Impact of pasture cropping system and phosphorous rate on weed management in cool- season pastures

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Article

Keywords: Temperate forage species, Pasture stand type, Phosphorous gradient, Weed infestation

Posted Date: December 18th, 2025

DOI: https://doi.org/10.21203/rs.3.rs-8179615/v1

Additional Declarations: No competing interests reported.

Abstract

Temperate forage species can complement natural rangelands to curb animal malnutrition during winter in communal areas where feeding depends solely on rangelands. However, weed infestation poses threatens cool-season pastures via competition for soil nutrients, largely phosphorous, thereby reducing forage productivity. This study assessed the influence of various pasture stand types (PSTs) and varying P rates on weed density, composition, richness and diversity. A grass species, Oats (*Avena sativa*), broadleaved species (*Raphanus sativus*) and two forage legumes [Bird's-foot-trefoil (*Lotus corniculatus*) and Vetch (*Vicia sativa*)] were planted in monocultures and grass-legume mixtures in communal gardens of Amakhuze communities in the Eastern Cape Province of South Africa. These monoculture and mixed PSTs were assigned varying rates of 0, 25, 45, 65 and 85 kg P/ha, totalling 30 treatment combinations, each replicated three times. The responses of the weeds along P gradient were species-specific, with *Cynodon dactylon* and *Cyperus rotundus* being the codominant graminoid species across all PSTs while *Ciclospermum leptophyllum* was the most dominant forb species. *C. rotundus* exhibited low relative abundance at 45 kg P/ha except for Lotus monoculture, whereas *C. dactylon* abundance was suppressed at 65 and 85 kg P/ha for all PSTs except Radish stands. Pure legume stands increased weed densities, whereas Radish, Oats monocultures and mixtures suppressed weed densities and richness at 65 kg P/ha. Hence, we conclude that 65 kg P/ha is optimal for weed suppression and that legume-grass intercropping, Oats monoculture and Radish are crucial for sustainable weed management in cool-season pastures.

Introduction

Pastoralists depend solely on rangelands for animal feeding. However, climate change and land degradation are the major threats in rangelands in developing countries (Mpongwana et al., 2023; Timpomg-Jones et al., 2023), leading to decline in forage production and sustainability of livestock production. During the dry season in particular, grasses become dormant, with subsequent decline in forage productivity and quality in rangelands, thus resulting in poor animal productivity (Mganga et al., 2015; Fynn et al., 2016). Hence, establishment of reserve pastures of highly productive temperature forage grasses, broadleaved species and legumes present a great opportunity for improvement of winter feeding in communal areas (Mpongwana et al. 2023). The establishment of these pastures requires a careful selection of highly competitive, productive and nutritious species to compensate for the nutrient deficiency and low productivity in rangeland grasses (Schultze-Kraft et al., 2018; Bayhan, 2023; Mumford, 2023).

However, weed infestation poses a significant threat to cool-season pasture establishment (Schaffner et al., 2021). As a result, weeds reduce the forage quality and productivity via competition for space, light, soil nutrients and water (Patterson, 1995; Reddy, 2018; Cannon et al., 2020). Moreover, certain weeds produce chemical substances which are allelopathic to forage species, thus reducing plant growth and performance (Qasem & Foy, 2001; Latif et al., 2017). Weeds can also indirectly affect plant growth by acting as host for pest and diseases, giving weeds a competitive advantage, thereby posing threats to forage plant performance and productivity (Kromp, 1999; Hawes et. al., 2003; Bohan et al., 2007; Franke et al., 2009).

To avert these catastrophic effects of weeds on pasture productivity, selective herbicides are applied in pastures (Ghanizadeh & Harrington, 2019; Sharpe, 2025). However, these chemicals are costly and can have long-term adverse effects on soil composition and fauna (Ogidi & Akpan, 2023). Nevertheless, the use of highly competitive forage species which grow vigorously can effectively reduce weed infestation without posing threats to soil fauna and health status (Layek et al., 2018; Misganaw & Ayalew, 2020). Pasture intercropping which involves planting annual forage crops in mixtures during winter season can serve as a cost-effective and sustainable strategy for weed management (Millar and Badgery, 2009; Lawes et al., 2014; Luna et al., 2020).

Some temperate grass species including Oats, are highly effective weed suppressors because of their rapid growth rate and efficient nitrogen uptake and use efficiency (Brennan and Smith 2005; Brainard et al., 2011; Dorn et al., 2015; Hayden et al., 2012; Finney et al., 2015). The fast growth rate of Oats facilitates effective competition against weeds by exploiting soil resources and light earlier than weeds. Brassicaceae species also suppress weeds through posing direct competition via intense light interception using broad leaves and by releasing allelopathic compounds (Björkman et al., 2015). The opposite is true for legumes which fix atmospheric N and grow slowly at first, thereby facilitating the infestation of nitrophilous weeds (Hayden et al., 2012; Lawson et al., 2015). Thus, the type of forage species and the type of pasture cropping system have direct effects on weed species composition, density, richness and diversity (Legere et al., 2005; Islam & Ashilenje, 2018). However, the effects of various plant stand/cropping system types on weed infestation remains understudied for cool-season pastures.

Weed infestation in tropical regions can also be suppressed by promoting the vigorous growth of selected temperate species through fertilization with essential macronutrients such as nitrogen (N), Phosphorous (P), and potassium (K) (Little et al., 2021; Ghosh et al., 2022). Of these nutrients, P is one of the deficient nutrients in South African soils, with its deficiency often restricting plant growth, performance and productivity (Schachtman et al., 1998; Shrivastav et al., 2020). According to Veneklaas et al. (2012) and Wang et al. (2022), P is required for adenosine triphosphate (ATP) synthesis in the Calvin cycle, which produces ribulose 1,5-bisphosphate (RuBP) and enhances the activity of nitrate reductase in plant roots, which facilitates nitrogen fixation. P fertilization increases photosynthetic capacity, growth rate and competitive ability of forage species, thus reducing weed competition (Muzangwa et al., 2012; Ward et al., 2012; Simpson et al., 2014). Thus, identifying the optimum P application rate that can maximise the performance of forage plants and minimise weed infestation is crucial for sustainable weed management in planted pastures. Nevertheless, the optimum P rate that can reduce weed infestation on various plant stand types is yet to be ascertained. This limits not only derivation of appropriate weed management for sustainable pasture production, but also development of policy that can help farmers to increase forage yields and sustain large livestock numbers during winter season. Hence, this study seeks to answer the following questions:

1. Do grass-legume intercropping and monospecies stands of Oats, legumes and broadleaved forage species suppress weed abundance, density and diversity?

