Effect of emergence timing on growth and phenotypic plasticity of feathertop Rhodes grass (*Chloris virgata* Sw.) in Southern New South Wales

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Summary Feathertop Rhodes grass (*Chloris virgata* Sw.) is now a problematic weed in many cropping and non-cropping areas of Southern NSW. This study evaluated the effect of emergence dates on the growth and phenotypic plasticity of this summer weed where cohorts of four different populations were initiated in early-spring (04 Sep), late-spring (04 Nov), mid-summer (04 Jan) and early-autumn (04 Mar) in southern NSW, Australia. Among the four sowing times, the late spring sowing treatment took the longest time from emergence to the first seed head emergence (70-110 days), while it had the shortest seed maturity period (8-16 days). Length of the reproductive and total life period of the four populations differed across the four sowing-time treatments. The plants that emerged in mid-summer had the longest reproductive period (30 days) whereas the early-autumn emerging plants died before the reproductive stage due to cold temperatures during winter. The mid-summer cohort required slightly longer time (63-85 days) to achieve seed head formation and less time (19-24 days) for seed maturity than those plants which emerged in early or late spring. All the reproductive features were varied by sowing times and population numbers. The reproductive biomass allocation pattern and seed production generally increased in the mid-summer emergence cohort. Seed production in the mid-summer (9,942 seeds/plant) cohort was higher than the late spring (8,000 seeds/plant) and early spring (3,240 seeds/plant) cohorts respectively. The ratio of reproductive biomass to vegetative biomass increased in the mid-summer sowing times in all populations, and this species displayed true plasticity in reproductive allocation.

Keywords biomass, allocation, reproductive fitness, climate change.

INTRODUCTION

Weed phenological features including the timing of emergence, growth and sexual reproduction can be used to predict the distribution of a weed species under varying environmental conditions (Ghersa and Holt 2006). Therefore, a biologically meaningful description of phenological events is fundamental for better understanding of the temporal dynamics of a weed species, which would contribute to the well-informed recommendation of suitable timing for effective control (Rafferty and Ives 2011). Properly timed control with suitable tactics could achieve maximum control efficacy, reducing both the cost of managing weeds and risks of new infestations into other areas.

Weed plasticity responses to environmental changes have become one of the most important aspects for evolutionary biology research in weeds and have been accelerated by climate change concerns (Clement *et al.* 2004). Feathertop Rhodes grass (*Chloris virgata* Sw.) is a warm-season, annual grass that is widely distributed globally (Anderson 1974) and was ranked in the top 10 weed species in Australia (Werth *et al.* 2013). In southern New South Wales (NSW), Australia, feathertop Rhodes grass mainly dominates roadsides, fence lines and wasteland areas. Now this small-seeded species has become an issue in the cropping country of southern NSW. Given the large area of feathertop Rhodes grass' expansion to diverse soil and climatic conditions, it is not surprising that feathertop Rhodes grass is very plastic.

The objectives of this research were 1) determine the impact of different emergence dates on the growth and development timing of phenological, morphological and reproductive traits, and 2) compare timing and duration of each phenophase among four different feathertop Rhodes grass populations.

MATERIALS AND METHODS

Environmental (emergence timing) and populations treatment There were four sowing time treatments: early spring (4 Sep 2020), late-spring (04 Nov 2020), mid-summer (04 Jan 2021) and early-autumn (04 Mar 2021). Four feathertop Rhodes grass populations from diverse geographical areas were selected to cover the phenotypic variability of this species. Seeds of four populations including FELT 04/20, GLEN 03/18, STURT 16-17 and PARK 01/20 were collected from Felton, Toowoomba, Wagga Wagga and Parkes respectively. Populations FELT 04/20 and STURT 16-17 were sourced from non-cropping situations.

Experiment set up and measurements A total of 400 seeds in each sowing operation were used for each population where sowing trays (32 cm x 40 cm) were prefilled with a commercial potting mix under natural conditions in a net house at Wagga Wagga Agricultural Institute (WWAI), NSW. The emergence time was recorded before seedlings were manually transplanted at 4-5 leaf stage to a plastic pot (18 cm in diameter) pre-filled with the potting mix. Two separate experiments were conducted.

The first experiment was set up for measurements of phenological events. For each sowing time, each population was maintained one seedling/pot to measure the date of: (1) emergence, (2) booting stage (3) first seed head emergence, (4) first mature seed observed in each of the first five emerged seed heads from each plant, and (5) plant senescence. This data was used to calculate: (1) emergence period, (2) vegetative period (number of days between emergence and booting stage), (3) seed maturity period (between seed head emergence and the first mature seed formed), (4) post-reproductive period (between the first mature seed and plant senescence), (5) reproductive period (between the first seed head emergence and plant senescence), and (6) total life period (between emergence and plant senescence).

