third-year fields were cut back in July 1999 to prevent lodging and fertiliser applied after cutting. Seed was dried and cleaned as in previous years. Seed yields and TSW were calculated on machine-dressed seed and corrected to 12% seed moisture.

Results

Rainfall

Rainfall in 1997 was above average with waterlogging occurring in Trial 1 from July until the beginning of October (Table 1). Rainfall in 1998 and 1999 was below average, with the trial sites waterlogged only in September of each year. During the 3-year study period, an average rainfall of 330 mm fell during the September–October flowering and seed-harvesting period at the trial sites.

Table 1. Rainfall (mm) at Ubon Ratchathani University during the study and the medium-term mean.

	Rainfall (mm)			
Month	Average[1]	1997	1998	1999
Jan	1	3	0	1
Feb	11	2	44	3
Mar	29	71	0	92
Apr	80	52	60	92
May	223	150	294	235
Jun	258	352	183	221
Jul	240	399	168	291
Aug	228	324	193	96
Sep	296	239	208	256
Oct	98	107	85	95
Nov	34	0	106	0
Dec	5	0	0	0
Total	1503	1699	1341	1382

[1]8-year average, 1993–1999.

Trial 1. Method of sowing

Method of sowing affected seed yields in the first year of establishment (Table 2a). Plots sown with seed produced no inflorescences at all. Second-year plants (T1) produced more seed than first-year plants (T3, T4) because they produced twice the number of inflorescences per m² ($P < 0.05$). However, there were large variations in seed yields between these plots due to foraging birds, resulting in no significant differences in seed yield. Treatments had no effect on TSW, which averaged 3 g.

Plots sown with seed produced some seed in the second year but yields were lower than from other plots as very few inflorescences were produced (Table 2b). Overall, yields were considerably less than in the previous year as foraging birds reduced seed yields in many plots There were more inflorescences and spikelets but fewer racemes and seeds/inflorescence than in the previous year.

Trial 2. Time of planting

Planting date significantly ($P < 0.05$) affected Ubon paspalum seed yields in the first year (Table 3). Planting tillers in May produced the highest seed yields 3–4 times those from plantings in June and more than 10 times the yields from plantings in mid-July. The number of inflorescences was significantly reduced by planting in June and July. However, the number of racemes/inflorescence and spikelets/raceme plus TSW were not significantly ($P > 0.05$) affected by planting date. Planting in early May produced significantly ($P < 0.05$) more seeds/inflorescence than later plantings.

Table 2. Effect of method of sowing on Ubon paspalum seed production

Treatment	Seed yield (kg/ha)	TSW (g)	Inflorescences /m²	Racemes /inflorescence	Spikelets /raceme	Seeds /inflorescence
(a) 1998						
T1 2nd year plants	171 a[1]	3.00 a	38 a	8 b	107 b	154 a
T2 Seed sown, 1st year	—	—	—	—	—	
T3 Tillers planted, 1st year	132 a	3.09 a	17 b	10 a	126 a	234 a
T4 Plastic bag seedlings, 1st year	91 a	2.88 a	16 b	8 b	107 b	197 a
(b) 1999						
T1 3rd year plants	44 ab	3.13 a	50 bc	6.0 ab	114 a	26 a
T2 Seed sown, 2nd year	13 b	3.06 a	15 c	5.7 b	131 a	40 a
T3 Tillers planted, 2nd year	85 a	2.98 a	123 a	6.5 a	122 a	24 a
T4 Plastic bag seedlings, 2nd year	56 ab	3.11 a	78 b	6.6 a	126 a	18 a

[1]Within columns and years, means followed by a common letter are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

Table 3. Effect of date of planting on Ubon paspalum seed production in the first year.

Treatment/ Planting date	Seed yield (kg/ha)	TSW (g)	Inflorescences /m²	Racemes /inflorescence	Spikelets /raceme	Seeds /inflorescence
T1 May 7	331 a[1]	3.22 a	148 ab	9.7 ab	133 a	73 a
T2 May 21	274 a	3.23 a	162 a	10.9 a	133 a	47 b
T3 June 4	115 b	3.15 a	100 bc	10.6 ab	155 a	39 b
T4 June 18	69 b	3.24 a	42 d	10.1 ab	157 a	51 b
T5 July 2	70 b	3.30 a	72 cd	9.7 ab	155 a	31 b
T6 July 16	25 b	3.02 a	28 d	9.4 b	133 a	30 b

[1]Within columns, means followed by a common letter are not significantly different at P = 0.05 by Duncan's Multiple Range Test.

Village farmer seed project

Delay in planting time severely reduced village seed yields in the first year of production (Table 4). The 6 farmers who planted in May 1997 harvested a mean machine-dressed seed yield of 315 kg/ha in October 1997. June plantings produced only 65 kg/ha of machine-dressed seed and July plantings produced no seed at all as these fields did not flower. May-planted fields averaged 32 inflorescences/m², 12.3 racemes/inflorescence, 149 spikelets/raceme and 336 seeds/inflorescence compared with June-planted fields which averaged 18 inflorescences/m², 11.8 racemes/inflorescence, 147 spikelets/raceme and 138 seeds/inflorescence (Table 5).

The mean seed yields of the 20 fields in 1998 and 1999 were 632 and 651 kg/ha, respectively (Table 4), with an average seed purity for both years of 99.6% and a TSW of 3.1 g. After 5-months post-harvest storage at ambient temperatures in hessian bags, germination rates for seed harvested in 1998 and 1999 were 81 and 91%, respectively.

Table 4. Ubon paspalum village farmer seed yields.

Farm	Planting time in 1997	1997	1998 (kg/ha)	1999
1	May	161	625	581
2	May	577	530	566
3	May	405	495	994
4	May	313	825	765
5	May	165	781	626
6	May	266	644	288
7	June	75	842	611
8	June	70	807	611
9	June	70	529	828
10	June	9	802	981
11	June	51	557	639
12	June	98	578	581
13	June	80	472	640
14	July	—	413	642
15	July	—	409	378
16	July	—	649	828
17	July	—	894	640
18	July	—	611	640
19	July	—	559	544
20	July	—	622	634
Mean		180	632	651

Table 5. Seed yield components of farmer seed fields in the establishment year (1997).

Farm	Planting time in 1997	Inflorescences /m²	Racemes/ inflorescence	Spikelets/ raceme	TSW (g)	Seeds/ inflorescence
1	May	27	11.9	132.9	3.15	189
2	May	78	13.8	160.0	3.36	220
3	May	23	12.7	146.4	3.28	537
4	May	34	12.7	149.2	3.49	263
5	May	18	12.2	147.0	3.03	303
6	May	16	10.8	159.5	3.28	506
7	June	18	10.8	146.9	2.77	150
8	June	10	11.5	166.3	3.38	207
9	June	35	10.2	144.4	3.24	212
10	June	21	12.0	131.1	3.35	13
11	June	14	12.5	139.8	3.12	115
12	June	21	12.4	160.9	3.39	137
13	June	20	11.4	142.1	2.90	138

Discussion

The method of establishment of Ubon paspalum is extremely critical for first-year seed production. In our studies, seed crops established by sowing seed produced no inflorescences in the first year. In Florida, Kalmbacher *et al.* (1997) also found that little flowering and seed set can be expected in the year of sowing *P. atratum*. We have also found that, in pastures sown by seed, no seed heads emerge until the second year after establishment. This is a bonus in grazed pastures, as the leafy, stem-free swards in the first year are generally of a higher nutritional quality than second year and older pastures which produce seed heads in September–October (M. Hare, unpublished data).

This behaviour sets Ubon paspalum apart from other tropical grasses used for seed production in Thailand. Seed crops of ruzi grass, *Panicum maximum*, *Paspalum plicatulum*, *Brachiaria decumbens*, *Setaria sphacelata* and *Andropogon gayanus* can all flower and produce seed in the first year following seed sowing. It seems that Ubon paspalum may have to pass through a juvenile phase during which plants have to be exposed to long days before they can respond to a flowering stimulus. Currently, we are conducting experiments in growth chambers to confirm whether or not a juvenile phase exists in Ubon paspalum.

Even in the second year after establishment, Ubon paspalum plants sown from seed produced very low yields compared with yields from spaced plants grown from tillers or seedlings. This may reflect strong inter-plant competition in the seed-sown treatments. Plant numbers in these treatments were high and plants were sparsely tillered and less robust than spaced plants. The seed sowing rate of 12 kg/ha was probably too high for seed production. Recent evidence has found that seed production of Ubon paspalum is higher in fields with distances of 50–100 cm between spaced plants (C. Phaikaew, personal communication).

Our research has shown that planting tillers or seedlings is the best method of establishing Ubon paspalum seed crops in Thailand but the time of planting must be early in the wet season for productive seed yields. Planting tillers in June–July (the traditional period for planting grass seed crops in Thailand) produces considerably less seed than planting in May. This behaviour again suggests that Ubon paspalum plants may require longer exposure to long days before they will flower profusely. Both late wet season planting and cutting (Hare *et al.* 1999c) will reduce potential seed yields.

The village farmer seed project demonstrated that village farmers can hand-harvest high seed yields. Many farmers achieved a gross income of over 60 000 baht/ha (equivalent to US$1395/ha). Ubon paspalum is now a new addition to the range of tropical grass and legume species village farmers can successfully hand-harvest for seed in Thailand (Hare 1993; Phaikaew and Hare 1998; Hare and Phaikaew 1999). However, seed production of Ubon paspalum is not without its difficulties. Heavy thunderstorms frequently occur during the September–October flowering and harvest period causing seed to shed, while foraging birds may dramatically reduce seed yields. Farmers have set up nets to capture the birds for sale or installed bird-scaring devices such as scarecrows and tins filled with stones. Some farmers sleep in their fields in order to chase away birds which forage in the early morning.

In order to enhance seed quality, we have emphasised drying the seed in the shade in order to prevent rapid moisture loss which produces non-viable shrivelled seed. Seed purity of the machine-dressed seed produced by farmers in 1998 and 1999 was excellent and satisfactory germination rates were obtained after 5 months storage in hessian bags at ambient temperatures to break embryo dormancy (Hare *et al.* 1999c). The method of hand-knocking mature seed from seed heads and then slow drying in the shade produces seed of high viability.

Site appears to have a significant impact on Ubon paspalum seed production. The university site where Ubon paspalum has been successfully grown for forage (Hare *et al.* 1999a; 1999b) has consistently produced lower seed yields in these and previous trials (Hare *et al.* 1999c) than yields harvested by farmers and at the Yasothon Animal Nutrition station, 70 km north of Ubon Ratchathani University (Phaikaew *et al.* 2001). By employing the method of knocking seed from seed heads, the highest seed yields at the university site, from the Yasothon station and from farmer fields have been 331, 622 and 994 kg/ha seed, respectively. The Yasothon station produced 1108 kg/ha seed when seed heads were covered with nylon net bags (Phaikaew *et al.* 2001). Drainage may play an important role. Both the university and the Yasothon sites are usually waterlogged during flowering and seed harvest, whereas farmer sites remain free-draining throughout the wet season. Soils at all sites are acid and low in organic matter, nitrogen, potassium and phosphorus. Trees appear to be the only other main physical difference between the sites. The university site has several large trees adjacent to the trials whereas the other two sites have no trees in the immediate vicinity of the seed fields. These trees may have produced some shading effect and also sheltered flocks of birds which foraged on the seed in the early morning. More studies are needed to examine the influence of trees and shading on Ubon paspalum seed production.

The critical potential seed yield components appear to be the number of inflorescences/m^2 and the number of seeds per inflorescence. Many plots in the university trials had more inflorescences/m^2 than those produced in the farmers' fields, but overall, the university inflorescences produced far fewer seeds/inflorescence leading to lower seed yields than those produced by farmers. This indicates that it may be better to have a smaller number of big heads than a larger number of small heads. Furthermore, fields which produced high seed yields generally had 10 or more racemes per inflorescence. More detailed studies need to be conducted into seed yield components of Ubon paspalum.

For high seed yields, Ubon paspalum seed crops should be hand-planted with tillers or seedlings early in the wet season. Sowing seed crops by seed or planting tillers late in the wet season will result in low seed yields or no seed at all in the first year of production.

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Juvenility and long-short day requirement in relation to flowering of *Paspalum atratum* in Thailand

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Abstract

In a study on flowering, *Paspalum atratum* cv. Ubon was confirmed as a long-short day plant exhibiting a quantitative response to long days followed by a qualitative response to short days. Plants 20, 40 and 60 days of age exposed to a full period of 60 long days in a plant growth chamber (14 h light) fully flowered after being placed outside in natural shortening day-lengths. Plants that were planted as sprouted seeds in the growth chamber at the beginning of the 60 long-day period took 2–3 days for first leaves to appear and incomplete flowering (88%) resulted when they were exposed to natural shortening day-lengths. Plants that received 0, 20 and 40 long days did not flower after being exposed to natural shortening day-lengths. Plants that were not transferred outdoors but remained growing under long-day conditions in the growth chamber also did not flower.

The study also confirmed that no juvenile stage exists in Ubon paspalum because all plants after being exposed to 60 long days in a growth chamber at 20, 40 and 60 days of age flowered following exposure to natural shortening day-lengths.

The importance of the long-short day flowering response for agronomic management of Ubon paspalum seed crops is discussed.

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Introduction

Farmers growing *Paspalum atratum* cv. Ubon in Thailand can consistently harvest seed yields >600 kg/ha (Hare *et al.* 2001) and in small plots on research stations, yields have reached 1100 kg/ha (Phaikaew *et al.* 2001). Agronomic management is a key factor for seed production success. To produce high seed yields in the establishment year in Thailand, Ubon paspalum seed crops should be hand-planted with tillers or seedlings early in the wet season (May). Sowing seed crops by seed or planting tillers later in the wet season (June–August) will result in low seed yields or no seed at all in the first year (Hare *et al.* 2001). In Florida, Kalmbacher *et al.* (1997) also found that little flowering and seed set can be expected in the year of sowing *P. atratum* cv. Suerte.

In the second and subsequent years of production, seed crops of Ubon paspalum cut late in the wet season (August and September in Thailand) produced little or no seed (Hare *et al.* 1999). In Florida, if seed crops of cultivar Suerte are mown after August 1, their seed yields are greatly reduced or eliminated (Kalmbacher *et al.* 1995; 1997).

The failure of *P. atratum* to flower profusely in the first year following seed sowing or late planting of tillers, suggested that *P. atratum* may have to pass through a juvenile phase during which plants have to be exposed to long days prior to the summer solstice (June 22), before they can respond to a flowering stimulus (Hare *et al.* 2001). Juvenility and the long-day requirement were advanced by Hare *et al.* (1999) as reasons for the flowering behaviour of *P. atratum* cut late in the wet season after the summer solstice. They suggested that removing reproductive tillers at this time did not allow sufficient time for new tillers to pass through another juvenile phase and receive a sufficient number of long days before responding to a flowering trigger.

Loch *et al.* (1999) commented that the predictable late-autumn flowering pattern of *P. atratum* cv. Suerte in Queensland (26°S) and in the Philippines (15°N) and the failure to flower when grown at a low-latitude site (5°N) were suggestive of a qualitative short-day plant. However, the failure in the higher latitudes of late-planted seed crops and late-summer-cut seed crops to flower in the same year in subsequent autumn–winter short days suggests otherwise and that there could be an effect of juvenility and/or long-short day requirements for floral initiation. These crops will flower only in the second year, 2–3 months after the summer solstice.

The characteristic known as juvenility is when plants will not flower until they reach a certain growth stage, irrespective of receiving the stimulus that causes mature plants to flower (Fisher 1999). In most tropical grass species, juvenility is very short-lived and unimportant, but in a few species the duration of the juvenile phase is longer and of more significance (Humphreys and Riveros 1986). *Paspalum plicatulum* flowers in response to 10 h days only if plants are at least 60 days old and no response occurs at age 40 days (Chadhokar and Humphreys 1974). *Andropogon gayanus* did not flower in 8 h days if plants were less than 6 weeks old at the start of treatment (Tompsett 1976).

The long-short day requirement for flowering has not been reported in any commercial tropical grass species commonly multiplied for seed (Loch *et al.* 1999), but the possibility of a long-short day requirement in *P. plicatulum* has been suggested (Humphreys and Riveros 1986). In tropical legumes, the long-short day requirement is more common and has been reported in *Stylosanthes guianensis* var. *guianensis* cv. Cook (Ison and Humphreys 1984), *S. guianensis* var. *pauciflora* (Andrade *et al.* 1983) and possibly *Desmodium intortum* (Andrade 1999).

Humphreys and Riveros (1986) stated that plants having a long-short day requirement for flowering should not be sown late in the summer and flowering might be expected to be earlier and more profuse in the higher latitudes of the tropics than in the lower latitudes and equatorial regions. Indeed, Ubon paspalum in Thailand appears to exhibit long-short day requirements as: little or no flowering occurs after late sowing and late cutting; and in the lower latitudes of south Thailand (6–9°N) little flowering occurs compared with the profuse flowering in north-east Thailand (15–18°N).

We examined the flowering behaviour of *P. atratum* under controlled growth room conditions to determine: (a) whether or not a juvenile phase exists; and (b) whether or not there is definitely a long-short day requirement for flowering.

Materials and methods

The trial was conducted at the Ubon Ratchathani University Research Farm (15°N) in 2000. The trial consisted of 7 main primary day-length treatments in a growth chamber (Table 1) with 4 replications.

Table 1. Growth chamber primary day-length[1] treatments and date of treatment commencement.

Treatment	No of short day-length days	No of long day-length days	Date of treatment commencement
T1	60	60	Mar 10
T2	40	60	Mar 30
T3	20	60	Apr 18
T4	0	60	May 9
T5	0	40	May 29
T6	0	20	Jun 17
T7	0	0	Jul 7

[1]Short days = 11 h light; long days = 14 h light.

Five days prior to the commencement of each primary day-length treatment, seeds of *P. atratum* cv. Ubon were germinated on moist filter paper in petri dishes on a bench at room temperature. Each treatment consisted of 4 replications with 4 pots per replication making a total of 16 pots per treatment. The 20 cm diameter pots contained soil from the university farm classified as a mixture of very sandy low humic gley soil with some gray podzolic soil previously described by Hare *et al.* (1999). On the morning when the primary day-length treatments commenced, 6 sprouted seeds were planted per pot and the pots immediately placed in the controlled climate plant growth chamber (model Conviron CMP4030). One month after planting, plants were thinned to a single plant per pot. A compound fertiliser (15N:15P:15K:9S) was applied at sowing and at 6-weekly intervals thereafter at a rate of 156 kg/ha. The pots were watered regularly.

The chamber was programmed for 60 short day-length days (March 10–May 8) and then long day-length days (May 9–October 5). Short day-length days were 11 h light at 30°C and 13 h dark at 25°C. Long day-length days were 14 h light at 30°C and 10 h dark at 25°C. Relative humidity and CO_2 levels were kept constant at 70% and 100 ppm, respectively. During light hours, all levels of incandescent and fluorescent lights were turned on to produce 198 micromoles.

On July 7, at the end of the primary day-length treatments, half the pots (2 pots per replication per treatment) remained inside the growth chamber in long day-lengths and the other pots were transferred outdoors and placed in a field to be exposed to natural shortening day-lengths and temperatures. Day-lengths (sunrise–sunset) were recorded at the north-east meteorological station in Ubon Ratchathani, 15 km from the university research site, and temperatures were recorded at the university research site (Table 2).

Table 2. Average monthly day-lengths (sunrise–sunset) and average monthly maximum and minimum temperatures at Ubon Ratchathani in 2000.

Month	Day-length	Temperatures	
		max	min
	(h:min)	(°C)	
Jan	11:20	32.4	17.3
Feb	11:37	33.1	16.5
Mar	12:03	36.1	22.2
Apr	12:29	35.2	24.6
May	12:50	33.9	24.4
Jun	13:01	33.1	24.4
Jul	12:55	32.6	24.1
Aug	12:37	33.2	24.4
Sep	12:13	31.7	23.5
Oct	11:47	31.7	22.9
Nov	11:25	30.7	19.6
Dec	11:14	31.5	18.7

Flowering commenced in the pots outside in mid-September, and at anthesis in early October, the number of inflorescences per plant, racemes per inflorescence and spikelets per raceme were counted. The plants that remained in long day-lengths in the growth chamber failed to flower and on October 5, plant height and stem diameter were recorded for these plants.

