The role of nitrogen and in-crop lucerne suppression for increasing cereal performance in companion cropping systems

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Abstract

Five field experiments located at four sites (Burraja, Grogan, North Boorhaman and Roseworthy) across south eastern Australia compared cereal grain yields in the presence of lucerne (companion cropping) and absence of lucerne (cereal monoculture). Top-dressed nitrogen (N) was applied to subplots at Burraja, Grogan and North Boorhaman, while in-crop lucerne suppression was applied to plots at Burraja and two separate, but adjacent experiments at Roseworthy, to determine if these management strategies could improve cereal performance in the presence of lucerne. In addition annual lucerne and cereal biomass was measured at North Boorhaman from a companion crop and compared with both a lucerne and cereal monoculture. Over the three years and four sites, cereals growing with lucerne yielded between 19% and 57% less (P<0.05) grain than cereals growing alone. There was no main treatment by top-dressed N interaction at all sites, indicating that applying N to cereals irrespective of whether they were growing with or without lucerne, resulted in same yield responses. Top-dressing N at North Boorhaman in 2003 and 2005 resulted in a 14% and 40% respectively, increase (P<0.05) in grain yield across all cereal crops. The absence of a response at Burraja and Grogan was probably due to sub-optimal growing season rainfall. In-crop lucerne suppression did not increase grain yields at either Burraja or Roseworthy, but in some seasons reduced (P<0.05) cereal grain contamination by lucerne pods and flowers. Companion cropping increased (P<0.05) total (cereal and lucerne) annual biomass production by 20-41%, compared with the lucerne monoculture, and 16% more (P<0.05) than the cereal monoculture. Demonstrating that while grain yield reductions reduce the attractiveness of companion cropping, this practice does offer other advantages in terms of improved yearly water use and quality out-of-season feed supply that cereal monocultures can not deliver.

Key words

Inter-cropping, companion cropping, grain yield reduction, in-crop lucerne suppression, top-dressed nitrogen, lucerne, wheat, barley.

Introduction

Lucerne companion cropping (also known as inter-cropping or over-cropping) involves sowing an annual crop directly into an existing lucerne stand. In comparison with conventional cropping systems, companion cropping promotes greater utilisation of rainfall by maintaining a perennial plant throughout the year, and therefore reducing the risk of excess rainfall leaking below the root zone and contributing to the harmful effects of dryland salinity.

Whilst lucerne's ability to dry soil profiles to depth is beneficial for reducing dryland salinity (Ridley *et al.* 2001), the implications on crop performance are generally not favourable. Growing annual crops with lucerne exposes the crop to direct competition for essential resources such as sunlight, soil water and nutrients, often penalising the yield of the annual crop. Egan and Ransom (1996) reported companion-cropping cereals into young lucerne stands resulted in grain yield reductions of 6 to 62% compared with stand-alone cereals in North Central Victoria. Humphries *et al.* (2004) reported similar grain yield reductions of 13 to 63% where wheat was sown into lucerne compared with wheat monoculture over two seasons in Southern Australia. Whilst grain yield reductions from companion cropping can be large, there is evidence in the literature documenting the potential for agronomic intervention to minimise grain yield reductions. Angus *et al.* (2000) concluded that additional nitrogen in wet environments might reduce the grain yield gap between companion crops and crop monoculture. In addition, research in the United States has shown that corn growing in chemically suppressed lucerne yielded significantly more than corn growing in unsuppressed lucerne (Eberlein *et al.* 1992).

If companion cropping is to become a more reliable cropping system for managing excess soil water and reducing the threat of dryland salinity, then the grain yield reductions commonly associated with this practice need to be better managed. In this paper we explore the possibility of minimising grain yield reductions in cereals growing with lucerne, through agronomic strategies of tactical nitrogen application and in-crop lucerne suppression.

Methods

Five-replicated field experiments located at four sites across South East Australia (Figure 1) compared cereal production in the absence of lucerne (cereal monoculture) and presence of lucerne (companion crop). At North Boorhaman a lucerne monoculture was included with the cereal monoculture and companion crop treatments to compare annual cereal and lucerne biomass production.

In-crop lucerne suppression was applied to plots at Burraja, Grogan and two separate adjacent experiments at Roseworthy (Roseworthy A and Roseworthy B). At Grogan there was no unsuppressed lucerne companion crop treatment. Top-dressed N was applied to subplots in all treatments at Burraja, North Boorhaman and Grogan. However, dry seasonal conditions at Burraja in 2002 meant no top-dressed N was applied.