2. What is the optimal P application rate that can effectively minimize weed infestation?

Methods and materials

Study site

The experiment was conducted at Amakhuze village (GPS coordinates: 33.1256 S, 27.0797 E) under the Amakhuze tribal authority in Alice, Raymond Mhlaba Municipality, Eastern Cape Province of South Africa. The area receives about 450 to 600 mm annual rainfall, with an average temperature of 19°C in winter and 28°C in summer. The vegetation types are the Amathole Montane Grassland, Bhisho Thornveld, and Eastern Cape Escarpment Thicket. The soil type is Oakleaf with a loam to silty texture, with sand, silt and clay ranging from 41.2–44.8%, 33.5–35.7% and 18.0–20.0%, respectively (Monde et al. 2012). The soil pH ranges from 4.87 to 5.64 KCl, whereas C (1.3%), P Bray (8.09 ppm), K (0.22–0.31 Cmol(+)/kg), Mg (0.94–1.36 Cmol(+)/kg), Ca (2.01–2.59), and Na (0.10–0.18 Cmol(+)/kg). This experiment abided by the ethics standards of environmental protect and the ethical certification of this research was applied and obtained from Inter-Faculty Research Ethics Committee of the University of Fort Hare with the following ethics clearance reference number: MND031SJOY01.

Experimental design and seedbed preparation

A grass species [Oats (*Avena sativa*)], broadleaved species [Radish (*Raphanus sativus*)] and two forage legumes [Bird's-foot-trefoil (*Lotus corniculatus*) and Vetch (*Vicia sativa*)] were planted in monocultures and grass-legume mixtures. The seeds of these forage species were purchased in the company named Kei seeds and Feeds (Pty) Ltd, in East London, Eastern Cape Province of South Africa. During planting, these plant stands were assigned varying phosphorous rates of 0, 25, 45, 65 and 85 kg P/ha from double triple superphosphate fertiliser (P_2O_5: 36%, P:16%), totalling 30 treatment combinations. Each of these treatment combinations was replicated three times in experimental plots of 2 m × 2 m size. This rain-fed factorial experiment was arranged as a randomized complete block design with 6 blocks and 15 plots per block, totalling 90 experimental plots (6 plant stand types × 5 P rates × 3 replicates). The garden was tilled a week before planting and disced using a tractor, after which it was divided into 90 plots, with soil in each plot levelled using hand-held rake. In each 2m × 2m plot, six rows interspaced by 0.3 m were delineated with 0.5 m buffer maintained between plots. Plant seeds were planted at a 2-cm depth and covered with a layer of soil. The Oats mixtures were planted at a ratio of 70:30% for Oats:Vetch and Oats:Lotus stands. For monocultures, Radish, Oats, Vetch, and Lotus were planted at recommended seeding rates of 3.5, 100, 20 and 5 kg/ha, respectively. A binary fertilizer of KNO_3 containing 130 g N/kg (13%) and 380 g K/kg (38%) and P rates were applied concurrently at planting. Specifically, all plots received a recommended uniform application of N and K at a rate of 60 kg N/ha and 175 kg K/ha, respectively.

Data collection

The experiment commenced on 12th March 2025 and data collection was conducted on 17th May 2025. The data for botanical composition of weeds was determined using a 0. 25 m² quadrat. Two quadrats were placed on two opposite corners of each experimental plot. Each quadrat was placed at 0.5m inside the experimental plot to prevent the edge effect. The weeds within the quadrant were identified and counted to determine the species composition and density. Then the species were classified according to their family, lifespan (annuals, biennials, and perennials), and photosynthetic pathway (C3, C4 and CAM). The weed density was expressed as number of weeds per m². For the weed species diversity, Shannon Wiener index with the following formula was used (Magurran, 2004):

$$H' = \sum_{i}^{S} Pi \times \ lnPi \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where: H' = Shannon Wiener's diversity index, *S* = the total number of species in each microsite replicate, Pi = relative abundance of the species, ln = natural log. The species diversity was determined by the relative abundance.

The chlorophyll content of the planted forage plants was determined using SPAD meter (SPAD-502 Plus, Minolta Camera Cooperative, Japan). The chlorophyll readings were taken as the average of three leaves per plant i.e., the bottom, middle and flag leaf. Each leaf was clamped in the middle using the SPAD meter. Decagon's AccuPAR LP-80 PAR/LAI Ceptometer was used to measure photosynthetically active radiation (PAR) using eighty individual sensors with a 180 $^{\circ}$ field of view on a 1-m probe (Huemmrich et al., 2005; Senna, 2005; Steinberg et al., 2006; Thomas et al., 2006). The PAR readings were taken above and below the canopy in two opposite corners of each plot. PAR sampling took place during clear and cloudless conditions between 12:00 and 13:00. The aboveground biomass (AGB) was sampled from two quadrates of 0.5 m × 0.5 m per plot (totalling 180 quadrats). The samples were oven-dried until constant weight was attained at 60 ℃, and weighed to determine the dry matter production of forage plants.

Statistical analysis

The data normality and homogeneity of variances were assessed using Shapiro-Wilk test and Levene's test, respectively. All these parameters met the assumptions of ANOVA, hence there was no need to transform the data. The analysis of variance was conducted to test fixed effects of stand type, P rate and their interactions on weed attributes such as density, richness and diversity using general linear mixed models (GLMMs). Replicates were entered as random factor in the model, whereas the quadrats were nested within the experimental plots. The general linear model used was as follows:

$$Y_{ijkl} = \mu \ + \ \beta_{\ i} + \ \lambda_{\ j} + \ \beta \lambda_{\ ij} + \ \epsilon_{\ ijl}$$

Where Y_{ijkl} = response variables, β_i = i^{th} effect of the stand type (n = 6), λ_j = Phosphorous rate (n = 5), $\beta \lambda_{\ ij}$ = interaction between stand type and Phosphorous rate.

The mean comparisons were conducted at 95% confidence interval using Tukey's test. Linear regression models were used to predict the relationship between weed densities and chlorophyll content, photosynthetically active radiation (PAR) and aboveground biomass (AGB) of planted forage species. The analysis was conducted using JASP, Jamovi and SigmaPlot statistical software's latest versions.

Results

Weed species composition

Table 1 shows weed species composition as affected by various plant stand types and phosphorous rates. A total of 37 weed species from 15 families were recorded, with Asteraceae being the most prevalent family, followed by Poaceae. Of these species, non-graminoids (forbs) were the most dominant functional group (73%), whereas the graminoids and succulents accounted for 21.6% and 5.4%, respectively. Moreover, annual weeds (73%) were dominant compared to biennials and perennial weeds. Similarly, C_3 plant weeds (65%) were dominant compared to C_4 plants. The relative abundance of graminoids was consistently higher, ranging from 53.5% in the control to 70.6% at 85 kg P/ha under Radish stands, whereas it was lower in Oats monocultures and mixtures. In contrast, relative abundance of forbs was highest across all P rates in all plant stands except at 45 kg P/ha in Vetch monoculture and Oats + Vetch stand. Notably, relative abundance of forbs was on average 43.6% lower than that of graminoids in the control across all plant stands except in Oats + Vetch stands. *Cyperus rotundus* and *Cynodon dactylon* were the codominant graminoid weed species across all plant stand types, with *C. rotundus* exhibiting low relative abundance at 45 kg P/ha except for Lotus monoculture, whereas the latter was lowest at 65 and 85 kg P/ha for all plant stand types except in Radish stands. Among the non-graminoids, *Tagetes minuta, Ciclospermum leptophyllum*, and *Galinsoga parviflora* were the three most dominant forbs. *T. minuta* was lower at 25 kg P/ha across all pasture stand type, except for Oats + Vetch mixture. However, *C. leptophyllum* had higher relative abundance in all other plant stand types at 25 kg P/ha, except for Oats + Vetch stand and Lotus monoculture. *G. parviflora* had low relative abundance in all P rates across all stand types except for 45 kg P/ha in Radish and Vetch stands.

