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Effect of shading on growth, development and reproductive biology of *Phalaris minor* Retz.

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Abstract
Despite the advancement in weed management methods, weeds continue to dominate over crops due to their aggressive competitiveness. Hence, understanding the nature of underpinning crop-weed competition is central to develop weed management methods and their continuous improvements. Since, both crops and weeds compete for light by shading each other, an understanding of the different competitive potentials of crops and weeds under shade is critical to design suitable IWM strategies. All the above inferences and reasoning formed the basis for the present experiment. The present experiment was conducted in winter season 2017 to evaluate the effects of shading on growth, development and reproductive biology of *Phalaris minor*. The treatments included full sunlight, 55% shade and 75% shade. The total duration was delayed by more than two weeks under 55% shading while under 75% shading, it was delayed by as much as four weeks due to cumulative increases in vegetative and reproductive stages as well as time taken from flowering to maturity. Plant height increased significantly under both the levels of shading. Total aboveground dry matter accumulation decreased by more than 80% under shading and almost two-three fold proportion of dry matter was partitioned towards leaves. Concomitant variation in SLA, RGR, NAR and LAR indicated adaption to shade at whole plant level. Number of seeds per plant was reduced by 67% under shading as a consequence of proportional reduction in number of inflorescences.

Keywords: Shade tolerance, weed physiology, phytochrome, net assimilatory rate, growth analysis

1. Introduction

Weed infestation is one of the principal factors limiting crop productivity in different crops and cropping systems. In order to realize full genetic yield potential of the crop, proper weed management is one of the essential ingredients. Weeds not only reduce the yield but also make the harvesting operations difficult. In India, the yield losses caused by weeds is 33% in general and exceeds the losses from any other category of agricultural pests like insects (26%), nematodes (6-8%), diseases (20%), rodents (6%), etc. Therefore, for sustaining food grain production, to feed ever-increasing population and for ensuring food security, effective weed management is very essential (Singh *et al.*, 2014) [13].

Post-green revolution weed management has been driven by chemical methods only owing to the relatively rapid control offered by herbicides (Weiner *et al.*, 2001) [15]. However, the negative effects of these herbicides on environment quality and human health as well as reduction in farm profits due to increasing number of herbicide resistant weed populations have led to increased interest in developing good agronomic practices and ecology as an alternate method of weed management (Harbur, 2003) [10]. Weeds have enjoyed dominance over crops basically because of poor agronomic management and better competitive aggressiveness. Hence to develop competitively better cropping systems, it is important to understand the nature of underpinning crop-weed competition (Chhokar and Sharma, 2012) [6].

Competition for light or photosynthetically active radiation (PAR) is the only major aboveground competition among the weed and crop species and becomes singularly important when moisture and nutrients are adequate (Guglielmini and Satorre, 2002) [8]. A photon of light is either captured and converted into chemical energy through photosynthesis or dissipated as heat. Light competition or shading influences the ability of weeds and crops to compete for water and nutrients by reducing the photosynthates available to support root growth (Blackman, 1968) [4]. Plant competition for light is also unique, since the superior competitor both reduces the quantity and changes the quality of light that is available to the less competitive plant (Patterson, 1995) [12]. Early dominance in light competition improves the long-term competitiveness of plants by modulating bioavailability of photosynthates. When solar radiation penetrates a canopy, it is selectively attenuated by scattering and absorption, resulting in changes in both quantity (amount of PAR) and quality of the radiation (reduction in R:FR ratio) within the canopy. The two processes are further linked. As the solar radiation, which provides energy for the photosynthesis, is reduced it affects the photo-equilibrium of the photoreceptor phytochrome, which in turn affects phenology as well as reproductive biology via altered chloroplast development, delayed onset of flowering and reduced aboveground dry matter (Gundel *et al.*, 2014) [9].

