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Effects of soil fertility and fertiliser nitrogen rate on seed yield and seed quality of *Paspalum atratum* in Thailand

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Abstract

Two experiments were carried out with the intention of determining the optimum rate of N application for seed production of *Paspalum atratum* in north-east and northern Thailand. Experiment 1 measured the effect of 5 N rates (0, 100, 200, 300 and 400 kg/ha/yr N) on a fertile clay soil at Pakchong and Experiment 2 measured the effects of 3 N rates (0, 125 and 250 kg/ha/yr N) on infertile sandy soils at 3 sites (Lampang, Chiang Rai and Prae provinces).

The response of seed yield to N application was different in the first and second years after planting. In the first year, N application had no significant effect on pure seed yield or seed quality of *P. atratum* at any of the sites. In the second year, at the fertile Pakchong site, a rate of 200 kg/ha/yr N produced significantly higher seed yield than other rates. Diminishing seed yields at rates above 200 kg/ha/yr were probably due to the severe lodging of grass by one month before flowering, while low yields at rates below 200 kg/ha/yr were attributed to lower availability of N in the soil. At the 3 infertile sites, seed yields were greater in the second than the first year, and in the second year responded to increases in applied N up to 250 kg/ha/yr N, at which the crop yielded 1459 and 1108 kg/ha of seed at Lampang and Prae, respectively. Seed germination and seed purity increased with increasing N rates at all 3 sites in the second year.

We considered that overall reduced yields in the second year at the lower N input levels were due to a reduction in available soil N resulting from the removal of large amounts of N in vegetation. We concluded that the optimum N rate for seed production of *P. atratum* in Thailand was approximately 200 kg/ha/yr N on fertile clay soil and at least 250 kg/ha/yr N on infertile sandy soil, with the greater need for high levels in the year after planting.

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Introduction

Paspalum atratum is a leafy, high yielding, tropical, perennial grass, native to the humid tropics of Brazil, and recently introduced into Thailand where it is called Ubon paspalum (Hare *et al*. 1999a). It is well suited to waterlogged, infertile and acid soils (Kretschmer *et al*. 1994; Kalmbacher *et al*. 1995, 1997a, 1997b, 1998; Barcellos *et al*. 1997; Hare *et al*. 1999a, 1999b), and can be established easily from seed, which is a more convenient and cheaper method for small farmers in Thailand than establishment from vegetative material (Phaikaew and Pholsen 1993; Phaikaew *et al.* 1993). *P. atratum* persists well under cut-and-carry systems as well as under moderate grazing. It is now a widely used species for low lying areas in smallholder livestock farms in Thailand and other countries in south-east Asia (Ibrahim *et al*. 1997), where para grass (*Brachiaria mutica*) was previously used as the main species (Stur *et al*. 1996). *P. atratum* has superior dry matter productivity to para grass in second-year pastures (Hare *et al*. 1999b).

P. atratum exhibits a high potential for seed production (Kretschmer *et al*. 1994; Phaikaew 1997; Phaikaew and Hare 1998; Hare *et al*. 2001). Forage seed is produced commercially in north-east Thailand by small farmers and the Thai Department of Livestock Development, which handles the processing and marketing (Hare 1993; Phaikaew *et al.* 1997; Hare and Phaikaew 1999). More than 38 tonnes of *P. atratum* seed was produced in Thailand in 2000 and the demand is increasing annually.

A high level of available soil N, normally obtained by applying N fertiliser, is necessary for high seed yields and forage quality in *P. atratum* and other tropical grasses (Hacker and Jones 1971; Boonman 1972; Hare *et al*. 1999c; Ishii *et al*. 1999; Kalmbacher and Martin 1999). There is very limited information on the effect of N fertiliser application on seed production of *P. atratum*, as most studies with N fertiliser have focussed on its effect on herbage yield and quality. In previous studies on seed production of *P. atratum* on infertile soils (Phaikaew *et al.* 2001a; 2001b), there was a decrease in seed yield in the second year, suggesting N deficiency. The main objective of this study was to determine appropriate rates of N fertiliser application for seed production of *P. atratum* in Thailand in the establishment and subsequent years, so as to ensure consistent high yields of good quality seed. We examined the effect of N application on seed production of *P. atratum* at 3 sites with infertile soils in the northern region during 1998–1999, and in another trial on a fertile soil in the north-east region during 1999–2000.

Materials and methods

Similar methods of establishment and harvesting were followed in this study as those already published (Phaikaew *et al.* 2001a; 2001b).

Site, experimental design and plant cultivation

Experiment 1 — N application on a fertile clay soil. A trial over 2 growing seasons comparing N fertiliser rates was conducted at Pakchong Animal Nutrition Research Center, north-east Thailand (14.42°N, 101.25°E; 356 m above sea level), from May 1999–October 2000. Annual mean temperature and annual rainfall at this site are 28.0°C and 1104 mm, respectively. The soil is Pakchong soil series (Pc), which grades from a clay loam to clay. It is a deep, poorly drained but fertile soil with high concentrations of organic matter and other soil nutrients (Table 1A).

