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PERSPECTIVE OF LOTKA-VOLTERRA MODEL IN INTERSPECIFIC COMPETITION BETWEEN *ZEA MAYS* AND *SORGHUM BICOLOR*

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Abstract

Plant-plant interaction plays a pivotal role during seed germination and vegetative growth. Interaction between the plants of the same species is known as intraspecific competition and between different species is called as interspecific competition. In the present pilot study, we have evaluated the interspecific competition of *Zea mays* and *Sorghum bicolor*, grown together in different density dependent growth modeling design. In series of different experimental design, we evaluated the intensity of interspecific competition between these two crops. To understand the intensity of competition, we evaluated the percent seed germination, shoot and root length, biomass (wet and dry), protein, chlorophyll content, proline and peroxidase activity of the two crops. All these parameters show no particular trend and changes randomly, revealing the complex nature of such type of experiments. However, overall growth is affected at higher density of plants showing that intensity of competition is evident. *Zea mays*, due to its faster growth rate out-compete *Sorghum* plants in majority of these experiments. We observed that intraspecific competition more than interspecific competition.

Key words : Carrying capacity, competition, logistic model, Lotka-Volterra model, percent seed germination.

Introduction

Plant-plant interaction is an important element in influencing the plant behavior and evolution. During interaction between plants, competition occurs for limited resources. Competition between individuals of same species is known as intraspecific competition and between individuals of different species is called as interspecific competition and it is fundamental to ecosystem functioning (Tilman *et al.*, 2004). Competition influences the community structure and evolution of the plants. Resources for which plants compete are water, mineral elements from soil, space, sunlight etc. Further, to out-compete the plant species, other plants devise many strategies, like they release chemicals, which are harmful to other competing plants (allelopathy), or they grow faster than other plants, produce many seeds etc. These strategies put the different plant species as having dominating behavior in relative terms. Overall impact of these strategies is successful survival of plant species. In this ecological game, biomass of plant play important role. The biomass allocation pattern is influenced, if there is change in above ground competition to below ground competition. Further, successful survival is influenced by reproductive allocation also. To understand the outcome of interspecific competition, Lotka-Volterra equation is best example to study in nature. According to Lotka-Volterra model, during plant-plant interaction, four different out-comes are possible. If species 1 is having dominating behavior and carrying capacity in the system then species 1 will win and vice versa. However, if plants have intense interspecific competition than intraspecific competition then species with higher abundance at the start will win in long run. But, if the intraspecific competition is more than interspecifc competition, than a stable equilibrium will be established and species can co-exist (Smith and Smith, 2012). In present study our objective was to assess the interspecific competition between to crop plant, alike in size and habitat. To measure the competition and to test the Lotka-Volterra model in practical sense, we measured the vegetative and biochemical parameters of two plants grown together. Such type of work has been reported earlier also (Hosono,

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Table 1 : Vegetative parameters of *Zea mays* (M) and *Sorghum bicolor* (S) at different seed density combination.

