Alternate row sowing: a novel approach to maintain sown species in mixed pasture swards

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Abstract
Establishing and maintaining a balanced mixture of perennial and annual pasture species is often difficult, especially in drier environments. One method to reduce the competition between pasture species and to improve the potential productivity and nitrogen fixed by the pasture is to establish pasture species in separate rows (alternate row sowings). An experimental field site was established in the autumn of 2012 near Mirrool in southern NSW. *Medicago sativa* and *Phalaris aquatica* were sown in combination with a range of annual legumes either as a monoculture, mixture, or arranged in alternate rows in 1:1 or 1:2 ratios. Legumes were inoculated with appropriate rhizobia and the sites were fertilised with Starter 15 at 150 kg/ha. Seedling establishment, regeneration and dry matter (DM) were measured each year until 2014. Annual legume seed reserves and nitrogen fixation (N-fix) were measured in 2013. Alternate row sowing improved seedling regeneration and annual legume seed reserves in some situations; however, it did not significantly improve mean DM, mean legume DM or N-fix. In contrast the choice of species combinations impacted on these responses. For example, the inclusion of P. aquatica in the pasture mix tended to increase mean DM, although if N-fix and mean legume DM were to be maintained at acceptable levels, *M. sativa* and *Trifolium subterraneum* were important inclusions in combination with P. aquatica.

Key words
Pasture legumes, alternate row sowing, nitrogen fixation

Introduction
Pastures in crop rotations are expected to contribute to both livestock and crop production. However, maintaining a resilient pasture mixture and in particular, an adequate legume component, is a common challenge in pasture management (Davies 2001). There are now a range of relatively new legume species that can be sown in mixtures and their contribution to crop and pasture systems is not well documented (Nichols *et al*. 2012). Previous research has indicated that maintaining the composition of a sown pasture could be better achieved by changing the row arrangement of components of the sward at sowing (Butler *et al*. 2011). The objective of the current study was to examine the performance of a range of pasture species combinations and sowing arrangements to determine if in principle alternate row sowing could a) improve the productivity and nitrogen fixation of the pasture sward compared to traditional mixed sowing methods, b) improve persistence when annual legume species were sown in wider rows with perennial species and c) determine what likely contribution the different pasture types make to crop or livestock production.

Methods
An experiment was established in the autumn of 2012 near Mirrool (470mm) in southern NSW. The pasture species combinations and sowing arrangements are shown in Table 1. Genus, species, cultivar and common name descriptions are: Medicago sativa cvv. Aurora and Genesis (lucerne); *Phalaris aquatica* cv. Sirolan (phalaris); *Biserrula pelecinus* cv. Casbah (biserrula); *Medicago littoralis* cv. Angel (strand medic); and *Trifolium subterraneum* cvv. Dalkeith, Trikkala and Bindoon (sub clover). All cultivars of the same species (e.g. cultivars Aurora and Genesis; Dalkeith, Trikkala and Bindoon) were sown in equal parts by weight.

The experiment was fertilised with Starter 15 (N:P:S 14.7, 13, 12) in autumn 2012, and soil analysed for phosphorus confirmed a Colwell P of 57 mg/kg. Seedling establishment and regeneration of annual legumes were estimated by counting a 1 m × 0.5 m quadrat with 10 cm × 10 cm grids. Dry matter (DM) was measured in the first year by cutting three 1 m long rows of plant material. Plant material was then dried at 70^{o}C for 72 hours and weighed. In the second and third years the pasture DM was estimated by visually estimating 10 quadrats per plot and calibrating visual assessments against 9 quadrat cuts per treatment. Botanical composition was estimated in 10 random quadrat locations using the botanal method with 9 calibrated cuts taken for each treatment. Seed yield was measured by extracting the soil and seed from two quadrates (0.2505 m^{-2}) and washing, drying, threshing, cleaning and weighing clean dry seed. Plant samples (shoots) from all measurement times were ground using a puck mill prior to analysing the tissue for nitrogen concentration and the percentage of nitrogen fixed from the atmosphere using 15N natural abundance technique (Herridge et al. 2008). Data were analysed using GenStat version 17 by applying Linear Mixed Models (LMM) with Rep+Row.Column as random effect and LSD values are provided at the 5% level.