Results

Plants that remained under long day-length conditions in the growth chamber became tall and stemmy but did not flower. Plants from T1-T6 averaged 180 cm in height with stems 75 mm in diameter but T7 plants were significantly ($P < 0.01$) shorter (104 cm), with significantly ($P < 0.01$) thinner stems (41 mm).

Of the plants transferred outdoors, all plants (8 plants per treatment) that were growing (T1-T3) before being exposed to 60 days of long day-lengths flowered (Table 3). Seven out of eight plants (88%) that received 60 days of long day-lengths but no prior short-day exposure (T4) flowered. Plants receiving long day-lengths for only 40 and 20 days (T5-T6) did not flower. Plants that were planted outdoors under natural shortening day-lengths (T7) also did not flower.

Plants growing in short days before being exposed to long day conditions (T1-T3) had significantly ($P < 0.05$) more spikelets per raceme than plants that did not receive short day-length exposure in the growth chamber (T4). T1 plants produced significantly more spikelets than other plants (Table 3). T2 plants were more robust than plants in other treatments and they produced twice as many inflorescences per plant as plants that flowered in other treatments. The numbers of racemes per inflorescence were not significantly different between plants that flowered (T1-T4).

Table 3. Effect of combination of short and long day-length treatments in controlled environment before natural short day exposure on flowering in Ubon paspalum.

Treatment	No short days/ No long days	% plants flowered	Inflorescences/ plant	Racemes/ inflorescence	Spikelets/ raceme
T1	60/60	100	2.5	7.9	66.5
T2	40/60	100	5.5	8.4	55.1
T3	20/60	100	2.0	7.6	52.9
T4	0/60	88	1.7	8.2	40.7
T5	0/40	0	00	00	0
T6	0/20	0	00	00	0
T7	0/0	0	00	00	0
LSD ($P < 0.05$)		14.1	1.2	0.92	10.1

Discussion

Juvenile plants will not flower until they reach a certain growth stage even though they may receive the same stimulus that causes more mature plants to flower (Fisher 1999). This study has shown that no juvenile stage exists in Ubon paspalum for flowering response. Firstly, all plants whether 20, 40 or 60 days of age flowered when they received 60 days of long day-length exposure in a growth chamber prior to flowering outdoors in natural shortening day-lengths. Secondly, nearly all plants (88%) that were planted as sprouted seeds in pots at the beginning of the 60 long-day period also flowered. These plants took 2–3 days for the first leaves to emerge and so as seedlings, they received a period of long days slightly less than the maximum 60-day period used in the study.

Exposure to long day-lengths appears paramount in determining flowering in Ubon paspalum. This study showed that there appears to be a threshold in the number of long days required to trigger a flowering response. Plants receiving 0, 20 and 40 long day-lengths did not flower at all while plants exposed to 60 long days flowered completely. The 88% flowering in plants exposed to slightly less than 60 long days suggests that 60 days may be close to the critical number of long days required. This time frame is important for agronomic management of seed crops.

Ubon paspalum sown as seed in May in Thailand will not flower in the first year (Hare *et al.* 2001) as plants do not receive the minimum requirement of 60 long days before days begin to shorten at the end of June. It usually takes about 14 days for seedlings to emerge, so the maximum number of long days they are likely to be exposed to would be 45 days, a period our study has shown to be insufficient to initiate a full flowering response. To obtain first-year seed crops, farmers either plant seed in nurseries in March and transplant well developed seedlings in late April and early May, or dig out rooted tillers from mature plants and transplant these tillers in May. Both methods guarantee that these plants will receive at least 60 long days before day lengths begin to shorten at the end of June.

Cutting near ground level after the summer solstice removes reproductive apices of Ubon paspalum and prevents new tillers on these plants from receiving sufficient long days to initiate flowering again that year. Kalmbacher *et al.* (1995) found that reproductive apices in cv. Suerte plants were at the soil surface in mid-June and mid-July but, by the end of August, were elevated 10–15 cm above the soil surface. High cutting or topping in June–July is not detrimental to seed crops (Hare *et al.* 1999) as reproductive apices are not removed and plants would have already received the minimum number of long days to flower.

This study shows that Ubon paspalum exhibits a long-short day response for flowering. Plants that remained under long-day conditions in the growth chamber did not flower at all, despite adequate moisture and suitable temperatures. These plants remained vegetative and produced long fibrous stems. Internode elongation occurred without inflorescence initiation (Hacker 1999) because the plants were not exposed to any short days to initiate the flowering response.

At Ubon Ratchathani, the longest days occur in June (Table 2), peaking at 13 h 2 min from June 14–25. Between early July and mid-September, when Ubon paspalum flower heads first appear, day-lengths shorten by approximately 48 min. As flowering would have been initiated earlier, it appears that Ubon paspalum plants can perceive day-length differences of approximately 30 min. The critical short day-length would appear to be 12.30 h which is reached in Ubon Ratchathani in the last week of August. Thus, there is a predictable rhythm of flowering in Ubon paspalum every year, with a qualitative response to short days (Loch *et al.* 1999) following a quantitative response to long days. Every year in Ubon Ratchathani, Ubon paspalum flower heads begin to emerge about mid-September and are harvested in the first week in October. Flowering is well synchronised and hand harvesting is usually completed within 7 days (Hare *et al.* 1999; 2001). This allows harvesting to be organised well in advance.

The long-short day response of Ubon paspalum is the first reported for a commercially grown tropical grass cultivar or species even though Humphreys and Riveros (1986) suggested the possibility of such a response in *P. plicatulum*. This has implications for planting method (Hare *et al.* 2001), sowing time (Hare *et al.* 2001), cutting and closing management (Hare *et al.* 1999) and site selection, with flowering more profuse in the higher latitudes than in the equatorial regions (Humphreys and Riveros 1986).

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Appendix 5

อิทธิพลของน้ำท่วมขังต่อผลผลิตและคุณภาพของหญ้าพาสพาลัมอุบล (*Paspalum atratum*)

Effects of Waterlogging on Yield and Quality of Ubon Paspalum (*Paspalum atratum*)

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บทคัดย่อ

การทดลองนี้เพื่อศึกษาระยะเวลาน้ำท่วมขังและช่วงอายุของหญ้าพาสพาลัมอุบลที่สามารถทนทานต่อสภาพน้ำท่วมขัง มี 2 ปัจจัยทดลองคือ อายุต้นกล้า 30, 60 และ 90 วัน และระยะเวลาน้ำท่วมขังคือ 0, 10, 20 และ 30 วัน ที่ระดับน้ำท่วมขัง 5 ซ.ม.เหนือผิวดิน จากการทดลองพบว่าหญ้าพาสพาลัมอุบลอายุ 30, 60 และ 90 วัน สามารถมีชีวิตรอดจากน้ำท่วมขังได้ อย่างไรก็ตาม หญ้าอายุ 30 และ 90 วัน ได้รับผลกระทบจากน้ำท่วมขังทำให้น้ำหนักแห้ง ทั้งส่วนใบและลำต้นต่ำกว่าหญ้าที่ไม่มีน้ำท่วมขัง ทั้งนี้น้ำหนักแห้งของหญ้าอายุ 90 วันลดลงมากกว่าหญ้าอายุ 30 วัน ในขณะที่หญ้าอายุ 60 วัน น้ำหนักแห้งไม่แตกต่างกันระหว่างมีและไม่มีน้ำท่วมขัง นอกจากนี้พบว่า สภาพน้ำท่วมขังไม่มีผลกระทบต่อจำนวนหน่อต่อกอ แต่ขนาดของหน่อหญ้าอายุ 90 วันที่ถูกน้ำท่วมขังมีขนาดเล็กกว่าหญ้าปกติ อย่างไรก็ตาม ไม่มีความแตกต่างกันระหว่างเปอร์เซ็นต์โปรตีนของหญ้าพาสพาลัมอุบลที่ถูกน้ำท่วมขังระยะต่างๆ ส่วนเปอร์เซ็นต์ฟอสฟอรัสเพิ่มสูงขึ้นภายใต้สภาพน้ำท่วมขัง

คำสำคัญ: พาสพาลัมอุบล น้ำท่วมขัง ผลผลิต และคุณภาพ

Abstract

This study was conducted to examine the effects of waterlogging duration (0, 10, 20 and 30 days duration) on Ubon paspalum seedlings of varying ages (30, 60 and 90 days of age). The seedlings were kept waterlogged at a constant depth of 5 cm. The results showed that all seedlings survived waterlogging but some seedlings were more affected than others. Waterlogging had no effect on 60 days old seedlings but dry matter yields of 30 and 90 days old seedlings were reduced. The effect of waterlogging was most severe on 90 days old seedlings. Tiller number was not affected by waterlogging but size of 90 days old seedling tillers were significantly smaller than other seedling tillers. Waterlogging had no effect on crude protein levels but phosphorus levels increased following waterlogging.

Key words: Ubon paspalum, waterlogging, yield and quality

คำนำ

หญ้าพาสพาลัมอุบล (*Paspalum atratum*) เป็นหญ้าที่นำเข้าจากประเทศบราซิลมาปลูกทดสอบในประเทศไทย สามารถปรับตัวเข้ากับสภาพภูมิอากาศได้เป็นอย่างดี ให้ผลผลิตสูง แม้ในสภาพที่ลุ่ม ดินทราย และมีความอุดมสมบูรณ์ต่ำ (Hare *et al*., 1999) อย่างไรก็ตาม ปัญหาการปลูกสร้างแปลงหญ้าในพื้นที่ดังกล่าวก็คือ ปัญหาน้ำท่วมขังซึ่งอาจทำให้หญ้าที่ถูกน้ำท่วมขังตายได้ แม้ว่าหญ้าพาสพาลัมอุบลจะเป็นหญ้าที่เจริญเติบโตได้ในที่ลุ่ม แต่ข้อมูลเกี่ยวกับการทนทานต่อสภาพน้ำท่วมขังยังมีน้อย ดังนั้น การทดลองครั้งนี้เพื่อศึกษาหาช่วงอายุของหญ้าพาสพาลัมอุบลและระยะเวลาที่หญ้าสามารถทนทานต่อสภาพน้ำท่วมขัง ซึ่งจะเป็นประโยชน์สำหรับการนำไปใช้ปลูกสร้างและการจัดการแปลงหญ้า ตลอดจนเป็นข้อมูลเพื่อประกอบการเลือกพื้นที่สำหรับปลูกสร้างแปลงหญ้าต่อไป

อุปกรณ์และวิธีการ

ใช้แผนการทดลองแบบ Factorial in RCBD จำนวนสี่ซ้ำ ประกอบด้วยสองปัจจัย ดังนี้

1.อายุต้นกล้าที่น้ำเริ่มท่วมขัง 30, 60 และ 90 วัน

2.ระยะเวลาน้ำท่วมขังนาน 0, 10, 20 และ 30 วัน

ทำการทดลองระหว่างเดือนธันวาคม 2540 – พฤษภาคม 2541 ที่คณะเกษตรศาสตร์ มหาวิทยาลัยอุบลราชธานี ปลูกหญ้าพาสพาลัมอุบลด้วยเมล็ดพันธุ์ในถังพลาสติกในเดือนธันวาคม มกราคม และกุมภาพันธ์ เพื่อเตรียมต้นกล้าอายุ 30 60 และ 90 วันตามลำดับ หลังปลูกหนึ่งสัปดาห์ถอนแยกต้นกล้าเหลือสามต้นต่อถัง เริ่มทดลองในเดือนมีนาคม โดยใส่ระดับน้ำท่วมขังสูงห้าเซนติเมตรเหนือผิวดิน เมื่อครบตามระยะเวลาที่กำหนดคือ 0, 10, 20 และ 30 วัน ระบายน้ำออก แล้วปล่อยให้หญ้าเจริญเติบโตต่อไปตามปกติ จนกระทั่งพร้อมกันกับครั้งสุดท้ายที่ 30 วัน หลังจากนั้น ปล่อยให้หญ้าพักตัวเป็นเวลาเจ็ดวัน ก่อนเก็บเกี่ยว

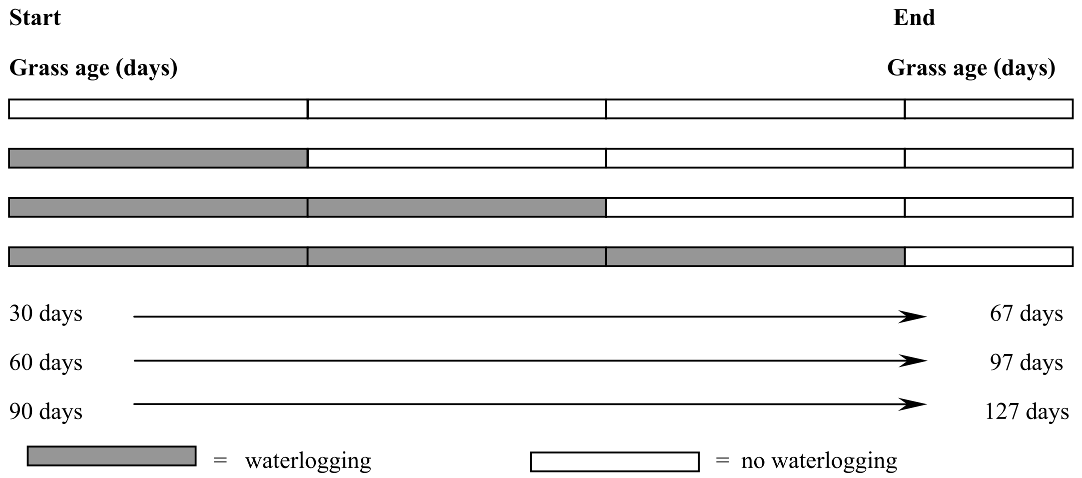

Figure 1 Waterlogging imposed to Ubon paspalum at different ages and durations.

เมื่อถึงกำหนด เก็บเกี่ยวโดยตัดต้นหญ้าชิดผิวดิน แล้วนำมาแยกส่วนลำต้นและใบ นำไปอบที่ 70 องศาเซลเซียส นาน 48 ชั่วโมง บันทึกน้ำหนักแห้ง นำตัวอย่างที่ได้วิเคราะห์หาร้อยละโปรตีนและฟอสฟอรัส

วิเคราะห์ความแปรปรวนของข้อมูลตามแผนการทดลอง โดยใช้โปรแกรม Irristat และเปรียบเทียบความแตกต่างโดยวิธี Duncan’s multiple range test (DMRT)

ผลการทดลอง

1. น้ำหนักแห้ง

จากการทดลองพบว่าหญ้าพาสพาลัมอุบลอายุ 60 วัน ไม่ได้รับผลกระทบจากสภาพน้ำท่วมขัง ในขณะที่หญ้าอายุ 30 และ 90 วัน ได้รับผลกระทบจากสภาพน้ำท่วมขัง ทำให้น้ำหนักแห้งทั้งส่วนใบ ลำต้น และน้ำหนักรวมต่ำกว่าสภาพที่ไม่มีน้ำท่วมขัง โดยเฉพาะหญ้าอายุ 90 วัน น้ำหนักแห้งลดลงมากกว่าหญ้าอายุ 30 วัน (Table 1)

Table 1 Effect of grass age and waterlogging duration on dry weight (g/plant) of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)								
	30			60			90		
	Leaves	Stems	Total	Leaves	Stems	Total	Leaves	Stems	Total
0	3.95 a	1.83 a	5.78 a	4.38 a	2.50 a	6.85 a	6.18 a	3.38 a	9.57 a
10	2.85 ab	1.50 ab	4.35 ab	4.25 a	2.05 a	6.30 a	4.25 b	1.90 b	6.15 bc
20	2.38 b	1.33 ab	3.70 b	3.80 a	1.98 a	5.78 a	4.98 b	2.35 b	7.32 b
30	1.96 b	1.08 b	3.03 b	3.35 a	2.08 a	5.43 a	2.98 c	1.78 b	4.75 c
Average	2.78	1.43	4.20	3.94	2.15	6.09	4.59	2.35	6.95

CV. Leaves = 21.2%, CV. Stems = 22.8% and CV. Total = 21.4%

In the same column, means followed by a common letter are not significantly different at the 5% level by DMRT.

2. จำนวนหน่อ

จากการทดลองพบว่า มีเพียงอายุของหญ้าพาสพาลัมอุบลเท่านั้นที่มีผลกระทบต่อจำนวนหน่อ แต่ระยะเวลาน้ำท่วมขังไม่มีอิทธิพลต่อจำนวนหน่อ โดยหญ้าอายุ 60 และ 90 วัน มีจำนวนหน่อใกล้เคียงกัน คือเฉลี่ย 4.8 และ 4.1 หน่อต่อกอตามลำดับ ส่วนหญ้าอายุ 30 วัน มีจำนวนหน่อต่อกอต่ำกว่าโดยมีเพียง 2.4 หน่อต่อกอ (Table 2)

Table 2 Effect of grass age and waterlogging duration on tiller no. (tillers/plant) of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)		
	30	**60**	**90**
0	2.8	4.5	3.8
10	2.3	4.8	4.8
20	2.5	4.8	4.3
30	2.0	4.8	3.5
Average	2.4 ns	4.7 ns	4.1 ns

CV. = 27.7%

ns = not significant

3. ขนาดของหน่อหญ้า

โดยทั่วไป น้ำท่วมขังในหญ้าพาสพาลัมอุบลอายุ 30 วันเกือบไม่มีผลกระทบต่อขนาดของหน่อหญ้า และไม่มีผลกระทบเลยในหญ้าอายุ 60 วัน แต่ในหญ้าอายุ 90 วัน ขนาดของหน่อหญ้าจะได้รับผลกระทบทำให้ขนาดหน่อเล็กลง (Table 3)

Table 3 Effect of grass age and waterlogging duration on tiller weight (g/tiller) of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)		
	30	**60**	**90**
0	2.06 a	1.53 a	2.68 a
10	1.93 ab	1.32 a	1.47 b
20	1.43 b	1.22 a	1.71 b
30	1.65 ab	1.12 a	1.44 b
Average	1.77	1.30	1.82

CV. = 23.0%

In the same column, means followed by a common letter are not significantly different at the 5% level by DMRT.

4. การเปลี่ยนแปลงสีของใบ

จากการสังเกตด้วยตา หลังน้ำท่วมขังประมาณ 3 วัน พบเห็นการเปลี่ยนแปลงของหญ้าพาสพาลัมอุบลอายุ 60 และ 90 วัน แต่หญ้าอายุ 30 วันจะไม่มีความแตกต่างกัน หญ้าอายุ 90 วันเปลี่ยนแปลงอย่างชัดเจน รองลงมาคืออายุ 60 วัน โดยพบว่าส่วนปลายใบแก่เปลี่ยนเป็นสีแดง หลังจากนั้นประมาณวันที่ 10 ใบที่เปลี่ยนสีจะมีอาการใบไหม้และตาย เมื่อเข้าสู่วันที่ 15 พบว่าบางต้นที่ใบไหม้มีการสร้างรากใหม่ขึ้นมาลอยอยู่บริเวณผิวน้ำ และพบว่าต้นที่มีการสร้างรากใหม่ได้รับความเสียหายน้อยกว่าต้นที่ไม่มีการสร้างราก ประมาณวันที่ 20 พบว่าไม่มีการเปลี่ยนแปลงมากนัก มีเพียงหญ้าอายุ 30 วันที่ใบเปลี่ยนเป็นสีเหลือง ส่วนต้นที่ใบไหม้และตายมีการสร้างใบใหม่ที่มีขนาดเล็กกว่าปกติมาทดแทน แต่ใบไม่มีอาการใบไหม้ (Table 4)

Table 4 Leaf color changes of Ubon paspalum at 30, 60 and 90 days old and during 0, 10, 20 and 30 days of waterlogging.