S. no.	Seeds combination	*Zea mays*			*Sorghum bicolor*		
		Percent seed germination (in %)	Shoot length (Mean±SD) (in cm)	Root length (Mean±SD) (in cm)	Percent seed germination (in %)	Shoot length (Mean±SD) (in cm)	Root length (Mean±SD) (in cm)
Exp 1							
1.	10M/50S	86.67	35.22±5.94	14.84±1.96	72.67	19.32±3.90	10.58±1.54
2.	20M/40S	83.33	31.90±4.18	15.26±1.04	70.83	21.60±1.16	10.00±1.92
3.	30M/30S	90.00	30.74±7.72	13.24±2.90	73.33	19.42±1.34	10.82±1.39
4.	40M/20S	90.00	31.62±5.07	13.74±0.45	83.33	18.70±1.52	10.24±1.55
5.	50M/10S	90.67	30.22±4.23	16.48±1.87	83.33	17.86±2.27	11.44±0.79
Exp 2							
1.	10M/10S	93.33	33.98±8.02	15.68±2.48	73.33	24.78±1.21	11.10±1.37
2.	20M/20S	86.67	33.66±3.47	17.18±1.53	58.33	18.80±1.90	13.48±2.21
3.	30M/30S	83.33	34.14±4.64	15.54±1.38	73.33	21.04±1.27	12.02±0.83
4.	40M/40S	82.50	35.90±1.13	15.10±1.30	80.83	18.64±1.72	13.42±1.78
5.	50M/50S	82.67	20.08±4.08	12.86±0.95	60.00	17.18±3.62	10.30±1.33
Exp 3							
1.	10M/10S	93.33	31.40±4.06	14.40±0.68	80.00	27.82±1.29	11.24±1.06
2.	20M/10S	86.67	30.68±8.31	15.64±3.85	76.67	16.24±4.68	11.18±1.86
3.	30M/10S	82.22	37.84±1.26	15.98±1.75	70.00	16.84±4.12	11.60±2.31
4.	40M/10S	63.33	32.54±3.70	15.74±0.95	80.00	17.14±1.53	11.24±1.94
5.	50M/10S	68.00	34.08±2.65	17.14±3.23	73.33	19.70±1.29	11.04±3.55
Exp 4							
1.	10M/10S	100.00	36.30±6.91	13.18±2.64	73.33	22.28±3.45	10.20±3.08
2.	10M/20S	86.67	34.62±5.98	15.08±1.33	83.33	27.20±4.09	11.96±1.13
3.	10M/30S	90.00	39.98±3.59	17.30±0.39	84.44	25.64±3.94	12.00±1.81
4.	10M/40S	93.33	42.22±5.62	16.38±2.36	66.67	24.26±7.11	9.90±1.44
5.	10M/50S	90.00	37.86±7.54	13.22±1.44	85.00	25.96±5.50	10.96±2.19

1998; Connolly *et al.*, 2000). We assumed that competition will influence the growth and vegetative parameters if two plants are grown together at different density. There can be interspecific as well as intraspecific competition, we hypothesized. This type of investigation is important in understanding the plant-plant interaction, competition, species distribution and community structure.

Materials and Methods

Experimental design

Two important crop plants, *Zea mays* (variety RMH4794) and *Sorghum bicolor* (variety SAMRAT) were taken to access interspecific competition. Crops were sown in as per four different experimental designs. Experiment 1, focuses on inverse gradient relationship, in which seeds of one plant increases while seeds of another plant decreases (fig. 1). Experiment 2 focuses on increasing density gradient of both the crop simultaneously. Experiment 3, maintain the constant number of *Sorghum* seeds, while seed number of *Zea mays* increases in five different treatments. In experiment 4, constant numbers of maize seeds were maintained, while increasing the seed number of *Sorghum* (fig. 1).

Vegetative parameters

Percent seed germination is observed after seven days of seed sowing. Plants were harvested after 30 days of vegetative growth. Vegetative parameters like shoot length, root length, wet biomass were estimated. After 24 hrs of oven dry period, dry biomass is also determined.

Determination of chlorophyll content

Chlorophyll is extracted in 80% acetone and the absorbance recorded at 663 nm in a spectrophotometer and the amount of chlorophyll is calculated as per Arnon (1949).

Total protein content

Protein level was estimated by Lowry *et al.* (1951)

	A1B1	A2B2	A3B3	A4B4	A5B5
Exp.1	10M/50S	20M/40S	30M/30S	40M/20S	50M/10S
Exp. 2	10M/10S	20M/20S	30M/30S	40M/40S	50M/50S
Exp. 3	10M/10S	20M/10S	30M/10S	40M/10S	50M/10S
Exp. 4	10M/10S	10M/20S	10M/30S	10M/40S	10M/50S

Fig. 1 : Experimental Design for understanding Interspecific competition between *Zea mays* (M) and *Sorghum bicolor* (S). In different experiment different seed combination are tested.

Table 2 : Biomass (wet and dry; mean of five replicates; in mg) of *Zea mays* and *Sorghum bicolor* at different seed density combination.

