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Weed-crop behaviour in pure and mixed stands of maize and *Echinochloa colona* Link.

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ABSTRACT

The interference between maize and *Echinochloa colona* was studied by growing the two species in pure and mixed stands under varied nutritional levels in the soil. Both the species responded to density stress in pure stands by mortality and plasticity. Density dependent mortality was comparatively higher for maize than for *E. colona*. The higher mortality rate of maize was related to the higher growth rate in this species. The dry matter production was also more sensitive to density stress for maize than for *E. colona*. The generally higher mortality in the more fertile soil was explained as due to the better expression of genotypic individual differences and the consequent elimination of the weaker individuals by more vigorous ones.

In mixed stands, whilst the reciprocal effects of the weed and the crop were brought out due to suitable experimental design, the effect of the weed on the crop was less marked as compared to the reverse effect. This was due to differences in size and growth habit of the two competing species. Whilst the effect of the weed on the crop may be purely a competition by roots for nutrients from the soil the reverse effect could be primarily due to shading of the weed by the crop. The plasticity and mortality responses of the two competing species are discussed and it was shown that : (i) the effect of the weed on the crop was enhanced due to an early start that the former may receive in the mixture and the adverse effect was realized in cob characters and (ii) the interference from the weed to the crop is a continued risk throughout the life cycle and that longer the period of association between the two, greater the damage done to crop yield.

1. INTRODUCTION

CONSIDERABLE studies have been made recently on weed-crop interference where competitive influences have been assessed not merely as an agronomic problem but more as an ecological problem (Harper and Gagic, 1961 : Ramakrishnan and Kumar, 1971*a*, *b*; Donald, 1963 ; Kapoor and Ramakrishnan, 1975).

The results presented here concern with weed-crop interference where competing species are dissimilar in size. *Echinochloa colona* Link. is a weed at Chandigarh and other parts of India associated with maize and also growing in waste lands during the rainy season. The weed exhibits a wide ecological amplitude due to the existence of a complex pattern of ecotype differentiation (Ramakrishnan, 1960 ; Kapoor and Ramakrishnan, 1974). For the present studies, the 'short form' of *E. colona* (Ramakrishnan, 1960) was used in pure cultures as well as in mixed cultures with maize, with the object of assessing reciprocal influences of one on the other.

2. METHODS

Ganga 101 hybrid maize plants and *E. colona* were raised from seeds. Excess seeds were sown and seedlings were thinned down on emergence to the desired level. All experiments were performed in the alluvial soil of the Experimental Garden at Chandigarh. The crops were irrigated once a week to supplement rain water. The experiments were conducted in plots of $0 \cdot 25\ m^2$ between July and October, 1969 and 1970, and were replicated three times. At harvest a 10 cm wide strip was discarded around each plot in order to avoid border effects. At the conclusion of the experiment, mature plants were harvested. The growth measurements are based upon 10 plants from each of the three replicates. The experimental design was completely randomized and the treatment combinations were as detailed below :

In experiment 1, maize and E. *colona* were raised in pure cultures in a low (unaltered soil) and high (NPK altered) nutrient soil with 24, 40, 100, 200, 400, 800, and 1,600 individuals/m^2. The mixed cultures at three density levels for maize (M) and *E. colona* (E) in experiment 2, had a low density of 100, a medium density of 200 and a high density of 400 plants/m^2 in combinations: 100 M+100 E, 100 M+200 E, 100 M+400 E, 200 M+100 E, 200 M+200 E, 200 M+400 E, 400 M + 100 E, 400 M + 200 E, 400 M + 400 E. In another mixed culture experiment (experiment 3) maize was kept at a constant density of 20 individuals/m^2 but *E. colona* had varied densities resulting in combinations : 20 M + 100 E, 20 M + 200 E, 20 M + 400 E, 20 M + 800 E and 20 M + 1600 E. Effect of NPK, N, P and K alterations in the soil was studied in these mixtures by applying appropriate salts either individually or in mixtures at the rate given below. In experiment 4, time of introduction of the two species into the mixture was varied : (i) maize 21 days before *E. colona* (M > E), (ii) both simultaneously introduced (M ≡ E) and (iii) *E.*

colona 21 days before maize (M < E). The time of removal of weed was varied in mixtures (experiment 5) by removing weed at vegetative, flowering and fruiting stages of its growth (R_1, R_2, R_3, respectively). These three stages of growth of the weed correspond more or less with the same stages in the growth of the crop. Mixtures for both the introduction and removal experiments had the same density combinations as were taken for the study of the effect of nutrient alterations in the soil.

The composition of salts used for NPK alterations which was given as a surface dressing was as follows : 25·06 g/m² of nitrogen as $NaNO_3$, 45·38 g/m² of potassium as K_2SO_4 and 7 g/m² of phosphorus as NaH_2PO_4. Where only one of the three nutrients were added, the appropriate salt was applied at the rate given above. An unaltered soil served as the control.

The chemical analysis of plant material for Ca and Mg was done by dry ashing leaf samples and following the methods outlined by Piper (1944). Nitrogen was estimated by the conventional method using a microkjeldahl's apparatus. Phosphorus in the plant tissue was determined by the chlorostannous reduced phosphomolybdic blue method (Snell and Snell, 1949).