2. Material and Methods

The field experiments were conducted during winter season of 2017 at the Norman. E. Borlaug Crop Research Centre, G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (29° N latitude, 79° 29'E longitude and at an altitude of 243.8 meter above mean sea level). The experiment was conducted via randomized complete block design and seeds of *P.minor* were obtained from the All India Coordinated Research Project on Weed Management, operating at the University itself. The weather parameters like minimum and maximum temperatures, relative humidity, sunshine and rainfall during the period of experimentation were recorded at agro-meteorological observatory located within Crop Research Centre of the University. The experimental area was divided into three separate blocks and was further divided into plots having dimensions of 1.5m x 2.5m (length x width). Inverted 'U' shaped tunnel framework was made using PVC pipes, bamboo and GI wires, to prepare the shade-nets. Two shade-nets one of 50% shading capacity and another of 75% shading capacity were installed on two of the three blocks, while the third was left uncovered to work as control for the experiment. Standard bifilament shade-net materials were used, with manufacturer guaranteed shading capacity. However reduction in Photosynthetically active radiation (PAR) was further calibrated using a PEA-Meter (Photosynthetic efficiency analyzer meter) and it was observed that shading nets caused an effective PAR reduction of 55% and 75%. Observations *viz.* total duration of different growth phases, number of flowering shoots, flowers, fruits per plant, seeds per fruit and growth parameters such as SLA, LAR, NAR, RGR etc were recorded. The formulae for growth parameters were taken from Blackman (1968) [4]. All statistical analysis was performed using STPR1 software and the treatments' were compared using Fisher's least significant difference method at 5% level of significance.

3. Result and Discussion

3.1 Phenology

A significant difference was observed in the phenology of different weed species under full sunlight and shading. In general duration of all the three i.e. vegetative stage, reproductive stage and the duration from flowering to maturity were increased by increasing levels of shading (Fig 1). The duration of vegetative stage was prolonged by 14 days at 55% shading while the increment was one to two weeks under 75% shading. The duration of reproductive stage increased only marginally while flowering was delayed by 9 days under 55% shading and by 13 days under 75% shading. 55% shading caused a 18 day increase in total duration while for 75% shading it was recorded as 27 days.

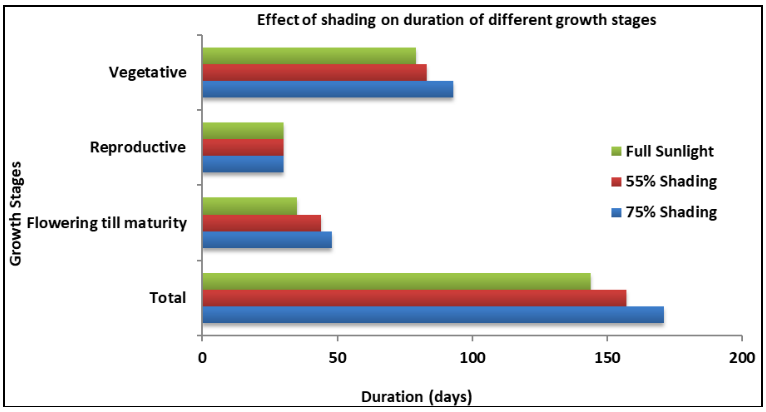

Fig 1: Effect of different levels on shading on the duration of different growth stages

3.2 Growth parameters

3.2.1 Plant Height

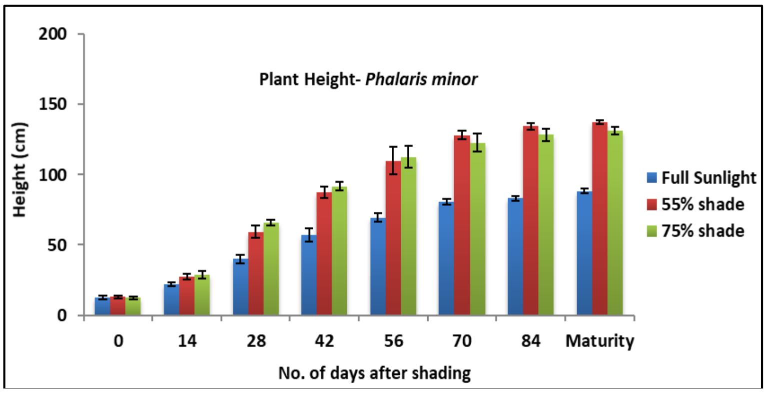

Fig 2: Plant height (cm) of *Phalaris minor* under full sunlight and shading at different time intervals

Plant height increases as one of the foremost physiological response under shading and same was observed in the present study (Fig 2) and it has been noted that the plant height/stem length just doubled within 14 days of shading. The difference in plant height in shading as compared to full sunlight was small initially but as the weeds grew the gap widened and again decreased at terminal growth stages. Under 55% shade plant height increased by 19, 30, 34 and 47 cm at 28, 42, 56 and 70 days after shading, as compared to full sunlight. Similarly under 75% shading, plant height increased by 26,35, 44 and 42cm for the same time interval.