The trial was arranged in a randomised complete block design with 4 replications of 5 treatments (rates of N application), as follows:

N_0 — 0 kg/ha/yr,
N_{100} — 100 kg/ha/yr,
N_{200} — 200 kg/ha/yr,
N_{300} — 300 kg/ha/yr,
N_{400} — 400 kg/ha/yr.

One-month-old seedlings of *Paspalum atratum,* BRA 9610 were planted on May 20, 1999 with spacing of 1 m × 1 m. Plot size was 4 m × 5 m. Basal fertiliser (62.5 kg/ha P as triple superphosphate and 62.5 kg/ha K as potassium chloride) dressing was applied at planting. N was applied as urea in equal applications at planting and before flowering, in early August, in 1999. In 2000, fertiliser was applied in May and August in the same form and amount as in 1999. In 2000, each plot was isolated by inserting plastic sheeting along all 4 sides, 10 cm deep in the ground and 30 cm in height above ground level, to prevent the movement of fertiliser to other plots. Soil from each plot was sampled for analysis prior to fertiliser application at planting and at the termination of the trial.

Experiment 2 — N application on infertile soils. The effect of 3 rates of N application was examined during 1998–1999 at 3 sites in northern Thailand:

1. Lampang Animal Nutrition Research Center (18.3°N, 99°E; 320 m asl). In 1998 and 1999, mean air temperatures were 26.1 and 27.3°C; and annual rainfalls were 934 and 1289 mm, respectively. The soil is classified as Renu soil series (Rn) and is a deep, poorly drained, infertile, acid (pH 5.4, in water) soil with sandy loam surface over a sandy clay subsoil (Table 1B).
2. Chiang Rai Animal Nutrition Station (19.6°N, 99.5°E; 518 m asl). Annual rainfalls in 1998 and 1999 were 1574 and 1806 mm, respectively. The soil is Chiang Rai soil (Cr), which consists of a sandy loam over a silty clay loam. Soil pH was 6.5 with low concentrations of organic matter and other soil nutrients (Table 1B).
3. Prae Animal Nutrition Station (18.2°N, 100.2°E; 209 m asl). The soil is a Satuk soil (Suk), which consists of a sandy loam over a

sandy clay loam. It is a deep, well drained, infertile, acid soil (pH 5.1, in water) with low nutrient-holding capacity (Table 1B).

At each site, the trial was arranged in a randomised complete block design with 4 replications of 3 treatments (rates of N application) as follows:

N_0 — 0 kg/ha/yr,
N_{125} — 125 kg/ha/yr,
N_{250} — 250 kg/ha/yr.

One-month-old seedlings of *P. atratum,* BRA 9610 were planted in May 1998, at a spacing of 75 cm × 75 cm. Plot size was 3 m × 4.5 m. A basal fertiliser (62.5 kg/ha P as triple superphosphate and 62.5 kg/ha K as potassium chloride) was applied at planting. N was applied as urea in equal dressings at planting and before flowering, in early August, in 1998. In 1999, fertiliser was applied in May and August in the same form and amount as in 1998.

Seed harvesting

From both experiments, all seed heads within each plot were harvested each year over the period of seed maturity (late September–early October). One week prior to the first seed collection, groups of adjacent seed heads were tied into bundles as "living sheaves". Seed heads were then covered with nylon net bags with an outlet to collect seed, and seed was collected 3 times at 3–5-day intervals (the "Cover" method of Phaikeaw *et al.* 2001a). Tiller number (TN), inflorescence number per plant (IN) and plant height were recorded on 6 randomly selected plants in each plot at harvest. In Experiment 1, raceme number per inflorescence and spikelet number per raceme were recorded from 20 inflorescences in each plot. The degree of lodging of the grass bunches (tillers) was measured twice, before flowering on August 4 and at flowering on September 4, 2000.

After seed harvest, the grass was cut at 10 cm above ground level and the cut forage removed. The grass was cut again at the beginning of the rainy season in May 2000. In Experiment 1, forage yield of each plot was measured following the seed harvest each year and the cut in May 2000, and crude protein concentration of the herbage remaining at seed harvest was determined for each plot.

Seed processing, seed quality testing and statistical analysis

Seed from both experiments was air-dried for 3–4 days in a seed shed before cleaning. Seed moisture content (SMC), thousand-seed weight (TSW),

Table 1. Soil analyses in Experiment 1(A) and Experiment 2(B).

(A) On fertile soil before and after a 2-year fertiliser experiment at Pakchong (Experiment 1).

Sampling stage	N treatment	pH	Organic matter	Available P	Exchangeable			CEC
					K	Ca	Mg	
	(kg/ha)		(%)	(ppm)		(ppm)		(meq/100 g soil)
Prior to planting	0	6.6	2.1	73	404	1565	297	10.9
After 2 yrs of experiment	0	6.7 a[1]	2.1	50	313	1538	319 ab	16
	100	6.6 ab	2.1	50	274	1595	326 a	17.7
	200	6.6 ab	2	40	285	1574	297 bc	15.6
	300	6.4 ab	2	53	269	1336	290 c	15.9
	400	6.3 b	2	49	286	1365	288 c	16.7
Mean		6.5	2	49	285	1481	304	16.4
CV (%)		4	6.9	49	16	14	5.1	23.9

[1] Within columns, treatment means after 2 years of the experiment followed by different letters differ significantly ($P < 0.05$).