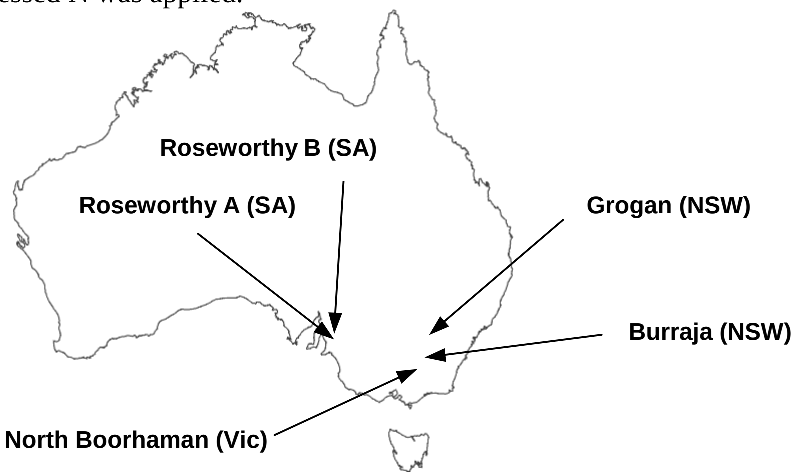

Figure 1. Locations of field experiments.

Treatments involving additional nitrogen received between 30 to 100 kg N/ha in the form of urea at cereal crop growth stages vary from second leaf (Z21) to first node (Z31) at Burraja, North Boorhaman and Grogan (Table 1). In-crop lucerne suppression treatments received Group I selective herbicide containing the active constituent clopyralid at varying rates and times (Table 1). Grain yield was measured by mechanical harvesting at all sites.

The contamination of cereal grain by lucerne pods and flowers was measured by counting their presence in a hectolitre (hL) of grain sample at Burraja. While at Roseworthy grain contamination was measured by weighing a representative sub-sample collected from the harvested grain, then sieving to separate lucerne pods and flowers before reweighing the sub-sample.

Biomass cuts at North Boorhaman were taken six times during each season from sowing of the companion crop until the following autumn break. Lucerne and cereal biomass was measured when cereal crops reached first node, anthesis and maturity growth stages. Lucerne biomass was also collected on three occasions over each of the two summers reported. In all years two 0.5 x 0.5 m quadrats were randomly placed within each sub-plot at each sampling date. Quadrats were cut to within 2 cm of the ground and bulked. Samples taken from the companion crop treatments were sorted into cereal and lucerne biomass, and all samples oven dried at 65^{o}C for 48 hours.

Table 1. Cereal crop type, dates and quantities of top-dressed N and in-crop lucerne suppression applied at all sites.

Site	Cereal crop	Top-dressed nitrogen management		In-crop lucerne suppression	
		Time applied	Quantity applied (kg N/ha)	Time applied	Quantity applied (g/ha)
Burraja	barley	NA	NA	21-Aug-02	30
	barley	28-Aug-03	60	4-Sep-03	45
	barley	31-Aug-04	60	31-Aug-04	36
Grogan	wheat	28-Aug-03	40	1-Aug-03	27
	wheat	26-Aug-04	50	8-Jul-04	27
Nth Boorhaman	wheat	23-Jul-03	60	NA	NA
	wheat	12-Aug-05	100	NA	NA
Roseworthy	wheat	30-Jul-04	30	22-Jul-04	36
	barley	9-Sep-05	30	16-Aug-05	36

NA = not applied

Results

Growing Season Rainfall

At Burraja growing season rainfall (GSR) was 174 mm and 122 mm below the long-term mean in 2002 and 2004 respectively, and 65 mm above the long-term mean in 2003 (Table 2). In both 2003 and 2004 Grogan received 83 mm and 89 mm respectively, less GSR than the long-term mean. In contrast North Boorhaman received 38 mm and 25 mm above the long-term mean GSR in 2003 and 2005 respectively. While Roseworthy GSR was 129 mm and 4 mm below the long-term mean in 2004 and 2005 respectively. Across the four sites, five growing seasons experienced decile rainfall less than 5, while the remaining 4 growing seasons recorded decile rainfall greater than 5.