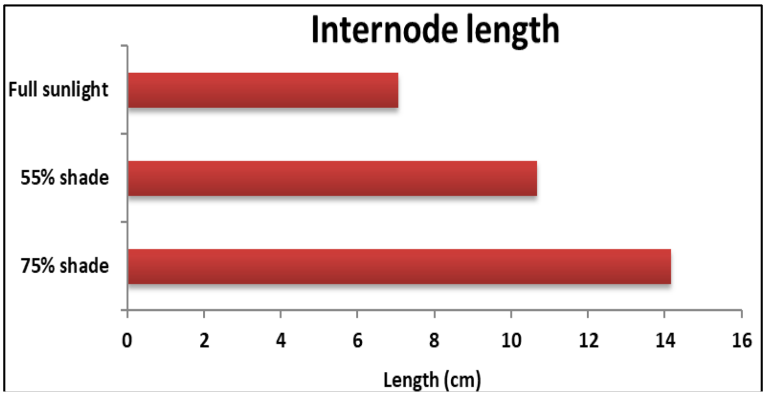

Fig 3: Plant height (cm) of *Phalaris minor* under full sunlight and shading at different time intervals

The increment in plant height is associated with an underlying increase in the internode length (Fig 3). Internode length almost doubled under 75% shading, while it increased by 4cm on an average under 55% shade. As a primary response to shading plant tries to elongate its stem so as to reach above the canopy. This process is primarily influenced by the change in R:FR(Red:Far Red) ratio under the canopy. R:FR ratio decreases under shading and causes the elongation response by mediating phytochrome based signaling. However elongation can only be supported until photosynthates are not limiting otherwise it causes reduction in stem growth with increasing levels of shading as seen in later stages of *P. minor* (Fig 4). In similar experiments on itch grass (*Rottboellia exaltata*), cogon grass (*Imperata cylindrica), Abutilon theophrasti* and Texas weed *(Caperonia palustris)* moderate to high stimulation in height has been reported (Patterson 1980; Bello *et al.*, 1995; Godara *et al.*, 2012) [11, 2, 7].

3.3 Leaf Growth Parameters

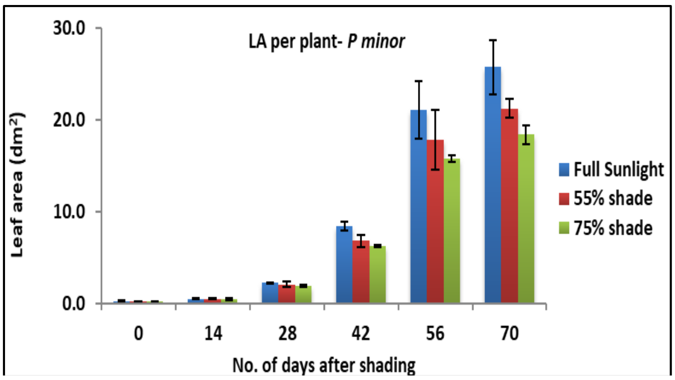

Fig 4: Leaf area (dm^2) of *Phalaris minor* under full sunlight and shading at different time intervals

Table 1: Average leaf area and main leaf number 70 days after shading

	Full sunlight	55% shading	75% shading	CD	SE(m)
Average Leaf Area	26.71	35.81	43.51	7.3	1.8
Main Leaf Number	96	59	41	15.8	3.9

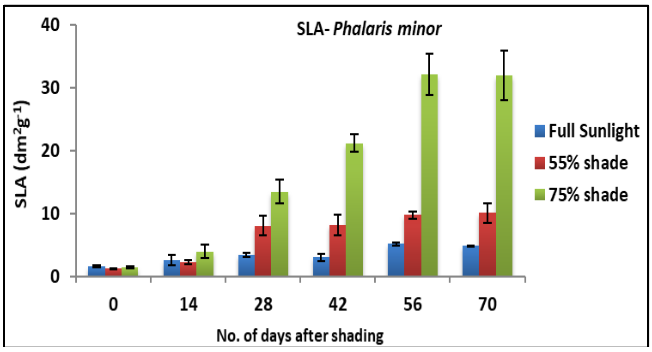

Fig 5: Specific Leaf area (dm^{2}g^{-1}) of *Phalaris minor* under full sunlight and shading at different time intervals

A significant decrease in leaf area was noted with increasing levels of shading (Fig 5). The difference was most steep at 70 and 84 days after shading and slightly marginalized as the weeds matured. Under 55% shading a decrease in leaf area by 14-16% was noted while at 75% it ranged from 26-30%. The above observation was in striking contrast with individual leaf area which increased by 34 and 62% at 55% and 75% shading respectively at 70 days after shading.