(B) At 3 infertile soil sites prior to initial fertiliser application (Experiment 2).

Sites	Soil series	pH	Organic matter	Available P	Exchangeable K
			(%)	(ppm)	(ppm)
Lampang	Renu	5.4	1.5	63	99
Chiang Rai	Chiang Rai	6.5	0.8	17	73
Prae	Satuk	5.1	1.5	20	48

seed purity (SP) and seed germination (SG) were determined using the seed-test methods of the International Seed Testing Association for *Paspalum plicatulum*. Seed was stored at room temperature for 2–3 months and treated with 0.2% KNO_3 before germination. TSW was determined from pure-seed spikelet weight. Seed yield (SY) and TSW were corrected to 10% SMC. The percentage of effective tillers (PET), seed number/inflorescence (SN/I), seed number/m^2 (SN), pure seed yield (PSY) and pure germinated seed yield (PGSY) were obtained by calculation.

Data from both experiments were statistically analysed by the analysis of variance procedures for a randomised complete block design, using the IRRISTAT programme from IRRI. The mean differences between treatments were tested for significance by least significant difference procedures.

Results

Experiment 1 — N application on fertile clay soil

Weather conditions. Monthly precipitation and monthly mean air temperatures at the Pakchong site in 1999–2000 are shown in Figure 1. Temperatures were similar over both years, except for a sudden drop to 20.6°C in December 1999. However, the amount and distribution of rainfall differed markedly between years. Annual totals in 1999 and 2000 of 1264 and 1501 mm, respectively, were above the medium–term average of 1104 mm (1986–1995). Heavy rainfall in September 1999 and August 2000 resulted in severe lodging of *Paspalum atratum* at harvest, especially in the plots with high N application.

Soils. The chemical properties of the soil are shown in Table 1A. The soil at planting was

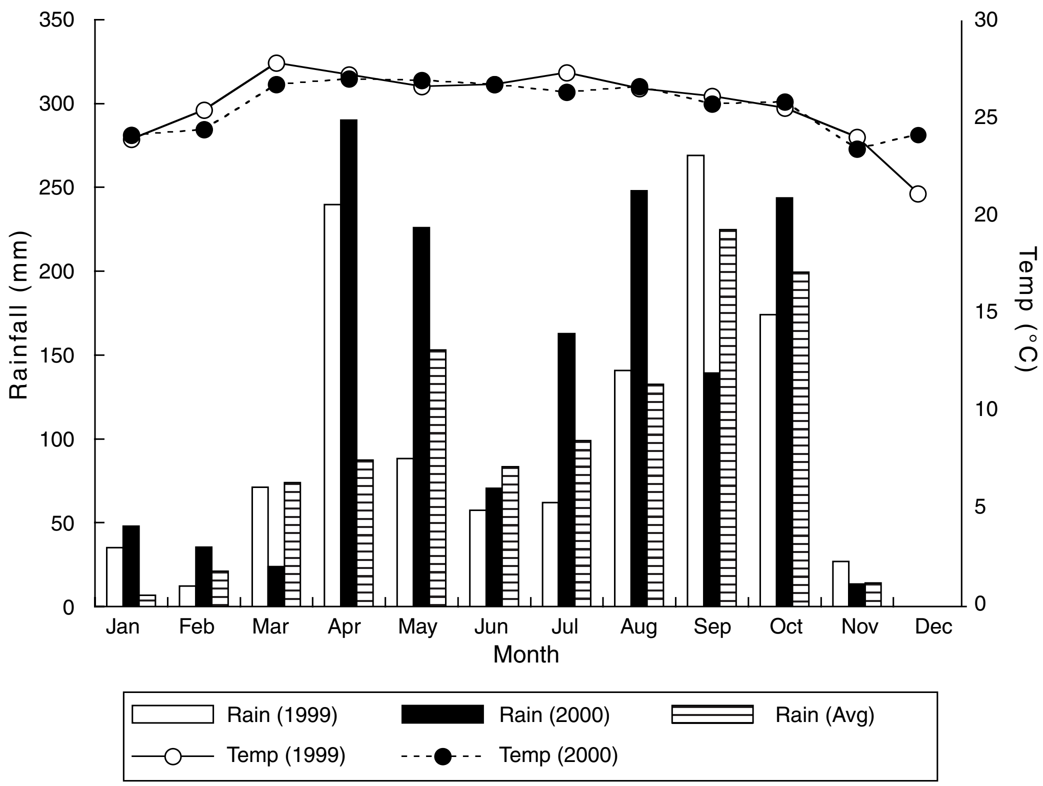

Figure 1. Monthly rainfall (Rain) and mean monthly temperature (Temp) in 1999–2000 and medium-term mean rainfall (1986–1995) (Avg) at the Pakchong site (Experiment 1).

almost neutral in reaction (soil pH 6.59, in water extract) and contained high concentrations of soil macro-elements (2.14% OM; 73 ppm available P, Bray II extraction method; 404, 1565 and 297 ppm of exchangeable K, Ca and Mg, respectively). At the end of the study, there were no significant differences between treatments in OM, available P, exchangeable K and Ca and cation exchange capacity (CEC), but soil pH of the N_{400} plots was significantly lower than that of the N_0 plots. This was associated with a decrease in the cations, K, Ca and Mg, which may have been removed with the leaching of some N as NO_3 in the N_{400} treatment.