Table 1

Species composition of weeds in different plant stands assigned varying Phosphorous rates. L = Lifespan, PP = Photosynthetic pat

				Radish					Oats					Oats + Lotus			
Species	**Family**	**L**	**PP**	**0**	**25**	**45**	**65**	**85**	**0**	**25**	**45**	**65**	**85**	**0**	**25**	**45**	**65**
Graminoids																	
Cyperus rotundus	Cyperaceae	P	C4	29.3	22.4	19.8	36.9	31.5	30.9	13.2	16.2	26.9	34.6	38.7	22.9	12.0	37.
Cynodon dactylon	Poaceae	P	C4	14.1	28.3	22.3	14.1	38.0	22.3	18.1	33.1	17.3	0	13.6	17.5	28.9	0
Digitaria sanguinalis	Poaceae	A	C4	8.6	3.9	3.3	1.1	1.1	2.2	0.4	0	0	0	1.3	1.2	0	0
Eragrostis curvula	Poaceae	P	C4	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Eragrostis species	Poaceaea	A	C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pennisetum clandestinum	Poaceaea	P	C4	0.5	0	7.4	0	0	0	0.8	0	0	4.6	0.4	0	0	5.2
Urochloa trichopus	Poaceae	A	C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eleusine coracana	Poaceae	A	C4	0.5	0	0.8	10.9	0	0	0.4	0	2.7	0	0	0	5.9	0
Total				**53.5**	**54.6**	**53.6**	**63**	**70.6**	**55.4**	**32.9**	**49.3**	**44.2**	**39.2**	**54**	**41.6**	**46.8**	**42.**
Forbs																	
Taraxacum officinale	Asteraceae	P	C3	0	0	0	2.4	0	0.5	0	6.9	0	0.9	1.7	1.2	1.8	0
Oxalis corniculata	Oxalidaceae	A	C3	0	2.6	0	0	1.1	0	1.7	1.5	0	0	0	0	3.6	0
Cleome monophylla	Cleomaceae	A	C3	4.0	0.7	0	8.7	0	0.5	4.5	0.8	0	0	1.3	3.6	1.8	0
Schkuhria pinnata	Asteraceae	A	C3	6.6	1.3	1.7	0	0	3.3	3.7	0	6.7	0	8.1	2.4	2.9	9.1
Tagetes minuta	Asteraceae	A	C3	12.1	2.6	5.8	19.6	7.6	5.9	4.9	6.9	9.6	18.2	7.2	6.0	6.5	12.
Ciclospermum leptophyllum	Apiaceae	A	C4	13.7	26.9	7.4	0	8.7	28.3	25.1	10	19.2	4.6	11.5	26.5	17.8	12.
Plantago lanceolata	Plantaginaceae	P	C4	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium vulgare	Asteraceae	B	C3	0	0	0	1.1	0	0	0	0	0.9	0	0.4	0	1.2	0
Gnaphalium pensylvanicum	Asteraceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solanum nigrum	Solanaceae	A	C3	0	0	0.8	0	0	2.7	11.1	0	0.7	0	8.1	5.4	1.2	0
Hypochaeris radicata	Asteraceae	P	C3	6.6	7.9	4.1	3.3	0	0	4.9	11.5	0.7	17.3	5.1	0	5.3	2.6
Datura stramonium	Solanaceae	A	C3	0	0	0.8	0	0	1.1	0.4	0.8	0	0	1.3	3.0	0	0
Ageratum conyzoides	Asteraceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	5.2
Galinsoga parviflora	Asteraceae	A	C3	0	0	20.7	3.3	9.8	0	7.8	4.6	10.6	12.7	0	1.8	7.7	6.5
Chenopodium album	Amaranthaceae	A	C3	0	0	0	0	0	0	0.4	0	0.9	0	0	0	0.6	0
Ipomoea purpurea	Convolvulaceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bidens pilosa	Asteraceae	A	C3	0	0.7	0	1.1	1.1	0	0	2.3	2.9	0	0.4	3.0	0.6	5.2

				Radish					Oats					Oats + Lotus			
Species	**Family**	**L**	**PP**	**0**	**25**	**45**	**65**	**85**	**0**	**25**	**45**	**65**	**85**	**0**	**25**	**45**	**65**
Graminoids																	
Xanthium spinosum	Asteraceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nicandra physalodes	Solanaceae	A	C3	0	0	1.6	0	0	0	0.8	0	0	0	0.4	0	1.8	0
Chemopodium carinatum	Amaranthaceae	A	C3	0	0.7		0	1.1	0	2.5	2.3	0	3.6	0	0	0	0
Centella asiatica	Apiaceae	P	C3	0	1.3	1.6	0	0	0	0.8	3.1	0.9	0.9	0	2.4	0.6	2.6
Emex australis	Polygonaceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hibiscus trionum	Malvaceae	A	C3	0	0	0	0	0	0.5	0.4	0	0	0	0	1.2	0	0
Raphanus raphanistrum	Brassicaceae	A	C3	0	0	0	0	0	0.5	0	0	0	0	0	0.6	0	0
Sonchus asper	Asteraceae	A	C3	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0
Amaranthus thunbergii	Amaranthaceae	A	C4	0	0	1.6	0	0	0	0	0	1.9	0	0	0	0	0
Argemone ochroleuca	Papaveraceae	A	C3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total				**44.5**	**44.7**	**46.4**	**37**	**29.4**	**43.5**	**67.1**	**50.7**	**55.8**	**60.8**	**46.0**	**57.2**	**53.2**	**57.**
Succulents																	
Succulent species	Portulacaceae	A	CAM	2.0	0.7	0	0	0	1.1	0	0	0	0	0	1.2	0	0
Portulaca oleracea	Portulacaceae	A	CAM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total				**2.0**	**0.7**	**0**	**0**	**0**	**1.1**	**0**	**0**	**0**	**0**	**0**	**1.2**	**0**	**0**

