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RESEARCH NOTE

Mathematical modelling for pea-weed competition

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ABSTRACT

A field experiment was conducted to investigate the pea-weed competition which revealed a significant reduction in pea yield with increasing duration of crop weed competition. The weed density in the season-long weedy plot was found to increase up to 60 days after sowing (DAS) and decreased thereafter. However, the weed dry matter accumulation increased progressively with duration of the weedy period. *Galinsoga parviflora* was the most dominant weed species as indicated by higher values of summed dominance ratio (SDR) in all the treatments. Relative yield loss (RYL) in peas was predicted using logistic and Gompertz equations in weed and weed free set of treatments, to determine 21 to 48 DAS as the beginning and end of the critical period of pea-weed competition, respectively, which is equivalent to 260 to 510°C day growing degree days (GDD). The economic threshold (ET) for multi-weed species for pea crop was estimated to range between 2.15 to 20.91 plants/m^2.

Keywords: Critical period of weed competition, Summed dominance ratio, Economic threshold level, Growing degree days, Relative yield loss, Weed diversity

Pea (*Pisum sativum* L.) is an important *Rabi* (winter) season pulse crop. Based on consumption, peas are of two types: dry peas and green peas. Dry peas (10-15% moisture) are used as split (dal) and green peas (72-80% moisture) are used as vegetables. Pea can provide nutritional security as they are an exemplary source of proteins and dietary fiber. Pea also leaves considerable residual soil nitrogen for the following crop, making it an important rotational crop. However, pea seed yield is subjected to wide variation, which can be attributed to various biotic and abiotic factors. Weeds are an important biotic factor, which hinders the growth of crops causing enormous yield loses. Weeds compete with crops mainly for nutrients, sunlight, soil moisture and CO2, which adversely affects the crops especially when these are limited in supply. Weeds also harbour various insects and pests, thus reducing both the quality and quantity of crop produce. Studying crop weed competition is important as uncontrolled weed growth has been reported to cause yield reductions of up to 45% in pea (Kaur *et al.,* 2020). In pea, the slow initial growth and wider spacing provide a congenial environment for weed growth. Though weeds compete with crops throughout the growing season, the extent of damage to the crop does not remain same during all the stages. Timing of weed emergence and duration of weed competition have significant effect on crop yield (Singh *et al.* 2016). Moreover, the removal of weeds throughout the growing season is neither feasible nor economical. Therefore, to reduce the yield losses as well as to avoid extravagant expanses on weed management, it is important to identify the exact critical period of weed and pea competition. The critical period of weed-crop competition (CPWC) is defined as the short span or ‘‘window’’ in the life cycle of a crop during which weed causes maximum yield reductions. Thus, the knowledge of CPWC as a part of integrated weed management strategy, would be useful in efficient weed management by targeting weed control measures at the right time. However, total eradication of weeds in a field might result in inefficient use of resources. Therefore, the economic threshold (ET) concept can be adopted which advocates maintaining the weed density at economic optimum levels. ET is the density of weeds at which the cost of control measures equals the benefits obtained (Hazra *et al.* 2011). Considering the above facts, it is evident that modelling of crop-weed interaction is of utmost necessity for developing a successful weed management strategy and its lacking in the sub-tropical hill (NEH-5) Agro-Climatic Zone of Meghalaya especially for pea crop. An experiment was conducted to determine the critical period of pea weed competition and ET for multi species weeds.

The field study was conducted in the winter (*Rabi)* season of 2020-21) at the experimental farm of College of the Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam, Meghalaya, India. The experimental site is situated at 25°68.157’ N latitude and 91°91.203’ E longitude and

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at an altitude of 950 m above the mean sea level. The soil of the experimental site was sandy clay loam in texture, acidic in reaction (pH 4.86), very high organic carbon (1.7%), low in available N (213.25 kg/ha) and P (18.24 kg/ha) and medium in K (202.72 kg/ha). The experiment was conducted in a randomised block design, with 14 treatments replicated thrice. The 14 treatments were divided into two sets *viz*., weedy set, where weeds were allowed to grow for 0 (W_0 : T1), 10 (W_{10} : T2), 20 (W_{20} : T3), 30 (W_{30} : T4), 40 (W_{40} : T5), 50 (W_{50} : T6) and 60 (W_{60} : T7) DAS; and weed free set, in which plots were kept weed free for 0 (WF_0 : T8), 10 (WF_{10} : T9), 20 (WF_{20} : T10), 30 (WF_{30} : T11), 40 (WF_{40} : T12), 50 (WF_{50}: – T13) and 60 (WF_{60} : T14) DAS. Pea (Variety '*Arkel*') was selected as the test crop and sown at a spacing of 30 x 10 cm. Standard agronomic practices other than weed management practices were followed during the crop growth period. Weeds were managed only by hand weeding according to treatment and no herbicides were used. The weed density, abundance and frequency in individual plots and the total dry weight of weeds were recorded from three randomly selected quadrates (0.25 m^2) in each plot at 10 days interval. No weeds were introduced to the experimental plots and weed density represents the naturally occurring weeds in the region. Weed samples were oven dried at 60 °C to constant weight. Pod yield, stover yield and seed index were recorded at harvest. A total of three pickings (harvests) were done and added to give the final harvest.