Waterlogging duration (days)	**Grass age (days)**		
	30	**60**	**90**
0	Dark green leaves, normal growth.	Dark green leaves, 1-3 lower leaves died.	Upper leaves dark green, 1-4 lower leaves died.
10	Dark green leaves, normal growth.	Upper leaf rims changed to green-red, leaf tips dried, 1-5 lower leaves died.	Base of upper leaves still green, leaf tips were green-red or dried, 1-6 lower leaves died.
20	Upper leaves dark green, lower leaves green-yellow.	Base of upper leaves still green but leaf rims dried. 1-7 lower leaves died. New leaves emerged, some plants developed new roots.	Base of upper leaves green-red, some leaves died. 1-9 lower leaves died. New leaves emerged, some plants developed new roots.
30	Leaves green-yellow, no leaves dried out. 1-2 mature leaves died	Base of upper leaves green, leaf tips dried. New smaller leaves emerged. 1-7 lower leaves died. Some new roots developed.	Leaf bases green-red or died. New smaller leaves emerged. 1-9 lower leaves died. Some new roots developed.

5. ร้อยละโปรตีน

สภาพน้ำท่วมขังไม่มีผลกระทบต่อร้อยละโปรตีนของหญ้าพาสพาลัมอุบล ทั้งอายุ 30, 60 และ 90 วัน แม้ว่าจะท่วมขังนานถึง 30 วัน อย่างไรก็ตาม เมื่อพิจารณาจากอายุหญ้า พบว่าเมื่อหญ้ามีอายุมากขึ้น จะทำให้มีร้อยละโปรตีนลดลง (Table 5)

Table 5 Effect of grass age and waterlogging duration on protein percentage of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)								
	30			60			90		
	Leaves	Stems	Total	Leaves	Stems	Total	Leaves	Stems	Total
0	8.8	5.4	7.8	4.4 b	2.0	3.5	3.9 b	2.0	3.2
10	8.0	5.0	6.9	5.8 a	2.8	4.8	5.9 a	3.4	5.1
20	7.7	5.0	6.7	6.0 a	3.5	5.2	5.6 a	3.2	4.8
30	8.3	4.1	6.8	5.6 a	2.8	4.5	5.3 a	3.4	4.6
Average	8.2 ns	4.9 ns	7.1 ns	5.5	2.8 ns	4.5 ns	5.1	3.0 ns	4.0 ns

CV. Leaves = 12.2%, CV. Stems = 27.8% and CV. Total = 15.2%

In the same column, means followed by a common letter are not significantly different at the 5% level by DMRT.

ns = not significant

6. ร้อยละฟอสฟอรัส

หญ้าพาสพาลัมอุบลที่มีอายุ 30 วัน มีร้อยละฟอสฟอรัสเพิ่มสูงขึ้นหลังจากน้ำท่วมขังนาน 20-30 วัน ในขณะที่หญ้าอายุ 60 และ 90 วัน พบว่าแม้น้ำท่วมขังเพียง 10 วัน มีผลทำให้ร้อยละฟอสฟอรัสสูงกว่าหญ้าที่ไม่ถูกน้ำท่วมขัง (Table 6)

Table 6 Effect of grass age and waterlogging duration on phosphorus percentage of Ubon paspalum.

Waterlogging Duration (days)	Grass age (days)								
	30			60			90		
	Leaves	Stems	Total	Leaves	Stems	Stems	Leaves	Stems	Stems
0	0.10 b	0.13 c	0.11 c	0.07 b	0.14 b	0.10 b	0.07 b	0.14 c	0.09 b
10	0.11 b	0.16 c	0.12 c	0.10 a	0.18 ab	0.13 ab	0.11 a	0.21 ab	0.14 a
20	0.12 b	0.23 b	0.16 b	0.10 a	0.19 ab	0.14 a	0.09 ab	0.17 bc	0.12 ab
30	0.19 a	0.30 a	0.23 a	0.12 a	0.22 a	0.16 a	0.11 a	0.23 a	0.15 a
Average	0.13	0.20	0.16	0.13	0.18	0.13	0.09	0.19	0.12

CV. Leaves = 21.2%, CV. Stems = 18.7% and CV. Total = 16.2%

In the same column, means followed by a common letter are not significantly different at the 5% level by DMRT.

วิจารณ์ผล

1. ผลผลิตน้ำหนักแห้ง

หญ้าพาสพาลัมอุบลอายุ 30 วัน เมื่ออยู่ภายใต้สภาพน้ำท่วมขังนานกว่า 20 วัน มีผลให้ผลผลิตน้ำหนักแห้งของใบ ลำต้น และทั้งต้นต่ำกว่าสภาพควบคุม (Table 1) ทั้งนี้คาดว่าเป็นอิทธิพลมาจากขนาดของหน่อหญ้าเป็นหลัก เนื่องจากหลังน้ำท่วมขังแล้วขนาดของหน่อหญ้ามีขนาดเล็กลง (Table 3) ในขณะที่จำนวนหน่อไม่แตกต่างกันแต่ลดลงเพียงเล็กน้อยเท่านั้น (Table 2) และอีกประการเมื่ออยู่ภายใต้สภาพน้ำท่วมขังนั้น หญ้าไม่สามารถนำไนโตรเจนไปใช้ได้ ทำให้ใบหญ้ามีสีเหลืองดังแสดงไว้ใน Table 4 ทำให้การสังเคราะห์แสงและการเจริญเติบโตหยุดชะงัก ซึ่ง Box (1986) และ Musgrave (1994) รายงานในข้าวสาลีที่ถูกน้ำท่วมขังว่า การสังเคราะห์แสงจะลดลงอย่างเด่นชัด เช่นเดียวกันกับ Kramer and Jackson (1954) เคยรายงานในข้าวสาลีที่ถูกน้ำท่วมขังว่าอัตราการสังเคราะห์แสงลดลงและทำให้ผลผลิตข้าวสาลีต่ำด้วย สอดคล้องกับ Hare *et al.* (1999) รายงานในหญ้าพาสพาลัมอุบลที่มีอายุ 84 วัน ที่อยู่ภายใต้สภาพน้ำท่วมขังนาน 10 วัน ทำให้น้ำหนักแห้งต่ำกว่าสภาพที่ไม่มีน้ำท่วมขัง

ในขณะที่หญ้าพาสพาลัมอุบลอายุ 60 วันทนทานต่อสภาพน้ำท่วมขังมากที่สุดโดยมีน้ำหนักแห้งร้อยละ 79 ของสภาพที่ไม่มีน้ำท่วมขัง อย่างไรก็ตาม แม้ไม่มีความแตกต่างระหว่างสองสภาพ แต่แนวโน้มของน้ำหนักแห้งลดลงเช่นกัน ซึ่งนอกจากจะมาจากสาเหตุเดียวกันกับหญ้าอายุ 30 วันแล้ว ยังเกิดจากการสูญเสียส่วนใบเพราะเกิดใบไหม้และตาย ทั้งนี้อาการใบไหม้ของพืชอาจจะเนื่องมาจากพืชมีการสะสมสารบางชนิด เช่น Ethylene ซึ่งถ้ามีในปริมาณสูงจะเป็นอันตรายต่อพืช (Jackson, 1994) อย่างไรก็ตาม หญ้าที่เกิดใบไหม้บางต้นมีการสร้างใบและรากขึ้นมาใหม่ ซึ่งเป็นลักษณะอย่างหนึ่งที่บ่งบอกถึงการต้านทานต่อสภาพน้ำท่วมขังของพืช (Musgrave and Ding, 1998)

พบว่าน้ำหนักแห้งหญ้าพาสพาลัมอุบลอายุ 90 วันลดลงอย่างเด่นชัด แม้ว่าน้ำขังเพียง 10 วัน ทั้งนี้เนื่องจากเมื่อน้ำท่วมขัง หญ้าอายุ 90 วันจะมีอาการใบไหม้มากกว่าหญ้าอายุ 30 และ 60 วัน ทำให้สูญเสียผลผลิตส่วนใบมาก นอกจากนี้ เมื่อเกิดใบไหม้ทำให้พื้นที่ใบซึ่งใช้ในการสังเคราะห์แสงลดลง ซึ่งมีผลกระทบต่อการฟื้นตัวและผลิใบใหม่เพื่อทดแทนใบเก่า จึงทำให้น้ำหนักแห้งต่ำกว่าสภาพควบคุมมาก

2. คุณค่าทางอาหาร

แม้ว่าสภาพน้ำท่วมขังไม่มีผลกระทบต่อร้อยละโปรตีนเฉลี่ยทั้งต้นของหญ้าพาสพาลัมอุบลทุกอายุ (Table 5) เมื่อพิจารณาเฉพาะส่วนใบ พบว่าหญ้าอายุ 30 วัน มีร้อยละโปรตีนไม่แตกต่างกันอย่างมีนัยสำคัญ ทั้งนี้เนื่องจากว่าผลผลิตหญ้าอายุ 30 วันมีทั้งใบอ่อนและใบแก่ ในขณะที่หญ้าอายุ 60 และ 90 วัน ร้อยละโปรตีนในหญ้าที่ถูกน้ำท่วมขังกลับสูงกว่าในสภาพควบคุม เนื่องจากหญ้าที่น้ำท่วมขังนั้นผลผลิตใบส่วนมากจะเป็นใบอ่อน เพราะใบแก่จะไหม้และตาย ในขณะที่ผลผลิตหญ้าที่ไม่ถูกน้ำท่วมขังนั้นประกอบด้วยทั้งใบอ่อนและใบแก่ จึงทำให้ร้อยละโปรตีนค่อนข้างต่ำ

ในส่วนลำต้นหญ้าพาสพาลัมอุบล พบว่าไม่มีความแตกต่างกันระหว่างสภาพที่มีและไม่มีน้ำท่วมขังในทุกอายุ เนื่องจากผลผลิตลำต้นประกอบด้วยส่วนลำต้นทั้งที่เกิดก่อนและหลังน้ำท่วมขัง จึงทำให้ร้อยละโปรตีนไม่แตกต่างกันมากนัก อย่างไรก็ตาม ยังไม่มีรายงานในด้านผลกระทบต่อการเจริญเติบโตของหญ้าหลังการตัดหญ้าภายใต้สภาพน้ำท่วมขัง

ร้อยละฟอสฟอรัสของหญ้าพาสพาลัมอุบลเพิ่มสูงขึ้นทั้งส่วนใบและลำต้นเมื่อน้ำท่วมขัง (Table 6) ทั้งนี้อาจเนื่องจากในสภาพที่น้ำท่วมขังหญ้ามีการสร้างใบใหม่ ซึ่งมีคุณค่าทางอาหารสูงกว่าใบแก่ นอกจากนี้อาจมาจากสภาพของดินภายใต้น้ำท่วมขัง ดังที่ทัศนีย์ (2531) รายงานว่า ฟอสเฟตที่อยู่ในดินจะเป็นประโยชน์มากขึ้นในสภาพน้ำท่วมขัง นอกจากนี้เมื่อน้ำท่วมขังค่า pH ดินจะเปลี่ยนแปลงสู่สภาพความเป็นกลางมากขึ้น ซึ่งในสภาพดังกล่าวฟอสเฟตที่เป็นประโยชน์ในดินจะละลายออกมามากขึ้น ทำให้พืชสามารถดูดไปใช้ประโยชน์ได้มากขึ้น (ยงยุทธ, 2527 และ Brix, 1990)

สรุป

หญ้าพาสพาลัมอุบลอายุ 60 วันทนทานต่อสภาพน้ำท่วมขังที่ระดับน้ำสูงห้าเซนติเมตรได้ดีที่สุด รองลงมาได้แก่หญ้าอายุ 30 และ 90 วัน โดยสภาพน้ำท่วมขังนาน 30 วันทำให้น้ำหนักแห้งของหญ้าลดลง โดยเฉพาะอย่างยิ่งหญ้าอายุ 3 เดือน ร้อยละโปรตีนของหญ้าพาสพาลัมอุบลลดลงเมื่อหญ้ามีอายุเพิ่มมากขึ้น แต่ระยะเวลาที่น้ำท่วมขังไม่มีผลกระทบต่อร้อยละโปรตีนเฉลี่ยทั้งต้น ในขณะที่หญ้าที่ถูกน้ำท่วมขังมีร้อยละฟอสฟอรัสสูงขึ้น อย่างไรก็ตาม หญ้าพาสพาลัมอุบลยังสามารถมีชีวิตรอดได้ภายใต้สภาพน้ำท่วมขัง

คำขอบคุณ

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Appendix 6

Waterlogging tolerance of some tropical pasture grasses

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Abstract
The waterlogging tolerance of 6 tropical grass species were studied under controlled conditions in plastic buckets in a greenhouse at Ubon Ratchathani University, Thailand in 1997 and 1998. In Trial 1 the species were *Paspalum atratum* cv. Ubon, *Brachiaria ruziziensis* (common Thailand type), *Paspalum plicatulum* (common Thailand type), *Digitaria milanjiana* cv. Jarra, *Brachiaria decumbens* cv. Basilisk and *Panicum maximum* cv. Purple. Five plant waterlogging treatments were imposed (Non-waterlogged control plants after 0, 10 and 20 days and waterlogged plants for 10 and 20 days). In Trial 2 effects of waterlogging were examined in detail on Ubon paspalum with 4 waterlogging duration treatments (0, 10, 20 and 30 days waterlogging) and 3 plant ages (30, 60 and 90 days of age).

In Trial 1 the species most tolerant of waterlogging were plicatulum followed by Ubon paspalum and Jarra digit. Purple guinea showed medium tolerance and ruzi and signal poor tolerance with 50% plant mortality after 20 days waterlogging. Ten days waterlogging reduced plant dry weights of all species compared to non-waterlogged control plants. After 20 days waterlogging there were no significant differences in plant dry weights between waterlogged and control plants of plicatulum, Ubon paspalum and Jarra digit.

In Trial 2 duration of waterlogging significantly reduced plant and tiller dry weights of Ubon paspalum plants, 30 and 90 days of age at the commencement of waterlogging, but had no significant effect on 60 day-old plants. In older plants (60 and 90 days of age) following waterlogging, leaf tips shriveled and turned greenish-red, lower leaves on the plants died and some new leaves developed. Nitrogen levels in Ubon paspalum plants were not significantly affected by waterlogging and phosphorous levels increased in all plants the longer the duration of waterlogging.

Introduction
In Thailand, many low-lying areas which formerly grew rice, are being used for pasture development for the expanding dairy and beef industries. These areas are exposed to short term or prolonged waterlogging or intermittent flooding in the wet season which often is a major limitation to pasture productivity.

Recent research has shown that *Paspalum atratum* cv. Ubon was the most productive grass on low-lying seasonally wet areas (Hare *et al.* 1999a; 1999b). Other species, *Setaria spacelata* var. *splendida* cv. Splenda, *Paspalum plicatulum* and *Brachiaria mutica*, grew well but were not as productive as Ubon paspalum in the second and third years after establishment. *Digitaria milanjiana* cv. Jarra and *Brachiaria humidicola* cv. Tully established slowly and with time became dense and persistent but not as productive as Ubon paspalum (Hare *et al.* 1999a).

Waterlogging damage to pasture grass plants is positively related to the duration of waterlogging and the depth of submergence, and the effects are less severe on dormant plants or plants not recently defoliated (Humphreys 1981). In the field, the depth and duration of waterlogging varies between areas and seasons, depending on the internal drainage of the soils and the amount of rain. The establishment year is often the most difficult for grass species to grow under waterlogged conditions, with the age of the plants at the time of waterlogging being of major importance to their survival. In some years some species survive waterlogging but in other years they fail to persist (Hare *et al.* 2002).

Experiments were conducted under controlled waterlogged conditions in plastic buckets to evaluate the response of 6 tropical pasture grasses to waterlogging and to examine in detail the tolerance of Ubon paspalum at various ages to different periods of waterlogging.

Materials and methods

The experiments were conducted at Ubon Ratchathani University, Thailand in a plastic greenhouse in 1997 (Trial 1) and 1998 (Trial 2). In both trials, the grass species were grown in 5 litre plastic buckets potted with sandy, low humic gley soil (Roi-et soil series) collected from the university farm. The soil was acid (pH 4.6-4.9), with low organic matter and very low concentrations of N, P and K (Hare *et al.* 1999a).

Trial 1-Effect of duration of waterlogging on the growth of 6 pasture grass species

The experiment was a two-factor factorial arranged in a randomised complete block design with 4 replications. There were 6 species [*Paspalum atratum* cv. Ubon, *Brachiaria ruziziensis* (common Thailand type), *Paspalum plicatulum* (common Thailand type), *Digitaria milanjiana* cv. Jarra, *Brachiaria decumbens* cv. Basilisk and *Panicum maximum* cv. Purple] and 5 plant waterlogging treatments (Non-waterlogged control plants after 0, 10 and 20 days and waterlogged plants for 10 and 20 days).

Twenty seeds/bucket/species were sown into plastic buckets (3 buckets/treatment/replication) on 30 June 1997 and thinned to 6 plants/bucket on 31 July. There were 360 buckets in total. Fertiliser was applied at sowing, thinning and at the commencement of waterlogging to provide the equivalent in kg/ha of 40 N, 50 K, 20 P and 20 S. The buckets were watered to field capacity until 26 August 1997 when the waterlogging experiment commenced with the waterlogged treatment plants flooded to 5 cm above the soil surface and maintained by once-daily applications of water. Non-waterlogged plants continued to be watered to field capacity.

At the end of each waterlogging treatment (10 & 20 days) visual symptoms were recorded on the stems and leaves of the waterlogged plants and then both the non-waterlogged plants and the waterlogged plants were given a 7 day recovery period before harvest. At each harvest, all 6 plants from each bucket were carefully removed and the roots and tops washed free of soil. The whole plants were dried at 70°C for 48 hours and then weighed.

Trial 2-Effect of duration of waterlogging on Ubon paspalum plants of varying ages

The experiment was a two-factor factorial arranged in a randomised complete block design with 4 replications. There were 4 waterlogging duration treatments (0, 10, 20 and 30 days waterlogging) and 3 Ubon paspalum plant ages (30, 60 and 90 days of age).

Ten sprouted seeds/bucket of Ubon paspalum were planted into plastic buckets (3 buckets/treatment/replication) on 25 December 1997 and were thinned to 3 plants/bucket 2 weeks later. There were 144 buckets in total. Fertiliser was applied at sowing and every 30 days thereafter to provide the equivalent in kg/ha of 40 N, 50 K, 20 P and 20 S. The buckets were watered to field capacity until the waterlogging experiment commenced with the waterlogged treatment plants flooded to 5 cm above the soil surface and maintained by once-daily applications of water. Non-waterlogged plants continued to be watered to field capacity, including those plants that had completed their waterlogging treatment (Figure 1).

Three days after the completion of each waterlogging duration period visual symptoms were recorded on the leaves of the waterlogged plants. Plants were then sampled from their respective waterlogging duration treatment all on the same day, 37 days after treatments commenced (Figure 1). The extra 7 days was to allow a recovery period for plants waterlogged for 30 days.

At sampling, tillers/plant, tiller dry weight and plant dry weight were recorded from 2 plants/treatment/replication. For dry weight measurement, plants were cut to soil level and dried in an oven at 70°C for 48 hours. The dried plants were analysed for total N and P.

Results

Trial 1-Effect of duration of waterlogging on the growth of 6 pasture grass species

The visual symptoms that developed during 10 and 20 days waterlogging are described in Table 1. Plicatulum was not affected by waterlogging but ruzi and signal were, with death of over 50% of the plants waterlogged for 20 days. A small proportion of Ubon paspalum and Jarra digit plants died after 20 days waterlogging and remaining Ubon paspalum plants displayed reddening of leaf tips. Purple guinea plants became stunted and leaves turned yellow during 20 days of waterlogging.

Ten days waterlogging reduced plant dry weights of all grass species compared to non-waterlogged control plants (Table 2). Twenty days waterlogging significantly reduced plant dry weights of ruzi, signal and Purple guinea but did not significantly affect Ubon paspalum, Jarra digit, and plicatulum compared to 20 day non-waterlogged control plants. Plant dry weights of Ubon paspalum, Jarra digit, and plicatulum from 10 to 20 days waterlogging increased by 83, 82 and 70%, respectively. After 20 days waterlogging, plant dry weights of ruzi, signal and Purple guinea had not increased significantly from their respective weights immediately prior to the commencement of the trial.

Trial 2-Effect of duration of waterlogging on Ubon paspalum plants of varying ages

Visual symptoms on leaves of Ubon paspalum plants during waterlogging are described in Table 3. Older plants were more severely affected by waterlogging than younger plants with leaf tips turning greenish red or drying out and many lower leaves dying. Older plants also developed new leaves the longer they were waterlogged.