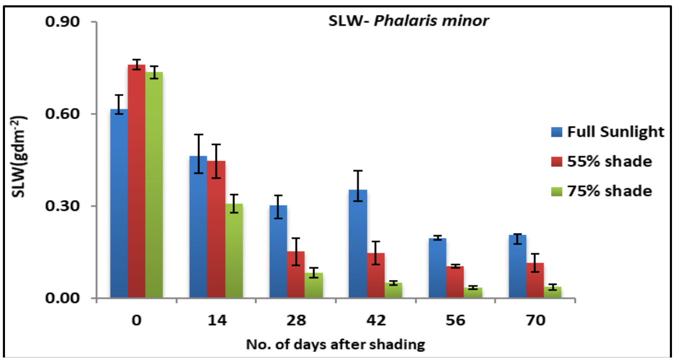

Fig 6: Specific Leaf Weight (SLW) (g dm^{-2}) of *Phalaris minor* under full sunlight and shading at different time intervals

A greater decrease in main leaf number vis-a-vis individual leaf area with increase in shading level seemed to be the underlying cause for this decrease in overall plant leaf area in view of increasing individual leaf area. The main leaf number at 70 days after shading was observed to be 38% and 57%

under 55% and 75% shading levels respectively. Similarly SLA increased 3-5 fold under 55% shading and by 6-8 fold under 75% shading. A concomitant decrease in SLW values by 45-60% under increasing levels of shade was observed. Based upon the results it follows that total leaf area per plant decreased under shading even though individually the leaf area increased as evident from the increased SLA values. This happens because the same R:FR mediated phytochrome signaling that causes stimulation in height, also suppresses branching and reduces the leaf emergence rate thus limiting the number of photosynthetic organs under shade. Thus ultimately the total amount of photosynthesis is adversely affected. However weeds offset this limitation by increasing the area of photosynthetic organs (leaves) thus maximizing the light capture. A concomitant increase in SLA values paralleled with a decrease in SLW values for all the weed species under study indicates that the increase in leaf area is not being accompanied by increase in biomass per se and it is just a consequence of better partitioning of the dry matter towards photosynthetic organs.

3.4 Total above ground dry matter production, leaf area ratio (LAR), net assimilatory rate (NAR), Relative Growth Rate (RGR)

Total aboveground dry matter significantly decreased under shading with increasing levels of shading causing a more severe reduction in dry matter (Fig 6). The decrease in dry matter ranged between 60-80% under 55% shading, while under 75% shading it decreased by more than 85%. LAR values increased 4-5 times under 55% shading and 9-12 times under 75% shading. Shading caused a drastic reduction in the RGR and NAR values. RGR and NAR decreased by more than 40% and 65% respectively under 55% shade. Under 75% shade the reduction in RGR and NAR was recorded at 82% and 90% respectively.

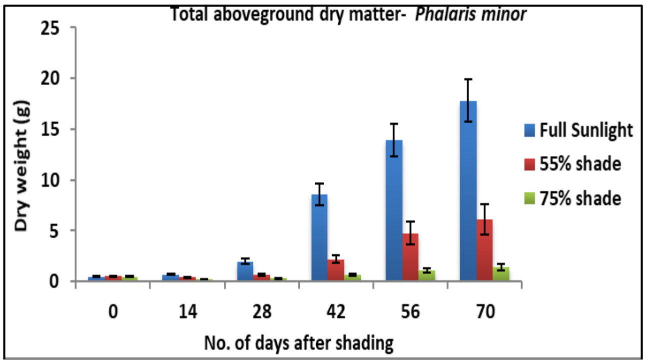

Fig 7: Total aboveground dry matter (g/plant) of *Phalaris minor* under full sunlight and shading at different time intervals

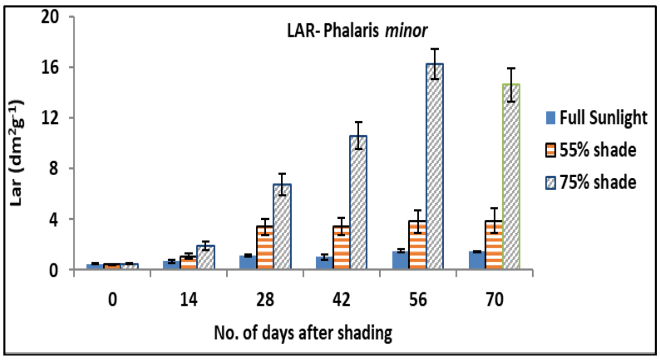

Fig 8: Leaf Area Ratio (dm^2g^{-1}) of *Phalaris minor* under full sunlight and shading at different time intervals