Table 1. Species, sowing arrangement, sowing rate and inoculum group descriptions for treatments sown at Mirrool in 2012.

Species	Arrangement	Sowing rate	Inoculum group
T. subterraneum	mono	4 kg/ha	C
M. sativa	mono	3 kg/ha	AL
M. sativa + T. subterraneum	mix	3 kg/ha + 4 kg/ha	AL + C
M. sativa + T. subterraneum	1:1	3 kg/ha + 4 kg/ha	AL + C
M. sativa + B. pelecinus	1:1	3 kg/ha + 1kg/ha	AL + WSM1497
M. sativa + M. littoralis	1:1	3 kg/ha + 3 kg/ha	AL + AM
M. sativa + T. subterraneum	1:2	3 kg/ha + 4 kg/ha	AL + C
P. aquatica + M. sativa + T. subterraneum	mix	1.5 kg/ha + 1.5 kg/ha + 4 kg/ha	AL + C
P. aquatica + M. sativa + T. subterraneum	1:1	1.5 kg/ha + 1.5 kg/ha + 4 kg/ha	AL + C
P. aquatica + M. sativa + T. subterraneum	1:2	1.5 kg/ha + 1.5 kg/ha +4 kg/ha	AL + C
P. aquatica + T. subterraneum	1:1	3 kg/ha +4 kg/ha	C
P. aquatica + T. subterraneum	mix	3 kg/ha + 4 kg/ha	C

Sown monoculture = mono, sown mixture = mix, sown species in alternate rows = 1:1 and sown in a higher alternate row ratio = 1:2. In the three way species combinations of 1:1 and 1:2 *T.subterraneum* was sown in each row and the perennials (*P. aquatica* and *M. sativa*) were sown in alternate rows.

Results

Alternate row sowing comparisons: *M. sativa* + *T. subterraneum* sowing arrangements included the traditional mixed sowing arrangement where each species is represented in each row, and the 1:1 alternate row sowing and 1:2 row sowings where each species occupies its own sowing row at a 1:1 or 1:2 ratio. In these treatments seedling establishment (year 1) of *T. subterraneum* was not impacted by sowing arrangement, however by year two *T. subterraneum* seedling regeneration was significantly higher in the 1:2 arrangement compared with the mixture. In year three the 1:2 sowing arrangement had significantly higher regeneration of *T. subterraneum* than the 1:1 which in turn had significantly higher regeneration then the mixture (Table 2). These sowing arrangements however had no significant impact on seed reserves of *T. subterraneum* (Table 2), mean DM, mean legume DM, mean annual legume DM or N-fix (Table 3).

Table 2. Annual legume establishment (plants m^{-2}, 2012) (P< 0.001), regeneration (plants m^{-2}, 2013 and 2014) (P< 0.001) and seed reserves (kg/ha, 2013) (P = 0.004) at Mirrool.

Species x Row Spacing	Establishment Year 1	Regeneration Year 2	Seed reserves	Regeneration Year 3
T. subterraneum mono	25	128	153	342
M. sativa mono	0	1	0	0
M. sativa + T. subterraneum mix	26	68	53	93
M. sativa + T. subterraneum 1:1	22	85	72	156
M. sativa + B. pelecinus 1:1	11	23	145	251
M. sativa + M. littoralis 1:1	55	91	77	165
M. sativa + T. subterraneum 1:2	30	118	87	211
P. aquatica + M. sativa + T. subterraneum mix	20	66	36	70
P. aquatica + M. sativa 1:1 + *T. subterraneum*	22	110	40	48
P. aquatica + M. sativa 1:2 + *T. subterraneum*	24	52	46	57
P. aquatica + T. subterraneum 1:1	28	116	58	79
P. aquatica + T. subterraneum mix	25	95	36	82
LSD	14	49	89	47

Table 3. Mean dry matter (DM), (*P* <0.001), mean legume DM (*P*<0.001) , mean annual legume DM (*P*<0.001) for pasture treatments at Mirrool over the 2012 to 2014 period as well as N-fix measure in spring 2013.