Seed yield and yield components. The response in seed yield to N application differed between years. N application rate did not affect seed yield of P. atratum in the first year of the experiment (P>0.05; Table 2). However, in the second year, an application rate of 200 kg/ha N gave significantly higher seed yield than other N rates. Mean seed yields were higher in the first year than in the second year (1314 *vs* 704 kg/ha). The lower seed yields in the second year were principally due to lower inflorescence numbers (IN) caused by a decrease in the percentage of effective tillers (PET), and reduced raceme numbers/inflorescence, giving fewer seed numbers/m^2 (SN). These components were not affected by N rates in the first year, but differed among N rates in the second year. The highest seed yield at N_{200} (due to highest SN) was a function of the combination of higher IN with higher seed number/inflorescence than at other rates. Inflorescence density, that is, the number of effective tillers per unit area, decreased above N_{200}. The only significant variations among treatments occurred in the second year and were in seed yield, IN, racemes/inflorescence, spikelet numbers/raceme, seed numbers/m^2 and seed numbers/inflorescence.

Seed quality. In the first year, N application had no significant effect on the overall seed quality of *P. atratum* (Table 3). There were significant differences among treatments in thousand-seed weight (TSW) and seed germination (SG) in the second year. However, overall seed quality was good with high SG (84–89%), seed purity (SP) (89–98%) and TSW (2.96–3.35 g) in both years.

The responses in pure seed yield (PSY) and pure germinated seed yield (PGSY) to N rate were quite similar to those in seed yield.

Lodging, plant height, forage dry matter yield and crude protein concentration. Effects of N application rate on plant growth characters such as plant height, dry matter (DM) yield, crude protein concentration and lodging percentage are shown in Table 4. N application significantly increased crude protein concentration in herbage after seed harvest in both years, forage DM yield at the beginning of the rainy season (May), and lodging percentage in the second year. Plant height was not affected by N rate in either year (P>0.05). While forage DM yield at seed harvest was similar among N rates in the first year, the N_{200} treatment produced more forage DM (P<0.05) than N_0 and N_{400} treatments in the second year.

Table 2. Effect of N rate on seed yield and its components of *Paspalum atratum* on fertile soil at Pakchong (Experiment 1).

Year	N treatment	Seed yield	Tillers	Inflores-cences	Effective tillers	Racemes/ Inflores.	Spikelets/ Raceme	Seed/ Inflores.	Seed
	(kg/ha)	(kg/ha)	(no/m^2)	(no/m^2)	(%)	(no)	(no)	(no)	(no/m^2)
1999	0	1332	87	66	76	17.4	120	640	41 510
	100	1294	86	59	68	17.3	118	700	40 630
	200	1332	81	64	79	17.2	119	680	42 490
	300	1281	89	64	73	17.2	118	610	39 290
	400	1333	85	63	74	17.3	116	640	39 830
	Mean	1314	86	63	74	17.3	118	660	40 750
	CV (%)	14.1	6.9	14.7	12.3	2.4	3.0	15.9	14.1
2000	0	592 b[1]	82	34 ab	42	10.9 c	164 b	540 cd	18 660 b
	100	661 b	96	48 a	51	11.5 bc	174 ab	460 d	21 550 b
	200	926 a	93	44 a	48	11.9 bc	178 a	710 ab	30 530 a
	300	671 b	93	37 ab	40	12.5 ab	184 a	620 bc	22 530 b
	400	669 bn	86	28 b	34	13.6 a	186 a	800 a	22 530 b
	Mean	704	90	39	43	12.1	177	630	23 160
	CV (%)	15.7	9.7	23.9	23.9	7.5	4.3	13.5	15.5

[1] Within columns and years, treatment means followed by different letters differ significantly (P < 0.05).

Crude protein concentration in forage residue at seed harvest increased progressively with the increase in N rate. The lowest crude protein concentration of 2.91% was obtained in the N_0 plots in the second year.

With the increase in N application, grass started lodging before the flowering stage. In 2000, between August 4 (1 month before flowering) and September 4 (flowering stage), lodging percentage increased in every treatment, especially at N_{400}, from 59% up to 94%, while lodging in the N_0 treatment increased from 2.5% to 44%. The N_{400} treatment, with high lodging percentage, had significantly lower seed and forage DM yields at seed harvest than the N_{200} treatment.

Experiment 2 — N application on infertile soil

Weather. Monthly rainfalls at the Lampang, Chiang Rai and Prae sites and monthly mean air temperature at the Lampang site in 1998–1999

Table 3. Effect of N rate on seed quality of *Paspalum atratum* on fertile soil at Pakchong (Experiment 1).