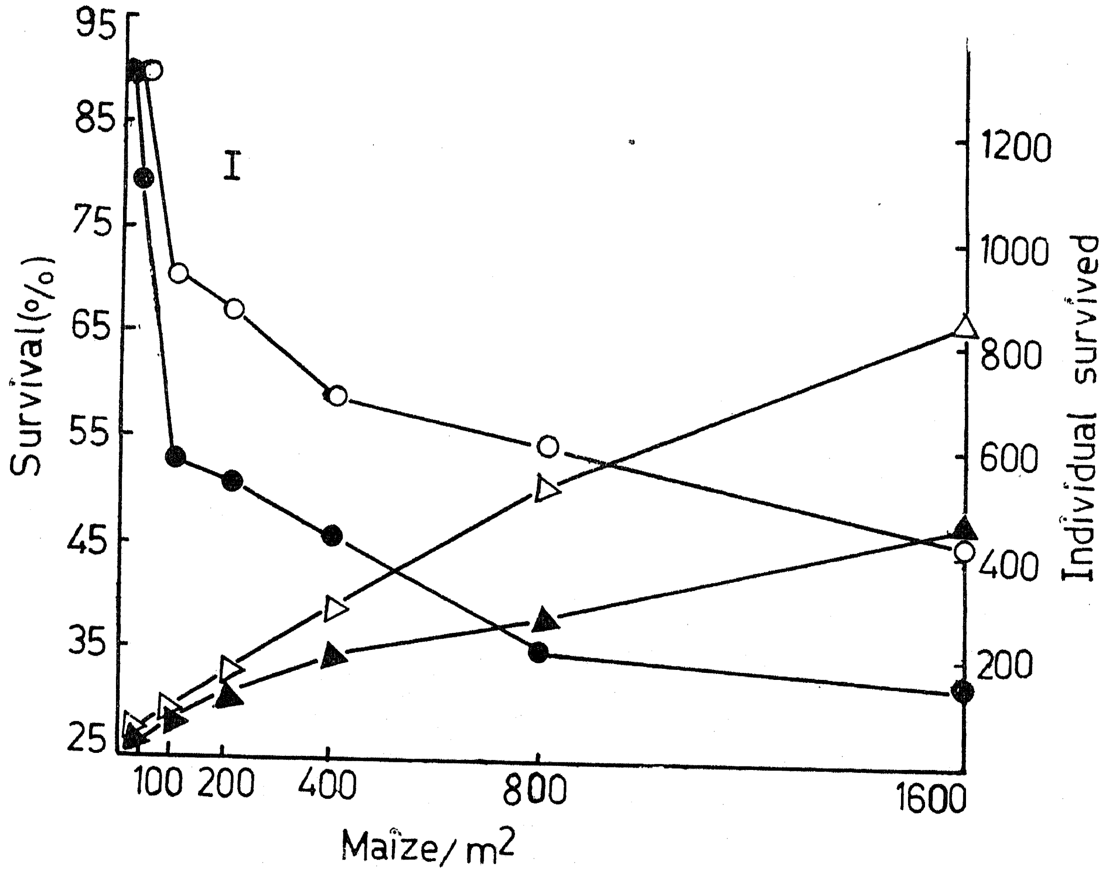

Figure 1. Relationship between survival of maize and density at two nutrient levels O ●, survival (%); Δ ▲, survival number; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at P = 0·05.

3. RESULTS

Experiment 1—Pure Stands

Maize responded to increased density both by mortality and plasticity. Mortality set in at a very early stage (within 7 days) of the life of plants particularly at higher densities (Ramakrishnan and Kumar, 1971 *a*) beyond a density of 40 plants/m^2 at both nutrient levels, and it was more pronounced in the nutrient rich soil (figure 1). Shoot yield per plant at both nutrient levels decreased markedly with increase in population size, though the yield was significantly higher in the more fertile soil. Whereas in the low nutrient soil the yield/m^2 improved with increase in density with a tendency for stabilization, in the high nutrient soil yield/m^2 improved with increase in plant population size and decreased significantly at 1,600 plants/m^2 (figure 2). Number of seeds per cob decreased significantly with increase in density though seed yield was higher in the more fertile soil. No cobs were formed beyond 40 and 100 plants/m^2 in the low nutrient and high nutrient soils, respectively. In those densities where cob formation was there seed output/m^2 was more or less unaffected in the less fertile soil but markedly decreased in the more fertile one (figure 3).

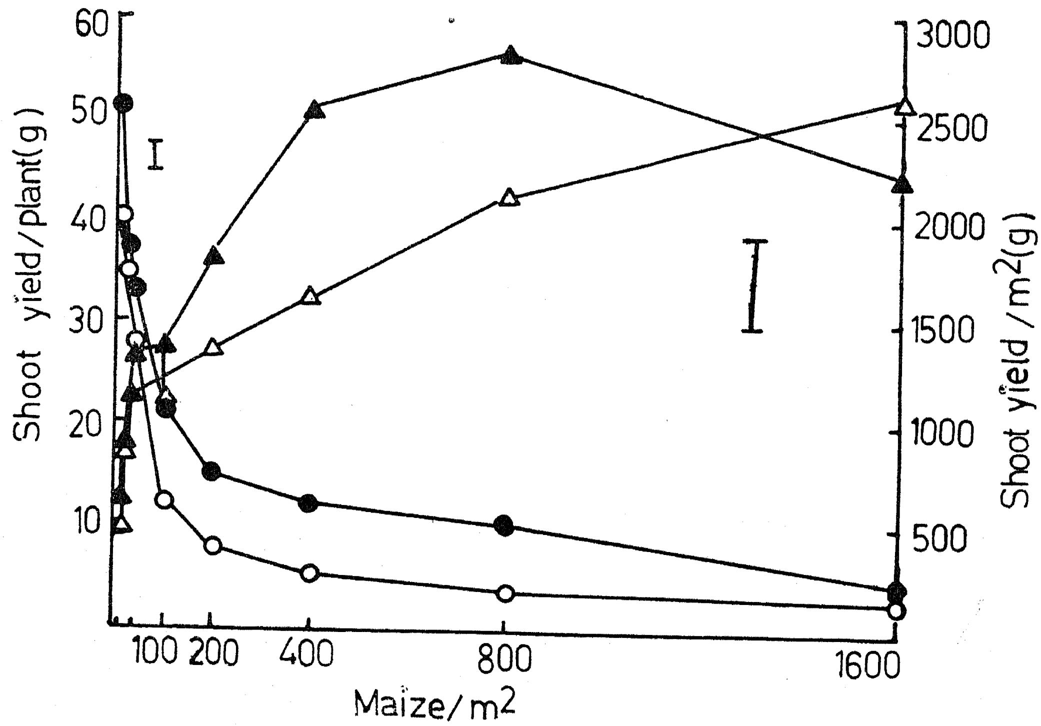

Figure 2. Relationship between shoot yield and density of maize at two nutrient levels. ○ ●, shoot yield/plant; △ ▲, shoot yield/m^2; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at $P = 0·05$.