The second experiment was set up for destructive measurements of plant biomass. There were two seedlings/pot for each population at each sowing time. Each plant at physiological maturity was carefully cut near the soil surface to obtain vegetative (leaf and stem) and reproductive biomass (seed head with seeds) separately. Based on 500-seed weight, we estimated seed production per plant. Other morphological measurements were carried out over time.

RESULTS

Effect of emergence timing and population treatments: Sowing time and population had a significant ($p<0.001$) effects on the timing of key phenological events, and more importantly on the period each population spent within a phenological growth stage (Table 1). Among the four sowing times, the late spring sowing treatment took the longest time from emergence to the first seed head emergence (70-110 days), had the longest post-reproductive period (8-23 days), and the shortest seed maturity period (8-16 days). The average reproductive period was longest in the mid-summer sowing time treatment (30 days) and the shortest in early spring (4 September) time (22 days). Similarly, the mid-summer sowing time treatment resulted in the longest total life period (92-116 days). Feathertop Rhodes grass that emerged in early autumn (04 Mar) did not progress to the reproductive stage in all four populations as a result of low temperatures and frosts in winter which eventually killed the plants.

Populations differed significantly ($p = 0.004$) in the duration required for vegetative growth and reproduction. Total life period of FELT 04/20 and STURT/16-17 was similar within a given sowing time treatment and responded in a similar manner with sowing time treatments. These two populations were sourced from non-cropping situations and their life period increased from the early spring to late spring sowing times and then decreased. PARK 01/20 and GLEN 03/18 were sourced from cropping situations and tended to have a longer life period when emerged in mid-summer than other sowing times. Across the four feathertop Rhodes grass populations, the variation in reproductive period (seed maturity + post-reproductive period) was greater in the late spring sowing (17-39 days), while it was narrower in both the early spring (20-24 days) and mid-summer sowing (28-32 days).

The total reproductive period (seed maturity + post-reproductive period) for all populations was higher in the mid-summer sowing time than early and late spring sowing times (Table 1). All four populations had a similar trend for reproductive period when they emerged in early spring.

Plasticity in reproductive effort Seed production of the four feathertop Rhodes grass populations across the four sowing treatments was significantly ($p = 0.003$) different (Table 1). On average, the seed production increased from the early spring (3,240 seeds/plant), and late spring (8,000 seeds/plant) to mid-. summer sowing time (9,942 seeds/plant). The ratio between reproductive tissue biomass and vegetative tissue biomass (R-V) increased from the early spring emergence to late spring and summer emergences (Table 1).

Table 1. Phenological traits, duration of developmental periods and seed production of four populations of feathertop Rhodes grass emerged at different times (environmental condition).

Sowing time	Population	Emergence to first seed head emerging (days)	Vegetative period	Seed maturity period	Reproductive period	Life period	Seeds/plant	Slope (R-V)
04 Sep	FELT 04/20	69-71	64. 00 (±0.28)	13.07 (±0.65)	22.45 (±0.70)	86.45 (±0.65)	6521 (±770)	0.045c
	STURT16-17	63-73	63.87 (±0.85)	14.50 (±1.11)	21.10 (±0.93)	84.97 (±1.34)	5951 (±390)	0.063b
	PARK 01/20	72-80	69.00 (±1.17)	10.00 (±1.30)	24.28 (±0.92)	93.75 (±1.5)	4390 (±415)	0.061b
	GLEN 03/18	85-95	65.27 (±4.90)	11.37 (±0.77)	20.37 (±0.92)	85.64 (±5.4)	1969 (± 600)	0.008c
04 Nov	FELT 04/20	70-72	68.10 (±2.00)	15.28 (±0.60)	39.07 (±0.85)	107.17 (±2.34)	11112 (±1575)	0.085b
	STURT16-17	85-95	77.07 (±4.00)	16.00 (±2.15)	28.72 (±2.76)	105.79 (±5.00)	9875 (±1362)	0.094b
	PARK 01/20	95-100	69.00 (±0.75)	8.25 (±0.80)	16.79 (±0.99)	85.79 (±3.86)	8071 (±446)	0.042c
	GLEN 03/18	100-110	90.00 (±2.26)	8.78 (±0.65)	17.67 (±0.71)	107.67 (±3.28)	2937 (± 1400)	0.059c
04 Jan	FELT 04/20	65-70	61.50 (±1.13)	19.75 (±1.30)	30.38 (±1.81)	91.80 (±1.61)	9930 (±1232)	0.233a
	STURT16-17	63-75	70.75 (±4.20)	18.75 (±1.03)	27.87 (±1.77)	98.62 (±0.73)	10867 (± 1362)	0.194a
	PARK 01/20	72-78	83.18 (±3.03)	23.75 (±1.04)	32.75 (±1.04)	115.93 (±1.07)	16687 (±670)	0.002c
	GLEN 03/18	78-85	70.37 (±1.50)	23.00 (±0.92)	32.25 (±1.04)	102.62 (±1.64)	12285 (± 579)	0.078b
04 Mar	FELT 04/20	67-80	69.57 (±1.34)	-	-	-	-	-
	STURT16-17	67-81	64.15 (±0.48)	-	-	-	-	-
	PARK 01/20	80-90	71.25 (±1.11)	-	-	-	-	-
	GLEN 03/18	80-90	79.26 (±1.63)	-	-	-		
-	*p*-value	$p = 0.003$	$p = 0.004$	$p = 0.003$	$p = 0.002$	$p = 0.002$	$p = 0.006$	$p = 0.005$