Year	N treatment	1000-seed weight	Seed purity	Seed germination	Pure seed yield	Pure germinated seed yield
	(kg/ha)	(g)	(%)	(%)	(kg/ha)	(kg/ha)
1999	0	3.21	97	86	1290	1110
	100	3.19	98	87	1270	1100
	200	3.14	96	85	1270	1080
	300	3.28	95	88	1230	1070
	400	3.35	95	84	1270	1060
	Mean	3.23	96	86	1270	1090
	CV (%)	4.7	1.9	4.8	15.0	12.0
2000	0	3.19 a[1]	92	84 b	550 b	460 b
	100	3.07 b	89	86 ab	590 b	520 b
	200	3.03 bc	92	86 ab	860 a	750 a
	300	2.97 c	90	86 ab	610 b	530 b
	400	2.96 c	93	89 a	630 b	560 b
	Mean	3.04	92	87	650	560
	CV (%)	1.6	4.8	3.1	18.1	18.8

[1] Within columns and years, treatment means followed by different letters differ significantly (P < 0.05).

Table 4. Effect of N rate on height, herbage dry matter (DM) yield, crude protein concentration and lodging of *Paspalum atratum* on fertile soil at Pakchong (Experiment 1).

Year	N treatment	At seed harvest (October)			DM yield[2] of early regrowth	Lodging in 2000	
		Plant height	DM yield	Crude protein		Aug 4	Sep 4
	(kg/ha)	(cm)	(kg/ha)	(%)	(kg/ha)	(%)	(%)
1999	0	188	15 940	5.71 c[1]	—	—	—
	100	185	17 350	5.97 c	—	—	—
	200	186	16 940	7.04 b	—	—	—
	300	187	17 430	7.27 ab	—	—	—
	400	189	16 730	8.09 a	—	—	—
	Mean	187	16 660	6.82	—	—	—
	CV (%)	3.6	11.9	7.9	—	—	—
2000	0	199	15 290 b	2.91 d	5340 c	3 d	44 d
	100	196	16 950 ab	4.26 c	5690 c	4 d	61 c
	200	198	18 850 a	5.40 b	6450 b	23 c	83 b
	300	193	17 440 ab	5.87 b	7080 ab	31 b	89 ab
	400	191	14 770 b	7.40 a	7540 a	59 a	94 a
	Mean	196	16 880	5.17	6440	24	74
	CV (%)	4.1	11.9	14.7	7.1	16.4	7.9

[1] Within columns and years, treatment means followed by different letters differ significantly (P < 0.05).
[2] Early regrowth measured at the beginning of the rainy season in the second year (May 2000).

are shown in Figure 2. Although Lampang received less rainfall than other sites, rainfall distribution was adequate for grass growth and seed production during the growing season. Heavy rainfall in July and August 1999 at Chiang Rai caused flooding and lodging, which might have contributed to the markedly lower seed yield at this site in the second year.

Seed yield and plant characters. N rates had no significant effect on either seed yield or plant characters of *P. atratum* in the first year of the experiment at any of the 3 sites (Table 5). Seed yields were remarkably high in the first year with mean yields of 1360, 1506 and 1093 kg/ha at Lampang, Chiang Rai and Prae, respectively.

In the second year, seed yield increased significantly with N application up to the highest level of 250 kg/ha N, with the magnitude of the response lowest at Chiang Rai (Table 5). Mean seed yields at all sites in the second year were lower than those in the first year.

N application increased plant height and IN at the Lampang site in the second year but not at the other 2 sites at Chiang Rai and Prae (Table 6).

Seed quality. In the first year, N application had no significant effect on overall seed quality of *P. atratum* at any of the sites (Table 5). Seed quality was good from all treatments at each site with high SG (84–92%) and TSW (2.94–3.22 g). SP was good at Chiang Rai (87–89%) and fair at Lampang and Prae (78–82%). Mean seed quality, PSY and PGSY at the Chiang Rai site were slightly better than at the other 2 sites in the first year.

In the second year, N application had significant effects on seed quality of *P. atratum* at all 3 sites (Table 5). SG increased significantly with the increase in N application at all 3 sites. Overall SP was good at all sites, averaging 87%. TSW was similarly good (averaging 2.97 g) and was significantly increased by N application at the Prae site.