Species x Row Spacing	Mean DM (kg/ha)	Mean Legume DM (kg/ha)	Mean Annual legume DM (kg/ha)	N-fix 2013 (kg N/ha)
T. subterraneum mono	3287	2627	2627	95
M. sativa mono	2979	2790	15	78
M. sativa + *T. subterraneum* mix	3019	2836	590	91
M. sativa + *T. subterraneum* 1:1	2813	2640	921	85
M. sativa + *B. pelecinus* 1:1	3295	3056	1145	98
M. sativa + *M. littoralis* 1:1	2744	2527	807	81
M. sativa + *T. subterraneum* 1:2	2781	2637	1055	85
P. aquatica + *M. sativa* + *T. subterraneum* mix	4433	2178	650	70
P. aquatica + *M. sativa* 1:1 + *T. subterraneum*	4153	2173	632	70
P. aquatica + *M. sativa* 1:2 + *T. subterraneum*	4382	2482	675	80
P. aquatica + *T. subterraneum* 1:1	4096	1056	1056	34
P. aquatica + *T. subterraneum* mix	4792	871	871	28
LSD	1436	1212	840	38

Comparisons of *P. aquatica* + *T. subterraneum* sowing arrangements included 1:1 and a mixed sowing. Sowing arrangement for these species had no significant effect on establishment, regeneration or seed reserves of *T. subterraneum* (Table 2). In addition there were no significant differences to measured mean DM, mean legume DM, mean annual legume DM or N-fix (Table 3).

Wherever *T. subterraneum* was sown in the same row as a perennial species (e.g. treatments *M. sativa* + *T. subterraneum* mix, *P. aquatica* + *M. sativa* 1:1 + *T. subterraneum, P. aquatica* + *M. sativa* 1:2 + *T. subterraneum, P. aquatica* + *M. sativa* + *T. subterraneum* mix and *P. aquatica* + *T. subterraneum* mix) it underperformed in either seedling regeneration for year two or three, or both when compared with treatments sown in alternate rows. Seedling regeneration of *T. subterraneum* and *M. littoralis* in year two was a good indicator of seed reserves measured later that same year, however for this test, data for *B. pelecinus* was excluded as its seedling regeneration was substantially higher than either *T. subterraneum* or *M. littoralis* (Figure 1A, Table 2). Seed reserves of all annual species in year two (2013) were a good predictor of seedling regeneration in year three (Figure 1B).

