48005	1.89601	247.30	0.000
Site x Treatment	5	0.21059	0.21059	0.04212	5.49	0.002

Table 3. Results of 2-Factor ANOVA of the new shoots on the cutting treatments of established plants from the data collected at February 2008. Factors were: Site (n=2, fixed) and Treatments (n=6, fixed). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	10.251	10.251	10.251	5.72	0.025
Treatment	5	933.213	933.213	186.643	104.19	0.000
Site x Treatment	5	26.039	26.039	5.208	2.91	0.034

Table 4. Results of 3-Factor ANOVA of the proportion alive on the cutting treatments in combination with mulch of established plants from the data collected at February 2008. Factors were: Site (n=2, fixid), Treatments (n=3, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	0.2727	0.2727	0.2727	14.82	0.000
Treatment	2	23.7495	23.7495	11.8748	645.49	0.000
Plot	4	0.0796	0.0796	0.0199	1.08	0.380
Site x Treatment	2	0.1423	0.1423	0.0712	3.87	0.030
Treatment x Plot	8	0.1592	0.1592	0.0199	1.08	0.398

Table 5. Results of 3-Factor ANOVA of the new shoots on the cutting treatments in combination with mulch of established plants from the data collected at February 2008. Factors were: Site (n=2, fixid), Treatments (n=3, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	0.15766	0.14498	0.14498	2.91	0.097
Treatment	2	0.28954	0.29410	0.14705	2.95	0.065
Plot	4	0.15821	0.14654	0.03664	0.74	0.574
Site x Treatment	2	0.28909	0.29410	0.14705	2.95	0.065
Treatment x Plot	8	0.29636	0.29636	0.03704	0.74	0.652

Table 6. Results of 3-Factor ANOVA of the proportion alive on the hand-pulling and mulching treatments of small plants from the data collected at February 2008. Factors were: site (n=2, fixid), Treatments (n=3, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	0.85462	0.85462	0.85462	37.89	0.000
Treatment	2	7.48824	7.48824	3.74412	165.99	0.000
Plot	4	0.33450	0.33450	0.08362	3.71	0.013
Site x Treatment	2	1.04092	1.04092	0.52046	23.07	0.000
Treatment x Plot	8	0.23301	0.23301	0.02913	1.29	0.279

Table 7. Results of 3-Factor ANOVA of the proportion alive of seedlings after treated with mulch. Data collected at February 2008 used for this analysis. Factors were: Site (n=2, fixid), Treatments (n=2, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	1.31077	1.31077	1.31077	18.53	0.000
Treatment	1	1.08061	1.08061	1.08061	15.27	0.001
Plot	4	0.77274	0.77274	0.19318	2.73	0.053
Site x Treatment	1	0.10916	0.10916	0.10916	1.54	0.226
Treatment x Plot	4	0.40702	0.40702	0.10176	1.44	0.252

Table 8. Results of 3-Factor ANOVA of the seed mergence in the early wet season from data collected at February 2008. Factors were: Site (n=2, fixid), Treatments (n=2, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	10.03	10.03	10.03	0.60	0.445
Treatment	1	42.25	42.25	42.25	2.54	0.124
Plot	4	850.89	850.89	212.72	12.78	0.000
Site x Treatment	1	1.36	1.36	1.36	0.08	0.777
Treatment x Plot	4	130.89	130.89	32.72	1.97	0.132

Table 9. Results of 1-Factor ANOVA of the whole stems length (cm) of felled alive of bellyache bush plants. Factor was site (n=3, fixed).

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	2	33309	33309	16655	8.18	0.001

Table 10. Results of 3-Factor ANOVA of the seedling emergence after burning in February 2008. Factors were: Site (n=2, fixed), Treatments (n=2, fixed) and Plot (n=3, random, nested in site). Transformed data (x'= arcsin [square root x]) were used.

Factor	Df	Seq SS	Adj SS	Adj MS	F	P
Site	1	8.82	8.82	8.82	0.18	0.675
Treatment	1	0.42	0.42	0.42	0.01	0.927
Plot(Site)	4	1860.27	1860.27	465.07	9.38	0.000
Site*Treatment	1	714.15	714.15	714.15	14.40	0.000
Treatment*Plot	4	780.53	780.53	195.13	3.93	0.008

Appendix B

Table 1: Monthly meteorological data for the weather station at Darwin Airport (12.42 ˚S, 130.89 ˚E) the closes to Channel Island. Precipitation averages were recorded from 1941 to 2008. Sunlight from 1951 to 2008. Sources: Australian Government Bureau of Meteorology (2008).