E. colona also reacted to density stress both by mortality and plasticity. Mortality set in beyond 100 plants/m^2 in the low nutrient soil and beyond 40 plants/m^2 in the high nutrient soil. Mortality was higher in the more fertile soil compared to the low nutrient soil. Within the range of densities tried, the size of the established population increased with increase in initial density (figure 4). The dry weight yield per plant decreased with increase in density but yield/m^2 initially improved markedly, and less markedly at higher density levels with a tendency to attain a plateau value (figure 5). Seed output per plant decreased with increase in plant density, though the seed output was higher in the more fertile soil. Seed production/m^2 increased due to larger plant population in both low and high nutrient soils except that in the latter soil it declined at the highest density level (figure 6).

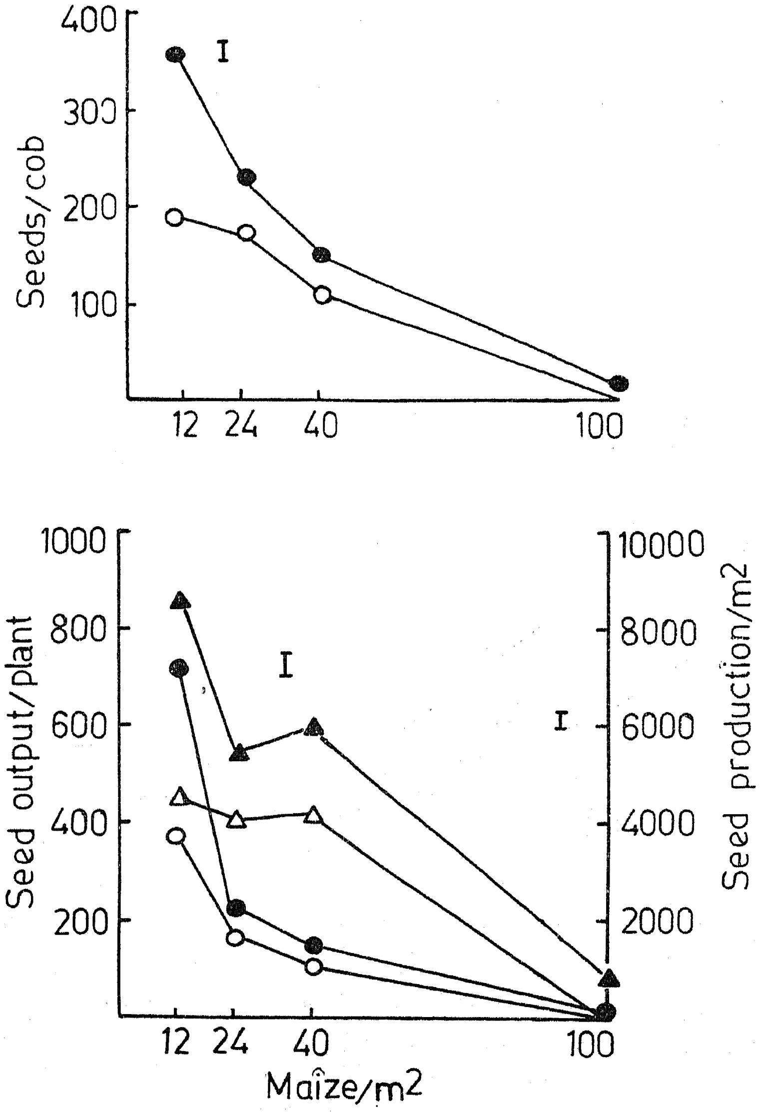

Figure 3. Relationship between reproductive characters and density of maize at two nutrient levels. O ●, seeds/cob and seed output/plant; △ ▲, seed production/m^2; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at $P = 0 \cdot 05$.

Experiment 2—Mixed stands at different densities of the two species

In maize, both increased intraspecific competition at a given weed density and interspecific competition from E. *colona* resulted in higher mortality. A similar mortality response was noted for *E. colona*. Whilst maize was more susceptible to intraspecific effect than interspecific one from the weed, the reverse was the case in the case of *E. colona*. The weed was susceptible to heavy mortality from maize and at very high densities of the crop and the weed, all individuals of the latter died (figure 7).

Shoot yield of maize suffered due to increased interference from the weed, this decline being more pronounced at lower densities of the crop in the mixture compared to higher densities. The yield of maize also declined due to increased intraspecific effect within maize population. Dry matter production/m^2 in maize declined due to interference from the weed at all densities of the former. At a density of 100 plants/m^2 of *E. colona* dry matter production of maize initially improved with increase in crop density