S. no.	Seeds combination	*Zea mays*				*Sorghum bicolor*			
		Wet biomas (Shoot)	Wet biomass (Root)	Dry biomass (Shoot)	Dry biomass (Root)	Wet biomas (Shoot)	Wet biomass (Root)	Dry biomass (Shoot)	Dry biomass (Root)
Exp 1									
1.	10M/50S	752	320	41	33	68	9	7	1
2.	20M/40S	553	267	31	36	90	9	9	1
3.	30M/30S	475	292	32	42	70	4	3	1
4.	40M/20S	597	287	37	39	68	11	5	1
5.	50M/10S	540	324	44	58	57	11	5	3
Exp 2									
1.	10M/10S	614	417	38	57	91	8	4	1
2.	20M/20S	608	453	37	66	190	12	6	2
3.	30M/30S	518	321	26	38	89	10	6	1
4.	40M/40S	570	298	46	48	65	8	4	1
5.	50M/50S	236	246	24	76	39	7	5	2
Exp 3									
1.	10M/10S	647	442	37	66	112	11	9	2
2.	20M/10S	660	329	36	51	56	14	3	2
3.	30M/10S	792	381	42	42	70	6	6	1
4.	40M/10S	648	408	42	51	59	13	4	1
5.	50M/10S	649	343	47	38	83	8	2	1
Exp 4									
1.	10M/10S	890	381	54	37	85	6	7	1
2.	10M/20S	580	315	39	37	103	11	10	3
3.	10M/30S	953	345	61	43	84	13	8	4
4.	10M/40S	1118	318	78	33	75	11	3	4
5.	10M/50S	763	252	50	39	86	9	8	2