Weed density

The P rate ($F_{20,149}$ = 3.38, p = 0.05), stand type ($F_{20,149}$ = 30.49, $p < 0.001$) and their interaction ($F_{20,149}$ = 1.96, p = 0.012) had a significant effect on total weed density. The interaction between P rate and stand type had no significant effect on graminoid ($F_{20,149}$ = 1.06, p = 0.392) and non-graminoid weeds ($F_{20,149}$ = 1.59, p = 0.063; Table 2). However, singular effects of P rate ($F_{20,149}$ = 3.88, p = 0.005) and stand type ($F_{20,149}$ = 12.68, $p < 0.001$) were significant on graminoid weed densities. Stand type, independently had a significant effect ($F_{20,149}$ = 20.45, $p < 0.001$) and neither P rate nor the interaction between P rate and stand type had a significant effect ($p > 0.05$) on non-graminoid densities (Table 2). Total, graminoid and non-graminoid weed densities depicted an exponential decay response as P rates increase in Radish, Oats, and Oats + legume stands. Pure legume stands of Vetch and Lotus exhibited two-fold higher total weed densities ($p < 0.05$) from 45 to 85 kg P/ha compared to Radish stand and Oats monoculture and mixtures (Fig. 1a). Notably, 65 kg P/ha attained the lowest total weed, graminoid and non-graminoid weed densities across all stands relative to pure legume stands (Fig. 1a, b **and c).** The mixtures exhibited similarly low weed densities at 65 kg P/ha, with densities lower than those observed in the Oats monoculture **(**Fig. 1a, b **and c)**.

Table 2
ANOVA results showing interactive effects of P rate and stand type on density, species diversity and richness of weeds. The significant effects are indicated with a bold p-value.

		Graminoids density		Non-graminoids density		Total density		Species diversity		Species richness	
Source of variation	**df**	***F***	***p***	***F***	***p***	***F***	***p***	***F***	***p***	***F***	***p***
P rate	4	3.88	**0.005**	1.61	0.174	3.38	**0.011**	0.826	0.511	3.83	**0.011**
Stand type	5	12.68	**< 0.001**	20.45	**< 0 .001**	39.62	**< 0.001**	5.192	**< 0.001**	30.49	**< 0 .001**
P rate * Stand type	20	1.06	0.392	1.59	0.063	1.96	**0.012**	1.178	0.281	1.87	**0.019**
df = degrees of freedom, F = F-value, p = p-value											

Weed richness and diversity

The P rate ($F_{20,149}$ = 3.83, p = 0.011), stand type ($F_{20,149}$ = 30.49, p < 0.001) and their interaction ($F_{20,149}$ = 1.87, p = 0.019) significantly affected the weed species richness. However, species diversity was significantly affected by stand type alone ($F_{20,149}$ = 5.192, p < 0.001) (Table 2). Pure legume stands had more weed species which ranged from 8 to 11 species compared to other plant stands with 4 to 8 species. Species richness exhibited a significant declining trend as P rate increases in Radish stand, with 65 kg P/ha suppressing weed richness (p = 0.005) by 3 species compared to the control. In Oats + Lotus stands, the weed species richness decreased by 50% from 45 to 65 kg P/ha (Fig. 2). Although the P rates had no significant effect on species diversity, a linear decline was observed in Radish stands, with 65 and 85 kg P/ha supressing weed diversity significantly (p < 0.05) compared to the control (Fig. 3).

The relationships between weed density and agronomic parameters of different plant stands

The negative relationships were observed between non-graminoids density and aboveground biomass (R^2 = 0.11) of Radish and Oats stands (Fig. 4). Similarly, both non-graminoid (R^2 = 0.21, p = 0.01) and graminoid weed densities (R^2 = 0.22, p = 0.012) were negatively related to the chlorophyll content in Radish stand. Although the relationships were not stronger, the linear declines in weed densities as chlorophyll content increased were observed in Oats stands (Fig. 5). For all plant stands except for Oats + Lotus stands, the photosynthetically active radiation (PAR) was negatively related, but non-significantly so with graminoid weed densities. In contrast, no discernible relationships were observed between graminoid and non-graminoids weed densities with aboveground biomass, chlorophyll content and PAR of legumes (Figs. 4, 5 and 6)

Discussion

The influence of stand types and Phosphorous rates on weed density and species composition

The results of this study revealed that the extent of weed infestation in terms of plant density in cultivated temperate pastures depends on the plant stand type and P application rates. Pure legume stands appeared to promote weed infestation relative to Radish, Oats monocultures and mixtures (Fig. 1a, b, c). These findings imply that legumes need to be intercropped with grasses e.g., Oats to suppress the dominance of weeds. In other studies, conducted elsewhere, cereal-legume mixtures also suppressed weeds more effectively than pure legume stands (Hauggaard-Nielsen et al., 2006; Corre-Hellou et al., 2011; Arlauskiene et al., 2014; Ranaldo et al., 2020). This was also evident in the studies of Lingorski and Kertikov (2010), and Kemper et al. (2020) where intercropping systems of common vetch and barley facilitated a significant decline in weed infestation. High weed density in legume monocultures may be attributed to the ability of legumes to fix atmospheric nitrogen via a mutual relationship with rhizobium bacteria, thereby benefiting nitrophilic weed species (Kocira et al., 2020). These findings concur with previous study of Kumar et al. (2012), which found that legumes facilitate rather than suppress weed growth.

The Radish and Oats stands reduced total, graminoid, and non-graminoid weed densities significantly, more so at a P rate of 65 kg P/ha (Fig. 1a, b, c), largely due to optimised productivity and performance of forages at this P rate. This was further justified by a negative relationship between non-graminoid weeds and aboveground biomass in Radish and Oats stands, indicating that Radish and Oats efficiently utilised P at the expense of weeds. (Fig. 1b, c). Radish, classified as a broadleaved plant, appears to compete primarily with forbs (broadleaved weeds), as evidenced by the decline in non-graminoid weeds in Radish stands. However, grasses remained dominant in Radish stands, comprising over 50% of weeds indicating weaker interspecific competition exerted by Radish on graminoid species. However, graminoids such as *Cyperus rotundus* and *Cynodon dactylon* were less abundant in Oats stands, indicating that the intraspecific weaker than interspecific competition (Table 1). This could be ascribed probably to the rhizomatous and stoloniferous growth habit of *C. dactylon* which enables it to exploit light in the interspaces of Radish plants, thereby avoiding the competition for light (Granger & O'Connor, 2015; Nitu et al., 2019). On the other hand, Oats with its fast growth and higher productivity, particularly at higher seeding rate and seeding emergence limits graminoid weed emergence by quickly occupying space and monopolising soil resources (Finnan et al., 2018; Maqbool et al., 2020; Studhalter et al., 2023).

Various studies suggest that conventional tillage practices may facilitate the spread of perennial weeds e.g., *C. dactylon* by distributing below-ground propagules (Tuesca et al., 2001; Hofmeijer et al., 2019). However, *C. rotundus* dominance in Radish stands is ascribed to its ability to thrive under low light intensity and wet environmental conditions induced by Radish broadleaves (Henry et al., 2021; Ameena et al., 2024). These Radish leaves intercept light, reducing light availability underneath plant canopies, making conditions more favourable for *C. rotundus*. According to Mumtaz et al. (2019) and Peerzada (2019), *C. rotundus* is tolerant to shade and low temperatures, justifying its tolerance to shaded environment underneath Radish stands.