Duration of waterlogging significantly reduced dry weights of Ubon paspalum plants, 30 and 90 days of age at the commencement of waterlogging, but had no significant effect on dry weight of 60 day-old plants (Table 4). Waterlogging had no significant on the number of tillers/plant which averaged 2.4, 4.7 and 4.1 tillers/plant, respectively, for the 30, 60 and 90 day age groups, but tiller weights were significantly reduced following waterlogging in plants 30 and 90 days of age (Table 5).

Nitrogen levels in Ubon paspalum plants were not significantly affected by waterlogging (Table 6) and were 1.13, 0.72 and 0.71 % in the 3 plant age groups, 67, 97 and 127 days of age, respectively, at the completion of the experiment. Phosphorus levels increased in all plants the longer the duration of waterlogging (Table 6).

Discussion
Pasture grass plant adaptation to former rice land on low lying areas subject to waterlogging or on soils with impeded drainage is of special interest in Thailand. These areas are increasingly being developed as pasture land for the expanding dairy and beef industries, but the rate of development is limited to the availability of suitable grass species adapted to these seasonally wet sites.

In the current studies, the ability of plants to maintain their dry weight and not die was used as the major indicator of the effects of waterlogging under controlled conditions in plastic buckets. Based on dry weight and plant mortality, plicatulum was the most tolerant species to waterlogging, with plants after 20 days waterlogging increasing their dry weight three-fold (Table 2), displaying no visual symptoms from waterlogging and no plants dying. Anderson (1970) classified plicatulum as one of the most tolerant grasses to waterlogging and in Thailand plicatulum for many years has been the most important pasture species sown on seasonally waterlogged soils with seed available from the Department of Livestock Development (Phaikaew 1997).

Jarra digit grass in the controlled study displayed good tolerance to waterlogging and despite 10% of the plants dying after 20 days waterlogging, the remaining plants were robust and green and had tripled their dry weight (Table 2). From field experience in Thailand the waterlogging tolerance of Jarra digit grass has varied from good persistence on the Ubon Ratchathani University farm (Hare *et al.* 1999a) where it still grows well after 8 years in pasture, to poor persistence in trials on heavily waterlogged sites (Hare *et al.* 2002). Where Jarra digit waterlogging tolerance has been poor makes it similar to cultivar, Mardi digit grass which has been reported as intolerant of waterlogging (Hacker and Wong 1992) but where Jarra digit grass has persisted makes it similar in behaviour to the closely related *Digitaria eriantha* (pangola grass).

Pangola grass is recommended for poorly drained soils in Malaysia and the Philippines and is tolerant of flooding (Hacker 1982). In Thailand pangola grass is being promoted as a high quality fresh grass cash crop for growing on former rice land (Khemsawat and Phonbumrung 2002). Pangola grass in Thailand can only be propagated vegetatively which limits its expansion but the ability to produce seed in Thailand makes Jarra digit grass (Gobius *et al.* 2001) a more easily propagated species. More research on the tolerance of Jarra digit grass to waterlogging needs to be carried out.

Purple guinea displayed moderate tolerance to waterlogging, with no plants dying and the plants doubling their dry weight after 20 days waterlogging (Table 2), despite becoming stunted and their leaves turning yellow (Table 1). Anderson (1970) and Whiteman (1979) also reported that guinea grass had moderate tolerance to waterlogging and in a series of trials in Thailand on waterlogged sites, Purple guinea grew well on moderately waterlogged sites but poorly on heavily waterlogged sites (Hare *et al.* 2002). Purple guinea is the second most popular pasture species sown in Thailand after ruzi grass, with seed produced by village farmers on contract to the Department of Livestock Development (Phaikaew 1997).

Both ruzi and signal grasses showed poor tolerance to waterlogging with 50% of the plants dying (Table 1) and the remaining plants not increasing their dry weight significantly after 20 days waterlogging (Table 2). While it was known that ruzi grass had poor tolerance to waterlogging (Anderson 1970, Whiteman 1979) it is the most important pasture grass produced in Thailand and with seed readily available (Hare and Phaikaew

1999; Phaikaew 1997) it is often mistakenly planted on waterlogged sites where it fails to persist. It was therefore included in the study as a control species to compare its performance against more waterlogging-tolerant species.

The surviving signal grass plants, even though stunted, remained green (Table 1) and from field observations in Thailand signal grass survives short-term waterlogging of 5-10 days suggesting that it does have moderate tolerance (Whiteman 1979). In Costa Rica, 7 months after planting in a site of high water saturation, two signal grass cultivars, CIAT 16497 and cv. Basilisk, had lost vigour but had shown no plant mortality (Argel and Keller-Grein 1996). Signal grass is not commonly planted for pastures in Thailand due to the difficulties of seed production but research is currently being undertaken at Ubon Ratchathani University to solve the problems of seed production.

The response of Ubon paspalum to waterlogging was moderate to good with 10% plant mortality in Trial 1 (Table 2) and decreased plant dry weight (Table 4) and tiller dry weight (Table 5) in Trial 2. Visual symptoms were apparent in both trials following waterlogging with leaf tips turning red and many lower leaves dying (Table 1; Table 3).

In both trials, the Ubon paspalum plants that were not significantly affected by waterlogging after 20 to 30 days inundation were approximately the same age, 56 days (Trial 1) and 60 days (Trial 2), at the commencement of waterlogging. The waterlogging effects were more severe on the younger plants (30 days of age) probably because the normal respiratory pathway in their small root systems was more effectively blocked by waterlogging (Whiteman 1979) than in the 60-day old plants. The more severe effects on older plants (90 days of age) may have been a combination of being stressed by becoming root-bound in the plastic buckets and then being inundated with water. In the field, established plants will tolerate saturated soil for several months (Kalmbacher *et al.* 1997; Hare *et al.* 2002) and flooding up to 5 cm depth for 3-4 weeks (Kalmbacher *et al.* 1997).

In the study on the waterlogging tolerance of subtropical legumes Shiferaw *et al.* (1992) found that nitrogen levels in legume shoots after 14 days waterlogging were reduced by 41% due to reduced nitrogen fixation compared to non-waterlogged control legumes. In the current study, nitrogen levels in Ubon paspalum were not significantly reduced by waterlogging and tended to increase with duration of waterlogging which was probably due to the regular 30 day applications of the equivalent of 40 kg/ha N and nitrogen not being leached out of the watertight plastic buckets. In the field, nitrogen fertiliser did not significantly increase nitrogen levels in waterlogged Ubon paspalum plants (Hare *et al.* 1999c).

Phosphorus concentrations in Ubon paspalum plants increased following waterlogging, due probably to the emergence of new leaves high in P and the retention of fertiliser P (20 kg/ha P every 30 days) in the watertight plastic buckets.

This study has shown that plicatulum remains one of the most tolerant forage species to waterlogging and for this reason continues to be widely grown in southern parts of Thailand regularly inundated with seasonal flooding. Due to superior dry matter yields and quality compared to plicatulum and its moderate to good waterlogging tolerance, Ubon paspalum is rapidly becoming the most popular species to grow on wet soils in other parts of Thailand. However, it will not establish if the soil is waterlogged or flooded within 1 month of sowing (Kalmbacher *et al.* 1998), but 2- to 3-week-old seedlings will survive standing water for several days (Kalmbacher *et al.* 1997). Jarra digit grass displayed moderate to good waterlogging tolerance and if seed becomes regularly available this high quality forage species could be grown more in Thailand. Purple guinea will survive short periods of waterlogging but with significantly reduced vigour. Both ruzi and signal grasses displayed low waterlogging tolerance though the latter will survive on wet soils waterlogged for short periods.

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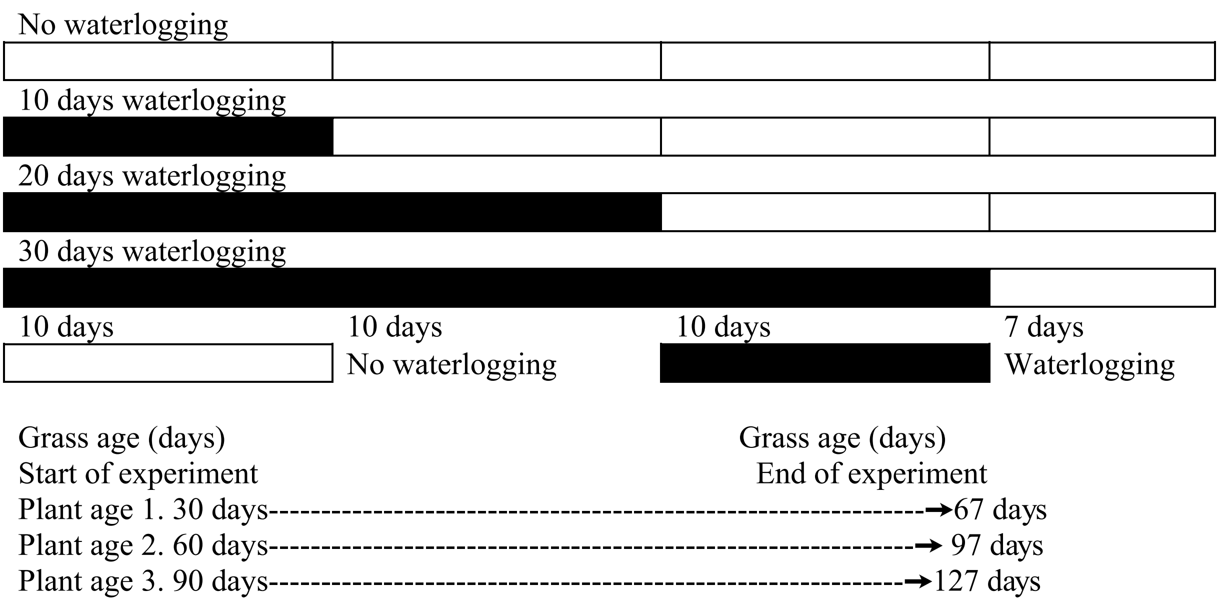

Figure 1. Duration of waterlogging (days) imposed on Ubon paspalum plants of 3 ages (Trial 2)

Table 1. Visual symptoms on plants of 6 forage grass species following 10 and 20 days waterlogging.

Grass species	10 days waterlogging	20 days waterlogging
Ubon paspalum	Leaves dark green with reddening of leaf tips	10 % plant death. Remaining plants green with red leaf tips
Ruzi	Death of large proportion of older leaves. Young leaves twisted	Over 50 % of plants dead. Remaining plants very stunted with dead leaves
Jarra digit	Death of small proportion of older leaves	10 % plant death. Remaining plants green and robust
Signal	Death of older leaves. Some plants stunted	Over 50 % of plants dead. Remaining plants green but stunted.
Purple guinea	Leaves light green with some death of older leaves	Plants stunted and all leaves yellow
Plicatulum	Plants displayed normal growth with no visual symptoms	Plants displayed normal growth with no visual symptoms

Table 2. Effect of waterlogging for 10 & 20 days on dry weight (g) per plant of six tropical grasses.

Treatment	Ubon paspalum.	Ruzi	Jarra digit	Signal	Purple guinea.	Plicatulum
Before trial	3.4 c[1]	3.1 c	2.3 b	3.0 b	3.3 b	2.4 c
10 d control	8.4 b	6.5 b	7.6 a	6.0 a	10.4 a	6.2 ab
10 d water*	4.1 c	2.8 c	4.5 b	3.0 b	4.1 b	4.7 bc
20 d control	11.8 ab	9.7 a	8.7 a	8.1 a	11.2 a	8.3 a
20 d water*	7.5 b	3.2 c	8.2 a	4.4 b	6.1 b	8.0 a

* waterlogging duration

[1] Within columns, means followed by different letters are significantly different (P<0.05) by Duncan's Multiple Range Test.

Table 6. Effect of waterlogging on nitrogen and phosphorus levels (%/plant) in Ubon paspalum.

Waterlogging duration (days)	Grass age (days)					
	30		60		90	
	(%/plant)					
	N	P	N	P	N	P
0	1.25a	0.11c	0.56a	0.10b	0.51a	0.09b
10	1.10a	0.12c	0.77a	0.13ab	0.81a	0.14a
20	1.07a	0.16c	0.83a	0.14a	0.77a	0.12ab
30	1.09a	0.23a	0.72a	0.16a	0.74a	0.15a

[1] Within columns, means followed by different letters are significantly different (P<0.05) by Duncan's Multiple Range Test.

Table 3. Visual symptoms on leaves of Ubon paspalum following waterlogging

Waterlogging duration (days)	Grass age (days)		
	30	60	90
10	Leaves dark green	Upper leave edges greenish red with shriveled leaf tips. 1-5 lower leaves dead.	Upper leaves green with leaf tips greenish red or shriveled. 1-6 lower leaves dead
20	Upper leaves dark green. Lower leaves light green to yellow	Upper leaves edges brown and shriveled. 1-7 lower leaves dead. Some new leaves emerged.	Upper leaves greenish red with some dead leaves. 1-9 lower leaves dead. Some new leaves emerged.
30	1-2 lower leaves dead. Remaining leaves light green to yellow	Upper leaves edges brown and shriveled. 1-7 lower leaves dead. Some new leaves emerge.	Leaves greenish red or dead. 1-9 lower leaves dead. Some new leaves emerged

Table 4. Effect of waterlogging on dry weight (g/plant) of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)		
	30	60	90
		(g/plant)	
0	5.8 a[1]	6.9 a	9.6 a
10	4.4 ab	6.3 a	6.2 bc
20	3.7 b	5.8 a	7.3 b
30	3.0 b	5.4 a	4.8 c

[1] Within columns, means followed by different letters are significantly different (P<0.05) by Duncan’s Multiple Range Test.

Table 5. Effect of waterlogging on tiller weight (g/tiller) of Ubon paspalum.

Waterlogging duration (days)	Grass age (days)		
	30	60	90
		(tiller weight)	
0	2.1 a[1]	1.5 a	2.7 a
10	1.9 ab	1.3 a	1.5 b
20	1.4 b	1.2 a	1.7 b
30	1.7 ab	1.1 a	1.4 c

[1] Within columns, means followed by different letters are significantly different (P<0.05) by Duncan’s Multiple Range Test.

Appendix 7

Effect of plant spacing, cutting and nitrogen on production of *Digitaria milanjiana* cv. Jarra in north-east Thailand

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Abstract
Three trials were conducted in north-east Thailand on Jarra digit (*Digitaria milanjiana)* to examine the effect of planting stolons at varying row spacings on sward establishment and the effect of cutting frequency and rate and time of nitrogen application on growth and forage quality. In Trial 1, at the first cut four months after planting, Jarra digit swards planted in narrow rows (0.5 m) produced over twice the amount of dry matter, were twice as dense and had fewer weeds than swards planted in wide rows (2.0 m). Immediate row spacings (1-1.5 m inter-rows) were not significantly lower in DM but had a higher proportion of weeds than swards planted in 0.5 m inter-rows. By the time of the second cut 6 months after planting, there were no significant differences in Jarra digit dry matter production between swards planted in varying row spacings.

In Trial 2, increasing the cutting interval and increasing the nitrogen rate significantly (P=0.05) increased both total DM and stem DM yields. The effect of cutting interval on leaf DM was slight but leaf DM yields significantly increased when nitrogen was applied. Cutting every 20 days over a 240-d period produced 70% (13.2 t/ha) of the total DM yield obtained by cutting every 60 days (18.8 t/ha) but crude protein concentrations were 30-50% higher and fibre concentrations (ADF and NDF) 7-10% lower. 20 kg/ha N applied every 60 days increased Jarra digit total DM yields by 36% above yields in control plots. Applying higher nitrogen rates every 60 days only increased total DM yields by 13% (40 kg/ha N vs 20 kg/ha N) and 7% (80 kg/ha N *vs.* 40 kg/ha N). The yield response (kg DM/kg N) from applying nitrogen as urea ranged from 23 (320 kg/ha N) up to 52 (80 kg/ha N).

In Trial 3, applying 20 kg/ha N every 30 days, compared to every 60 days, increased dry matter yields of leaves and stems by approximately 16%. Applying 40 kg/ha N every 30 days, compared to every 60 days, increased leaf DM but not stem and total DM yields. Increases in cutting interval (20 *vs*. 60 days) and time of nitrogen application (30 *vs*. 60 days) reduced leaf and stem crude protein concentrations by up to 40% and increases in nitrogen rate (20 *vs.* 40 kg/ha) increased leaf and stem crude protein concentrations by 15%.

The inter-row spacing for Jarra digit establishment and the cutting interval and rate and time of nitrogen application are discussed in terms of the combination of yield and quality desired by farmers.

Introduction

Digitaria milanjiana cv. Jarra was released in Australia in 1991 and registered in 1993 (Hall *et al.* 1993). In Thailand, Jarra digit has been evaluated in a series of forage trials (Hare *et al.* 1999a; Hare *et al.* 2003a) and for seed production (Gobius *et al.* 2001), but despite being studied on research stations in Thailand for nearly 10 years, Jarra digit is still not promoted as a pasture species for smallholder farmers.

The difficulty of producing good quality seed of Jarra digit, with flowering over a long period in the middle of the wet season, is seen as a barrier to its wider use in Thailand (Gobius *et al.* 2001). However, lack of seed is not seen as a barrier to successful production of *D. milanjiana* cv. Mardi for pastures in Malaysia (Hacker and Wong 1992) and the closely related *D. eriantha* (pangola grass) in Thailand for fresh grass cash cropping (Khemsawat and Phonbumrung 2002). In Malaysia, Mardi digit is vegetatively propagated and when stolons are planted into moist seed-beds the spaces rapidly fill in (Hacker and Wong 1992). Similarly in Thailand, pangola grass is vegetatively propagated with 1500-1800 kg/ha of green stolons broadcast into flooded fields (Anon. 2002). In Australia, planting pangola grass runners 1-2 m apart gives adequate coverage (Jones *et al.* 1986).

Spreading large quantities of green stolons across fields is very labour intensive and the fields, which are former rice paddies, must be flooded to ensure successful establishment of pangola grass in Thailand (Anon. 2002). Pangola grass is tolerant of flooding (Hacker 1992) but even though Jarra digit does tolerate some degree of waterlogging (Hare *et al.* 2003b) it does not tolerate flooding (Hacker and Wong 1992; Hare *et al.* 2003a). It grows better on well-drained soils (Hacker and Wong 1992; Hare *et al.* 1999a). If Jarra digit pastures could be successfully established on upland soils by planting stolons in widely spaced rows to reduce the time taken to establish pastures and reduce labour costs, interest in Jarra digit pasture production may increase in Thailand.

In village pasture systems in north-east Thailand, pastures are usually grown on the poorest soils, as more fertile soils are used for growing food and cash crops (Hare *et al*. 1999b). Furthermore, village farmers apply little if any fertiliser (Hare *et al.* 1999b; Tudsri *et al.* 2001) and consequently, most improved pastures in north-east Thailand are nitrogen-deficient.

The level and frequency of nitrogen application and the frequency of cutting influence the quantity and quality of tropical forage grasses. Nitrogen applied at 20 kg/ha every 30 days throughout the wet season in north-east Thailand, increased dry matter yields of *Paspalum atratum* by nearly 90% in one trial and over 250% in a second trial (Hare *et al.* 1999a). Cutting *P. atratum* every 20 days over a 240-day period in north-east Thailand produced 74% of the total DM yield from cutting every 60 days but crude protein concentration was nearly twice as high (10.0 *vs* 5.3%) (Hare *et al.* 2001). Cutting pangola grass in central Thailand every 30 days also produced 74% of the total DM yield from cutting every 60 days and crude protein concentrations were 42% higher (Tudsri *et al.* 1998).

On well-drained soils in north-east Thailand, when 40 kg/ha N was applied after every 45-50 day cutting interval in the wet season, Jarra digit produced over 27 t/ha DM, with average crude protein levels of 6.6% (Hare *et al.* 1999a). These crude protein levels are considerately lower than the levels of 8.1-18.7% recorded for Mardi digit in Malaysia (Hacker and Wong 1992). The low crude protein levels in Thailand were probably a result of the 45-50 day cutting interval because swards of Jarra digit very quickly become stemmy and produce seed heads in the wet season. This stemmy and quick flowering habit of Jarra digit has been observed by researchers in the Department of Livestock Development and for this reason they prefer to promote the more leafy non-flowering pangola grass for fresh grass cash cropping. However, frequent cutting may prevent Jarra digit pastures from becoming stemmy and flowering and increase leafiness and quality.