Summed Dominance Ratio (SDR) =

(Relative density + Relative abundance + Relative frequency)/3

The analysis and interpretation of data were done using the Fisher's protected least significant difference (LSD) test and means were separated at pd"0.05.

The Gompertz equation (Anwar *et al.,* 2012) was used to describe the effect of the increasing duration of weed free period on yield:

$$y = y0 + a * \exp\left[-\exp\left\{-\frac{(x - x0)}{b}\right\}\right]$$

A logistic equation (Smitchger *et al.* 2012) was used to describe the effect of the increasing duration of weed interference on yield:

$$y = y0 + \left[\frac{a}{\left\{1 + abs\left(\frac{x}{x0}\right)^{b}\right\}}\right]$$

Where, y is the relative yield (% of season-long weed-free yield), y0 is the lower limit of y, a is the upper limit for y, x0 is the number of days/GDD to give 50% yield, x is number of days/GDD after sowing and b is the slope. Estimation of the parameters and curve fitting was done using Sigma Plot 12.0.

Economic Threshold (ET)

$$ET\ (Economic\ Threshold) = \frac{Cost\ involved\ in\ weeding}{Y0 * P * L}$$

Where, Y0 weed free pea yield (t/ha), P is the value per unit of crop (Rs/ha), L is proportional loss per unit weed density (Hazra *et al*. 2011).

Cost involved in weeding was calculated considering 10 man-days are needed for each weeding and price per man-day was Rs 300. Value per unit of pea was Rs 48/kg.

Weed density, dry matter and SDR

Weed density significantly varied with various weedy and weed free treatments (**Figure 1**). The highest weed density was observed in the weedy plot throughout the growing season (WF_0) at 60 DAS (480/m^2). However, in the same plot at harvest, lower weed density was recorded (467/m^2). This suggests that weed density increased up to a certain point and then a decreasing trend was noticed. The shading effect of taller weeds and crops on newly germinated weeds might be a reason for the decrease. However, the dry matter of weeds increased progressively with increasing duration of the crop-weed competition (**Figure 2**). At the harvest stage, the highest dry matter accumulation was recorded from the weedy plot throughout the growing season (WF_0). **Table 1** shows the weed flora observed in the experimental field along with their summed dominance ratio (SDR). *Galinsoga parviflora* recorded the highest value of SDR disparate of various duration of crop weed competition, signifying its overall dominance. Treatment of weedy set W_{10} and W_{20} showed higher values of SDR for *Galinsoga parviflora*, indicating its ability to germinate and establish earlier than other weeds, which might be the reason for its dominance in the weed composition.

Yield and yield attributes

Season-long weed free plot (WF_0) resulted in maximum seed index, pod yield and stover yield (**Table 2**). As the period of crop weed interference increased, yield decreased and lowest values were observed in season-long weedy plot, which differed significantly from weed free control (WF_0). Lesser duration of crop-weed interference resulted in reduced weed density and weed dry matter accumulation, which in turn reduce the weed competitiveness and allelopathic effect. Conversely, when weeds were allowed to grow for longer duration, it caused taller weeds, thereby reducing light availability for photosynthesis, attributing to decrease in yield attributes of pea. The yield of field pea was decreased by 44.3% when weeds were allowed to compete for the entire season. Pea yield losses of up to 50% due to weed competition were also reported by Singh *et al.* (2016).