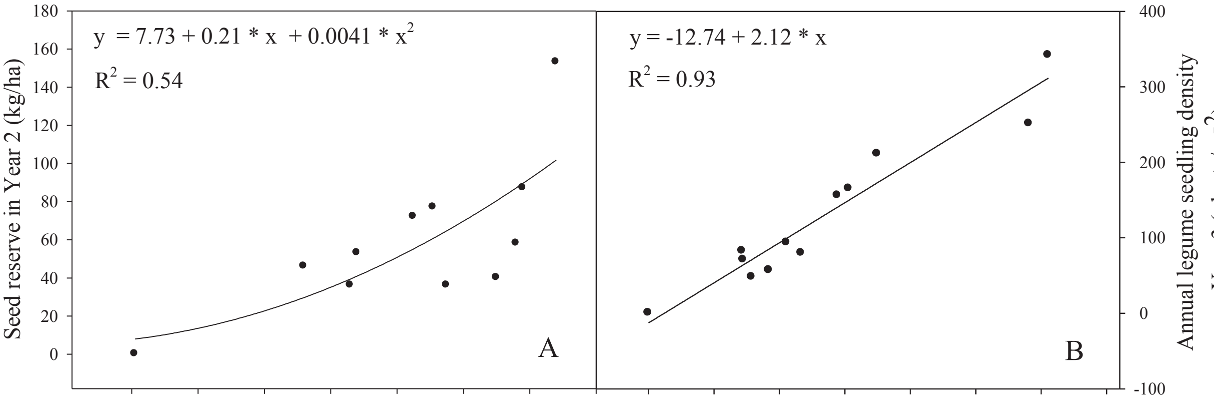

Figure 1. (A) *T. subterraneum* and *M. littoralis* seedling density in year two plotted against seed reserves measured in December 2013 (year 2) (*P*< 0.0001) and (B) seed reserves (kg/ha) of all annual species in year two (2013) plotted against seedling regeneration (plant m^{-2}) in year three (2014) (*P*< 0.0001) at Mirrool.

Species combinations: The highest mean DM was achieved with treatments containing *P. aquatica* and the lowest mean pasture DM was achieved by *M. sativa* + *M. littoralis* 1:1, although this was not significantly lower than a number of other treatments (Table 3). The highest legume DM occurred in treatments *M. sativa* + *B. pelecinus* 1:1, *P. aquatica* + *M. sativa* + *T. subterraneum* mix, *M. sativa* monoculture and *P. aquatica*

+ *M. sativa* + *T. subterraneum* 1:1 and1:2, the lowest mean legume DM was achieved by *P. aquatica* + *T. subterraneum* mix. N-fix was highest in *M. sativa* + *B. pelecinus* 1:1, T. subterraneum mono and lowest in *P. aquatica* + *T. subterraneum* 1:1 and *P. aquatica* + *T. subterraneum* mix (Table 3).

Discussion

Alternate row sowing comparisons: In *M. sativa* + *T. subterraneum*, the 1:1 sowing arrangement had higher year three seedling regeneration compared to the mix, however for *P. aquatica* + *T. subterraneum* the 1:1 sowing arrangement showed no significant difference in seedling regeneration in any year compared to the mix. This may be due to the potentially larger crowning ability of *P. aquatica* relative to *M. sativa*, thus the alternate row sowing of 1:1 may not have been effective at reducing competition from *P. aquatica* against *T. subterraneum*. However the 1:1 arrangement appears effective at reducing competition from *M. sativa* against *T. subterraneum*.

Alternate row sowing did not reduce mean DM, mean legume DM or N-fix, consequently this method of sowing could be used in precision agriculture to target other issues such as, savings in phosphorus application for species with lower critical phosphorus requirements than *T. subterraneum* or perhaps where in the future different pre-emergent herbicide application are directed at different sowing rows.

Species combinations: Species combinations impacted significantly on mean DM, mean legume DM and N-fix. For example treatments containing *P. aquatica* conveyed the highest mean DM yields as all treatment containing this species had mean DM yields > 4000 kg/ha (Table 3). However, where both DM yield and N-fix are important considerations the combinations of *P. aquatic*, *M. sativa* and *T. subterraneum* performed well with N-fix ≥70 kg N/ha which was not significantly different from the highest N-fix value recorded of 98 kg N/ha for M. sativa + B. pelecinus 1:1. These results suggest that maximising pasture production and N-fix can be achieved with a three way mix comprising *P. aquatica* + *M. sativa* and annual legume.

Annual legumes species: Despite having a low initial establishment (Table 2, year 1), B. pelecinus did particularly well in combination with lucerne (1:1) and outperformed its equivalent comparators (*M. sativa* + *M. littoralis* 1:1 and *M. sativa* + *T. subterraneum* 1:1) in seed reserves and year three seedling regeneration (Table 2). It also had a tendency for a higher mean annual legume DM and N-fix, although these differences were not significant at P=0.05.

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