The overall weed density tended to decrease at higher Phosphorous rates of 65 and 85 kg P/ha, due likely to: 1) nutrient thresholds being exceeded for weeds with low nutrient requirements, 2) enhanced growth and productivity of forage plants at higher P rates and 3) higher competitive ability for light facilitated by faster growth rate and higher uptake of growth resources at optimal P rates. This was further justified by higher weed infestation at low P rates indicating that weeds are more competitive at low P rates, as weeds take advantage of low productivity and performance of planted forage plants. The seasonal dominance of annual weeds observed in this study reflects their opportunistic colonization in annual pasture systems, while the prevalence of C_3 plants suggests adaptation to temperate conditions. The variability in abundance of dominant forb species such as *Tagetes minuta*, *Ciclospermum leptophyllum*, and *Galinsoga parviflora* along P gradients illustrate differential nutrient requirements and competitive abilities, influencing weed community dynamics across stand types. *Tagetes minuta* was the most dominant forb and showed reduced abundance at 25 kg P/ha and higher abundance at 65 kg P/ha across all pasture stand types except the Oats + Vetch mixture (Table 1), indicating that this forb might pose challenges to forages at higher P rates. *T. minuta* produces compounds such as α-pinene and β-pinene that inhibit the germination and growth of forage plants, thereby challenging weed control efforts (Hao et al., 2010; Arora et al., 2015; Martin-Fores et al., 2018). Plants of the Asteraceae family, to which *T. minuta* belongs, possess rapid growth rates, efficient seed dispersal mechanisms, and good adaptation to diverse environmental conditions, conferring significant competitive advantages during invasions (De Waal, 2015; Kaur et al., 2024).

Effect of stand types and Phosphorous rate on weed richness and weed diversity

The study showed that Phosphorous fertilization rates and stand type significantly impacts the weed species richness in cultivated pastures. While both factors and their interaction affect species richness largely at 65 kg/ha, species diversity was primarily influenced by stand type only. These findings indicate that more weed species are less competitive at higher forage productivity, particularly around optimal P application. Hence, these weed species are displaced due largely to reduced growth resources by forage plants such as Radish and Oats. The results of this study further showed evidence that legume stands are more weed species rich due to their nitrogen-fixing ability, which facilitates the establishment of nitrophilic weed species by increasing soil nitrogen content (Temperton et al., 2007; Pedrol et al., 2014; Leuschner and Ellenberg, 2017; Huang, 2024). Conversely, Radish and Oats stands suppressed weed richness more effectively, particularly at optimal Phosphorous rates. As depicted by Fig. 2, greater P rates led to reduced species richness in Radish stands signifying the role of Phosphorous in mediating competitive exclusion of certain weed species by forage plants. *Brassica* residues contain glucosinolates and phenolic compounds which are converted into several isothiocyanates compounds through myrosinase activity that express allelopathic activity. These allelochemicals are potentially responsible for the reduction of weed growth in the paddy (Davis & Liebman, 2001; Askarzadeh, 2025). These findings further justified that more weed species have low P requirements hence they occur under low P rates. In mixtures e.g., Oats + Lotus mixtures, richness declined by approximately 50% from 45 to 65 kg P/ha, indicating a synergistic effect of both plant stand and nutrient availability on weed establishment. Although Phosphorous application influenced species richness, it had little effect on species diversity, with legume monocultures showing consistently higher weed diversity due to high weed species richness.

Legume stands support more complex and species-rich weed communities, complicating weed management by requiring broader control measures, potentially increasing management costs, and challenges for farmers (Wenzel et al., 2024; Wróbel et al., 2025). Moreover, in pasture systems where weeds are interspersed with forage species, the forage contamination by weeds may lead to the risk of livestock exposure to toxic plants, thereby impacting animal health and forage utilization efficiency (Abdisa & Dilbato Dinbiso, 2024). However, non-legume stands like Oats and Radish can reduce both weed richness and diversity under optimal fertilization (65 kg P/ha), indicating a potential use of these combinations as part of integrated weed management programs to minimise weed proliferation (Belesky et al., 2020; Jaramillo et al., 2021; Singh and Verma, 2025).

Conclusion and recommendations

This study revealed that plant stand type and P rate interact significantly to suppress weed total plant density and species richness. These findings highlighted that selection of appropriate pasture cropping system and appropriate P rate is a crucial strategy for weed management in temperate pastures. Pure legume stands, however, promoted weed species diversity and densities relative to other stands, signifying that legumes should be incorporated as companion plants in intercropping systems rather than planted as sole legume stands. More interestingly, 65 kg P/ha significantly suppressed weed infestation underscoring this rate as the most effective fertilizer level for weed management in temperate pastures.

Therefore, it is recommended that livestock farmers must intercrop legumes with grasses or plant Radish pure stand at 65 kg P/ha for effective control of weeds. However, the choice of the plant stand type should be informed by farmers objectives. Moreover, this study provides insights on how P rate and plants stand type affects weeds infestation and the present findings are crucial for policy development. The findings of this study are also significant for minimising costs and adverse environmental effects of herbicides in controlling weeds in cool-season pastures.

Declarations

Acknowledgements

The authors would like to thank postgraduates of the department of the pasture section at University of Fort Hare for their assistance during experimental layout, land preparation and data collection. We also extend our gratitude to Mr Monelisi Makanya for reviewing and providing important comments that improved this manuscript.

Author contributions

NJ, MM, AF and UG conceived the research idea and designed the study. NJ, and MM collected and analyzed the data. NJ wrote the manuscript. MM, AF and UG reviewed and provided valuable and critical comments on the manuscript. All authors agreed on the submission of the manuscript for publication.

Funding

National Research Foundation of South Africa.

Conflict of interest

Authors are not aware of any potential conflict of interest associated with this study.

Data availability

The data used in this study will be made available on request by the corresponding author.