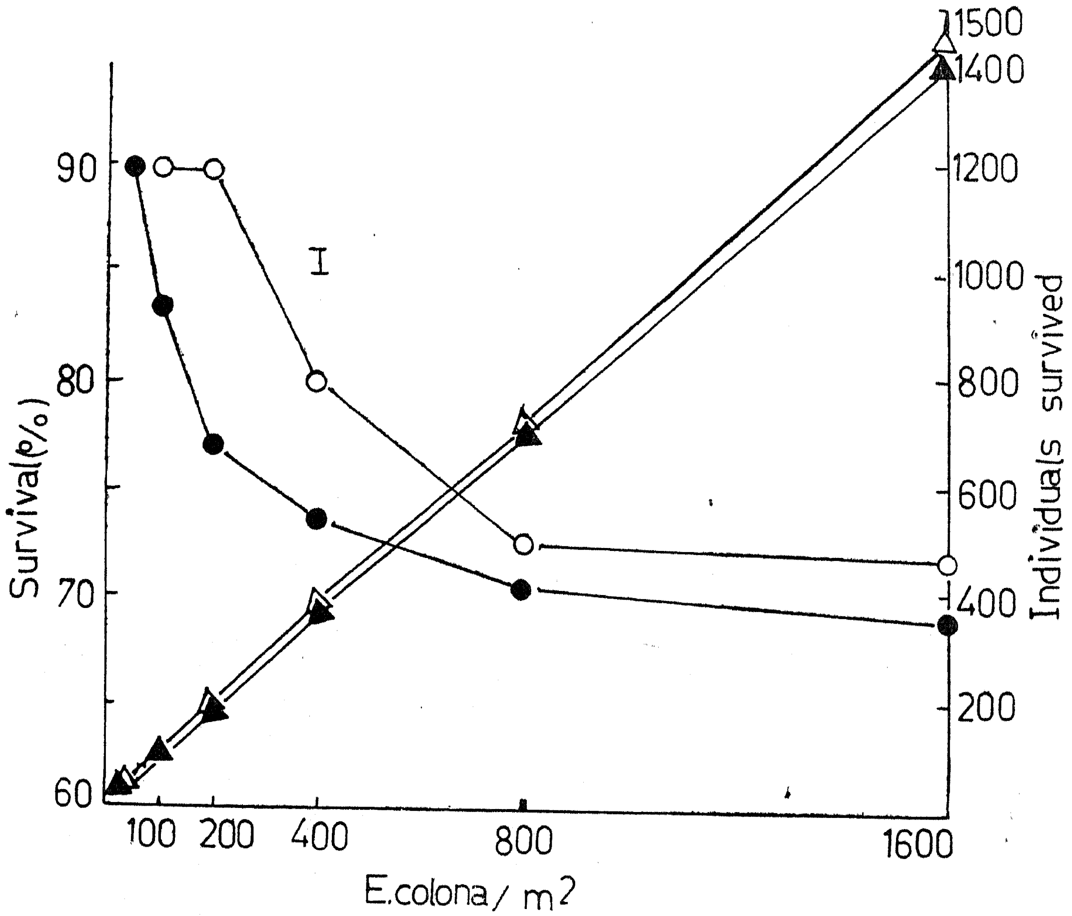

Figure 4. Relationship between survival of *E. colona* and density at two nutrient levels. O ●, survival (%); Δ ▲, survival number; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at P = 0·05.

but declined at the highest crop density. At densities of 200 and 400 *E. colona*/m² dry matter production improved at higher crop densities (figure 7). Dry weight yield of *E. colona* also decreased with increase in interference from the crop. In mixtures of higher densities of the two species, the weed failed to reach maturity and even in others, the plants remained depauperate (figure 8). At the densities of maize tried here, cob formation did not occur. Seed output of *E. colona* was adversely affected due to increased interference from the crop resulting in decreased seed yield or in the death of the individuals before maturity (figure 8).

Experiment 3—Mixed cultures at varied nutrient alterations

At the density used here, maize showed no mortality. *E. colona* showed considerable mortality in mixtures and it was generally higher in the altered soils as compared to the control. NPK altered soils showed greater mortality than those with only N, P or K alterations. Mortality was not significantly affected by N, P or K alterations. Increased intraspecific effect within this species resulted in increased mortality which was more marked in the altered soils compared to the control (table 1).

Dry weight yield of shoot per plant of maize was maximum in the NPK rich soil as compared with the control or other alterations. N and P alteration, at lower densities of *E. colona*, gave higher dry weight yield per plant for

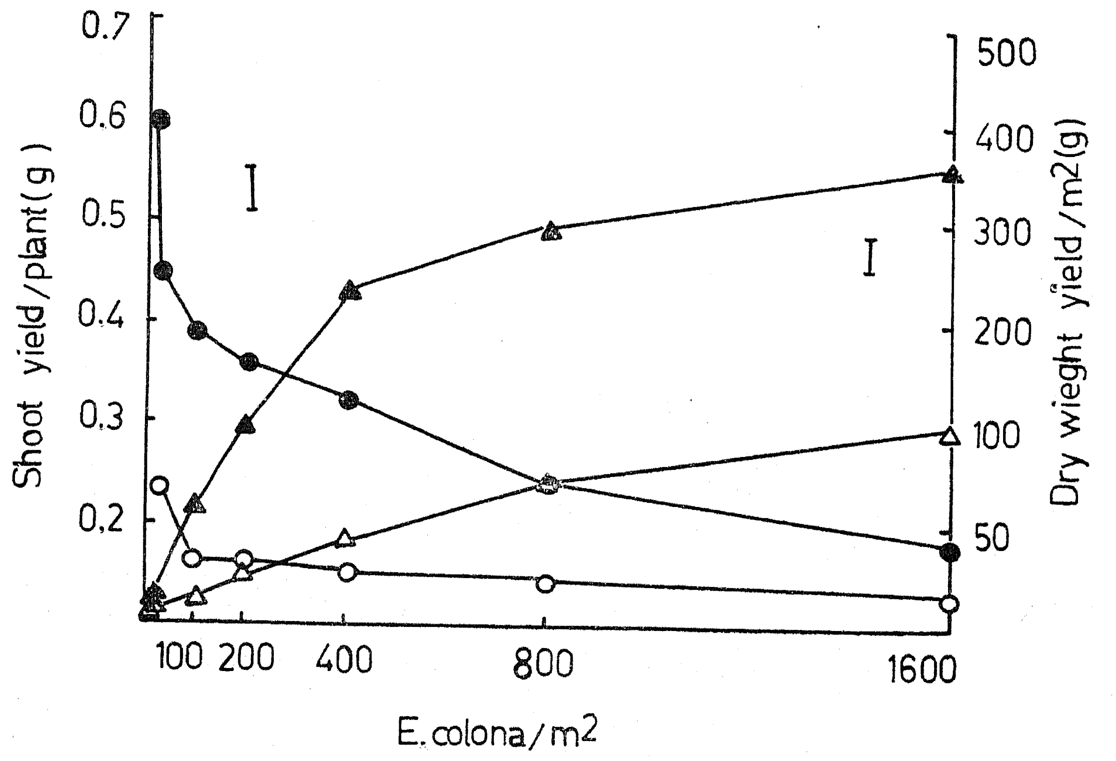

Figure 5. Relationship between shoot yield and density of *E. colona* at two nutrient levels. O ●, shoot yield/plant; Δ ▲, shoot yield/m²; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at $P = 0{\cdot}05$.

Table 1. Survival (%) of *E. colona* (mean values) in mixed stands of maize and *E. colona* at varied densities and nutrient alterations (angular transformation values in parentheses).