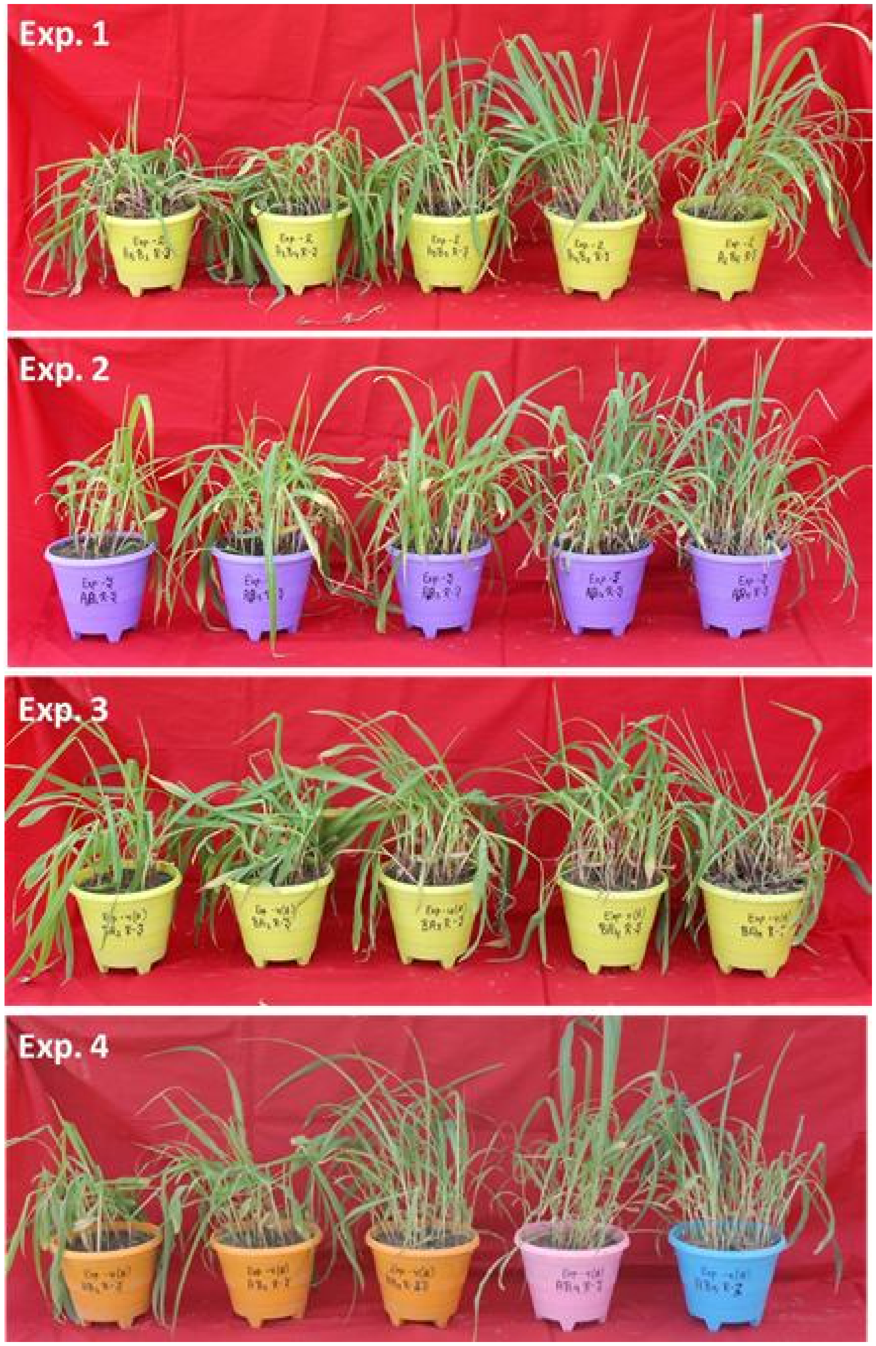

Fig. 2 : Plants of *Zea mays* and *Sorghum bicolor* grown with different density of seeds for interspecific competition assessment.

as modified by Herbert *et al*. (1971) using BSA as the standard.

Proline estimation

As per protocol given in Plummer (1971).

Estimation of peroxidase activity

As per protocol given in Plummer (1971).

Results and Discussion

For both the crops, seed germination percentage remains above sixty percent. For *Zea mays*, minimum and maximum percent seed germination recorded is 63.33% and 100% respectively, as mentioned in table 1. Careful observation reveal that as the density of *Sorghum* plant increase, it shows lower seed germination percentage, which means that, for *Sorghum*, intraspecific competition is more dominant than interspecific competition with maize plants. Further, we observed that percent seed germination does not show any particular trend or direction as per our experimental design and