The objectives of the research were: to examine the planting of Jarra digit stolons at varying row spacings in order to recommend an optimum stolon planting density for Jarra digit pasture establishment; and to determine the effect of varying cutting intervals and rates and time of nitrogen application on growth and forage quality of Jarra digit pastures, in order to provide recommendations on cutting and nitrogen management to farmers.

Materials and methods

The field experiments were conducted in Ubon Ratchathani province, north-east Thailand (15°N, 104°E) on the Ubon Ratchathani University farm in a 0.3 ha field from 2000 to 2002. Rainfall was recorded 1 km from the trial site (Table 1). The soil is classified as a sandy low humic gley soil (Roi-et soil series) and was on an upland site. Soil samples taken at sowing in May 2000 showed that the soil was acid (pH 4.7), and low in organic matter (1%), N (0.05%), P (10.7 ppm; Bray II extraction method) and K (19.5 ppm) concentrations. The site prior to cultivation had been planted for 6 years in ruzi grass (*Brachiaria ruziziensis*), mixed with some Verano stylo (*Stylosanthes hamata*). The site was ploughed twice in March and April 2000 and rotary hoed to produce a fine seed bed the day before Jarra digit stolons were planted into moist soil in July 2000.

Trial 1 – Effect of plant spacing on establishment of Jarra digit

Freshly dug green Jarra digit stolons were planted on July 6, 2000 in a randomised block design with 4 plant row spacing treatments (stolons planted in rows 0.5, 1.0, 1.5 and 2.0 m apart and 0.5 m apart within rows) and 5 replications. The stolons were planted in clumps with a handful of stolons planted in holes and soil firmly pressed in around the base of the stolons. Plots measured 10 m x 4 m. Fertiliser (23 kg/ha N, 23 kg/ha K and 23 kg/ha P) was applied on September 25, 2000 and after every sampling cut.

Sampling cuts (October 24 and December 25, 2000, April 25, June 12, September 5 and October 22, 2001) were taken from eight 0.25 m^2 quadrats cut 5 cm from ground level in each plot. Samples were taken for botanical composition (Jarra digit % and weeds % on a fresh weight basis) and Jarra dry matter yield (200 g subsample dried at 70°C for 48 h). After each sampling cut, the remaining herbage was cut to 5 cm above ground level and removed before applying fertiliser.

Trial 2 – Effect of cutting interval and nitrogen on Jarra digit

The research area (2000 m^2) was planted with freshly dug Jarra digit stolons on July 6-7, 2000 in 50 cm x 50 cm grid spacings and allowed to establish throughout the first wet season and dry season. The area was cut to ground level on October 24, 2000 and on April 19, 2001 and all herbage removed. No fertiliser was applied during this period.

The trial was a randomised complete block design comprising 4 replications, 4 cutting intervals (20, 30, 40 and 60 days) and 4 rates of nitrogen (0, 20, 40 and 80 kg/ha N) applied as urea every 60 days. All plots received P (20kg/ha), S (20 kg/ha) and K (50 kg/ha) every 60 days. The trial commenced on April 19, 2001 and finished on December 15, 2001, a total of 240 days. In total, the N treatments received 0, 80, 160 and 320 kg/ha N. Each plot measured 5 m x 5 m.

There were twelve 20-day, eight 30-day, six 40-day and four 60-day interval sampling cuts. At each cut, 4 x 0.25 m^2 quadrats were cut 5 cm above ground level in each plot, separated into leaf and stem components and weighed fresh. A 200 gram subsample was taken from each component, dried at 70°C for 48 h and dry weight recorded. The dried leaf and stem subsamples were analysed for total N to calculate crude protein levels (% N x 6.25), % ADF and % NDF. After each sampling cut, the remaining herbage in the plots was cut to 5 cm above ground level and removed.

Trial 3 – Effect of cutting and time and amount of nitrogen on Jarra digit

This trial was on the same site as Trial 2. The field was cut to ground level on December 19, 2001 and on April 19, 2002 and all herbage removed. No fertiliser was applied during this period.

The trial was a randomised complete block design comprising 4 replications, 3 cutting intervals (20, 40 and 60 days), 2 times of nitrogen application (30 and 60 days) and 2 nitrogen rates (20 and 40 kg/ha). On April 19, 2000, nitrogen as urea was applied and all plots received P (20 kg/ha), S (20 kg/ha) and K (50 kg/ha) every 60 days. The trial commenced on April 19, 2002 and finished on December 15, 2002, a total of 240 days. Each plot measured 5 m x 5 m. Sampling was the same as in Trial 2.

Data from all trials were analysed using the IRRISTAT program from The International Rice Research Institute (IRRI).

Results

Rainfall

Rainfall during the studies was above the medium-term mean of 1593 mm/annum in all 3 years (Table 1). Rainfall in the first establishment year, 2000, was 30% above the medium-term mean with over 400 mm/month falling in May, July and August, making the soil very moist for good stolon establishment. Rainfall at the beginning of the nitrogen trials in May 2001 and May 2002 was more than 50% below the medium-term mean but heavy thunderstorms in the latter half of both wet seasons, increased the annual rainfall above the mean.

Trial 1 – Effect of plant spacing on establishment of Jarra digit

At the first cut at the end of the first wet season, Jarra digit swards planted in narrow rows (0.5 m) produced over twice the amount of dry matter, were twice as dense and had fewer weeds than swards planted in wide rows (2.0 m) (Table 2). By the time of the second cut 2 months later and through until the completion of the trial, row spacing had no more significant effect on dry matter production of Jarra digit. Dry matter yields were low in all swards at the end of the dry season (3rd cut) but total production in the second wet season (4th-7th cuts) was high in all swards, averaging 13 t/ha DM.

Jarra digit planted in narrow rows (0.5 m) were significantly denser and with significantly fewer weeds than swards planted in wider rows (1 and 2 m) for the first 2 cuts (Table 2). Weeds were mainly pusley (*Richardia braziliensis*) and some ruzi grass (*B. ruziziensis*). At the end of the dry season (3rd cut), all swards, except for the 0.5 m spaced swards, had a higher proportion of weeds than Jarra digit. During the second wet season this trend quickly reversed, and Jarra digit increased in density and at the 3rd and 4th cuts, all swards, on average, had less than 5% weed composition.

Trial 2 – Effect of cutting interval and nitrogen on Jarra digit

In Trial 2, increasing the cutting interval and increasing the nitrogen rate significantly (P=0.05) increased both total DM and stem DM yields (Table 3). Leaf DM yields significantly increased when nitrogen was applied but the effect of cutting interval on leaf DM was slight, with leaf DM only increasing in plots cut every 20 days when 20 kg/ha N were applied. There was also a significant cutting interval x nitrogen rate interaction for total DM and stem DM yields.

Increasing the cutting interval from 20 to 60 days produced, on average, twice the amount of stem DM (Table 3). From June to September all plots, except the 20-day cutting interval plots, produced flowering stems. Cutting interval had no effect on total DM yields when no nitrogen was applied and cutting had no effect when the interval was increased from 30 to 40 days. Applying 40 and 80 kg/ha N increased total dry matter yields by more than 50% when Jarra digit was cut every 60 days compared to cutting every 20 days.

Applying 20 kg/ha N significantly increased DM of all components at all cutting intervals compared to 0 kg/ha N (Table 3). Increasing nitrogen rates above 20 kg/ha did not generally affect leaf DM yields. Cutting Jarra digit every 30 and 60 days and at the same time increasing the nitrogen rate from 20 kg/ha to 40 kg/ha, significantly increased both total DM and stem DM. Increasing the rate of nitrogen from 40 to 80 kg/ha did not increase DM yields, except total DM yields in plots cut every 60 days.

Crude protein concentrations in Jarra digit stems and leaves were significantly affected by length of cutting interval and increasing rates of nitrogen (Table 4). There was also a significant cutting interval x nitrogen rate interaction for crude protein concentrations. Increasing the cutting interval from 20 days to 60 days reduced crude protein concentrations in stems and leaves by 50% and 30%, respectively. Nitrogen applied at 80 kg/ha N compared to applying no nitrogen, increased crude protein concentrations in both stems and leaves by 20%. When no nitrogen was applied, crude protein concentrations in stems and leaves cut every 20-30 days were on average more than 7% and 11%, respectively.

Leaf ADF concentrations decreased with increasing rates of nitrogen and increased as cutting interval lengthen (Table 4). Stem ADF concentrations increased as the cutting interval lengthen but were not affected by increasing rates of nitrogen. NDF concentrations in leaves and stems significantly increased as cutting interval increased but nitrogen only affected stem NDF concentrations (Table 4). There was a significant cutting interval x nitrogen interaction for stem NDF concentrations, with high rates of nitrogen (80 kg/ha) reducing stem NDF at 30-day cutting intervals but increasing stem NDF at 60-day cutting intervals.

Trial 3 – Effect of cutting and time and amount of nitrogen on Jarra digit

In Trial 3, increasing the interval of cutting significantly reduced the amount of leaf DM and increased stem DM (Table 5). Applying nitrogen every 30 days, compared to every 60 days, did not increase total dry matter yields until a 60-day cutting interval was reached (Table 5). There was a significant interaction between time and rate of nitrogen for stem and total DM yields.

Applying 20 kg/ha N every 30 days, compared to every 60 days, increased dry matter yields of all components by approximately 16% (Table 6). Applying 40 kg/ha N every 30 days, compared to every 60 days, increased leaf DM but not stem and total DM yields. Increasing the rate of nitrogen from 20 to 40 kg/ha, increased total DM and leaf DM, but stem DM only increased when 40 kg/ha N, compared to 20 kg/ha N, was applied every 60 days (Table 6).

Increases in cutting interval and time of nitrogen application reduced leaf and stem crude protein concentrations by up to 40% and increases in nitrogen rate increased leaf and stem crude protein concentrations by 15% (Table 7). There was a significant interaction between time and rate of nitrogen for leaf and stem crude protein concentrations (Table 7). Leaf crude protein concentrations increased by 21% when nitrogen increased from 20 to 40 kg/ha and was applied every 30 days, but when the same amounts of nitrogen were applied every 60 days, crude protein concentrations only increased by 9% (Table 8). Increasing rates of nitrogen increased stem crude protein concentrations by 30% when nitrogen was applied every 30 days but had no effect when nitrogen was applied every 60 days (Table 8).

Leaf and stem ADF and NDF concentrations significantly increased with increases in cutting interval but were not affected by increases in nitrogen rates (Table 7). Time of nitrogen application slightly increased leaf ADF and stem NDF concentrations when 20 kg/ha N and 40 kg/ha N, respectively, were applied every 60 days compared to every 30 days (Table 8).

Discussion

This study has shown that Jarra digit pastures can be successfully established by vegetative propagation by planting freshly dug stolons as soon as possible after collection and the absence of seed should no longer be seen as a barrier to its wider use in Thailand. Unlike pangola grass establishment where lowland fields are flooded for successful establishment (Anon. 2002), Jarra digit can be planted in upland soils provided the soils are kept moist during the establishment phase. Many smallholder farmers in other parts of south-east Asia prefer to establish pastures from vegetative material (Stür and Horne 2001). For most grasses they find vegetative planting easy and reliable, establishment is rapid, provided there is plenty of soil moisture, land does not have to be fully cultivated and planting can be done late in the wet season. However, planting material has to be available locally and with a new species like Jarra digit, nurseries would have to be established on government research stations. This would be similar to the pangola grass program in Thailand, where large fields are managed on government research stations to provide initial first year planting material to smallholder farmers (Anon. 2002). After swards are established by smallholder farmers, these swards can be used to provide planting material for farmers to further expand pastures.

In our study, the vegetative establishment of Jarra digit swards followed 2 stages. The first stage was the plant establishment phase in the first wet season during which there was a period of growth as the stolons rooted and spread out slowly to cover the inter-row spaces. The second stage in the second wet season was the consolidation or 'thickening-up' stage in which the inter-row spaces rapidly filled up, weeds reduced and the swards became grass-dominant.

Planting Jarra digit on 50 cm squares provided the most forage in the establishment phase in the first wet season with the lowest proportion of weeds. Immediate spacings (1-1.5 m inter-rows) were not significantly lower in DM but had a higher proportion of weeds. Humphreys (1987) recommended spacings of 0.7 m inter-row and 0.3 m within the row for most vegetatively propagated grass species in order to provide rapid first season production. However, if early season grazing is of little importance, Humphreys (1987) suggested that wider spacings on 2 m squares are adequate for running grass species if there is good weed control. In our study, 2 m spaced rows swards took 6 months to produce the same amount of dry matter as narrower inter-row spaced swards and over a year to reduce weed density to below 10%.

Smallholder farm sizes in Thailand are small (2-4 ha) (Hare *et al.* 1999a) and most farms experience forage feed shortages. When farmers sow pastures they usually want rapid first year establishment to try and overcome forage shortages, with pastures needed to provide forage within 2-3 months after planting. Therefore, the optimum Jarra digit planting density, to provide the maximum amount of DM and a dense cover quickly, would be to plant stolons in 50 cm squares. Wider row spacings could be used if labour and planting material were scarce but first year DM production would be lower and more time would be required to allow the pastures to 'thicken-up'.

The cutting interval for Jarra digit had a significant impact on the yields of total DM, leaf DM and stem DM and forage quality. Frequent cutting reduced yields but increased forage quality, with the major response between 20- and 60-d cutting intervals. In Trial 2, cutting every 20 days over a 240-d period produced 70% (13.2 t/ha) of the total DM yield obtained by cutting every 60 days (18.8 t/ha) but crude protein concentrations were 30-50% higher and fibre concentrations (ADF and NDF) 7-10% lower. These responses were very similar to the cutting responses recorded in Thailand for Ubon paspalum (Hare *et al.* 2001) and pangola grass (Tudsri *et al.* 1998). In Trial 3, total DM yields were reduced by only 10% when Jarra digit was cut every 20 days (13.8 t/ha) compared to 60 days (15.4 t/ha), but crude protein concentrations were 30-40% higher and fibre concentrations 7-8% lower.

Differences in DM yields between 20-d and 30-d cutting, and 30-d and 40-d cutting in Trial 2 were, on average, minor. Increasing the cutting interval from 40 to 60 days, significantly increased DM yields in Trial 2, when high rates of nitrogen (80 kg/ha) were applied, but not in Trial 3, when intermediate rates of nitrogen (20-40 kg/ha) were applied.

Data from our trials would suggest that an optimum cutting interval for Jarra digit of between 30 and 40 days would produce high DM yields of leafy forage of good quality. Cutting every 20 days reduces the amount of DM and cutting every 60 days produces high yields of stemmy, fibrous forage of lower quality. Cutting intervals of 30 days for pangola grass (Tudsri *et al.* 1998) and *P. atratum* (Hare *et al.* 2001) were found to produce optimum yields of high quality forage, with 60 day cutting intervals for both species producing high yields of low quality forage.

Nitrogen rates as low as 20 kg/ha N applied every 60 days increased Jarra digit DM yields by 36% in Trial 2 above yields in control plots. Applying higher nitrogen rates in Trial 2 only increased DM yields by 13% (40 kg/ha N *vs.* 20 kg/ha N) and 7% (80 kg/ha N *vs*. 40 kg/ha N). The response in dry matter per unit of N applied in Trial 2 was typically curvilinear (Humphreys 1987), with increased dressings of N giving, overall, less increase in dry matter per unit of N (Table 9). The yield response of Jarra digit was typical of the general response of tropical grasses to N of 20-50 kg DM/kg N (Humphreys 1987) when N as urea was applied (with P, K and S as a basal dressing). However, the yield response of Jarra digit in our study was considerably higher than responses recorded for pangola grass in Thailand which averaged 12-29 kg DM/kg N in one study (Tudsri *et al.* 1999) and 17 kg DM/kg N in another (Tudsri *et al.* 1988).

In Trial 3, nitrogen rates of 20 kg/ha were generally as effective as rates of 40 kg/ha but when Jarra digit was cut every 60 days, the higher N rate produced higher DM yields containing significant amounts of stem. Applying nitrogen every 30 days compared to every 60 days in Trial 3 produced no increase in DM yields unless the cutting interval was extended to 60 days.

Crude protein concentrations of Jarra digit increased by 1-2 units as rates and frequency of nitrogen increased. When no nitrogen was applied, leaf concentrations were 11-12% when cut every 20-30 days. However, concentrations of leaf protein reached 16% when nitrogen was applied every 30 days. When Jarra digit was cut every 20-40 days and nitrogen applied, stem crude protein concentrations were, on average, above the 7% critical protein level (Milford and Minson 1966), below which voluntary intake is depressed. Cutting every 60 days reduced Jarra digit stem crude protein concentrations below 7%, regardless of nitrogen application.

A feature of this study was the very high nutritive quality of Jarra digit forage with crude protein concentrations among the highest reported in Thailand in the wet season for a tropical forage grass. Even when little or no nitrogen was applied, crude protein concentrations of Jarra digit grown on very infertile soils were twice as high as those recorded for *P. atratum* grown in an adjacent trial (Hare *et al.* 2003c*).* Smallholder farmers who apply very little or no fertiliser can maintain high forage quality by cutting Jarra digit every 20-30 days, though DM production will be compromised. In Thailand, Jarra digit is commonly compared to pangola grass. Crude protein concentrations in leaves of pangola grass only reached 9.8% when 80 kg/ha N was applied (Tudsri *et al.* 1998) and very high rates of nitrogen (468-930 kg/ha) were needed to increase crude protein concentrations to levels between 12-14% (Tudsri *et al.* 1999). Furthermore, concentrations of ADF and NDF% in leaves and stems were 3-5 units lower in Jarra digit in our study compared to pangola grass (Tudsri *et al.* 1998; Tudsri *et al.* 1999).

Jarra digit is a tropical forage of higher-than-average nutritive quality. It can be easily established by planting stolons in moist soil with 50 cm spacings producing high dry matter yields in the first wet season. The frequency with which Jarra digit should be cut or grazed will depend on the relative importance of quality and quantity of forage produced but an optimum cutting interval of between 30 and 40 days is recommended for production of large amounts of high quality forage. Nitrogen application to Jarra digit pastures growing on infertile soils in northeast Thailand, will improve grass production with increases in crude protein concentrations. Applying 20 kg/ha N every 60 days will give the highest response in dry matter production per unit of nitrogen. Economics are usually the ultimate determinant of the amount of nitrogen to apply (Hare *et al.* 1999b), so therefore amounts above 20 kg/ha N and more frequent nitrogen applications than every 60 days, are not necessary.

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Table 1. Rainfall at Ubon Ratchathani University during the study and the medium-term mean.

Month	Rainfall (mm)			
	Mean[1]	2000	2001	2002
Jan	1	0	0	0
Feb	11	16	17	0
Mar	32	15	65	43
Apr	83	140	23	98
May	226	494	94	105
Jun	251	257	323	122
Jul	279	469	288	389
Aug	270	419	294	435
Sep	294	218	262	389
Oct	110	55	239	131
Nov	32	16	53	10
Dec	5	0	0	11
Total	1593	2099	1658	1733

[1]11-year mean, 1992-2002.

Table 2. Effect of row spacing on Jarra digit dry matter production and botanical composition.

Row spacing	1st cut (24/10/00)	2nd cut (25/12/00)	3rd cut (25/4/01)	4th cut (26/6/01)	5th cut (27/7/01)	6th cut (5/9/01)	7th cut (22/10/01)
	Jarra digit DM (kg/ha)						
0.5 m	2536 a[1]	2313 a	753 a	3795 a	2808 a	3918 a	3406 a
1.0 m	2150 a	1669 a	602 a	2858 a	2021 a	3077 a	3199 a
1.5 m	1782 ab	1811 a	572 a	3847 a	3169 a	3647 a	3046 a
2.0 m	1071 b	1553 a	555 a	2506 a	2459 a	4047 a	3254 a
	Jarra digit %						
0.5 m	81 a	87 a	53 a	98 a	91 a	96 a	98 a
1.0 m	51 b	66 b	41 a	86 ab	76 a	91 a	95 a
1.5 m	66 ab	79 ab	40 a	95 a	81 a	95 a	95 a
2.0 m	39 b	66 b	44 a	79 b	75 a	93 a	98 a
	Weeds %						
0.5 m	19 b	13 b	47 a	2 b	9 a	4 a	2 a
1.0 m	49 a	34 a	59 a	14 ab	34 a	9 a	5 a
1.5 m	34 ab	21 ab	60 a	5 ab	19 a	5 a	5 a
2.0 m	61 a	34 a	56 a	21 a	35 a	7 a	2 a

[1] Within columns, means followed by a common letter are not significantly different at P+0.05 by Duncan's Multiple Range Test.