Table 1. SDR and Weed composition of pea during the experimental season

Summed dominance ratio	*W_{10}	W_{20}	W_{30}	W_{40}	W_{50}	W_{60}	**WF_0	WF_{10}	WF_{20}	WF_{30}	WF_{40}	WF_{50}	WF_{60}
Galinsoga parviflora	100.00	67.46	44.84	39.04	47.53	49.53	42.71	39.63	45.89	36.46	33.78	36.26	32.78
Polygonum aviculare	-	-	8.42	14.28	10.14	7.12	5.36	5.21	5.00	8.52	6.09	6.07	6.60
Vicia sativa	-	-	-	7.17	3.83	-	4.15	-	-	-	-	-	-
Bidens bipinnata	-	10.09	12.00	11.70	8.51	3.83	4.99	5.14	3.54	5.90	7.08	5.74	8.29
Oxalis acetocella	-	12.36	9.38	-	4.86	15.76	10.62	9.17	6.64	9.97	10.38	9.01	7.45
Echinochloa crusgalli	-	10.09	15.99	9.13	5.50	6.86	4.26	4.59	5.47	5.90	6.09	3.91	5.29
Cynodon dactylon	-	-	9.38	9.64	7.50	6.86	5.48	6.65	6.35	5.61	6.42	7.17	5.81
Ambrosia artemnisifolia	-	-	-	2.68	2.79	-	4.15	5.89	5.47	5.63	7.08	3.91	4.24
Emalia sonchifolia	-	-	-	2.68	-	-	4.01	3.65	3.54	2.86	3.72	4.37	4.24
Ageratum conyzoides	-	-	-	3.69	5.50	3.14	3.54	3.65	4.59	2.86	4.54	6.07	6.33
Crassocephalus crepidioides	-	-	-	-	3.83	4.80	4.26	6.40	4.63	5.90	4.28	6.44	7.03
Cardamine flexuosa	-	-	-	-	-	2.11	1.97	5.39	4.59	5.32	5.10	5.33	5.34
Bidens Pilosa	-	-	-	-	-	-	4.50	4.64	4.30	5.08	5.43	5.70	6.60
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

*W-weedy (where weed to allow to grow for different days); **WF-Weed free (where plots were kept weed free for different days)

Table 2. Seed index, pod yield, stover yield of pea and ET as influenced periodically by different stages of weedy and weed free treatments

Treatment	Seed index (g)	Pod yield (t/ha)	Stover yield (t/ha)	ET
*W_0	54.85a	8.17a	7.24ab	0
W_{10}	54.77a	8.13a	7.14ab	0.2146
W_{20}	52.44abc	7.85ab	7ab	0.5143
W_{30}	51.36bcde	7.22ab	6.68abc	0.3546
W_{40}	49.72cde	6.18cd	6.64abc	0.2731
W_{50}	48.9e	5.97d	6.54abc	0.2880
W_{60}	48.67e	5.31de	6.41abc	0.4113
**WF_0	48.45e	4.55e	4.7d	0
WF_{10}	49.25de	4.92e	5.59cd	0.4367
WF_{20}	49.28de	5.38de	5.89bcd	0.3502
WF_{30}	50.71bcde	6.16cd	6.1abc	0.4043
WF_{40}	51.18bcde	6.97bc	7.03ab	0.5709
WF_{50}	52.04abcd	7.92ab	7.32a	2.1484
WF_{60}	53.09ab	8.15a	7.36a	20.910
LSD (p=0.05)	2.69	0.98	1.37	-

*Figures not sharing the same letters in the same column differs significantly at pd”0.05; *W-weedy (where weed to allow to grow for different days); **WF-Weed free (where plots were kept weed free for different days); (Weed free pea pod yield = 8.17 t/ha); ET, economic threshold

Growing Degree Day (GDD)

Accumulated heat units in terms of growing degree day (GDD) were estimated for the entire growing season of the pea crop, with 5 °C as base temperature. The total heat units accumulated in terms of °C day from sowing to final harvest was 1289.9 °C day.

Critical period of weed- crop competition (CPWC)

The CPWC was determined using relative pea yield (% of weed free pea yield) and Days after sowing DAS or GDD. The logistic equation was best fitted to the relative yield of weedy set of treatments and gave the beginning of the critical period. While, the Gompertz equation was a good fit for the relative yield of weed free set of treatments and was used to estimate the end of critical period. The experimental results showed that at 5% relative yield loss (RYL), the critical period for pea weed competition began at 21 DAS and continued up to 48 DAS. At 10% RYL, the critical period was estimated to be from 28 to 44 DAS (**Figure 3**). Mostly the critical period of crop weed competition of various crops has been reported as days after sowing (DAS). Similarly, Singh *et al.* (2016) reported that the CPWC for field pea varied from 20-63 days at 5% RYL, and 30-53 days at 10% RYL. Zimdahl *et al.* (1988) opined that CPWC is not an inherent property of a crop and can vary depending on weed species, site, specific crop and even season. Ka *et al.* (2020) reported the CPWC for sorghum between 15-45 and 15-55 DAS under unfertilized conditions and 10-55 and 15-55 DAS under fertilized conditions. Elamin *et al.* (2019) reported that the critical period of weed-okra competition was between 6 and 8 weeks after sowing.

However, differences in prevailing climatic conditions and varied sowing dates may lead to greater variability in the CPWC among locations and even seasons, thereby making results for experiments conducted on same crop in a specific season and location unreliable in other location. As GDD provides more meaningful insights into the time required for plant growth and development, in recent studies it has been used as a basis to estimate the CPWC, over DAS. In the current study, the critical period of pea weed competition was 260 to 510 °C GDD and 330 to 480 °C day GDD, at 5% and 10% RYL, respectively (**Figure 4**). Smitchger *et al.* (2012) also estimated that weeding should be done between 270 to 999 °C day GDD in lentils so as to prevent yield loss more than 5%.