Table 2. Growing season rainfall (mm).

Site	Year	Total	Decile	Long-term mean
Burraja	2002	150	1	324
	2003	389	7	
	2004	221	2	
Grogan	2003	265	3	355
	2004	258	3	
Nth Boorhaman	2003	396	6	358
	2005	383	6	
Roseworthy	2004	196	1	325
	2005	321	6	

Cereal grain yields in the presence and absence of lucerne

The grain yields of cereals growing with lucerne were reduced (P<0.05) by 19% to 57% compared with the cereal monoculture across the five field experiments (Table 3). Given that data were collected from a number of sites and seasons, we have combined the cereal grain yield results to examine the potential effect of rainfall on cereal performance in the presence (companion crop) and absence of lucerne (cereal monoculture). In both the companion crop and cereal monoculture treatments there was a significant (P<0.05) positive association between growing season rainfall and cereal grain yield (Figure 2). This analysis showed that growing season rainfall explained 83% of the response measured in cereals growing in monoculture, and 61% of the response measured in the cereals growing with lucerne.

Table 3. Grain yield (t/ha) in the absence (cereal monoculture) and addition of lucerne (Companion crop) and grain yield reduction (%) from companion cropping. Data from Burraja, Grogan and North Boorhaman mean of the two N rates. Companion crops at Burraja, North Boorhaman and Roseworthy grown with unsuppressed lucerne, while at Grogan with suppressed lucerne.

Year	Cereal crop	Cereal monoculture	Cereal/lucerne	l.s.d (P<0.05)	Grain yield reduction (%)
			Burraja		
2002	barley	0.7	0.3	0.10	57
2003	barley	5.2	5.2	n.s	
2004	barley	2.4	2.1	n.s	
			Grogan[A]		
2003	wheat	2.4	1.7	0.52	29
2004	wheat	2.9	3.1	n.s	
			Nth Boorhaman		
2003	wheat	3.8	2.8	0.76	26
2005	wheat	4.3	3.3	0.29	23
			Roseworthy A		
2004	wheat	1.6	1.3	0.25	19
2005	barley	3.7	2.8	0.58	24
			Roseworthy B		
2005	barley	4.2	3.1	0.41	26