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Figures

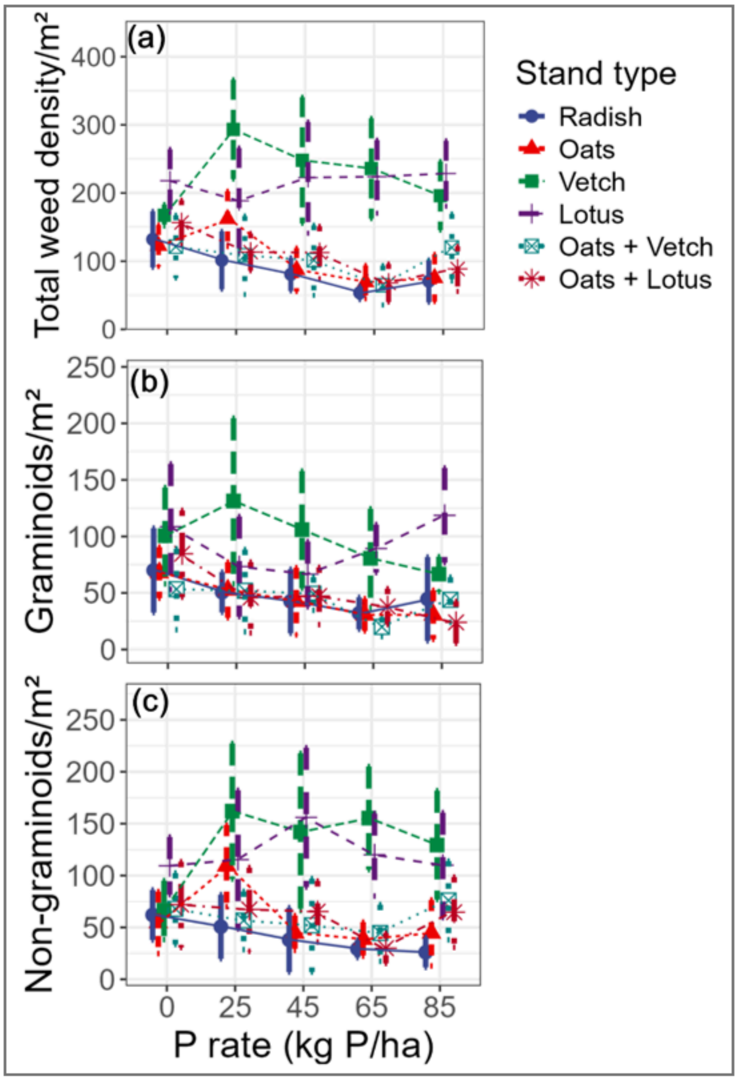

Figure 1

Weed density in different stand types along a gradient of P application rates. P stands for Phosphorous. The upper and lower whiskers denote the ±95% CIs (upper and lower limits, respectively).

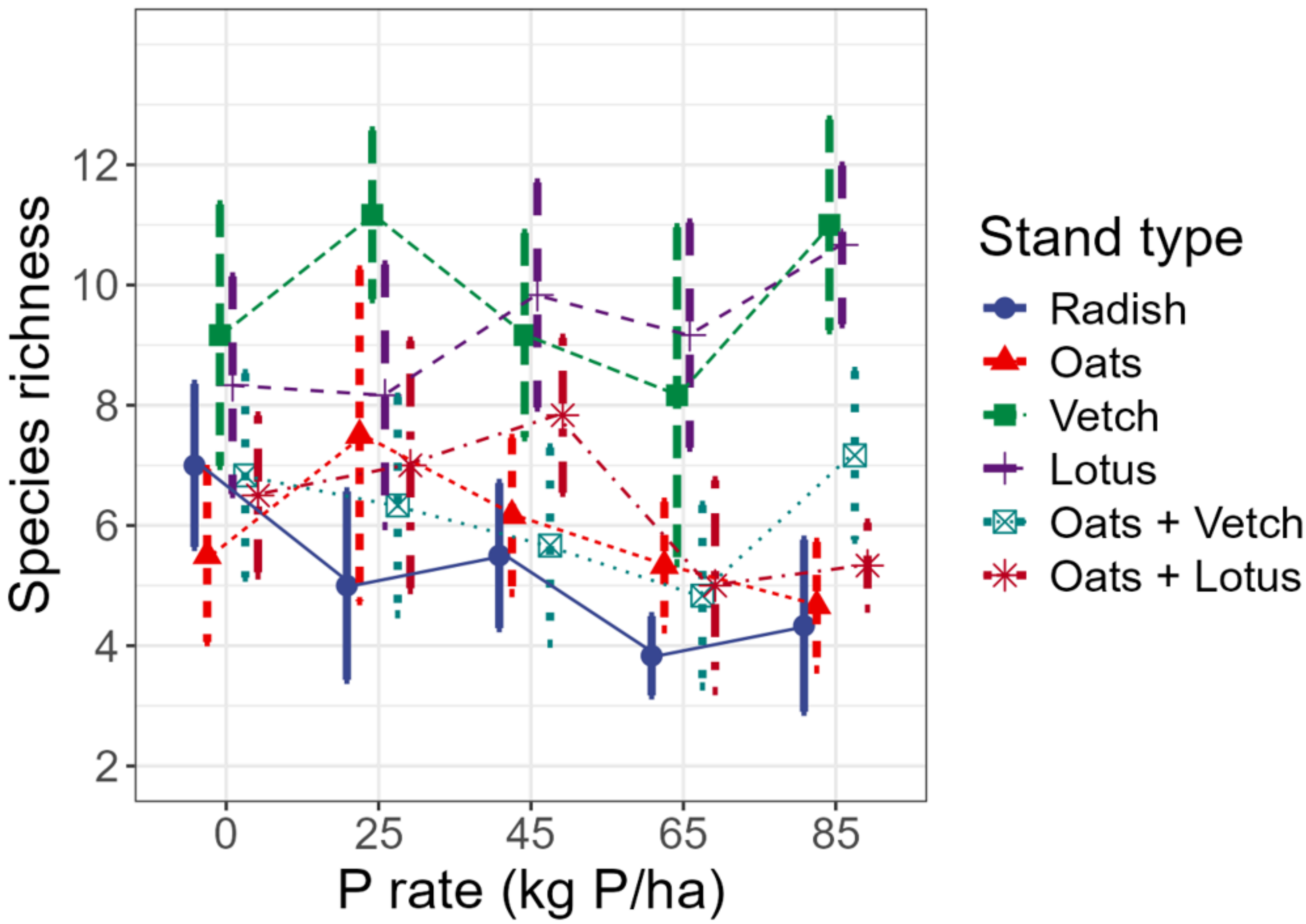

Figure 2

Weed species richness in different plant stand types along a gradient of P application rates. P stands for Phosphorous. The upper and lower whiskers denote the ±95% CIs (upper and lower limits, respectively).