Initial density (Plants/M²)	Control	NPK	N	P	K	L.S.D. (P = 0·05)
20 M + 100 E	84·6 (67·2)	38·0 (38·1)	54·0 (47·3)	62·0 (51·9)	52·3 (46·1)	
20 M + 200 E	41·6 (40·4)	11·6 (20·3)	37·3 (37·5)	40·3 (39·2)	37·8 (38·1)	(4·6)
20 M + 400 E	28·3 (31·9)	10·3 (18·4)	14·3 (22·0)	16·8 (24·4)	13·2 (21·1)	
20 M + 800 E	27·4 (31·3)	8·6 (17·5)	9·9 (18·4)	11·6 (20·3)	11·6 (20·3)	
20 M + 1600 E	27·1 (31·3)	4·1 (11·5)	4·8 (12·9)	7·5 (16·4)	7·0 (15·3)	

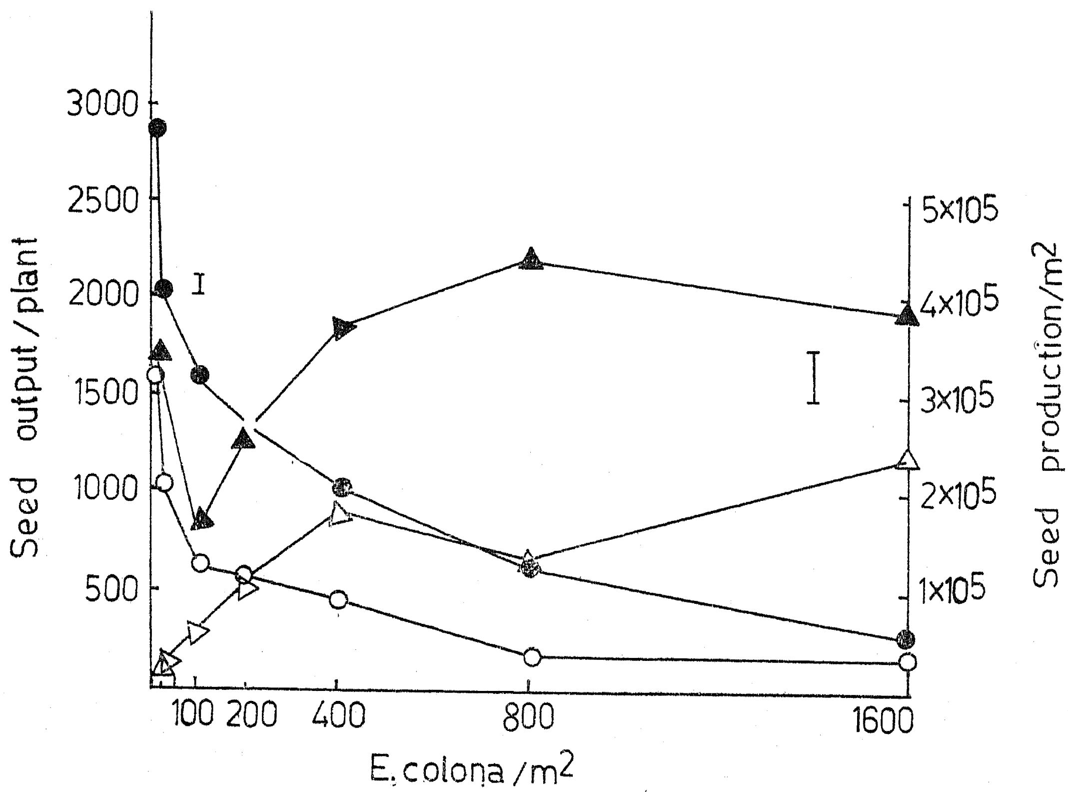

Figure 6. Relationship between reproductive characters and density of *E. colona* at two nutrient levels. O ●, seed output/plant; Δ ▲, seed production/m²; open symbols, low nutrient; closed symbols, high nutrient. Vertical line, L.S.D. at P = 0·05.

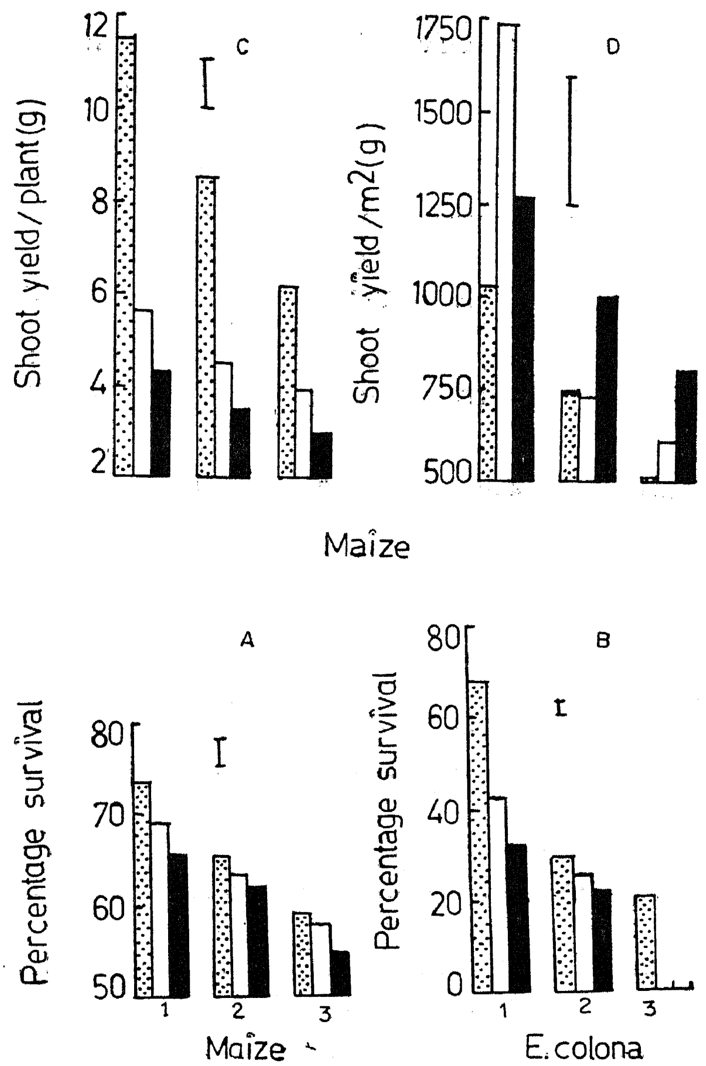

Figure 7. Percentage survival, shoot yield/plant and shoot yield/m^2 of maize in mixtures with *E. colona* (*a*, *c*, *d*) and survival of *E. colona* in mixtures with maize (*b*). Vertical line, L.S.D. at P = 0·05. 1,100 *E. colona*; 2,200 *E. colona*; 3,400 *E. colona*; stippled column, 100 maize; open column, 200 maize, closed column, 400 maize. Vertical line, L.S.D. at P = 0·05.