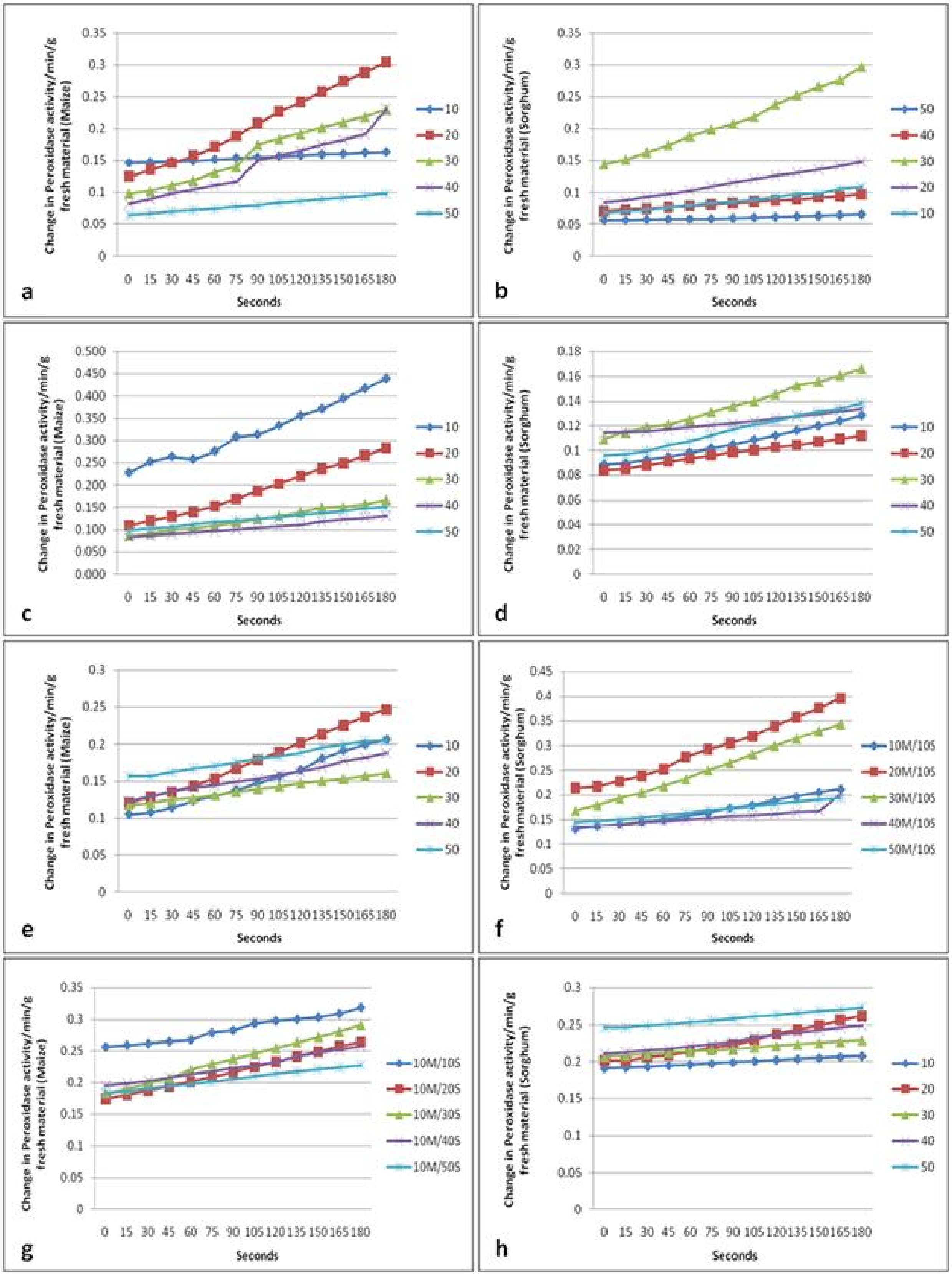

Fig. 3 : Peroxidase activity in *Zea mays* and *Sorghum* observed after density dependent interspecific competition. Annotation mentioned in this figure belongs to as follows: Exp.1 *Zea mays* (a), *Sorghum* (b), Exp.2 *Zea mays* (c), *Sorghum* (d), Exp.3 *Zea mays* (e), *Sorghum* (f), Exp.4 *Zea mays* (g), *Sorghum* (h).

Table 3 : Biochemical parameters of *Zea mays* (M) and *Sorghum bicolor* (S) at different seed density combination.