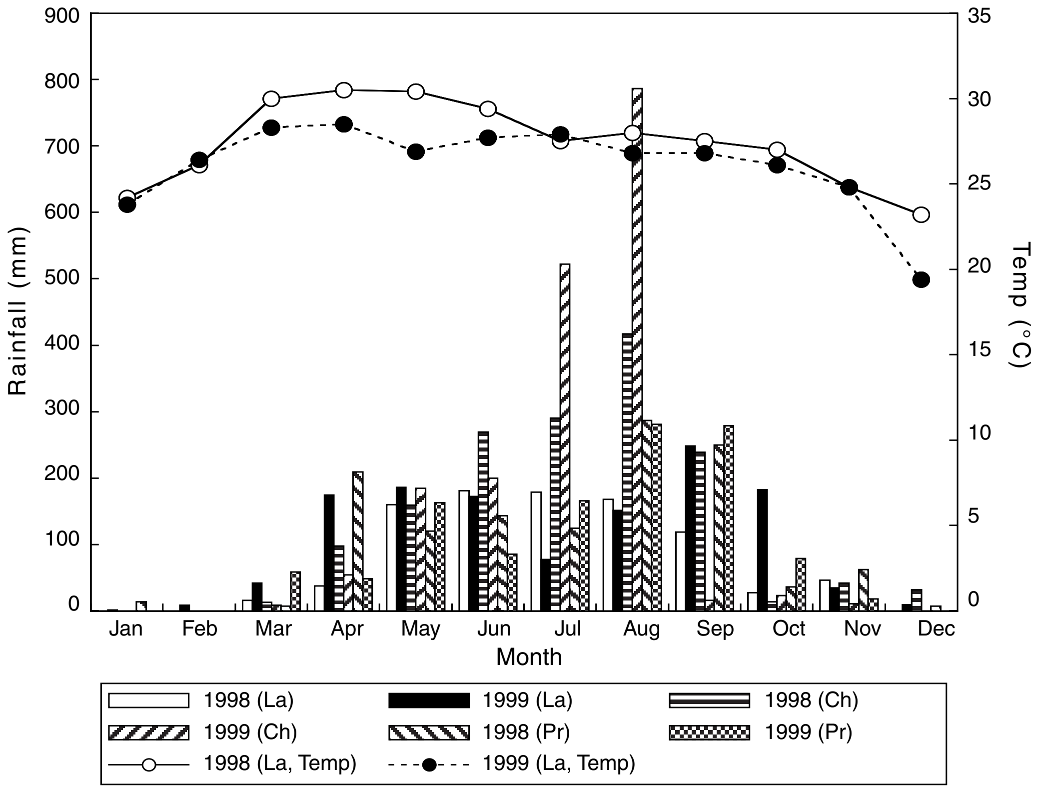

Figure 2. Monthly rainfall and mean monthly temperature (Temp) at Lampang (La) and monthly rainfall at Chiang Rai (Ch) and Prae (Pr) in 1998–1999 (Experiment 2).

PSY and PGSY increased significantly with N application at all sites in the second year.

Discussion

The results of these two experiments conducted, firstly on fertile soil at Pakchong site, and secondly on infertile soil at Lampang, Chiang Rai and Prae sites, have provided valuable information on N requirements for seed production. The responses in seed yield and quality to N application differed markedly between the first and second year after establishment, with different trends for fertile and infertile soils in the second year. Thus, these responses are discussed firstly in separate parts for the first and second year, and the common features are combined to be discussed later.

N application in the first year after establishment

In the establishment year, N application did not have any significant effect on seed yield of *P. atratum* on either fertile or infertile soil sites. High seed yields (averaging over 1310 kg/ha) with good seed quality were obtained at all 4 sites, even on infertile soil. Seed yields may, in some circumstances, be higher in the first year than in subsequent years (Hacker 1994 in *Setaria sphacelata*; Phaikaew *et al.* 2001a, 2001b in *P. atratum*). Requirements for applied N tend to be lowest in the establishment year (Boonman 1972; Chadhokar and Humphreys 1973; Bahnisch and Humphreys 1977), presumably due to the mineralisation of N in the soil that follows cultivation. Moreover, seed yield from the Chiang Rai site was very high (average of 1500 kg/ha) with better seed quality than at the other three sites. This high seed yield might be associated with the higher latitude at Chiang Rai, where the critical day length for flower initiation is reached earlier than at the other sites (Phaikaew *et al.* 2001b).

The heavy yields of good quality seed produced at all N rates in this experiment may be

Table 5. Effect of N rate on seed yield and seed quality of *Paspalum atratum* at 3 infertile sites in 1998–1999 (Experiment 2).

Site	Year	N treatment	Seed yield	1000-seed weight	Seed purity	Seed germination	Pure seed yield	Pure germinated seed yield
		(kg/ha)	(kg/ha)	(g)	(%)	(%)	(kg/ha)	(kg/ha)
Lampang	1998	0	1408	3.04	78	85	1090	930
		125	1336	2.94	79	90	1060	950
		250	1337	2.97	81	85	1080	920
		Mean	1360	2.98	80	87	1080	940
	1999	0	834 c[1]	3.02	85	74 b	700 c	520 c
		125	1255 b	2.96	87	83 a	1090 b	900 b
		250	1459 a	2.94	91	87 a	1320 a	1140 a
		Mean	1183	2.97	87	81	1040	860
Chiang Rai	1998	0	1420	3.16	87	88	1230	1080
		125	1533	3.22	87	91	1330	1210
		250	1566	3.19	89	92	1400	1290
		Mean	1506	3.19	88	90	1320	1190
	1999	0	836 b	2.94	83 b	69 b	690 b	480 b
		125	993 a	3.02	87 ab	76 a	860 ab	660 a
		250	1029 a	3.02	90 a	81 a	930 a	750 a
		Mean	952	3.00	87	75	830	630
Prae	1998	0	1114	2.97	79	84	900	730
		125	1096	3.07	82	86	890	770
		250	1068	2.98	79	87	840	730
		Mean	1093	3.01	80	85	880	740
	1999	0	844 b	2.83 c	85 b	72 b	720 b	520 c
		125	947 b	2.94 b	90 a	77 a	860 b	660 b
		250	1108 a	3.02 a	91 a	79 a	1010 a	800 a
		Mean	966	2.93	89	76	860	660

[1] Within columns for each site and each year, treatment means followed by different letters differ significantly ($P < 0.05$).

attributed principally to the method used to collect seed. Covering inflorescences with nylon net bags and collecting seed every few days during the harvesting period improved seed recovery rates in both Ubon paspalum and guinea grass (Phaikaew *et al.* 1995; 2001a).