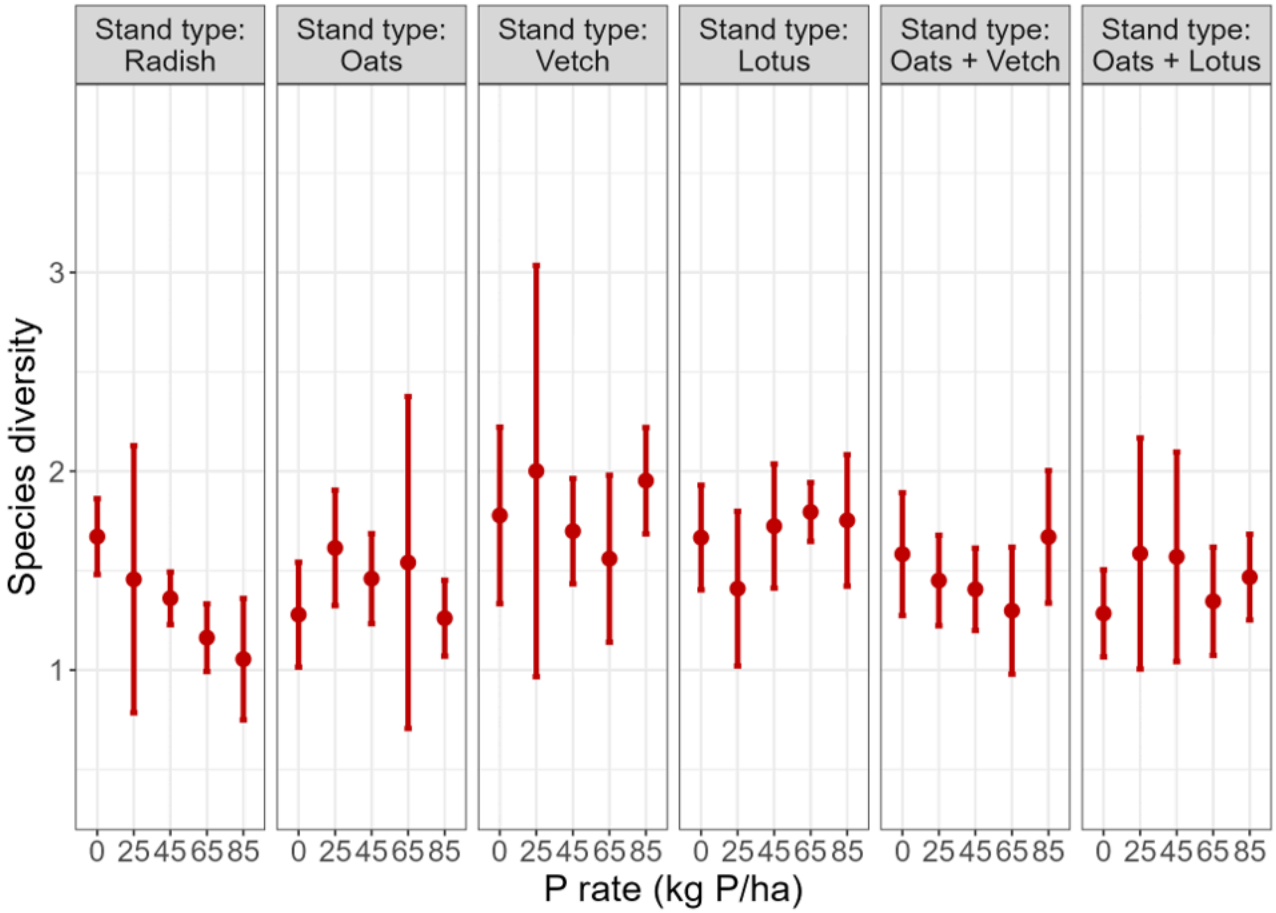

Figure 3

Species diversity in different stand types along a gradient of P application rates. P stands for Phosphorous. The upper and lower whiskers denote the ±95% CIs (upper and lower limits, respectively).

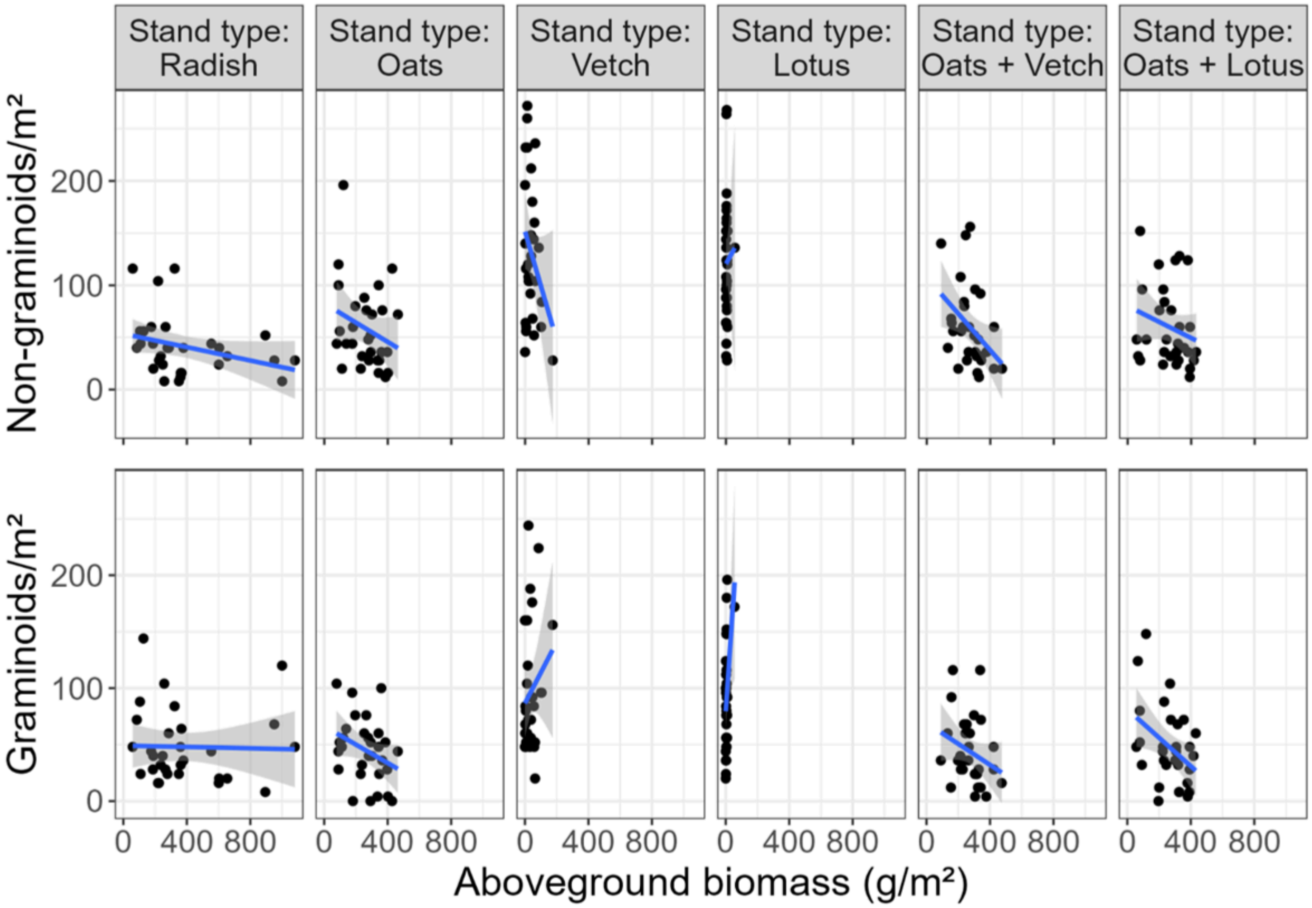

Figure 4

Relationships between aboveground biomass and density of graminoid and non-graminoids weeds in different plant stand types.