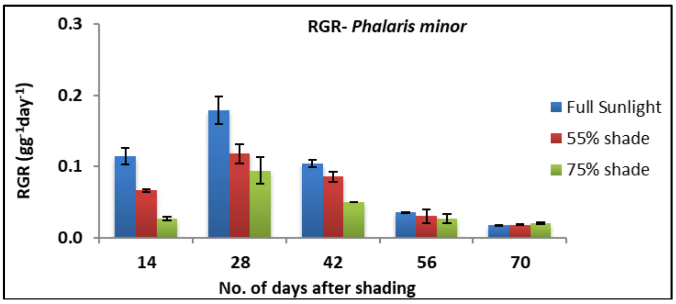

Fig 9: Relative Growth Rate (g g^{-1} day^{-1}) of *Phalaris minor* under full sunlight and shading at different time intervals

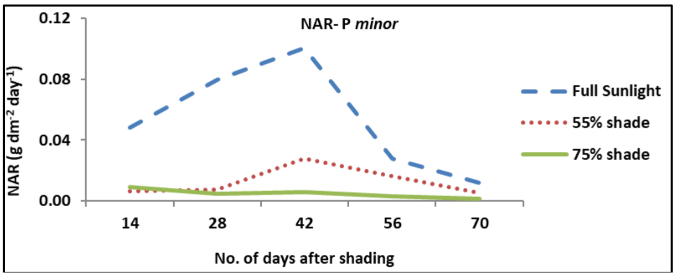

Fig 10: Net Assimilatory Rate (g dm^{-2} day^{-1}) of *Phalaris minor* under full sunlight and shading at different time intervals

It follows from the results that greater reduction in PAR yielded greater decrease in total dry matter accumulation due to limiting values of photosynthesis under shade. The dramatic increase in LAR with shading represents an adaptation to low irradiance at the whole-plant level, because a greater LAR results from a greater investment of plant material in photosynthetic light-harvesting structure. NAR reflects the whole plant's effectiveness in incorporating dry matter over time based on its total leaf area because it corresponds closely to average photosynthetic rate and thus competitive ability as compared to other weed species. The changes in LAR observed in response to shading are important because LAR is one of the two components of RGR, which is the product of NAR and LAR and it can be used to classify plant as shade tolerant or intolerant. In shade tolerant plants, the decreases in NAR with reduced growth irradiance are partially compensated by concomitant increases in LAR, with the result that the maximum RGR occurs at less than full sunlight. (Steckel 2003; Basett *et al*., 2011; Godara *et al*., 2012) [14, 1, 7].

3.5 Reproductive Biology

Table 2: Effect of shade on parameters related to reproductive biology of *P. minor*

Parameters	Full sunlight	55% shade	75% shade	CD	SE(m)
Number of seeds per plant	3911	1482	727	7.2	1.87
100 seed weight (g)	0.19	0.16	0.16	0.021	0.005
Number of Panicles per plant	15	6	3	1.8	0.45

As compared to full sunlight, under 55% shading number of panicles per plant, 10 seed weight and number of seeds per plant decreased by 60, 15 and 62% respectively. Similarly under 75% shading a decrease of 80% in number of panicles per plant, 15% in 100 seed weight and 81.4% in number of seeds per plant was recorded. It follows from the results that there was a close link between reproductive activity and lighting conditions. The qualitative changes in light under shading (reduction in R:FR) ratio causes decrease in branching or tiller production. It has already been noted under previous headings that under shade the resource partitioning towards reproductive organs is declined and that there is a species dependent delay in onset of flowering. Together the above processes acted such as to partition resources in a way that led to maximum allowable growth under given conditions but penalized seed production. A similar trend has been reported in *Solanum ptycanthum*, *Amaranthus powellii* (Powell amaranth) *Abutilon theophrasti*, *Datura stramonium* L., *Sorghum halepense* L, *Amaranthus rudis* and Texasweed. (Benvenuti *et al*., 1994; Bello *et al*., 1995; Steckel 2003; Brainard *et al*., 2005; Godara *et al*., 2012) [3, 2, 14, 5, 7].

4. Summary
The quantitative reduction in PAR leads to low photosynthetic carbon fixation under shade resulting in reduced dry matter accumulation. The qualitative changes (Reduction of R: FR ratio) causes changes in phenology of different growth stages, stem elongation and reduced branching. As a shade avoidance strategy, the weeds tend to maximize their light harvesting area and thus SLA and LAR are enhanced multifold. The concomitant changes in LAR, NAR and RGR indicate the adaptive plasticity of weeds under shade at the whole plant level. However the molecular basis of this adaptive plasticity remains to be well elucidated mechanistically.

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