S. no.	Seeds combination	*Zea mays*			*Sorghum bicolor*		
		Protein ($\mu g\ \mu l^{-1}$) (Mean±SD)	Proline ($\mu g\ \mu l^{-1}$) (Mean±SD)	Chl a (mg/g) (Mean±SD)	Protein ($\mu g\ \mu l^{-1}$) (Mean±SD)	Proline ($\mu g\ \mu l^{-1}$) (Mean±SD)	Chl a (mg/g) (Mean±SD)
Exp 1							
1.	10M/50S	662.28±9.39	33.65±0.11	5.03±0.06	600.00±0.60	30.00±0.29	4.22±0.00
2.	20M/40S	1154.80±2.12	11.73±0.28	3.99±0.01	674.08±1.19	0.87±0.82	4.40±0.02
3.	30M/30S	829.45±1.79	14.13±0.14	2.90±0.02	1519.20±1.19	2.78±0.15	6.81±0.02
4.	40M/20S	542.32±1.19	13.62±0.20	3.48±0.01	681.67±2.38	10.84±0.05	4.89±0.04
5.	50M/10S	594.29±7.55	10.10±0.14	3.23±0.04	463.93±1.19	13.81±0.02	3.25±0.02
Exp 2							
1.	10M/10S	754.16±2.98	1.89±0.06	1.76±0.03	600.00±1.79	30.00±11.91	2.48±0.02
2.	20M/20S	642.34±1.79	0.02±0.05	2.55±0.02	694.31±2.38	7.23±0.28	3.97±0.02
3.	30M/30S	594.85±2.38	-1.37±0.02	1.74±0.01	533.04±1.19	6.45±0.06	2.55±0.01
4.	40M/40S	554.40±0.60	0.32±0.03	3.94±0.23	762.30±1.79	1.79±0.22	2.03±0.04
5.	50M/50S	603.28±0.60	3.45±0.02	3.60±0.02	878.90±1.19	3.71±0.11	2.11±0.02
Exp 3							
1.	10M/10S	403.52±0.60	-1.05±0.03	5.63±0.01	600.00±0.60	30.00±0.05	4.77±0.03
2.	20M/10S	340.87±0.60	6.33±0.17	5.77±0.02	243.94±1.19	-1.96±0.02	5.24±0.02
3.	30M/10S	518.15±1.79	6.09±0.05	3.22±0.04	391.44±1.19	-1.46±0.03	3.20±0.06
4.	40M/10S	457.75±1.19	2.54±0.02	5.11±0.02	1147.50±2.98	0.69±0.05	2.74±0.02
5.	50M/10S	386.66±0.60	5.41±0.06	7.59±0.06	290.30±1.19	3.83±0.06	5.32±0.14
Exp 4							
1.	10M/10S	820.46±1.19	-2.60±0.06	4.69±0.03	600.00±7.15	30.00±0.05	2.87±0.02
2.	10M/20S	939.87±2.38	1.88±0.02	2.44±0.05	694.03±1.19	-2.27±0.02	2.71±0.02
3.	10M/30S	963.75±2.98	13.55±0.08	5.03±0.05	651.89±1.19	-1.49±0.02	4.12±0.05
4.	10M/40S	905.59±2.98	-2.82±0.05	5.19±0.01	832.54±0.60	-2.63±0.02	3.12±0.02
5.	10M/50S	998.59±1.19	-3.20±0.02	7.54±0.03	728.87±1.79	10.20±0.06	5.70±0.00

therefore nothing much can be predicted from the present study. More in-depth study is required before any final conclusion can be made. Earlier studies have reported that as the density of plant increases, percent seed germination decreases (Chatworthy, 1960). Interspecific competition assessment of *Zea mays* and *Sorghum* plants revealed that as the intensity of competition increases we observed decrease in shoot length; however root length increase slightly for both the crops in all of the experiments (table 1, fig. 2). Intraspecific competition however seems to play more dominating role and it is found that as the density of *Zea mays* plant increases, shoot length decrease, irrespective of density of *Sorghum* plant and vice versa. Increase in root length indicates more competition for water resources, forcing the plant to reallocate its biomass towards more growth of root, thereby compromising shoot growth. Such switch over of plant biomass from shoot to root has been reported earlier also (Stoll *et al*., 2001). Shoot biomass (wet) decreases significantly as the intensity of interspecific and intraspecific competition increases in both the crops (table 2). Root biomass increases slightly as the density of plants increases in different set of experiments. At higher intensity of interspecific and intraspecific competition, overall growth is significantly affected. This is in conformity with earlier reported studies (Donald, 1951). Dry biomass also shows increasing root biomass (dry) as the intensity of competition increases confirming reallocation of biomass for more root growth. In the present study we found that biochemical parameters are not good indicator to assess the intraspecific and interspecific competition. In all the experiments, protein, proline and chlorophyll content changes randomly and nothing can be predicted from the observed results (table 3). This may be due to experimental error. More studies are required to understand the role of biochemical parameter in understanding the competition level in plants. However, peroxidase activity revealed that physiological state of the plant suggests that plant is under stress (fig. 3).

Conclusion

Vegetative parameters clearly reveal the reduction in overall plant growth and reallocation of plant biomass from shoot to root. Most of the parameter shows metabolic switch due to severe interspecific and intraspecific competition at higher density level of *Zea mays* and *Sorghum bicolor*. In this study, we observed that intraspecific competition is more severe than interspecific competition and therefore co-existence is possible in short term.

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