n.s not significant, [A] suppressed lucerne

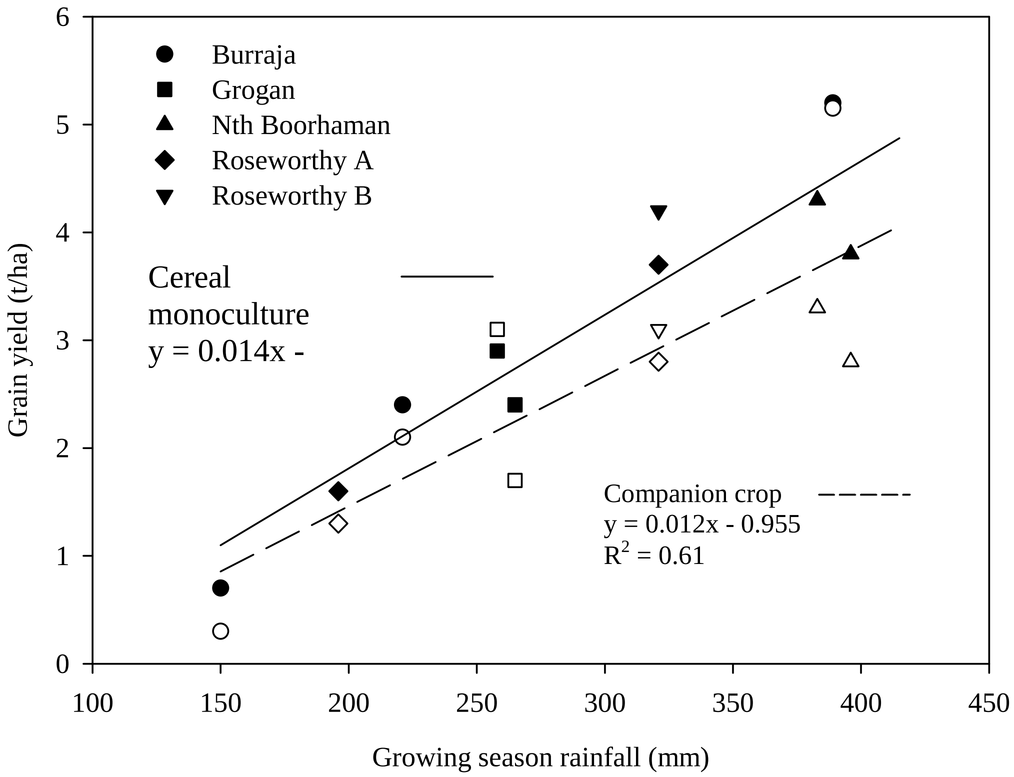

Figure 2. Relationship between growing season rainfall and grain yield of cereals growing with lucerne (open symbol) and without lucerne (solid symbol). Data from Burraja, Grogan and North Boorhaman mean of the two N rates. Companion crops at Burraja, North Boorhaman and Roseworthy grown with unsuppressed lucerne, while at Grogan with suppressed lucerne.

Impact of additional Nitrogen

There was no significant main treatment by fertiliser interaction in any year at the three sites where N was applied (data not shown). However, top-dressing N at North Boorhaman resulted in a 14% and 40% increase ($P<0.05$) in cereal grain yield (Table 4), irrespective of whether cereals were growing with or without lucerne. While no response to the application of additional N, was measured in cereal grain yield at Burraja and Grogan.

Impact of in-crop lucerne suppression

In-crop lucerne suppression did not improve cereal grain yields at Burraja or Roseworthy in all seasons (Table 5). But, cereal grain contamination by lucerne pods and flowers were reduced ($P<0.05$) at Burraja in 2004 and in both experiments at Roseworthy in 2005. There was an insignificant trend ($P = 0.127$) towards less cereal grain contamination at Burraja in 2003 where in-crop lucerne suppression was applied, and no apparent effect of suppression in 2002.

Table 4. Cereal grain yields (t/ha) in the absence and addition of top-dressed nitrogen (N). Mean of cereal monoculture and companion crop treatments

Year	Absence of nitrogen	Addition of nitrogen	l.s.d ($P<0.05$)
		Burraja	
2003	5.3	5.1	n.s
2004	2.3	2.2	n.s
		Grogan[A]	
2003	2.2	1.9	n.s
2004	3.2	2.9	n.s
		Nth Boorhaman	
2003	3	3.5	0.27
2004	2.8	4.7	0.30

n.s not significant, [A]cereals growing in the presence of suppressed lucerne

Table 5. Cereal grain yield (t/ha) and cereal grain contamination in the absence and addition of in-crop lucerne suppression. Mean of two rates of nitrogen at Burraja.

Site	Year	Cereal/ unsuppressed lucerne	Cereal/ suppressed lucerne	l.s.d ($P<0.05$)
	(a)	Cereal grain yield (t/ha)		
Burraja	2002	0.3	0.2	n.s
	2003	5.2	5.5	n.s
	2004	2.1	2.3	n.s
Roseworthy A	2004	1.3	1.4	n.s
	2005	2.8	3.1	n.s
Roseworthy B	2005	3.1	3.1	n.s
	(b)	Grain contamination		
Burraja[A]	2002	92	65	n.s
	2003	34	1	n.s
	2004	46	1	23
Roseworthy A[B]	2005	0.44	0.12	0.258
Roseworthy B[B]	2005	0.54	0.09	0.188

n.s not significant, NA not assessed, [A] number of lucerne pods and flowers per hectolitre of grain sample
[B] lucerne pods and flowers as a % of grain weight

Annual biomass production from companion cropping

Total (cereal and lucerne) annual aboveground biomass production at North Boorhaman in both 2003/04 and 2004/05 was greater ($P<0.05$) in the companion crop treatment compared with the lucerne monoculture (Figure 2). In fact the companion crop treatment produced 20% and 41% more total annual biomass in 2003/04 and 2005/06 respectively than the lucerne monoculture. Although there was no difference in total annual biomass production between the companion crop treatment and the cereal monoculture in 2003/04, in the 2005/06 season the companion crop treatment produced 16% more (P<0.05) biomass.