Table 3. Effect of cutting interval and nitrogen on production of Jarra digit in 2001 (Trial 2).

Cutting interval (d)	Nitrogen rate[1] (kg/ha N)			
	0	20	40	80
	Total DM yield (kg/ha)			
20	9962	14311	13667	15132
30	11448	14638	18347	17114
40	11577	15780	17148	19202
60	12622	17503	21253	23985
	LSD (P<0.05) 2725			
Treatment**; Cutting**; Nitrogen**; Cutting x Nitrogen*				
	Leaf DM yield (kg/ha)			
20	5337	8050	7223	7657
30	5160	6517	7868	7301
40	5524	6922	7447	8248
60	4727	5908	6793	7577
	LSD (P<0.05) 1115			
Treatment**; Cutting*; Nitrogen**; Cutting x Nitrogen ns				
	Stem DM yield (kg/ha)			
20	4625	6261	6444	7475
30	6288	8121	10479	9813
40	6053	8858	9701	10954
60	7895	11595	14460	16408
	LSD (P<0.05) 1974			
Treatment**; Cutting**; Nitrogen**; Cutting x Nitrogen**				

[1] Total N applied over trial (0, 80, 160 and 320 kg/ha)

Table 4. Effect of cutting interval and nitrogen on herbage quality of Jarra digit in 2001 (Trial 2).

Cutting interval (d)	Nitrogen rate[1] (kg/ha N)			
	0	20	40	80
	Leaf crude protein concentration (%)			
20	12.32	13.19	13.17	15.18
30	11.03	12.70	13.02	13.61
40	9.57	10.78	11.39	13.60
60	8.65	8.68	9.84	11.16
	LSD (P<0.05) 0.81			
Treatment**; Cutting**; Nitrogen**; Cutting x Nitrogen*				
	Stem crude protein concentration (%)			
20	8.60	8.27	8.25	10.47
30	6.38	7.32	7.92	8.04
40	5.68	6.74	7.08	8.03
60	5.02	3.73	4.02	5.29
	LSD (P<0.05) 1.19			
Treatment**; Cutting**; Nitrogen**; Cutting x Nitrogen*				
	Leaf ADF (%)			
20	31.46	31.25	30.70	30.37
30	31.87	31.06	31.25	30.73
40	33.53	32.34	33.11	32.33
60	33.77	33.85	33.06	32.20
	LSD (P<0.05) 0.69			
Treatment**; Cutting**; Nitrogen**; Cutting x Nitrogen*				
	Stem ADF (%)			
20	34.75	35.70	34.94	34.82
30	35.75	35.61	35.55	36.09
40	36.55	37.70	38.45	38.03
60	37.91	38.33	39.31	39.90
	LSD (P<0.05) 1.45			
Treatment**; Cutting**; Nitrogen ns; Cutting x Nitrogen ns				
	Leaf NDF (%)			
20	52.20	52.75	52.64	53.46
30	53.67	52.63	53.79	52.92
40	55.48	54.48	53.81	55.55
60	56.07	56.56	56.59	55.22
	LSD (P<0.05) 2.75			
Treatment*; Cutting**; Nitrogen ns; Cutting x Nitrogen ns				
	Stem NDF (%)			
20	62.19	63.48	62.73	62.25
30	64.76	63.11	65.11	62.88
40	66.28	66.04	66.81	65.79
60	66.52	69.09	69.49	69.16
	LSD (P<0.05) 1.57			
Treatment**; Cutting**; Nitrogen*; Cutting x Nitrogen**				

[1] Total N applied over trial (0, 80, 160 and 320 kg/ha)

Table 5. Effect of rate and time of nitrogen and cutting interval on yield of Jarra digit in 2002 (Trial 3).

Cutting interval (d)	N rate[1] (20 kg/ha N)	N rate (40 kg/ha N)	N every 30 days	N every 60 days
		Total DM yield (kg/ha)		
20	13064	14540	14202	13401
40	13249	15760	15232	13777
60	13926	16879	16242	14563
LSD (P<0.05)		1588		
Treatment**; Cutting*; Rate of N**; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N *				
		Leaf DM yield (kg/ha)		
20	7294	8127	7984	7437
40	6037	6939	6819	6156
60	5299	6084	6351	5032
LSD (P<0.05)		678		
Treatment**; Cutting**; Rate of N**; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N ns.				
		Stem DM yield (kg/ha)		
20	5770	6413	6218	5964
40	7212	8821	8413	7621
60	8627	10795	9891	9531
LSD (P<0.05)		1209		
Treatment**; Cutting**; Rate of N**; Time of N ns; Cutting x Rate of N ns; Cutting x Time of Nitrogen ns; Time of N x Rate of N *				

[1] Total N applied over trial
(20 kg/ha N every 30 days = 160 kg/ha; 20 kg/ha N every 60 days = 80 kg/ha;
40 kg/ha N every 30 days = 320 kg/ha; 40 kg/ha N every 60 days = 160 kg/ha)

Table 6. Effect of time and rate of nitrogen application on yield of Jarra digit in 2002 (Trial 3).

Nitrogen rate[1] (kg/ha N)	N every 30 days	N every 60 days
	Total DM yield (kg/ha)	
20	14554	12273
40	15897	15555
LSD (P<0.05)	1297	
	Leaf DM yield (kg/ha)	
20	6755	5664
40	7347	6752
LSD (P<0.05)	553	
	Stem DM yield (kg/ha)	
20	7799	6609
40	8550	8803
LSD (P<0.05)	987	

[1] Total N applied over trial
(20 kg/ha N every 30 days = 160 kg/ha; 20 kg/ha N every 60 days = 80 kg/ha;
40 kg/ha N every 30 days = 320 kg/ha; 40 kg/ha N every 60 days = 160 kg/ha)

Table 7. Effect of rate and time of nitrogen and cutting interval on quality of Jarra digit in 2002 (Trial 3).

Cutting interval (d)	N rate[1] (20 kg/ha N)	N rate (40 kg/ha N)	N every 30 days	N every 60 days
	Leaf crude protein concentration (%)			
20	13.91	16.09	16.07	13.92
40	11.90	13.95	14.15	11.69
60	9.85	11.13	11.62	9.36
LSD (P<0.05)	1.04			
Treatment**; Cutting*; Rate of N**; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N **				
	Stem crude protein concentration (%)			
20	9.67	11.09	11.62	9.14
40	8.31	9.29	9.81	7.79
60	5.59	6.80	6.93	5.46
LSD (P<0.05)	0.94			
Treatment**; Cutting**; Rate of N**; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N **				
	Leaf ADF (%)			
20	30.45	30.27	30.01	30.72
40	32.10	31.68	31.60	32.18
60	32.91	32.43	32.45	32.90
LSD (P<0.05)	0.74			
Treatment**; Cutting**; Rate of N ns; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N ns.				
	Stem ADF (%)			
20	34.19	34.81	34.37	34.64
40	35.69	35.44	35.33	35.81
60	36.97	36.37	36.56	36.78
LSD (P<0.05)	0.64			
Treatment**; Cutting**; Rate of N ns; Time of N ns; Cutting x Rate of N ns; Cutting x Time of N*; Time of N x Rate of N *				
	Leaf NDF (%)			
20	52.43	51.30	52.32	51.40
40	55.56	55.19	55.81	54.94
60	56.67	56.47	56.40	56.75
LSD (P<0.05)	2.18			
Treatment**; Cutting**; Rate of N ns; Time of N ns; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N ns.				
	Stem NDF (%)			
20	61.09	61.45	60.53	62.05
40	63.75	62.92	63.12	63.55
60	65.66	65.15	65.11	65.70
LSD (P<0.05)	1.01			
Treatment**; Cutting**; Rate of N ns; Time of N**; Cutting x Rate of N ns; Cutting x Time of N ns; Time of N x Rate of N ns.				

[1] Total N applied over trial
(20 kg/ha N every 30 days = 160 kg/ha; 20 kg/ha N every 60 days = 80 kg/ha;
40 kg/ha N every 30 days = 320 kg/ha; 40 kg/ha N every 60 days = 160 kg/ha)

Table 8. Effect of time and rate of nitrogen application on quality of Jarra digit in 2002 (Trial 3).

Nitrogen rate[1] (kg/ha N)	N every 30 days	N every 60 days
	Leaf crude protein concentration (%)	
20	12.61	11.16
40	15.28	12.16
LSD (P<0.05)	0.85	
	Stem crude protein concentration (%)	
20	8.22	7.49
40	10.69	7.43
LSD (P<0.05)	0.77	
	Leaf ADF (%)	
20	31.51	32.13
40	31.19	31.73
LSD (P<0.05)	0.61	
	Stem ADF (%)	
20	35.67	35.17
40	35.57	35.74
LSD (P<0.05)	0.52	
	Leaf NDF (%)	
20	54.59	55.18
40	55.10	53.54
LSD (P<0.05)	1.78	
	Stem NDF (%)	
20	63.25	63.75
40	62.59	63.78
LSD (P<0.05)	0.82	

[1] Total N applied over trial
(20 kg/ha N every 30 days = 160 kg/ha; 20 kg/ha N every 60 days = 80 kg/ha;
40 kg/ha N every 30 days = 320 kg/ha; 40 kg/ha N every 60 days = 160 kg/ha)

Table 9. Yield responses (kg DM/kg N) from applying nitrogen to Jarra digit (Trial 2).

Cutting interval (d)	Nitrogen level (kg/ha N)		
	80	160	320
	Yield response (kg DM/kg N)		
20	54	23	16
30	40	43	17
40	52	35	24
60	61	54	36

Appendix 8

Planting *Paspalum atratum* cv. Ubon and forage legumes in alternate rows to establish pasture swards in north-east Thailand

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Abstract
Two field trials on a low fertility upland soil were conducted in north-east Thailand to find legumes that when planted in alternate 50 cm rows in Ubon paspalum (*Paspalum atratum*) swards would persist and improve the quality of the pasture. In Trial 1, annual legumes *Lablab purpureus* cv. Rongai, *Vigna unguiculata* and *Canavalia ensiformis* were dominant at the first cut, 60 days after sowing, but these legumes failed to regrow after the second cut 45 days later. Other legumes *Aeschynomene americana* cv. Lee, *Macroptilium gracile* cv. Maldonado, *Stylosanthes guianensis* cv. Tha Phra (CIAT 184), *Centrosema pascuorum* cv. Cavalcade, *Calopogonium muncunoides* and *Pueraria phaseoloides* were slower to establish but produced consistent yields when cut 4 times during the wet season. The highest cumulative wet season dry matter yields in Trial 1 were produced by the grass only swards, 12.2 t/ha DM, which was 35% higher than the average yields produced by the mixed grass/legume swards. The low average crude protein content of Ubon paspalum (4.5%) lowered the total crude protein yields of the grass only swards by up to 35% compared to the best legume/grass sward of *Centrosema pascuorum* that produced 808 kg/ha crude protein from 4 cuts.

In Trial 2 in the second year, the inter-rows between the existing rows of Ubon paspalum were cultivated at the beginning of the wet season and legumes oversown along the cultivated inter-rows. The best performing legumes in the first wet season in Trial 2 were *S. guianensis* var. *vulgaris* x var. *pauciflora* (ATF 3308, Ubon stylo), *Macroptilium gracile* cv. Maldonado, *S. guianensis* cv. Tha Phra (CIAT 184), *S. hamata* cv. Verano, and *C. mucunoides*. However, total wet season crude protein yields between the best legume mixed grass swards and grass only swards were not significantly different.

In the second wet season in Trial 2, the legumes were not resown in the pasture swards but were allowed to reestablish from fallen seed produced in the preceding dry season. All 3 stylo species, *S. guianensis* var. *vulgaris* x var. *pauciflora, S. guianensis* cv. Tha Phra and *S. hamata* cv. Verano, produced significant amounts of dry matter (2.0-2.3 t/ha) and these treatments produced 89% more total wet season crude protein than swards with only Ubon paspalum. Tha Phra stylo mixed grass swards twice the amount of crude protein than grass only swards. *S. hamata* cv. Verano aggressively invaded the inter-rows in the other mixed grass/legume swards where the twining legumes were either very sparse or had disappeared, thereby increasing significantly the crude protein yields of these swards compared to grass only swards.

Management strategies to maintain a strong legume composition in alternate rows in Ubon paspalum swards are discussed and include using high legume seeding rates, selectively cutting only the grass in the early part of the wet season and reducing the

amount of fertiliser used. Stylo species were identified as suitable legume companion species to establish in Ubon paspalum pastures on low fertility upland soils in north-east Thailand.

Introduction

The concept of a grass/legume mixture as an ideal pasture is based on the better balanced diet on offer to animals with respect to protein provided by the legume and energy provided by the grass, which in turn benefits from the symbiotic nitrogen fixed by the associated legume. However, the management of tropical grasses and legumes to maintain the original botanical composition is a difficult operation as each has differing growth patterns with the faster growing C_4 grasses usually dominating the slower growing C_3 legumes (Humphreys 1981).

The comparative advantage of C_4 grasses over the C_3 legumes, particularly above the ground for space and light, usually leads to mixed grass/legume swards becoming grass dominant within 1-2 years after establishment. The nature of the competition does vary from one field situation to another so that a particular species may be a strong competitor in one site but a weak competitor in another (Grime 1977). However, the general experience in Thailand and many other tropical countries is the failure of legumes to persist in mixed swards for more than 2 years (Ibrahim and Mannetje 1998; Hare *et al.* 1999b; 2002).

On infertile, low lying, seasonally wet-seasonally dry soils in north-east Thailand, *Macroptilium gracile, Centrosema pascuorum* and *Aeschynomene americana* did not persist after the second wet season in association with either *Brachiaria mutica* or *Paspalum atratum* (Hare *et al.* 1999b). On fertile, well-drained soils in central Thailand, sowing *Stylosanthes hamata* at twice the seeding rate as that of *B. ruziziensis* (24 vs 12 kg/ha) did not prevent the pasture swards becoming grass dominant (97%) within 4 months after sowing (Wongsawan and Watkin 1990) and in places that legumes did persist, they only contributed 5-10% of the botanical composition of the pasture sward (Hongyantarachi *et al.* 1989).

The primary pasture production system in Thailand is to grow pure swards of cultivated grasses. The quality of these pastures is usually low as most farmers apply little if any fertiliser (Tudsri *et al.* 2001) and even where fertiliser has been applied, crude protein concentrations remained low, ranging from 4.4-8.6% on infertile soils (Hare *et al.* 1999a).

P. atratum cv. Ubon grows well on wet, waterlogged acid soils in Thailand (Hare *et al.* 1999a; 1999b) but it has low crude protein concentration, frequently falling below 7%. This crude protein level is considered a critical point (Milford and Minson 1966) where nitrogen needed by rumen microorganisms becomes limiting unless some other nitrogen source is provided. Crude protein concentrations of *P. atratum* increased above 7% if nitrogen rates of 80 kg/ha N were applied every 30 days and the forage cut every 20-30 days (Hare *et al.* 1999c; Hare *et al.* 2001). However, the amount of nitrogen fertiliser applied in these trials is too expensive for smallholder farmers and the frequent cutting regime (every 20-30 days) significantly lowers dry matter yields. This is undesirable for farmers where land pressure on smallholdings is great and as much dry matter as possible must be produced from average farm sizes of 2-4 ha (Hare *et al.* 1999a). Introducing legumes into *P. atratum* pasture swards could be a cost-effective method for smallholder farmers to improve pasture quality.

Tropical grass/legume mixtures have been successful where different strategies using management leads to the legume species competing successfully with the neighbouring competing grass species. It is common practice to increase the legume seeding rate in order to increase the legume percentage in the first year (Jones *et al.* 1986), particularly on low fertility soils (Humphreys 1987). But in some cases even this strategy is not successful (Wongsawan and Watkin 1990), particularly if the grass is stoloniferous. Legumes are generally more compatible with erect bunch grasses than with stoloniferous grasses. The legumes are able to compete for light by climbing up the grass canopies if they are twinning types or if they are low-growing types, removing the grass leaves by heavy grazing or close cutting will enable the legumes to receive sufficient illuminance.

Arachis pintoi persisted well, especially at high stocking rates, in association with a less aggressive accession of *B. humidicola* (Ibrahim and Mannetje 1998) and *B. brizantha* (Hernandez *et al.* 1995) in Costa Rica, because of its prostate growth habit and dense mat of stolons ensured protection of a high percentage of growing points from defoliation. Leucaena planted as seedlings in wide rows, 1-2 m apart, on fertile soils in Thailand, successfully grew with *B. ruziziensis* and *Pennisetum purpureum* (Dwarf napier) by cutting the grasses lower than leucaena in the establishment year, enabling the greater stature of leucaena to receive sufficient sunlight (Tudsri *et al.* 2001; 2002).

P. atratum is an erect bunch grass which does not spread into vacant areas in pastures and often these open spaces are invaded by weeds (Kalmbacher *et al.* 1997) when they could be better utilized by legumes. On seasonally wet-seasonally dry soils in Thailand legumes failed to persist in *P. atratum* swards but in these studies the grass seeding rate was higher than the legume rate (Hare *et al.* 1999a; 2002). If the legume seeding rate was higher than the grass rate and sites were on slightly better drained soils, legumes may have more chance to persist (Hare *et al*. 2002), especially in the open spaces in *P. atratum* pastures.

The objective of the research was to plant a range of legumes in alternate rows with *P. atratum* in order to find legumes that would persist and improve the quality of *P. atratum* swards in north-east Thailand on soils that are not waterlogged.

Materials and methods

The field experiments were conducted in Ubon Ratchathani province, north-east Thailand (15°N, 104°E) on the Ubon Ratchathani University farm in a 0.15 ha field from 2000 to 2002. Rainfall was recorded 1 km from the trial site (Table 1). The soil is classified as a sandy low humic gley soil (Roi-et soil series) and was on an upland site. Soil samples taken at sowing in May 2000 showed that the soil was acid (pH 4.7), and low in organic matter (1%), N (0.05%), P (10.7 ppm; Bray II extraction method) and K (19.5 ppm) concentrations. The site prior to cultivation had been planted in ruzi grass, mixed with some Verano stylo, for 6 years. The site was ploughed twice in March and April 2000 and rotary hoed to produce a fine seed bed the day before seed sowing in May 2000.

Trial 1 – Seed sowing Ubon paspalum and forage legumes in alternate rows

This trial was a randomised complete block design with 10 seed sowing treatments and 4 replications. The treatments were *Paspalum atratum* cv. Ubon (Ubon paspalum) sown alone (T1) or in alternate rows with *Lablab purpureus* cv. Rongai (T2), *Aeschynomene americana* cv. Lee (America jointvetch) (T3), *Macroptilium gracile* cv. Maldonado (Llanos macro) (T4), *Stylosanthes guianensis* cv. Tha Phra (CIAT 184) (T5), *Centrosema* *pascuorum* cv. Cavalcade (T6), *Vigna unguiculata* (Cowpea) (T7), *Canavalia ensiformis* (Jackbean) (T8), *Calopogonium muncunoides* (Calopo) (T9) and *Pueraria phaseoloides* (Puero) (T10).

In April 2000, all seeds were weighed for thousand seed weight and tested for seed germination in order to calculate seed sowing rates (Table 2). Lee American jointvetch, llanos macro, Tha Phra stylo, calopo and puero seeds were soaked in hot water and Cavalcade seeds were scarified with sandpaper prior to germination testing and at seed sowing in May. Seeds of Lablab, Lee American jointvetch, Cavalcade, cowpea, calopo, and puero were also inoculated with the appropriate rhizobium strains (Table 2).

Ubon paspalum and the legumes were sown at their respective sowing rates (Table 2) on May 3, 2000 in plots measuring 6 x 5 m. Ubon paspalum in T1 was sown alone in 50 cm spaced rows and each legume species (T2-T10) was sown in alternate 50 cm spaced rows with Ubon paspalum. The seed was lightly covered with soil and fertilised with 22 kg/ha N, 22 kg/ha P, 22 kg/ha K and 13 kg/ha S. The plots were hand weeded 2 weeks after sowing.