maize compared to K alterations. Interference from *E. colona* adversely affected the crop yield in altered as well as unaltered soils and this reduction was maximum in the control (table 2). *E. colona* also showed maximum dry weight yield per plant in NPK rich soils compared with the control or other alterations in the soil. K-rich soil had more favourable effect on its yield at higher densities when compared with N or P altered soils. Intra-specific competition from its own individuals resulted in marked decrease in its shoot yield (table 3).

Table 2. Dry weight yield of shoot per plant (mean values) (g) of maize in mixed stands with *E. colona* at various nutrient alterations and densities.

Initial density (Plants/M²)	Control	NPK	N	P	K	L.S.D. (P = 0·05)
20 M + 100 E	65·3 (2·8217)	96·3 (2·9837)	88·3 (2·9460)	84·5 (2·9250)	79·3 (2·8994)	
20 M + 200 E	29·6 (2·4718)	69·0 (2·8385)	48·6 (2·6869)	49·6 (2·6959)	41·1 (2·6145)	(0·03)
20 M + 400 E	27·5 (2·4393)	46·5 (2·6673)	35·7 (2·5525)	31·5 (2·4978)	37·0 (2·5688)	
20 M + 800 E	21·1 (2·3271)	33·0 (2·5183)	29·5 (2·4696)	27·0 (2·4305)	28·3 (2·4515)	
20 M + 1600 E	9·3 (1·9678)	20·8 (2·3182)	19·0 (2·2783)	19·0 (2·2798)	18·2 (2·2593)	

Table 3. Dry weight yield of shoot per plant (g) (mean values) of *E. colona* in mixed stands of maize and *E. colona* at varied densities and nutrient alterations.

Initial density (Plants/M²)	Control	NPK	N	P	K	L.S.D. (P = 0·05)
20 M + 100 E	0·363 (2·5592)	6·986 (3·8442)	5·946 (3·7738)	5·710 (3·7565)	3·788 (3·5786)	
20 M + 200 E	0·263 (2·4184)	4·150 (3·6175)	3·156 (3·4990)	2·070 (3·3159)	1·886 (3·2752)	(0·04)
20 M + 400 E	0·206 (3·3151)	1·976 (3·2952)	1·420 (3·1510)	0·956 (2·9806)	1·406 (3·1480)	
20 M + 800 E	0·186 (2·2700)	1·480 (3·1701)	0·776 (2·8899)	0·560 (2·7473)	0·860 (2·9342)	
20 M + 1600 E	0·035 (1·5412)	1·040 (3·0170)	0·560 (2·7476)	0·490 (2·6898)	0·653 (2·8141)	

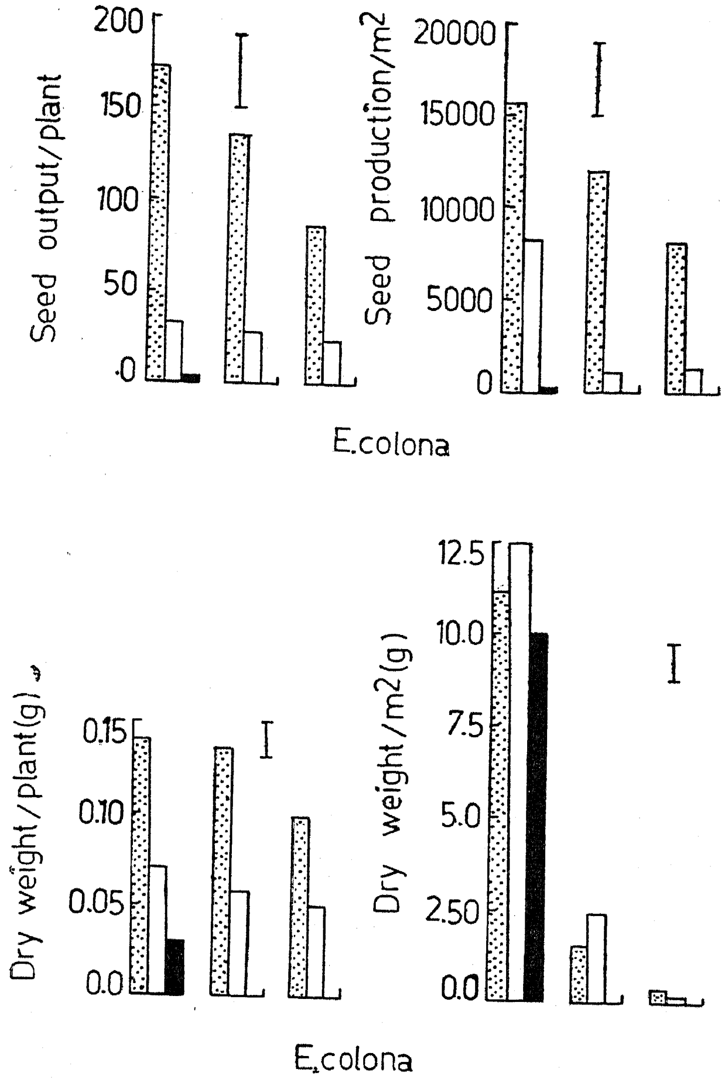

Figure 8. Shoot yield and seed yield of *E. colona* in mixtures with maize. 1,100 *E. colona*; 2,200 *E. colona*; 3,400 *E. colona*; stippled column, 100 maize; open column, 200 maize and closed column, 400 maize. Vertical line, L.S.D. at P = 0·05.