Month	Rainfall (mm)			Temperature (C°)			Mean 9am Rel. Hum. (%)	Mean 9am Wind speed (Km/h)	Mean Daily Eva-trans. (mm)
	Aver.	max.	min.	Aver.	Max.	Min			
JAN	420.4	940.4	136.1	31.8	35.6	25.7	81	11.2	6.0
FEB	358.1	814.5	103.3	31.4	36.0	25.6	83	10.9	5.7
MAR	324.7	1013.6	88.0	31.9	36.0	25.7	82	8.8	5.8
APR	101.7	396.2	0.6	32.7	36.7	24.6	74	10.3	6.4
MAY	21.0	298.9	0.0	32.0	36.0	22.7	65	13.4	6.8
JUNE	2.0	50.6	0.0	30.6	34.5	22.7	60	14.5	6.9
JULY	1.3	26.6	0.0	30.5	34.8	21.1	60	12.7	6.9
AUG	5.4	83.8	0.0	31.3	36.0	25.1	65	10.5	7.2
SEPT	15.3	129.8	0.0	32.5	37.7	27.6	68	8.9	7.7
OCT	68.5	338.7	0.0	33.2	38.9	24.7	69	8.7	8.0
NOV	140.4	370.8	17.2	33.2	37.3	26.2	72	8.6	7.5
DEC	246.2	664.5	18.8	32.6	37.0	24.0	76	9.8	6.7
Annual	1709.1	2776.6	1024.7	32.0	38.9	21.1	71	10.7	6.8

Table 2: Monthly meteorological data for the weather station at Middle Point (12.58 ˚S, 131.31 ˚E) the closes weather station to Acacia site. Precipitation averages were recorded from 1957 to 2008. Relative humidity from 1967 to 2008. Sources: Australian Government Bureau of Meteorology (2008).

Month	Rainfall (mm)			Temperature (C°)			Mean 9am Rel. Hum. (%)	Mean 9am Wind speed (Km/h)	Mean Daily Evapo. (mm)
	Aver.	max.	min.	Aver.	Max.	Min			
JAN	338.2	865.8	135.0	32.6	38.2	25.2	84	5.9	4.7
FEB	271.8	522.5	70.0	32.0	36.2	24.5	87	5.3	4.5
MAR	252.2	552.9	0.0	32.4	37.5	26.1	85	5.1	4.7
APR	79.8	488.2	0.8	33.1	39.0	25.8	79	6.1	5.2
MAY	21.1	298.4	0.0	32.5	35.9	22.2	72	8.0	5.2
JUNE	1.7	30.0	0.0	31.3	34.9	25.3	68	8.2	5.2
JULY	0.8	22.4	0.0	31.3	35.5	19.9	65	7.4	5.5
AUG	2.5	38.5	0.0	32.9	37.1	18.6	68	6.5	6.1
SEPT	12.2	67.8	0.0	34.7	38.8	27.6	70	6.3	6.8
OCT	57.4	162.6	0.0	35.6	40.3	24.5	70	5.7	7.1
NOV	129.6	235.6	29.0	35.1	40.2	26.5	76	5.1	6.3
DEC	221.0	484.3	19.0	33.8	38.7	25.4	80	5.2	5.2
Annual	1388.9	2185.7	774.9	33.1	40.3	18.6	75	6.2	5.5

Table 3: Monthly meteorological data for the weather station at Katherine (2007). Precipitation averages were recorded from 1941 to 2008. Sunlight from 1951 to 2007. Sources: Australian Government for Bureau of Meteorology (2008).

Month	Rainfall (mm)			Temperature (C°)			Mean 9am Rel. Hum. (%)	Mean 9am Wind speed (Km/h)
	Aver.	max.	Min.	Aver.	Max.	Min		
JAN	207.8	Data Not Available	Data Not Available	Data Not Available	35.6	23.6	80	4.3
FEB	178.8				35.0	23.4	83	4.1
MAR	152.9				35.2	22.2	79	3.6
APR	43.6				34.0	19.6	70	4.6
MAY	5.6				32.4	15.6	63	5.8
JUNE	0.4				30.1	13.2	59	5.9
JULY	2.1				30.1	12.7	57	5.3
AUG	1.2				32.5	14.3	53	4.9
SEPT	3.9				35.3	18.3	55	5.2
OCT	28.2				37.7	22.7	59	5.7
NOV	79.8				38.0	24.1	67	4.9
DEC	165.9				36.3	23.6	74	4.5
Annual	875.0				34.4	19.4	66	4.9

Table 4: Monthly meteorological data at Automatic weather station at Dili Airport (East Timor) 2008. Altitude 25m, Latitude -8.53237 and Longitude 126.00514. Precipitation averages were recorded from 2000 to 2008.