Plant counts were made from 3 x 1 m rows of legumes and Ubon paspalum in each plot, 4 weeks after sowing. Dry matter cuts were taken from 4 x 1 m rows of each legume and Ubon paspalum per plot, cut 10 cm from ground level on July 4, August 17, September 29 and November 13, 2000. At each cut samples were sorted into Ubon paspalum and legume species. 200 g separate subsamples of Ubon paspalum and legume species from each plot were dried at 70°C for 48 hours and dry weights recorded. Samples from the dried grass and legumes were analysed for total N in order to calculate crude protein levels (%N x 6.25).

After each sampling, the plots were cut to 10 cm above ground level and fertilised with N, P, K and S at the same rates applied at sowing.

Trial 2 – Inter-row planting forage legumes in alternate rows between 1 year-old rows of Ubon paspalum

This study used the same plots as in Trial 1 comprising of 10 treatments replicated 4 times. The treatments were *P. atratum* cv. Ubon alone (T1), and *P. atratum* cv. Ubon inter-row planted with *S. guianensis* var. *vulgaris* x var. *pauciflora* (ATF 3308, Ubon stylo) (T2), *M. atropurpureum* cv. Aztec siratro (T3), *Macroptilium gracile* cv. Maldonado (Llanos macro) (T4), *S. guianensis* cv. Tha Phra (CIAT 184) (T5), *C. pascuorum* cv. Cavalcade (T6), *C. pubescens* (Centro) (T7), *S. hamata* cv. Verano (T8), *C. mucunoides* (Calopo) (T9) and *P. phaseoloides* (Puero) (T10).

On May 10, 2001, Ubon paspalum in all plots was cut to ground level and the inter-rows between the 1 m spaced grass rows in the legume treatments cultivated into a fine seed-bed by a small plough and harrow. On May 15 the legume seeds were sown in the inter-rows in their respective plots. The seed was lightly covered with soil and all the plots fertilised with 23 kg/ha N, 23 kg/ha P and 23 kg/ha K. The legume seeding rates were 10 kg/ha for the 3 stylo species, 20 kg/ha for Aztec siratro, llanos macro and centro and 40 kg/ha for calopo and puero. All the legume seeds were sandpaper scarified but were not treated with rhizobium.

On June 25 dry matter samples of Ubon paspalum only were cut 10 cm above ground level from 4 x 1 m rows in all plots and dry weight and crude protein determined as in Trial 1. Following sampling cuts, Ubon paspalum rows in all plots were cut to 10 cm above ground level and fertilised at the same rates used at time of legume sowing. No legumes were cut at this time. On August 14 and October 17, 4 x 1 m rows of both legumes and Ubon paspalum were cut at 10 cm above ground level and analysed for dry matter and crude protein content. After each sampling cut, the remaining rows were cut to 10 cm above ground level and fertilised with the same rates of N, P and K.

Two dry season sampling cuts, 10 cm above ground level, were taken from each plot on December 26, 2001 and April 26, 2002. At each dry season cut, only samples of grass were taken from 4 x 1 m rows in each plot as the legumes present were below the 10 cm cutting height. At the April cut, the legume seedlings in the inter-rows were scored for percent cover in each plot. After each cut the same rates of N, P and K were applied again. Wet season cuts, 10 cm above ground level, were taken on June 17, August 21 and October 22, 2002, and analysed for dry matter and crude protein content. Only grass was sampled at the first cut in June. Fertiliser was only applied once in the 2002 wet season on August 21.

Results

Rainfall

Rainfall during the studies was above the medium term of 1593 mm/annum in all 3 years (Table 1). Rainfall in the first establishment year, 2000, was 30% above the medium-term average with over 400 mm/month falling in May, July and August. Rainfall in the May, the first month of the wet season, in 2001 and 2002 and in June, 2002, was more than 50% below the medium-term mean but heavy thunderstorms in the latter half of the wet season, increased the annual rainfall above the mean.

Trial 1 – Seed sowing Ubon paspalum and forage legumes in alternate rows

Plant populations of all species was good at 4 weeks after sowing (Table 3). The density of Ubon paspalum was slightly higher in the pure swards but there were no significant differences between Ubon paspalum plant density in all the plots strip-planted with legumes. Legume plant density varied significantly with the large seeded jackbean having the lowest plant number/m^2 and the small seeded Lee joint vetch the highest plant density at 4 weeks after sowing. Lablab established very well with plant densities similar to puero, llanos macro and Tha Phra stylo. However, the lower seed germination of calopo (Table 2) resulted in calopo having lower plant densities compared to most other legumes, except jackbean, at 4 weeks after sowing.

At the first cut, legumes were either dominant or at least equal in dry matter to Ubon paspalum, but at later cuts Ubon paspalum out yielded the legumes (Table 4). Annual legumes, jackbean, cowpea and lablab, were dominant at the first cut, producing significantly more dry matter than Ubon paspalum and all the other legumes except Cavalcade. However, these 3 annual legumes quickly died out and had disappeared in all plots by the third cut. The other biannual and perennial legumes grew more slowly, with Cavalcade and Lee jointvetch producing the most legume dry matter at the second and third cuts, respectively. By the fourth cut, there were no significant differences in dry matter production between the remaining legume species.

Ubon paspalum only produced significantly more dry matter when grown in the pure grass swards than when grown in association with the legumes, at the first and third cuts (Table 4). Dry matter production of Ubon paspalum in the mixed swards was similar in all the grass/legume swards at all cuts except at the fourth cut, when Ubon paspalum in the puero swards produced significantly more dry matter than when grown with other legumes.

The highest total first wet season dry matter yield was produced by the grass only swards, 12.2 t/ha DM, which was 35% higher than the average yields produced by the mixed grass/legume swards (Table 5).

Levels of crude protein in Ubon paspalum was low at all cuts, on average 4.5%, and only reached 7% at the fourth cut in association with puero (Table 4). When grown with lablab, crude protein levels of Ubon paspalum were slightly higher at the first 3 cuts than in other treatments. Levels of crude protein in the legumes was on average 14.5%, with puero producing the highest levels, except at the first cut, when Lee jointvetch produced a slightly higher level (Table 4). Cowpea produced the lowest concentration of legume crude protein, 10.2%, at the first cut, before it disappeared from the plots.

Total crude protein yields for the season were the highest in the Cavalcade mixed swards, 808 kg/ha, which was 35% higher than crude protein yields produced by the grass only swards. (Table 5).

Trial 2 – Inter-row planting forage legumes in alternate rows between 1 year-old rows of Ubon paspalum

At the first cut, differences in Ubon paspalum dry matter production between treatments were slight, with the highest yield being produced from the Ubon stylo swards and the lowest yield from the centro swards (Table 6). At the second cut, there were no differences in Ubon paspalum dry matter production between treatments. At the third cut, pure swards of Ubon paspalum produced significantly more dry matter than Ubon paspalum in mixed grass/legume swards.

Llanos macro, Tha Phra stylo, calopo, Ubon stylo and Verano stylo produced the highest legume dry matter yields when legumes were first sampled at the second cut (Table 6). The 3 stylo species and calopo produced the most dry matter at the end-of-wet season cut in October.

Total wet season dry matter yields were over 10 t/ha in the pure grass and llanos macro swards, which were 30% higher than dry matter yields produced by the centro and puero swards (Table 7). Total crude protein yields in the llanos macro swards were significantly higher than yields produced by the Cavalcade, centro, calopo and puero swards.

Ubon paspalum crude protein levels were very low at all cuts, averaging 4.7% (Table 6). Crude protein levels of the legumes were 3-4 times higher than levels in Ubon paspalum. Aztec siratro, llanos macro and calopo produced crude protein levels 2-3% lower than the other legume species.

In the dry season (November-April), dry matter production of Ubon paspalum was on average 2200 kg/ha with no significant differences between plots that had legumes and the grass only plots. Legumes were very small and prostrate at the first dry season cut (December) and as they were below the 10 cm cutting height no legume dry matter data were collected. In April many legumes seedlings were starting to emerge in the plots and even though no dry matter production data were collected as they were too small, their presence was scored visually in each treatment. Ubon stylo, Tha Phra stylo and Verano stylo were dense along the inter-rows in all their respective plots; llanos macro, Cavalcade, centro, and calopo were between 20-30% in their respective plots; puero only constituted 5% cover in its plots and no Aztec siratro seedlings were observed. However, in the twining legume plots dense numbers of small Verano seedlings were observed emerging.

Grass only plots at the first cut in the third wet season produced significantly more grass dry matter than plots mixed with Ubon stylo, Tha Phra stylo, Cavalcade and centro (Table 8). At the second cut, nearly all plots produced similar grass yields, except for the Cavalcade and centro plots, which produced nearly 60% less grass dry matter than grass only plots.

At the second cut, the 3 treatment stylos, Ubon, Tha Phra and Verano, produced significantly more dry matter than the combined dry matter weights of the other legumes (Table 8) which were either very sparse (Aztec siratro, llanos macro, Cavalcade, centro and calopo) or had disappeared (puero). Self-sown Verano stylo was very dense in these twinning legume swards and a small amount of self-sown calopo also grew in the Verano stylo plots. Total dry matter production (grass and legume) was similar between all plots at the second and third cuts.

At the third cut, Ubon paspalum in the centro swards produced less than half the amount of dry matter produced by the grass only swards (Table 8). The 3 stylo species were again dominant at the third cut and self-sown Verano stylo produced equal amounts of dry matter in the other legume swards. Aztec siratro had disappeared by the time the third cut was taken.

In the third wet season there were no significant differences in cumulative dry matter production between grass only and mixed/legume grass swards (Table 9). However, the mixed grass/legume swards produced more significantly more (67%) crude protein than grass only swards. The 3 stylo treatment swards produced 89% more total crude protein than the grass only swards with Tha Phra stylo swards producing twice the amount of crude protein produced by grass only swards.

Discussion

The primary objective of this research was to improve the quality of Ubon paspalum swards through management of appropriate forage legumes introduced either when sown with Ubon paspalum or when oversown into alternate inter-rows in established grass swards. Management of the trials was to ensure that conditions were made suitable for the legumes by using high legume seeding rates, cultivating the inter-rows before oversowing in second-year grass swards, selectively cutting the grass only and delaying cutting the legumes at the beginning of the second and third growing seasons and reducing the amount of fertiliser in third-year swards in order to reduce the competitiveness of Ubon paspalum.

Using high legume seeding rates in Trial 1 was a successful management strategy in that it ensured that at the first cut, 2 months after sowing, most of the legumes were either dominant or at least equal in dry matter to Ubon paspalum. Cultivating the inter-rows and selectively cutting only the grass rows early in the second growing season promoted successful establishment of all the legumes in second year grass swards. Selectively cutting the grass rows and not cutting the legumes early in the third growing season made conditions suitable for the successful reestablishment of stylo species from fallen seed.

Fertiliser management appeared to play an important role in the successful growth of stylo species in the third year. The amount of fertiliser applied in the third year was reduced to half of what was used in the previous year without affecting the quality of the pasture sward. Grass production was reduced but the production of stylo species increased 5-6 times compared to the previous year and this increase, which included self-sown Verano stylo in other legume plots, enabled crude protein yields for the third year to be 165 kg/ha higher in the mixed grass/legume swards than in the second year. Ubon paspalum crude protein levels remained low throughout the trials and when fertiliser applications were halved in the third year, crude protein levels remained the same.

With management strategies assisting the successful establishment and growth of legumes in Ubon paspalum pasture swards, it appeared that legume growth habit was the major determinant of the subsequent performance of the different legumes species.

Annual legumes, lablab, jackbean and Cavalcade, with their vigorous early growth, significantly increased the quality of the Ubon paspalum swards with increased crude protein yields compared to grass only swards in Trial 1. Another annual species used, cowpea, produced over 1500 kg/ha DM at the first cut, but its relatively low crude protein content for a legume (10.2%) meant that the cowpea mixed pasture sward crude protein yield was not significantly higher than grass only swards.

However, except for Cavalcade and Lee jointvetch, the contribution of these annual legumes to sward productivity and quality was short-lived and by the third cut they had disappeared. Their demise was not caused by grass competition because Ubon paspalum under a 45-day cutting regime did not shade out the legume inter-rows. Their demise was caused by a combination of their annual habit and the repeated cutting of their elevated growing points. Even though Cavalcade and Lee joint vetch are annual legumes, they persisted in the first wet season because their growth habits protected many of their growing points from defoliation.

Cavalcade is trailing legume rather than a twining legume and can root from trailing stems (Clements 1992). Cutting at 10 cm above ground level did not remove many of its growing points and Cavalcade was able to successfully regrow after each cut in Trial 1. Cavalcade in Trial 1 maintained consistently good yields throughout the wet season, producing the highest legume dry matter yield for the season (3t/ha DM) and producing the sward with the highest crude protein yield in the first season. Lee jointvetch under grazing or repeated cutting changes its erect habit to branch close to the ground (Bishop 1992) and many growing points were protected from defoliation. In north-east Thailand the long dry season causes Lee jointvetch to behave as an annual rather than a short-lived perennial in moist conditions.

Perennial twining legumes, with their elevated growing points are for the most part vulnerable to heavy grazing or repeated cutting. In these trials the performance of twining legumes varied, with all of them competing strongly in Trial 1 but many performing weakly in Trial 2. In Trial 1, Llanos macro, calopo and puero were persistent throughout the first wet season and at the final wet season harvest in October there were no significant differences in their yields and those of the remaining legumes. Their competitive performance in this trial may have been partly due to the above average rainfall creating moist soil conditions under which all 3 legumes thrive (Skerman *et al.* 1988; Cameron 1992; Halim 1992; Hare *et al.* 1999a). In Trial 2, llanos macro, and calopo were both vigorous at the first legume harvest but at the end of the wet season only calopo showed good persistence. This may be due to the growth habit of calopo, which under cutting or grazing can creep along the ground and then root at the nodes under moist conditions. Llanos macro does not have this habit of rooting from trailing stems. Both puero and Aztec siratro established performed poorly in Trial 2 and thereafter throughout the trial were very sparse. We have observed that both species normally establish slowly in north-east Thailand and under the increased competitiveness of second year grass swards were never vigorous enough to compete strongly.

In Trial 2 in the second wet season after oversowing into grass swards, the twining legumes produced insignificant amounts of dry matter. After the final harvest in October only 16 mm of rain fell from November to February, the period of main flowering of these legumes which produce pods. We have observed that unless some dry season rain falls or irrigation is applied, pod-forming legumes either fail to flower or produce shriveled pods and seed. During a long dry season these perennial twining legumes become annual legumes but without fallen seed they disappear from pasture swards.

The performance and persistence of the stylo species demonstrated that these legumes are good companion species in Ubon paspalum swards on upland soils. In Trial 1, only Tha Phra stylo was planted. It established slowly but from the second cut in August onwards its dry matter yields were not significantly lower than any other legume species. In Trial 2 in the first wet season when they were planted, all 3 stylo species, Ubon stylo, Tha Phra stylo and Verano stylo, were in the top group of legumes for dry matter production at all cuts.

These 3 stylo species, were the only legumes that regenerated well from fallen seed in third-year Ubon paspalum swards. These 3 legumes are free-seeding, and flower and produce large amounts of seed under dry conditions in north-east Thailand (Hare and Phaikaew 1999). Even though they were very small and prostrate in the plots during the dry season, they still flowered and produced enough seed in order to start germinating and emerging before the final dry season cut in April. Therefore in the second wet season the 3 treatment stylos, Ubon, Tha Phra and Verano, produced significantly more dry matter than the combined dry matter weights of the other remaining legumes.

In the second season of Trial 2, Verano stylo invaded all the plots where the twining legumes had either disappeared or were very sparse. The trial site was in a former ruzi grass and Verano stylo pasture and the invasion of Verano stylo must have come from buried seed. Verano stylo is ubiquitous along roadsides throughout north-east Thailand and it persists year after year due to its ability to set large amounts of seed. Tha Phra stylo is also very persistent on upland sandy soils but with the reported occurrence of anthracnose in CIAT 184 stylo (Tha Phra stylo) in several situations in south-east Asia (Chakraborty *et al.* 2001), seed production of the anthracnose resistant hybrid species, Ubon stylo (ATF 3308) (Grof *et al.* 2001), is currently being undertaken by Ubon Ratchathani University. In small trials at the university dry matter production of Ubon stylo is equal to that of Tha Phra stylo but it is superior in seed production.

The good growth of several legumes in Trial 1, the first year of Trial 2 and the stylo species in the second year of Trial 2, did not appear to benefit the associated Ubon paspalum plants in the mixed grass/legume swards. Crude protein content of Ubon paspalum plants in grass only swards was generally only slightly lower than in plants in the grass/legume swards. The benefits to animals having a better balanced diet would have to come from the legumes providing a higher crude yield on offer in the mixed swards. Even though the differences in total season crude protein yields were often insignificant between grass only and some mixed swards there was a strong trend for the best legume swards to be significantly higher in crude protein yield. In Trial 1, Cavalcade swards produced 35% more crude protein than the grass only swards. In the second season of Trial 2, the 3 stylo treatment swards produced 89% more crude protein than grass only swards. In that same season the invasion of Verano stylo in other treatments increased by 67% the average crude protein yields above the yields in grass only plots.

This research has shown that with management legumes can successfully establish and grow in Ubon paspalum swards. High legume seeding rates and the selective cutting of only grass during the legume establishment phase will assist the survival and production of legumes. Smallholder farmers apply very little fertiliser and when fertiliser in these trials was reduced by half, legume production increased 6 fold. Reducing the amount of fertiliser is a good management strategy for smallholder farmers. Even though dry matter production of Ubon paspalum is reduced, the associated increase in legume sward composition raises the overall crude protein content on offer in the mixed grass/legume swards thereby achieving the primary objective of these trials to improve the quality of Ubon paspalum pastures.

Ubon paspalum is not an aggressive competitive grass but the companion legumes that are introduced must be adapted to cutting and seed freely in order to survive the long dry season. Whenever legumes grow in close proximity with grasses they must have mechanisms in order to survive both the physical and biotic environment (Grime, 1977). Ubon stylo, Tha Phra stylo and Verano stylo were identified as suitable species to grow with Ubon paspalum. By having many low growing points, good drought tolerance and free-seeding habits they persisted and regenerated in the second year after sowing. Other twining legumes were productive in the first season but most failed to reestablish adequately in the second season to be of any medium term benefit.

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Table 1. Rainfall at Ubon Ratchathani University during the study and the medium-term mean.

Month	Rainfall (mm)			
	Mean[1]	2000	2001	2002
Jan	1	0	0	0
Feb	11	16	17	0
Mar	32	15	65	43
Apr	83	140	23	98
May	226	494	94	105
Jun	251	257	323	122
Jul	279	469	288	389
Aug	270	419	294	435
Sep	294	218	262	389
Oct	110	55	239	131
Nov	32	16	53	10
Dec	5	0	0	11
Total	1593	2099	1658	1733

[1]11-year mean, 1992-2002.

Table 2. Thousand seed weight (TSW), germination %, seed treatment, rhizobium treatment and seed sowing rate of Ubon paspalum andf 9 forage legumes (Trial 1).

Treatment	TSW (g)	Germination (%)	Seed treatment	Rhizobium treatment	Sowing rate (kg/ha)
Ubon paspalum	2.9	70	None	None	12
Lablab	253.5	83	None	CB 756 cowpea group J	500
Lee jointvetch	3.4	65	Hot water 70°C, 3 min.	Cowpea jointvetch	20
Llanos macro	3.4	44	Hot water 70°C, 3 min.	None	20
Tha Phra stylo	2.9	98	Hot water 70°C, 5 min.	None	10
Cavalcade	21.9	83	Sandpaper	CB 1923 centrosema	50
Cowpea	203.8	90	None	Cowpea Group I	200
Jackbean	1348.7	92	None	None	400
Calopo	11.5	38	Hot water 60°C, 3 min.	Cowpea Group M	40
Puero	12.2	46	Hot water 60°C, 3 min.	Cowpea Group M	40

Table 3. Plant populations (4 weeks after sowing) in Ubon paspalum and legume swards (Trial 1).