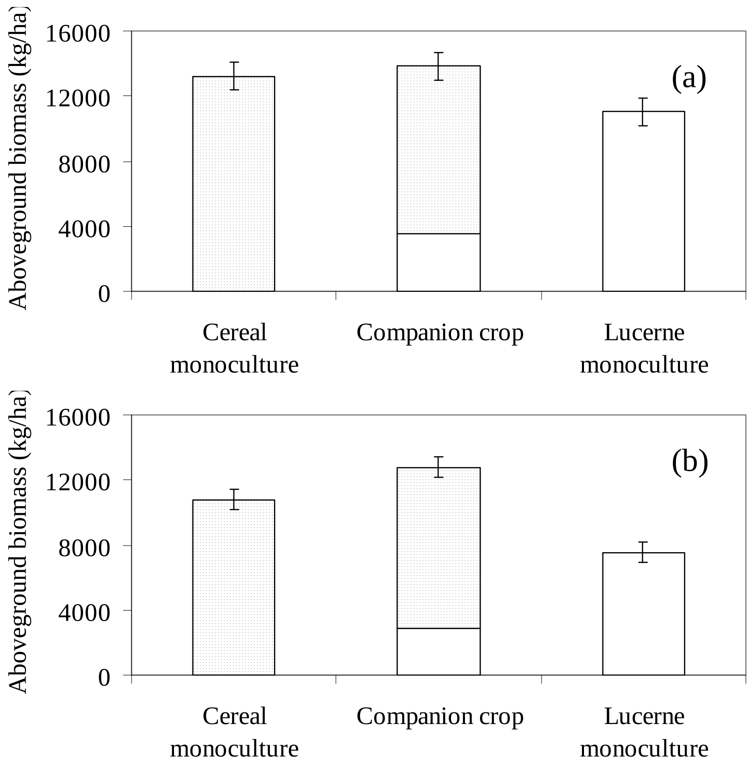

Figure 3. Total (cereal and lucerne) annual aboveground biomass (kg/ha) at North Boorhaman in (a) 2003/04 and (b) 2005/06 years. Bars denote l.s.d (*P*<0.05).

Discussion

Cereal grain yield was reduced in the presence of lucerne to within the ranges of 6 to 63% as previously reported by both Egan and Ransom (1996) and Humphries *et al.* (2004). Growing season rainfall had a strong influence on both the performances of cereals growing with and without lucerne. While the relationship was significant for cereals growing with lucerne (P = 0.005), it was found to be highly significant for cereals growing in monoculture (P<0.001). This suggests that the performance of lucerne and therefore its competitiveness with neighbouring cereals were not uniform across all sites or seasons. Without detailed lucerne measurements from all sites, it's difficult to quantify the reasons for the variation in performance. However, other researchers such as Egan and Ransom (1996) have shown that increasing lucerne plant density can result in less associated cereal productivity. In addition, Humphries *et al.* (2004) found that companion crop yield can be associated with the winter activity of lucerne, reporting reduced cereal productivity in the presence of winter-active lucerne cultivars. Another contributing factor may have been the age of the lucerne stand; lucerne productivity tends to peak in the third year after establishment before declining thereafter. At Burraja, Grogan and Roseworthy cereals were sown into lucerne stands nearing the end of their life (eg > four years of age), whereas at North Boorhaman, cereals were sown into lucerne in the first and third year after establishment.

In our experiments N was applied to test the hypothesis that N immobilisation by lucerne was a constraint to cereal growth in the presence of lucerne. Hirth *et al.* (2001) measured significantly lower soil mineral N at the autumn break under lucerne pastures compared with annual pastures in four out of five seasons. Although the authors do not speculate why this result occurred, it was probably due to lucerne's largely continuous active growth immobilising available mineral N. Angus *et al.* (2000) had also concluded that N availability was likely to be a limiting factor to crop growth in the presence of lucerne, particularly when there was adequate soil water supply.

In our experiments top-dressing N resulted in improved cereal yields at only one site. Regardless of whether cereals were growing with or without lucerne, growing season rainfall largely influenced whether additional N led to improvements in cereal grain yield. At North Boorhaman where rainfall deciles reached six in both the 2003 and 2005 growing seasons, rainfall was sufficient to allow N application to be expressed in the cereal grain yield. In 2003, Burraja recorded a rainfall decile of seven, and again growing season rainfall increased ($P<0.05$) cereal biomass at crop maturity (data not shown) but unfortunately resulted in extensive crop lodging, and therefore the potential increase in grain yield was never realised. When unfavourable growing season rainfall occurred at Grogan and at Burraja in 2004 (rainfall deciles <4) there was no response to the application of N. Therefore we conclude that additional N can increase companion crop yield where application is accompanied by optimal growing season rainfall.