Table 6. Effect of N rate on height plus tiller and inflorescence number of *Paspalum atratum* at 3 infertile sites in the second year, 1999 (Experiment 2).

Site	N treatment	Plant height	Tillers	Inflores-cences	Effective tillers
	(kg/ha)	(cm)	(no/m²)	(no/m²)	(%)
Lampang	0	266 b[1]	121	53 b	43 b
	125	289 ab	140	90 a	64 a
	250	309 a	153	96 a	62 a
	Mean	288	138	79	56
	CV (%)	6.0	12.3	22.6	11.6
Chiang Rai	0	269	79	56	71
	125	255	88	52	59
	250	265	80	52	66
	Mean	263	82	54	65
	CV (%)	8.6	14	24.4	13.3
Prae	0	268	96	40	43
	125	276	132	50	38
	250	272	131	48	37
	Mean	272	120	46	39
	CV (%)	5.1	19.3	23.1	16.6

[1] Within columns for each site, treatment means followed by different letters differ significantly ($P < 0.05$).

N application in the second year after establishment

In the second year after establishment, N application significantly affected seed yield and seed quality on both fertile and infertile soils, although the trends were somewhat different depending on soil fertility at the different sites. On the fertile soil, seed yield peaked at a N application rate of 200 kg/ha N with a decline at higher rates. The decrease in seed yield with higher N rates of N_{300} and N_{400} was probably due to severe lodging of stands before the flowering stage, which decreased inflorescence density. However, the lower seed yields at the lower N rates (N_0 and N_{100}) were possibly due to low available soil N.

The response of seed yield to N rate was linear on all infertile soil sites in the second year, with increases up to the maximum level applied (250 kg/ha/yr), especially at Lampang and Prae where seed yields at N_{250} were even higher than those in the first year. N fertiliser cost was calculated as 17.4 baht/kg N. Even though seed yield may increase further at higher N fertiliser rates, the farmers who produce seed for sale may be reluctant to outlay more money on fertiliser.

Figure 3 demonstrates that the removal of both seed and residual forage in a seed production enterprise depletes soil N and this needs to be rectified by substantial dressings of fertiliser N. The responses to N fertiliser in the second year can be attributed as much to this removal of N as to lower soil N mineralisation in the second year. The data are a theoretical calculation for the amount of N removed from the system in both cut residual forage plus seed (NR) and the cumulative difference (ND) between NR and amounts of N applied as fertiliser at the Pakchong site. In this calculation, we did not measure the other N flows, such as denitrification to the air, leaching by rainfall, locking-up and mineralisation of N, and we assumed that the N concentration of seed was equal to that of the herbage, assessed by chemical analysis using the Kjeldahl method. Therefore, although ND is not a real N balance in the system, it can be said that ND is a rough estimate of N depletion or N accumulation in the soil under this seed-harvesting system. Figure 3 clearly suggests that NR will increase with the increase in fertiliser rate due to increases in both crude protein concentration in herbage and herbage yield. ND was negative at the lower rates of 0 and 100 kg/ha/yr N and positive at the higher rates of 300 and 400 kg/ha/yr N. Given the assumption mentioned above, the rate of N applied in fertiliser and NR were nearly equilibrated ($ND \approx 0$) at the medium rate of 200 kg/ha/yr N at the Pakchong site.

Although a high seed yield in the first year was obtained from N_0 plots without artificial fertilisation, soil nutrients were depleted following growth, and removal of seed and residual forage. This depletion of soil nutrients significantly reduced the number of racemes/inflorescence and spikelets/raceme in the second year, which resulted in a seed yield of less than half that of the first year at Pakchong. This suggests that N fertilisation is needed for second-year seed crops even on fertile soils. However, the need for N is lower on more fertile soil than on infertile soil, and varies from year to year and from site to site depending on weather conditions, soil fertility and age of stands (Loch 1980; Loch *et al.* 1999).

With high N application on the fertile soil at Pakchong, *P. atratum* started lodging one month