Treatment	Ubon paspalum	Legume plant
	(plants/ m²)	
Ubon paspalum only	129 a[1]	-
Ubon paspalum & Lablab	108 ab	120 bc
Ubon paspalum & Lee jointvetch	115 ab	166 a
Ubon paspalum & Llanos macro	109 ab	107 bcd
Ubon paspalum & Tha Phra stylo	86 b	97 bcd
Ubon paspalum & Cavalcade	96 ab	130 ab
Ubon paspalum & Cowpea	116 ab	79 cd
Ubon paspalum & Jackbean	97 ab	27 d
Ubon paspalum & Calopo	114 ab	66 cd
Ubon paspalum & Puero	126 ab	104 bcd

[1]Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.

Table 4. Dry matter yields and crude protein levels per cut from 4 wet season cuts of Ubon paspalum and legumes planted in alternate rows in the first year of establishment (Trial 1).

Treatment	Dry matter (kg/ha)			Crude protein (%)		Crude protein (kg/ha)
	Grass	Legume	Total	Grass	Legume	
			First Cut[1]			
Ubon only	1398 a[2]	-	1398 b-e	5.2 ab	-	73 cd
Ubon + Lablab	667 b	1521 b	2188 ab	6.5 a	15.9 abc	285 b
Ubon + Lee jointvetch	431 b	161 d	592 e	4.6 b	18.2 a	49 d
Ubon + Llanos macro	371 b	396 cd	767 de	6.3 a	12.7 cd	73 cd
Ubon + Thaphra stylo	429 b	455 cd	884 de	5.3 ab	16.6 ab	98 cd
Ubon + Cavalcade	576 b	1088 bc	1664 bcd	5.5 ab	15.5 abc	200 b
Ubon + Cowpea	331 b	1565 b	1896 abc	5.4 ab	10.2 d	179 bc
Ubon + Jackbean	354 b	2298 a	2652 a	5.7 ab	14.6 abc	356 a
Ubon + Calopo	496 b	480 cd	976 cde	5.2 ab	13.6 bc	91 cd
Ubon + Puero	737 b	366 cd	1103 cde	5.9 a	17.0 ab	106 cd
			Second cut			
Ubon only	3202 a	-	3202 a	3.8 c	-	122 bcd
Ubon + Lablab	2256 ab	290 c	2402 ab	5.4 a	15.4 abc	166 abc
Ubon + Lee jointvetch	1036 b	342 c	1378 b	3.9 c	15.0 abc	91 cd
Ubon + Llanos macro	1027 b	525 bc	1552 b	4.5 bc	12.4 bc	111 bcd
Ubon + Thaphra stylo	1266 b	760 ab	2026 ab	4.4 bc	15.3 abc	172 abc
Ubon + Cavalcade	1761 b	876 a	2637 ab	4.3 bc	16.9 a	224 a
Ubon + Cowpea	1337 b	-	1337 b	4.2 bc	-	56 d
Ubon + Jackbean	1485 b	271 c	1756 b	4.8 ab	15.8 ab	114 bcd
Ubon + Calopo	1250 b	544 bc	1794 b	4.5 bc	12.2 c	123 bcd
Ubon + Puero	2128 ab	483 bc	2611 ab	4.5 bc	18.0 a	183 ab
			Third cut			
Ubon only	4421 a	-	4421 a	4.4 b	-	196 a
Ubon + Lablab	2370 b	-	2370 b	6.1 a	-	145 ab
Ubon + Lee jointvetch	1466 b	808 a	2274 b	4.7 ab	14.2 ab	184 a
Ubon + Llanos macro	1452 b	256 b	1708 b	5.2 ab	12.1 b	106 ab
Ubon + Thaphra stylo	1899 b	474 ab	2373 b	5.0 ab	13.8 ab	160 ab
Ubon + Cavalcade	2254 b	623 ab	2877 b	5.2 ab	12.7 b	196 a
Ubon + Cowpea	1787 b	-	1787 b	4.3 b	-	77 b
Ubon + Jackbean	1673 b	-	1673 b	4.4 b	-	74 b
Ubon + Calopo	1613 b	335 ab	1948 b	5.2 ab	12.3 b	125 ab
Ubon + Puero	2088 b	417 ab	2505 b	4.9 ab	16.2 a	170 ab
			Fourth cut			
Ubon only	3150 a	-	3150 a	4.5 b	-	142 abc
Ubon + Lablab	2267 ab	-	2267 ab	5.3 ab	-	120 bc
Ubon + Lee jointvetch	1760 b	350 a	2110 ab	5.5 ab	14.8 b	149 abc
Ubon + Llanos macro	1950 b	189 a	2139 ab	5.3 ab	12.0 c	126 abc
Ubon + Thaphra stylo	1960 b	247 a	2207 ab	4.9 b	14.2 b	133 abc
Ubon + Cavalcade	2291 ab	450 a	2741 ab	5.4 ab	14.2 b	188 ab
Ubon + Cowpea	1729 b	-	1729 b	4.9 b	-	85 c
Ubon + Jackbean	1828 b	-	1828 b	4.9 b	-	90 c
Ubon + Calopo	2112 b	190 a	2302 ab	4.9 b	13.2 bc	128 abc
Ubon + Puero	2317 a	200 a	2517 ab	7.0 a	17.1 a	196 a

[1] First cut July 4, Second cut August 17, Third cut September 29, Fourth cut November 13.

[2] Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.

Table 5. Total dry matter yields and crude protein yields of Ubon paspalum and legumes planted in alternate rows in the first season of establishment (Trial 1).

Treatment	Dry matter yield			Crude protein yield		
	Grass	Legume	Total	Grass	Legume	Total
			(kg/ha)			
Ubon only	12171 a[1]	-	12171 a	533 a	-	533 bcd
Ubon + Lablab	7560 b	1811 bc	9371 ab	404 b	312 ab	716 ab
Ubon + Lee jointvetch	4693 b	1661 c	6354 bc	226 d	247 ab	473 cd
Ubon + Llanos macro	4800b	1366 c	6166 c	248 cd	168 b	416 d
Ubon + Thaphra stylo	5544 b	1936 bc	7480 bc	269 cd	294 ab	563 bcd
Ubon + Cavalcade	6882 b	3037 a	9919 ab	348 bc	460 a	808 a
Ubon + Cowpea	5184 b	1565 c	6749 bc	236 d	161 b	397 d
Ubon + Jackbean	5340 b	2569 ab	7909 bc	255 cd	379 ab	634 abc
Ubon + Calopo	5471 b	1549 c	7020 bc	295 cd	172 b	467 cd
Ubon + Puero	7270 b	1466 c	8736 bc	404 b	251 ab	655 abc

[1] Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.

Table 7. Total dry matter yields and crude protein yields of Ubon paspalum and legumes, with the legumes inter-row planted in alternate rows in second year grass swards (Trial 2).

Treatment	Dry matter yield			Crude protein yield		
	Grass	Legume	Total	Grass	Legume	Total
			(kg/ha)			
Ubon only	10832 a	-	10832 a	481 ab	-	481 ab
Ubon + Ubon stylo	8262 abc	387 ab	8649abc	399 abc	67 ab	466 ab
Ubon + Aztec siratro	8107 abc	42 c	8149 abc	401 abc	5 c	406 ab
Ubon + Llanos macro	10081 ab	413 a	10494 ab	508 a	56 ab	564 a
Ubon + Thaphra stylo	7812 abc	447 a	8259 abc	370 abc	84 a	454 ab
Ubon + Cavalcade	7536 abc	138 bc	7672 abc	261 abc	23 bc	384 b
Ubon + Centro	6429 c	129 bc	6558 c	298 c	22 bc	320 b
Ubon + Verano stylo	7046 bc	358 ab	7404 bc	335 c	71 a	406 ab
Ubon + Calopo	7106 bc	433 a	7439 abc	313 c	61 ab	374 b
Ubon + Puero	6964 bc	42 c	7006 c	330 bc	7 c	337 b

[1] Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.

Table 9. Total wet season dry matter yields and crude protein yields of third year Ubon paspalum and second year legumes swards, planted in alternate rows (Trial 2).

Treatment	Dry matter yield			Crude protein		Crude protein yield
	Grass	Legume[1]	Total	Grass	Legume	Total
		(kg/ha)			(%)	(kg/ha)
Ubon only	7188 a[2]	-	7188 a	4.8[3]	-	345 d
Ubon + Ubon stylo	4418 b	2243 a	6261 a	5.2	17.1	613 ab
Ubon + Aztec siratro	5748 ab	1435 a	6783 a	5.5	18.4	580 ab
Ubon + Llanos macro	5032 ab	1154 a	5786 a	5.2	14.0	423 cd
Ubon + Thaphra stylo	4539 b	2396 a	6535 a	5.6	18.9	707 a
Ubon + Cavalcade	4369 b	1702 a	5671 a	5.3	15.3	491 bc
Ubon + Centro	3753 b	1814 a	5167 a	5.5	21.0	587 ab
Ubon + Verano stylo	5150 ab	2004 a	6754 a	5.3	18.4	641 ab
Ubon + Calopo	5967 ab	1734 a	7301 a	5.3	15.9	592 ab
Ubon +Puero	4649 b	2001 a	6250 a	5.7	14.9	563 b

[1]Legume includes treatment legume species + self-sown Verano stylo and Calopo.
[2]Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.
[3]Crude protein % not statistically analyzed because plots were pooled across treatments and cuts.

Table 6. Dry matter yields and crude protein levels per cut from 3 wet season cuts of Ubon paspalum and legumes, with the legumes inter-row planted in alternate rows in second year grass swards (Trial 2).

Treatment	Dry matter (kg/ha)			Crude protein (%)		Crude protein (kg/ha)
	Grass	Legume	Total	Grass	Legume	
		First	Cut[1]		-	
Ubon only	2397 ab[2]	-	2397 ab	3.9[3]	-	94 abc
Ubon + Ubon stylo	2787 a	-	2787 a	4.7	-	131 a
Ubon + Aztec siratro	2373 ab	-	2373 ab	4.7	-	112 abc
Ubon + Llanos macro	2609 ab	-	2609 ab	4.5	-	117 abc
Ubon + Thaphra stylo	2546 ab	-	2546 ab	4.7	-	120 ab
Ubon + Cavalcade	2067 ab	-	2067 ab	4.2	-	87 abc
Ubon + Centro	1763 b	-	1763 b	4.7	-	83 bc
Ubon + Verano stylo	1946 ab	-	1946 ab	4.4	-	86 abc
Ubon + Calopo	1929 ab	-	1929 ab	3.8	-	73 c
Ubon + Puero	2010 ab	-	2010 ab	5.1	-	103 abc
		Second cut				
Ubon only	4071 a	-	4071 b	4.1	-	167 b
Ubon + Ubon stylo	3111 a	273 ab	3384 ab	4.4	17.2	184 b
Ubon + Aztec siratro	3207 a	5 c	3212 ab	4.9	12.9	158 b
Ubon + Llanos macro	4891 a	363 a	5254 a	5.2	13.5	303 a
Ubon + Thaphra stylo	3324 a	314 a	3638 ab	4.5	18.8	209 ab
Ubon + Cavalcade	2909 a	63 bc	2972 ab	4.7	17.2	148 b
Ubon + Centro	2410 a	77 bc	2487 b	4.3	17.3	117 b
Ubon + Verano stylo	2637 a	193 abc	2830 b	4.6	19.8	160 b
Ubon + Calopo	2611 a	311 a	2922 ab	4.0	14.1	148 b
Ubon + Puero	2717 a	18 c	2735 b	4.3	17.6	120 b
		Third cut				
Ubon only	4365 a	-	4365 a	5.1	-	223 a
Ubon + Ubon stylo	2364 bc	114 abc	2478 b	5.3	17.9	151 bc
Ubon + Aztec siratro	2528 bc	37 bc	2565 b	5.3	13.1	139 bc
Ubon + Llanos macro	2581 bc	51 bc	2632 b	5.3	14.8	144 bc
Ubon + Thaphra stylo	1942 c	133 ab	2075 b	5.3	16.4	125 bc
Ubon + Cavalcade	2561 bc	72 abc	2633 b	5.4	15.5	149 bc
Ubon + Centro	2255 bc	52 bc	2307 b	4.9	17.7	120 c
Ubon + Verano stylo	2463 bc	166 a	2629 b	5.3	18.0	160 b
Ubon + Calopo	2816 b	122 abc	2938 b	4.9	12.6	153 bc
Ubon + Puero	2238 bc	24 c	2262 b	4.9	19.4	114 c

[1] First cut July 25, Second cut August 14, Third cut October 17.

[2] Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.

[3] Crude protein % not statistically analyzed because plots were pooled per treatment.

Table 8. Dry matter yields and crude protein levels per cut from 3 wet season cuts of third year Ubon paspalum and second year legumes swards, planted in alternate rows (Trial 2).

Treatment	Dry matter								
	First cut	Second cut				Third cut			
		G[1]	L	V	T	G	L	V	T
	(kg/ha)								
Ubon only	2061 a[2]	2921 a	-	-	2921 a	2206 ab	-	-	2206 a
Ubon + Ubon stylo	1196 c	1509 ab	1424 a	-	2533 a	1712 abc	803 a	17 c	2532 a
Ubon + Aztec siratro	1550 abc	1843 ab	15 b	1009 a	2467 a	2354 a	-	413 abc	2767 a
Ubon + Llanos macro	1607 abc	1925 ab	145 b	655 b	2325 a	1500 abc	98 b	256 abc	1854 a
Ubon + Thaphra stylo	1380 bc	1674 ab	1416 a	-	2690 a	1485 abc	980 a	-	2465 a
Ubon + Cavalcade	1413 bc	1389 b	14 b	1030 a	2033 a	1567 abc	200 b	458 abc	2225 a
Ubon + Centro	1356 c	1214 b	82 b	829 ab	1725 a	1183 c	37 b	866 a	2086 a
Ubon + Verano stylo	1540 abc	1912 ab	1433 a	40 c[3]	2985 a	1699 abc	489 ab	41 bc[3]	2229 a
Ubon + Calopo	1996 ab	2523 ab	14 b	844 ab	2981 a	1448 bc	112 b	764 ab	2324 a
Ubon + Puero	1608 abc	1704 ab	-	1171 a	2475 a	1337 bc	-	830 a	2167 a

[1]G = Grass; L = Sown treatment legume: V = Verano stylo self-sown from buried seed: T = Total (G+L+V).
[2]Within columns, means followed by a common letter are not significantly different at P=0.5 by Duncan's Multiple Range Test.
[3] Self-sown Calopo in Verano stylo plots.

วิทยานิพนธ์

เรื่อง

การศึกษาอิทธิพลของปุ๋ยไนโตรเจน ฟอสฟอรัสและโพแทสเซียม ต่อการเจริญเติบโต ผลผลิตและคุณภาพของหญ้าอุบลพาสพาลัม (*Paspalum atratum* cv. Ubon)

Study on Nitrogen, Phosphorus and Potassium Fertilizer on Growth, Yield and Quality of Ubon Paspalum (*Paspalum atratum* cv. Ubon)

โดย

นางสาวนพมาศ นามแดง

เสนอ

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การศึกษาอิทธิพลปุ๋ยไนโตรเจน ฟอสฟอรัสและโพแทสเซียมต่อการเจริญเติบโต ผลผลิตและคุณภาพของหญ้าอุบลพาสพาลัม (*Paspalum atratum* cv. Ubon) ในสภาพดินทรายปนร่วน ที่มีสภาพเป็นกรดและความอุดมสมบูรณ์ต่ำ โดยวางแผนการทดลองแบบ Factorial in RCB จำนวน 4 ซ้ำ ประกอบด้วย 3 ปัจจัย คือ 1) ไนโตรเจน อัตรา 0, 10 และ 20 กก.N/ไร่/ครั้งหลังการตัด 2) ฟอสฟอรัส อัตรา 0, 4 และ 8 กก.P/ไร่/ครั้งหลังการตัด และ 3) โพแทสเซียม อัตรา 0, 10 และ 20 กก.K/ไร่/ครั้งหลังการตัด โดยใส่ห่างกัน 30 วัน จำนวน 4 ครั้งติดต่อกัน จากผลการทดลองพบว่า การใส่ปุ๋ยไนโตรเจนอัตรา 10 และ 20 กก.N/ไร่/ครั้งหลังการตัด มีผลทำให้หญ้าอุบลพาสพาลัมเจริญเติบโตดี สร้างผลผลิตน้ำหนักแห้งและมีเปอร์เซ็นต์ไนโตรเจนสูงกว่าแปลงที่ไม่ได้ใส่ปุ๋ยไนโตรเจนอย่างมีนัยสำคัญยิ่งทางสถิติ แต่พบว่าความเข้มข้นของฟอสฟอรัสและโพแทสเซียมลดลงอย่างมีนัยสำคัญทางสถิติยิ่ง การใส่ปุ๋ยฟอสฟอรัสในอัตราต่างๆ กัน (0, 4 และ 8 กก.P/ไร่/ครั้งหลังการตัด) ส่งผลให้หญ้ามีการสะสมฟอสฟอรัสในส่วนต่างๆ ของต้นหญ้าเพิ่มขึ้น ส่วนการใส่ปุ๋ยโพแทสเซียมอัตรา 10 และ 20 กก.K/ไร่/ครั้งหลังการตัด ทำให้หญ้าอุบลพาสพาลัมสร้างผลผลิตน้ำหนักแห้งรวมและมีเปอร์เซนต์โพแทสเซียมสูงกว่าแปลงที่ไม่ได้รับปุ๋ยโพแทสเซียมอย่างมีนัยสำคัญยิ่งทางสถิติ แต่พบว่าความเข้มข้นของไนโตรเจนและฟอสฟอรัสในต้นหญ้าอุบลพาสพาลัมลดลงอย่างมีนัยสำคัญทางสถิติ

การใส่ปุ๋ยไนโตรเจนร่วมกับโพแทสเซียมอัตรา 10-10 และ 10-20 ก.N-K/ไร่/ครั้งหลังการตัด ทำให้หญ้าอุบลพาสาพลัมเจริญเติบโตและสร้างผลผลิตน้ำหนักแห้งรวมได้สูงสุด แต่ปฏิกิริยาสัมพันธ์ระหว่างปุ๋ยดังกล่าวมีผลทำให้ความเข้มข้นของไนโตรเจน ฟอสฟอรัสและโพแทสเซียมในต้นหญ้าลดลงอย่างมีนัยสำคัญทางสถิติ เมื่อเปรียบเทียบกับแปลงที่ไม่ได้ใส่ปุ๋ย

ลายมือชื่อนิสิต | ลายมือชื่อประธานกรรมการ

Noppamat Namdang 2002: Study on Nitrogen, Phosphorus and Potassium Fertilizer on Growth, Yield and Quality of Ubon Paspalum (*Paspalum atratum* cv. Ubon). Master of Science (Agriculture), Major Field: Soil Science, Department of Soil Science. Thesis Advisor: Associate Professor Yongyuth Osotsapar, Ph.D. 240 pages.
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The effect of nitrogen fertilizer (N), phosphorus fertilizer (P) and potassium fertilizer (K) on growth rate, dry matter and quality of a pasture grass Ubon paspalum (*Paspalum atratum* cv. Ubon) was examined in a low fertility and low pH Roi-et series soil in a randomized complete block design with three fertilizer treatments and four replications. The first fertilizer treatments consisted of three nitrogen fertilizer rates at 0, 10 and 20 kgN/rai/cut, the second fertilizer treatments were phosphorus fertilizer at 0, 4 and 8 kgP/rai/cut and the third fertilizer treatments were potassium at 0, 10 and 20 kgK/rai/cut. The fertilizer applications were applied for four times every 30 days cutting interval. The nitrogen application at 10 and 20 kgN/rai/cut significantly increased Ubon paspalum growth rate, dry matter and N concentration and significantly decreased phosphorus and potassium accumulation. Phosphorus fertilizer application at all rates increased phosphorus accumulation in all parts of the Ubon paspalum. Potassium fertilizer application at 10 and 20 kgK/rai/cut significantly increased dry matter and K accumulation and decreased N and P accumulation in Ubon paspalum.

There was an interaction between N and K at 10-10 and 10-20 kgN-K/rai/cut with increased Ubon paspalum growth rates and dry matter but decreased N, P and K accumulation.

Noppamat. N.
Student's signature

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