Vegetative period = the interval from emergence to booting stage; seed maturity period = the interval from seed head emergence to the first mature seed formed; post-reproductive period = the interval from the first mature seed to plant senescence; reproductive period = the interval from the first seed head emergence to plant senescence, and life period = the interval from emergence to plant senescence. Slope (R-V) from the reproductive biomass which was regressed with the vegetative biomass using linear functions.

Principal component analysis (PCA) shows that, the proportion of the first and second components were 56.6% and 14.4% respectively (Figure 1). The first component (PC1) mainly consists of reproductive features, and these are plotted in proximity, including reproductive period, reproductive mass, seed head length, number of spikelets, seed head mass, and post-reproductive period. The second component was mainly due to the vegetative period, and total life period.

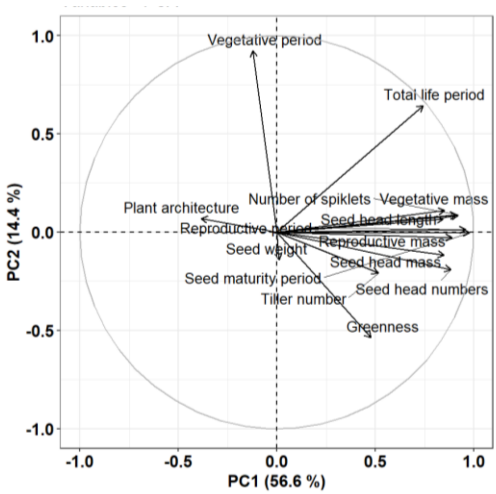
DISCUSSION

This study demonstrated that feathertop Rhodes grass can emerge throughout the warmer months (early September to March) of southern NSW. The late-spring emerged plants had the longest vegetative period and the shortest seed maturity period conversely the mid-summer plants produced seed heads earlier in their life span compared to the early- and late- spring sowing times. The results suggest that photoperiod and temperature could be primary environmental factors in determining when the reproductive events occur. The low temperatures during winter (June to August) in southern NSW significantly impacted the growth and development of feathertop Rhodes grass. Therefore, the frost frequency and intensity are an important benchmark for implementing an economic post-emergent control program of feathertop Rhodes grass particularly in southern NSW.

All populations tended to have the highest post-reproductive period at the mid-summer sowing treatment. This could have a positive effect on high seed production and contribute to the overall fitness by replenishing extra seeds in the soil seed banks.
The total life period was affected by reproductive period which can correlated to reproductive performance including seeds production per plant. Under favourable conditions, both total life and reproductive periods are maximised for higher seed head production and higher number of seeds, thereby improving the overall fitness.

The slope of the relationship between reproductive tissue biomass and vegetative tissue biomass within a population also varied among sowing time treatments and between populations (Table 1) and this relationship indicated true plasticity in biomass allocation across treatments.

Figure 1. Principal component analysis (PCA) of plant morphological and reproductive features of feathertop Rhodes grass. The first axis explains 56.6% and the second axis 14.4% of the variance.



The study confirmed the major role of environmental conditions such as temperature and day length as the driving factors of feathertop Rhodes grass phenological development and confirmed the diversity of the populations and their suitability to different environments. Low temperatures or frosts can slow the rate of plant development and can stop the seed production. The January sowing (mid-summer) produced the greatest number of seeds whereas the early spring resulted in the lowest seed production. The recommendation is that controlling feathertop Rhodes grass seedlings prior to reproduction will reduce populations growth and alleviate their negative effects on crop yield in future generations. The control action should be diverted to control early emergence, especially the mid-summer emergence due to the removal of crop competition after harvest and due to more aggressive growth and seed production.

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