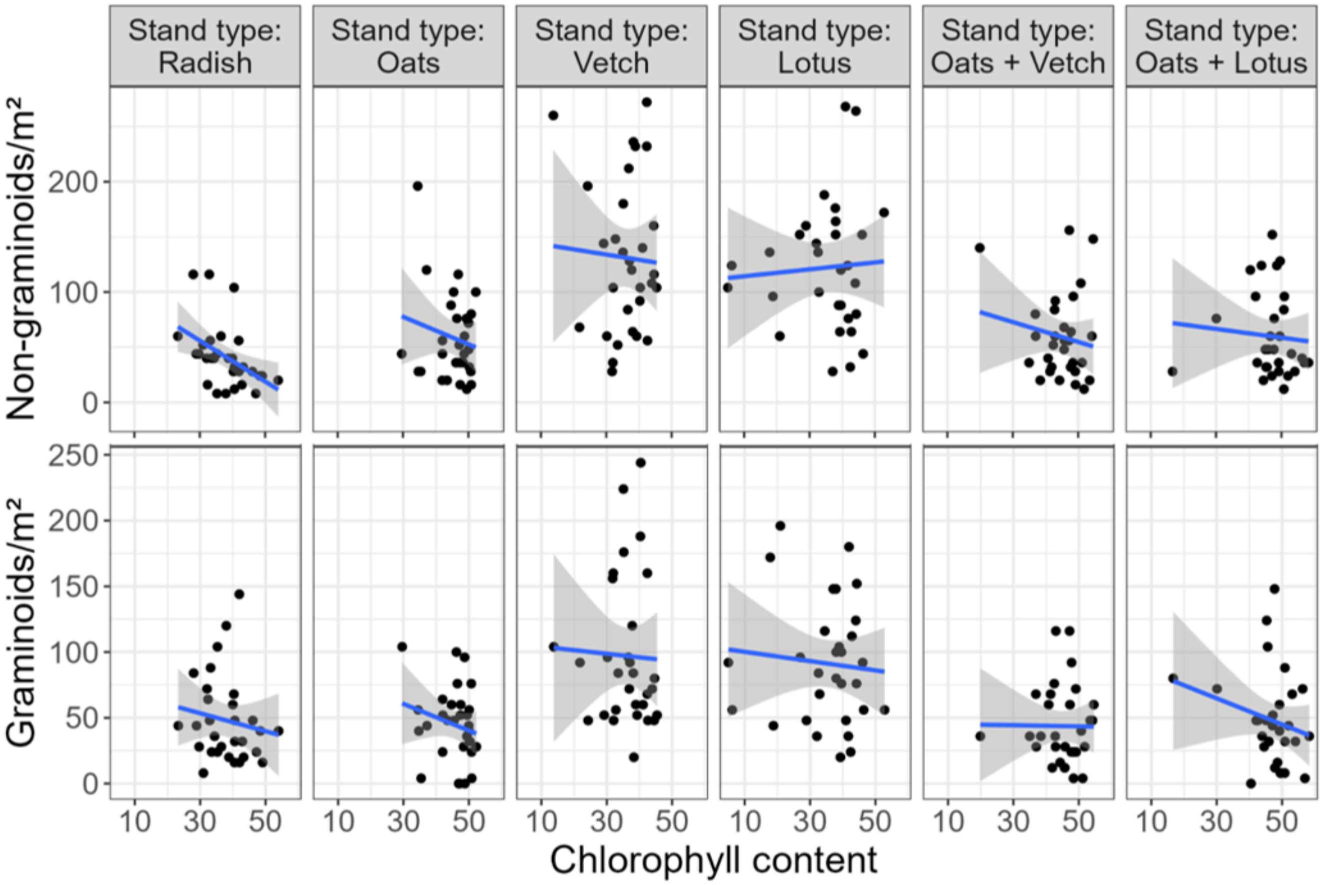

Figure 5

Relationships between chlorophyll content and weeds density of graminoid and non-graminoids in different stand types.

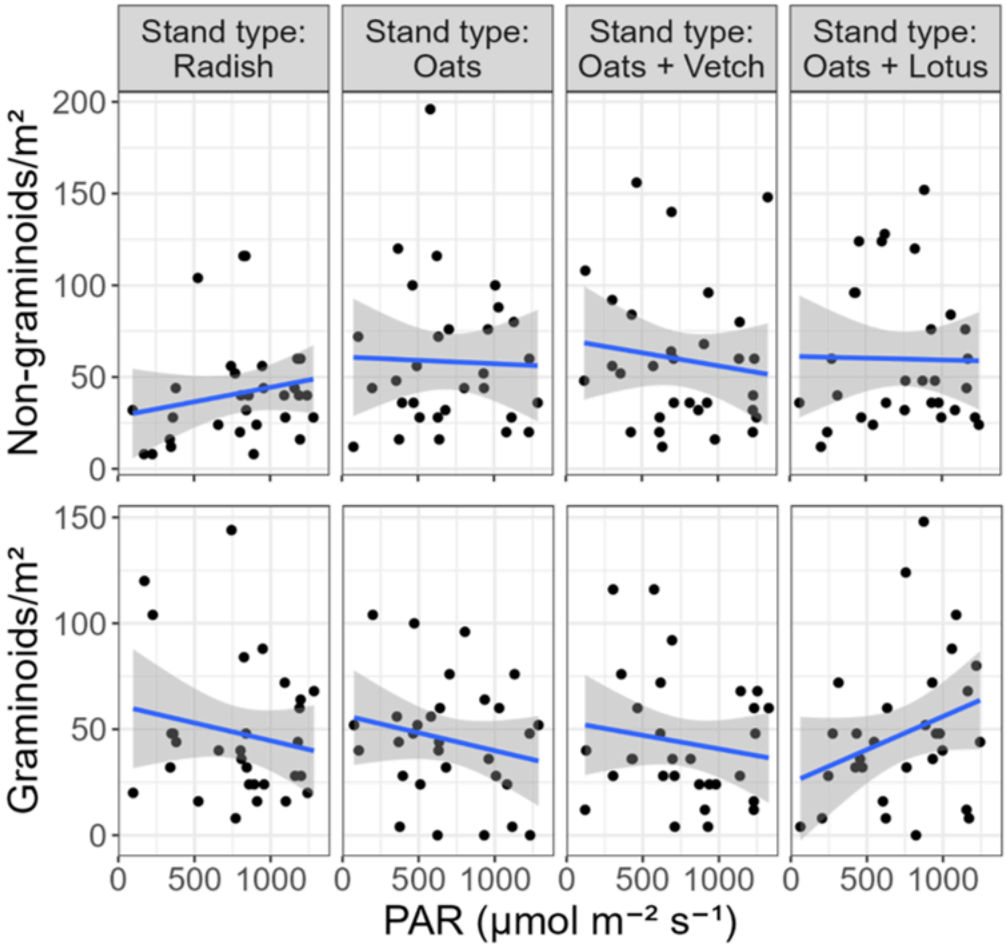

Figure 6

Relationships between photosynthetically active radiation (PAR) and density of graminoids and non- graminoids across different stand types.