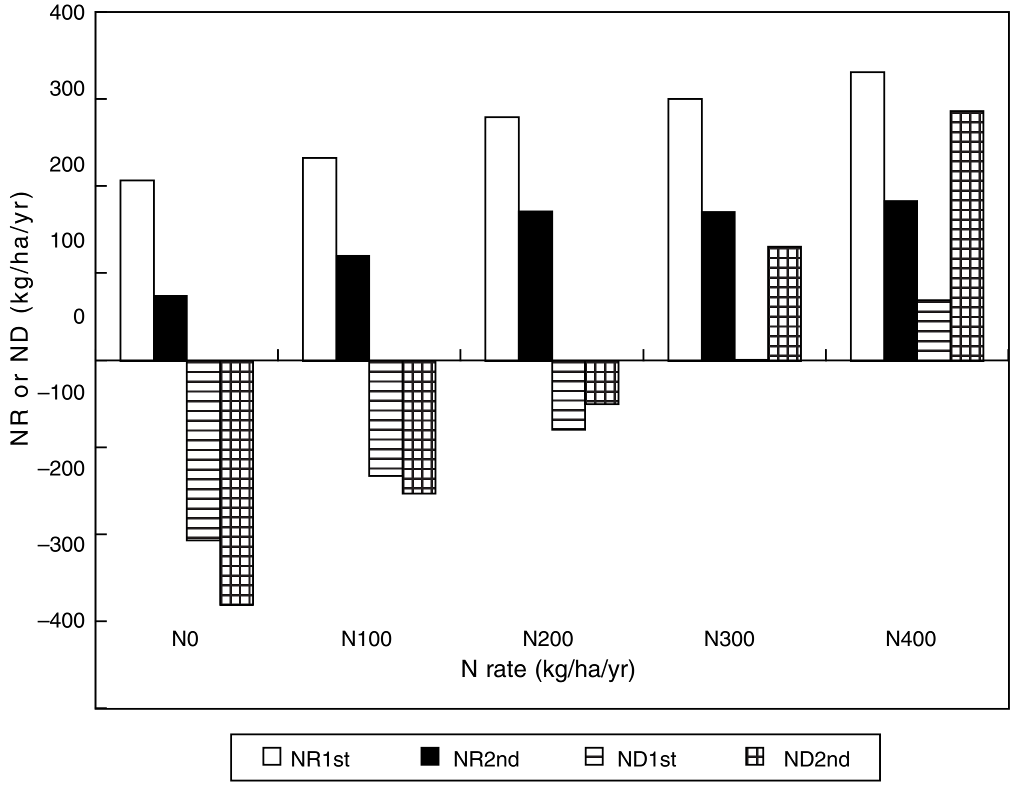

Figure 3. Amounts of nitrogen removed from the system in cut vegetation (NR) and the cumulative difference (ND) between amounts of N applied as fertiliser and NR in the first and second years after planting on fertile soil at Pakchong site (Experiment 1).

before flowering started. From measurements of lodged grass bunches (tillers) at a plant level on August 4 and September 4, 2000, lodging percentage increased greatly from 31% to 89% in N_{300} plots and from 59% to 94% in the N_{400} plots. A similar result was found by Loch *et al.* (1999) who stated that the degree of lodging increased dramatically if N application exceeded the optimal rate. Even though the lodging percentages in early September were relatively similar for N_{200} and N_{400}, the lodging percentage for N_{400} in early August was significantly higher at 59% than for N_{200}. It indicated that the canopy structure at N_{400} would have been affected before panicle formation, which reduced the penetration of light believed to be necessary for spikelet initiation. This early lodging reduced the number of inflorescences/m^2 and PET at the higher N rates, which was reflected in lower seed yields in the N_{300} and N_{400} plots. This significant change in inflorescence density affecting seed yield drastically was reported previously by Humphreys and Riveros (1986) who stated that the main effect of fertiliser N on tropical/subtropical grass seed crops was to boost seed yield via increased inflorescence density with the increase in N application. Gobius *et al.* (2001) reported a similar N effect in signal (*Brachiaria decumbens*), Jarra (*Digitaria milanjiana* cv. Jarra) and gamba (*Andropogon gayanus* cv. Kent) grasses, namely that N application increased seed yield and inflorescence density, while it produced significant lodging in all species at 200 kg/ha N with minimal effect on seed quality.

Severe lodging during the vegetative phase suppressed grass growth and injured the vigorous above-ground growth before the flowering stage. Therefore, this severe lodging in plots receiving high N applications not only reduced seed yield but also decreased herbage DM yield of grass when cut after seed harvest in both N_{300} and N_{400} plots.

Even at the optimum application rate of N_{200}, assessed to be almost equal to the amount of N removed in vegetation, seed yield decreased markedly in the second year. This occurred despite the fact that tiller number/m^2 and DM yield as the index of vegetative growth in the second year were quite similar to those in the first year. The decrease in seed yield was due to a shortage of seed heads caused by low rates of tiller fertility and raceme no./inflorescence. This failure of head emergence appears to be associated with early lodging (above 80%) which occurred even in N_{200} plots at the flowering stage. Plants lodged apparently less in the first year because of lower plant height and lower growth rate of transplants in May, compared with the vigorous regrowth from the stubble cut in May in the second year. This suggests that there may be a need to consider delaying N application in the second year.

Crude protein concentration in grass (cut at seed harvest) increased progressively with N application in both years. The herbage DM yield cut at the beginning of the rainy season in the second year also increased markedly with N rate (Table 4). This result was similar to the findings of Hare *et al*. (1999c) and Kalmbacher and Martin (1999) with this grass. High levels of crude protein are beneficial for farmers who use this grass as forage. Even at 200 kg/ha N in both years, crude protein concentration was nearly 6%, which approached the level of 7% considered necessary for maximum growth of rumen bacteria (Minson 1990). This suggests that forage produced with 200 kg/ha N will require little additional rumen degradable nitrogen supplements.

For satisfactory seed yield and high yields of residual forage of adequate quality, the optimal N fertiliser required for *P. atratum* on fertile soil appears to be 200 kg/ha N in north-east Thailand, especially in the second year after planting. There is a need to investigate further the timing of this application so as to minimise lodging. The recommended N fertiliser rate for infertile sandy soil is at least 250 kg/ha/yr N, in split applications at the beginning of the growing season and before flowering. Split applications are recommended on infertile soils because of their lighter texture and the greater chance of N loss by leaching than on heavier textured soils.

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