Economic threshold (ET)

The economic threshold of multi-species weeds in pea varied with pea weed competition, yield and cost of weeding. The ET of W_0, W_{10}, W_{20}, W_{30}, W_{40}, W_{50}, W_{60}, WF_0, WF_{10}, WF_{20}, WF_{30}, and WF_{40}

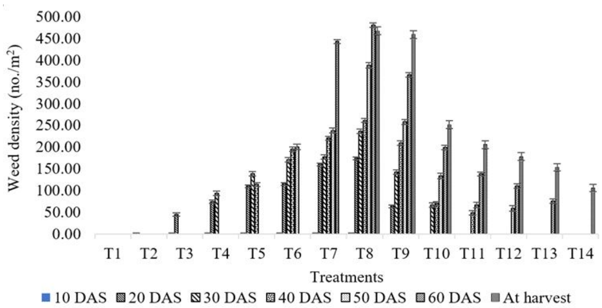

Figure 1. Density of weeds in pea as influenced periodically by different stages of weedy and weed free treatments

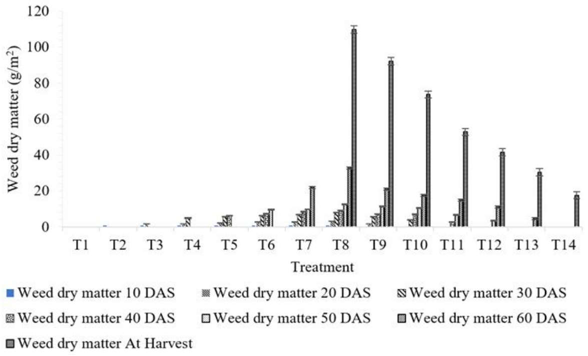

Figure 2. Dry matter accumulation of weeds in pea as influenced periodically by different stages of weedy and weed free treatments

ranged from 0 to 0.57 plants/m^2 (**Table 2**), which were uneconomical. Further, the ET of weed free plot up to 50 DAS (WF_{50}) and 60 DAS (WF_{60}) was 2.15 and 20.91 plants/m^2, where the cost of weeding/ha as ₹ 10800 and ₹ 12600, yield was 7.92 and 8.15 t/ha, price of the produce was ₹ 3,80,000 and ₹ 3,91,360/ha, proportional loss of yield per unit weed density was 0.17% and 0.19%, respectively. The findings are in accordance with Galon *et al.* (2016), who reported an ET of 2.20-8.72 plants/m^2 for various bean cultivars and Al Mamun (2014) reported when weed population exceeds 2.93 plants/m^2 can embark economic and yield losses.

It can be concluded that for optimum utilization of resources and maximization of yield, weeding practices in pea should begin at 21 DAS and continue up to 48 DAS, which is equivalent to 260-510 °C day GDD, at 5% RYL. At 10% RYL, the CPWC for pea was 28 to 44 DAS or 330 to 480 °C day GDD. The ET for pea crop was estimated to be 2.15 to 20.91 plants/m^2. Maintaining weed population below 2.15 plants/m^2 will be uneconomical, while weed population above 20.91 plants/m^2 will cause economic losses.

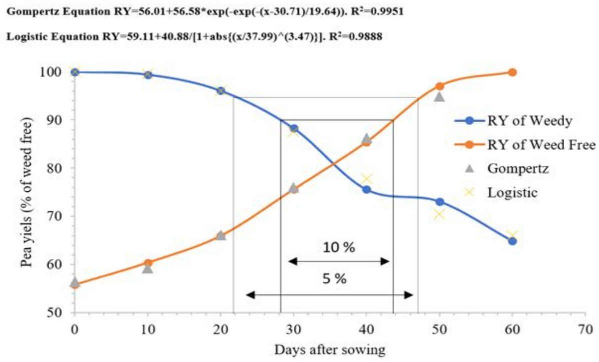

Figure 3. Critical period for pea-weed competition (DAS basis)

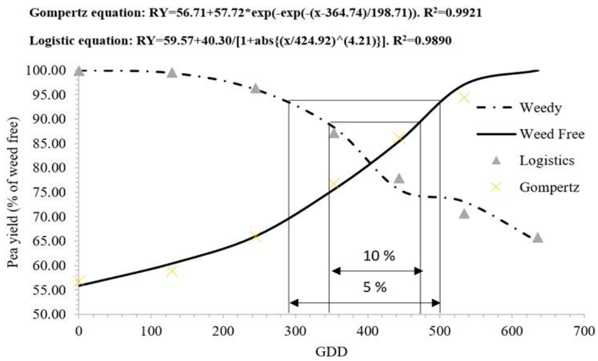

Figure 4. Critical period for pea-weed competition (GDD basis)

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