Individuals of maize in all the treatments produced only one cob per plant. Number of seeds per cob and average mean seed weight of 100 seeds of maize was significantly higher in the nutrient rich soils, maximum weight being in the NPK altered soils as compared to the control. Increase in the density of *E. colona* resulted in a significant decrease in both the parameters of the crop irrespective of the nutritional status of the soil (table 4).

Seed output per plant of *E. colona* at a given density improved significantly in the treated soils as compared to the control and this improvement was more obvious at higher densities of *E. colona*. Thus at the lowest density of *E. colona*, K and P altered soils did not differ significantly from the control

Table 4. Seeds/cob and average seed weight (g) per 100 seeds of maize (mean values) in mixtures of maize and *E. colona* at various nutrient levels and densities (seed wt. in parentheses).

Initial density (Plants/M²)	Nutrient levels: Low (Control)	High NPK	High N	High P	High K	L.S.D. (P = 0·05)
20 M + 100 E	209 (19·0)	396 (13·5)	380 (30·0)	335 (22·0)	338 (27·0)	
20 M + 200 E	199 (16·0)	384 (29·0)	328 (27·6)	293 (20·0)	313 (24·5)	8·6
20 M + 400 E	193 (15·2)	288 (27·0)	255 (24·6)	217 (18·5)	218 (21·8)	(2·8)
20 M + 800 E	181 (14·0)	254 (24·8)	166 (22·5)	163 (16·2)	165 (19·2)	
20 M + 1600 E	130 (14·0)	219 (21·7)	141 (20·0)	138 (14·0)	130 (16·0)	

Table 5. Seed output per plant (mean values) of *E. colona* in mixed stands of maize and *E. colona* at various nutrient levels and densities.

Initial density (Plants/M²)	Control	NPK	N	P	K	L.S.D. (P = 0·05)
20 M + 100 E	584·0 (3·7694)	860·3 (3·9324)	788·8 (3·8943)	641·4 (3·8069)	598·4 (3·7765)	
20 M + 200 E	180·1 (3·2530)	599·4 (3·7775)	517·1 (3·7085)	396·0 (3·5919)	380·0 (3·5760)	(0·95)
20 M + 400 E	62·2 (2·7936)	329·9 (2·3175)	316·8 (3·5006)	133·7 (3·1200)	189·0 (3·2719)	
20 M + 800 E	19·6 (2·2801)	97·5 (2·9841)	92·5 (2·9603)	97·0 (2·9840)	78·7 (2·8957)	
20 M + 1600 E	10·3 (2·0166)	62·6 (2·7966)	58·0 (2·7634)	53·2 (2·7253)	48·6 (2·6955)	

(table 5). As observed for other growth parameters, increase in the density of *E. colona* resulted in a significant decrease in the seed output per plant of this species, the decrease being less pronounced in the altered soils (table 5). Mineral uptake by maize showed a decline with increasing density of *E. colona* in the mixtures at low nutrient as well as NPK altered soils, with respect to Ca, Mg, P, K and N. Plants showed increased content of various nutrients in NPK altered soils as compared to the unaltered one (table 6).

Table 6. Mineral uptake by maize in mixtures of maize and *E. colona* at varied densities and at two nutrient levels (Values for NPK altered soil are given in parentheses).

Nutrients	Initial density (Plants/M^2)			L.S.D.
	20 M + 100 E	20 M + 400 E	20 M + 1600 E	(P = 0·05)
Ca (%)	1·50 (1·74)	1·28 (1·37)	1·09 (1·18)	0·0123
Mg (%)	1·72 (1·96)	1·14 (1·63)	0·92 (1·46)	0·1151
K (%)	3·51 (4·53)	3·02 (4·22)	2·71 (3·80)	0·091
N (%)	1·09 (1·56)	0·95 (1·28)	0·81 (1·10)	0·757
P (%)	1·62 (1·91)	1·35 (1·56)	1·15 (1·32)	0·0431

Table 7. Survival percentage (mean values) of *E. colona* in mixed stands at varied densities and at different introduction timings of *E. colona* (Angular transformation values given in parentheses).

Initial density (Plants/M^2)	Early	Simultaneous	Late	L.S.D. (P = 0·05)
20 M + 100 E	76·0 (60·7)	70·6 (57·4)	0·0	
20 M + 200 E	65·3 (53·7)	62·6 (52·5)	0·0	(3·9)
20 M + 400 E	75·0 (60·0)	56·6 (49·0)	0·0	
20 M + 800 E	66·0 (54·3)	53·0 (46·7)	0·0	
20 M + 1600 E	69·9 (57·3)	66·5 (54·9)	0·0	

Experiment 4—Mixed stands with varied times of planting

At the density level tried, the crop did not suffer any mortality. With the early introduction of weed into the mixtures mortality of the weed was considerably decreased as compared to where both the crop and the weed were introduced simultaneously. Late introduction of *E. colona*, however, resulted in no survival of its individuals (table 7).

Dry weight yield of shoot per plant of maize was higher at late introduction of the weed into the mixtures compared with other introduction treatments. Early or simultaneous introductions of *E. colona* did not significantly affect the crop yield (table 8). Interspecific effect from *E. colona* reduced dry weight yield of the crop irrespective of the time of introduction of the former into the mixture. Shoot yield of *E. colona* was very much higher in those mixtures where it was introduced earlier to maize as compared to simultaneous introduction. Increase in the density of *E. colona* in mixtures resulted in decreased yield of this species irrespective of the time of introduction of the former into the mixture (table 8). There was a significant decrease in the number of seeds per cob of maize in those mixtures where *E. colona* had an early start when compared with other introductions. Seed output by maize was favoured due to late introduction of the weed. Increase in the density of *E. colona* in the mixtures resulted in reduced number of seeds per cob in all the introductions of the species into the mixtures (table 9). Where the weed had an early start, seed output was higher particularly at its higher densities. Increase in the density of *E. colona* in the mixture resulted in decreased seed output per plant (table 10).

Table 8. Dry weight yield of shoot/plant (g) (mean values) of maize and *E. colona* mixed stands at varied densities and at different timings of introduction of *E. colona*.