Month	Rainfall (mm)			Temperature (C°)			Mean 9am Rel. Hum. (%)	Mean 9am Wind speed (Km/h)	Mean Daily Eva-trans. (mm)
	Aver.	max.	min.	Aver.	Max.	Min			
JAN	411.0	910.4	131.1	32.2	36.6	26.7	84	12.2	7.0
FEB	328.0	804.5	100.3	32.8	36.0	26.6	83	11.9	5.7
MAR	322.1	1113.6	83.0	32.9	36.0	26.7	84	8.8	6.8
APR	100.2	376.0	0.6	33.7	36.7	25.6	73	10.3	6.4
MAY	20.2	288.0	0.0	32.0	36.0	22.7	67	13.4	6.8
JUNE	2.0	40.6	0.0	30.6	36.5	22.7	62	15.5	6.9
JULY	1.0	22.0	0.0	30.5	36.8	21.1	61	12.7	7.9
AUG	4.4	81.1	0.0	31.3	36.0	24.1	65	10.5	7.2
SEPT	13.3	120.8	0.0	32.5	37.7	26.6	68	9.9	7.7
OCT	65.5	311.7	0.0	33.2	38.9	24.7	70	8.7	8.0
NOV	120.1	370.8	15.2	33.2	37.3	26.2	73	9.6	7.5
DEC	233.2	664.5	14.8	32.6	37.0	25.0	76	9.8	7.7
Annual	109.1	2576.0	1014.7	32.0	38.9	22.1	73	11.7	6.8

Appendix C

The following is summary table of soil temperature after imposing fire treatment at Acacia and Katherine site in 2007.

Table 1. Summary of soil temperature at Acacia site.

Site	Block	Button	Pre-fire temperature (2.00pm)	Max temp	5% of max	Temperature 5% below max.	Duration within 5% of max (s)
Acacia	1	1	46.585	112.3	5.62	106.681	234
Acacia	1	3	47.086	126.13	6.3065	119.8235	522
Acacia	1	4	44.079	126.13	6.3065	119.8235	672
Acacia	1	5	42.146	54.17	2.7085	51.4615	2241
Mean			44.974	104.6825	5.234125	99.448375	917.25
Acacia	2	1	46.075	76.067	3.80335	72.26365	471
Acacia	2	2	46.067	126.096	6.3048	119.7912	1629
Acacia	2	4	51.079	67.077	3.35385	63.72315	1587
Acacia	2	5	46.067	126.096	6.3048	119.7912	1629
Mean				98.834	4.9417	93.8923	1329
Acacia	3	1	43.15	88.069	4.40345	83.66555	285
Acacia	3	2	43.1	126.35	6.3175	120.0325	699
Acacia	3	3	42.648	79.123	3.95615	75.16685	426
Acacia	3	4	39.521	55.033	2.75165	52.28135	723
Acacia	3	5	39.134	126.13	6.3065	119.8235	1533
Mean				94.941	4.74705	90.19395	733.2

Table 2. Summary of soil temperature at Katherine site.

Site	Block	Button	Pre-fire temperature (3.00pm)	Max temp	5% of max	Temperature 5% below max.	Duration within 5% of max (s)
Katherine	1	1	39.063	87.012	4.3506	82.6614	246
Katherine	1	3	38.561	126.131	6.30655	119.824	144
Mean			19.406	53.2858	2.66429	50.6215	195
Katherine	2	1	36.632	63.202	3.1601	60.0419	405
Katherine	2	2	34.057	70.074	3.5037	66.5703	591
Katherine	2	3	38.565	126.38	6.319	120.061	858
Katherine	2	5	37.539	67.072	3.3536	63.7184	1386
Mean				81.682	4.0841	77.5979	810
Katherine	3	1	32.601	96.997	4.84985	92.1472	255
Katherine	3	2	37.088	69.105	3.45525	65.6498	2955
Katherine	3	3	38.565	126.38	6.319	120.061	858
Mean				97.494	4.8747	92.6193	1356