In 2005 additional N at North Boorhaman resulted in cereals yielding an extra 1.9 t/ha, a large response in comparison to 2003. The magnitude of this response may have been due in part to the extra 40 kg N/ha applied in 2005, and exhausted soil nitrogen levels after three consecutive years of cereal crops, severely limiting cereal production where N was not applied.

The main contribution of in-crop lucerne suppression was to improve grain quality, by reducing lucerne (pod and flowers) contamination of the harvested cereal grain. But in our study no significant increase in grain yield could be attributed to this practice. Depending on the rate of application, the herbicide clopyralid would either desiccate or stunt lucerne plants, temporarily halting growth, delaying maturity, and ensuring that lucerne pod formation did not coincide with cereal crop maturity. Although at most sites and seasons this practice was successful in reducing contamination, at Burraja in 2002 there was no apparent effect of suppression. At the time of application the dry conditions had caused symptoms of water stress in the lucerne plants, so that the effectiveness of the herbicide was reduced. Therefore, like N application, the effectiveness of in-crop lucerne suppression appears to be influenced by rainfall stimulating lucerne growth and consequently clopyralid uptake.

While soil moisture strongly influences the impact of clopyralid, we also note that the timing of application may also contribute to its effectiveness. Both Burraja and Roseworthy recorded decile one growing season rainfall in 2002 and 2004 respectively, and yet the in-crop lucerne suppression was successful at reducing contamination at the Roseworthy site. In-crop suppression was applied earlier at Roseworthy (22 July), at a time when adequate levels of soil moisture were more likely compared with Burraja (21 August) when soil moisture was declining rapidly, providing further supporting evidence that soil moisture probably plays an important role in the effectiveness of this practice.

On the basis of the data presented in this paper, companion cropping for grain production is more likely to be suited to high rainfall cropping environments. Although the economic feasibility still remains in question given that the grain yield reductions from companion cropping were approximately 20% where growing season rainfall was favourable (rainfall decile >6). However, to focus solely on reduced grain yields ignores other factors that contribute to the economics of the total companion cropping system. For example, the economic value of grazing lucerne-crop stubbles over the summer. At this stage the authors are unaware of any comprehensive economic analyses that examines companion cropping at a whole farm level. Such analyses would need to put a value on the quantity and nutritional quality of the summer feed supply, which may vary considerably, depending on the summer rainfall, as well as the savings in lucerne removal and re-establishment costs. Until such an analysis is undertaken it's difficult to conclude whether the practice has commercial merit.

Whilst agronomic strategies such as additional N and in-crop lucerne suppression can improve cereal crop performance in the presence of lucerne under the right seasonal conditions, the practice of grain production from companion cropping remains a high risk option. Our study demonstrates the potential of companion cropping to increase annual biomass production and therefore promote more efficient utilisation of rainfall (Figure 3). Companion cropping lucerne introduces an annual plant that is more efficient at converting growing season (April to October) rainfall into biomass, compared with a lucerne monoculture over the same period. Lucerne growth over the summer period captures and utilises rainfall that may otherwise not be used by a cereal monoculture.

Given that companion cropping promotes more efficient utilisation of rainfall, the challenge remains to produce economically viable products from this practice. Our study suggests that cereal grain is unlikely to be that product, and that agricultural production designed to take advantage of the additional biomass on offer may be a more viable option. For example companion cropping may be a valuable means of providing high-value forage for animal production systems.

Conclusion

Nitrogen application to cereals growing with lucerne can increase cereal grain yields, but only when accompanied by favourable growing season rainfall. In-crop lucerne suppression does not enhance cereal grain yields in the presence of lucerne. But when applied with adequate surface soil moisture to allow for clopyralid uptake by lucerne, can significantly reduce lucerne contamination of the harvested cereal grain.

Whilst agronomic intervention can improve cereal performance in the presence of lucerne under some conditions, this practice remains a high-risk option. Our study has demonstrated the potential of companion cropping to significantly improve rainfall utilisation and boost annual biomass production. This practice may be a beneficial option for livestock production systems.

Disclaimer

The herbicide clopyralid used in our study for in-crop lucerne suppression was used for research purposes only, and is not currently registered for the suppression of lucerne. The authors and the organisations we represent do not endorse the use of this product for lucerne suppression.

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