Initial density (Plants/M²)	Early		Simultaneous		Late	L.S.D. (P = 0·05)
	Maize	*E. colona*	Maize	*E. colona*	Maize	
20 M + 100 E	61·3	3·193	61·5	1·280	72·0	
20 M + 200 E	41·0	1·896	41·5	0·700	50·3	4·7070
20 M + 400 E	29·3	0·838	27·9	0·464	35·6	
20 M + 800 E	19·9	0·723	20·9	0·268	26·5	
20 M + 1600 E	15·0	0·520	15·9	0·157	20·7	

Table 9. Number of seeds/cob (mean values) of maize in mixed stands of maize and *E. colona* at different introduction timings of *E. colona* at varied densities.

Initial density (Plants/M^2)	Early	Simultaneous	Late	L.S.D. (P = 0·05)
20 M + 100 E	202·0	213·0	231·0	
20 M + 200 E	185·0	195·0	205·0	
				7·1
20 M + 400 E	174·0	182·0	196·0	
20 M + 800 E	151·0	160·0	178·0	
20 M + 1600 E	120·0	128·0	139·0	

Table 10. Seed output/plant and/m^2 (mean values) of *E. colona* in mixed stands of maize and *E. colona* at different timings of introduction of *E. colona* at varied densities.

Initial density (Plants/M^2)	Early		Simultaneous		L.S.D. (P = 0·05)	
	Per Plant	Per M^2	Per Plant	Per M^2	Per Plant	Per M^2
20 M + 100 E	1194·3	77859·8	1098·2	96224·6		
	(3·0770)	(4·8913)	(3·0406)	(4·9833)		
20 M + 200 E	519·6	67544·8	538·3	32435·4		
	(2·7157)	(4·8296)	(2·7310)	(4·5109)		
20 M + 400 E	91·4	62786·6	28·8	28523·8		
	(1·9609)	(4·7979)	(1·4594)	(4·4551)		
					(0·1970)	(0·2363)
20 M + 800 E	39·8	61040·0	14·4	21023·4		
	(1·5999)	(4·7856)	(1·1584)	(4·3226)		
20 M + 1600 E	30·6	45300·0	5·7	41246·6)		
	(1·4857)	(4·6561)	(0·7559)	(4·6153)		

Experiment 5—Mixtures with varied times of removal of E. colona

General decrease in different growth parameters of maize like dry weight, yield per plant and leaf area per plant was observed with increase in the time period of association between the crop and the weed in all the mixtures. The adverse effect of the weed on the crop was realised even when the association was short as seen from the comparison of the data in mixtures with that obtained from pure stands of maize (table 11).

4. DISCUSSION

Pure stand studies

Increase in density of plants may place a stress on the development of individuals and this stress may be measured in terms of either mortality or plasticity of the individuals. In pure stands of maize and *E. colona* increase in density stress was reflected in both mortality and plasticity. Mortality was more pronounced especially in the nutrient rich soils and it set in at a very early stage of plant growth. At lower densities, mortality was comparatively lesser as each individual had a larger environment to exploit compared to those at higher densities. It was a continuing risk throughout the life of the population and adjustment in numbers took place all the time in relation to increase in the size of the plants (Harper, 1967). In wheat, on the other hand,

Table 11. Effect of time of removal of *E. colona* on shoot yield (g) and leaf area per plant (cm^2) of maize in mixed stands of *maize* and *E. colona* at varied densities (leaf area given in parenthesis).

Initial density (Plants/m^2)	Removals		
	R_1	R_2	R_3
20 M + 100 E	63 (6298)	57 (6229)	51 (5887)
20 M + 200 E	43 (5634)	41 (5112)	39 (4891)
20 M + 400 E	38 (3613)	34 (4319)	31 (3670)
20 M + 800 E	27 (3038)	27 (2862)	23 (2610)
20 M + 1600 E	20 (2602)	19 (2451)	15 (2347)

20 M alone :

Dry wt. yield—62·69.

Leaf area—6444 cm^2.

density stress was reflected only in plasticity (Ramakrishnan and Kumar, 1971 *b*). This was believed to be due to slower growth rate of wheat in contrast to maize which has a faster growth rate and hence, makes more demand on the resources of the environment at a given time period resulting in severe mortality (Ramakrishnan, 1972; Ramakrishnan and Kumar, 1971 *a*). Recently, such a relationship between growth rate and density induced mortality was also shown in a comparative study of some leguminous species (Ramakrishnan, 1973). Increased fertility resulted in lesser population survival and larger plant size which is in agreement with the results of other workers (Sukatchev, 1928; Yoda *et al.* 1963; White and Harper, 1970). This is due to the improved growth of some of the plants in the fertile soil resulting in the death of the weaker ones. In other words, genotypic individual differences became more pronounced in the more fertile soil which accounted for such a mortality pattern.

The plastic response of plants to density stress are sometimes interpreted as a result of competition between the parts of one plant for growth substrates. On this view plant density induces a shortage of essential requirements. A major consequence of density stress was that mean plant weight became a function of population size whereas dry matter accumulation per unit area became independent of the population size (Kira *et al.*, 1953; Harper, 1964; Eddowes, 1969; Ramakrishnan and Kumar, 1971 *b*). Whilst such a tendency for levelling off was noted in the unaltered soil, a tendency for decrease in yield/m^2 was noted in the nutrient altered soil. It may be noted here that an earlier study on maize indicated a fall in dry matter production/m^2 when the density was raised beyond 1,600 plants/m^2 (Ramakrishnan and Kumar. 1971 *a*). In the case of *E. colona* the levelling off in yield/m^2 was not attained at the density levels tried. An important aspect of nutrition-density interaction was such that at high density levels the stress had the effect of obliterating plastic differences that were related to nutrient status of the soil. Thus, at higher densities the differences with respect to plant weight due to nutritional differences in the soil were less marked as compared to that at lower densities.

Cob formation in maize was very sensitive to density stress and failed to occur beyond 100 plants/m^2 in the nutrient rich soil even at a lower density in the low nutrient soil. Different organs may show different degrees of plasticity in response to the same factor (Bradshaw, 1965). This would account for the greater sensitivity of the cob development in maize to density stress. Seeds per Cob was also considerably affected due to both density and nutritional status of the soil. Unlike shoot yield, seed production/m^2 of *E. colona* declined at 1,600 plants/m^2 indicating that the proportional allocation of assimilates to the various organs of the plant may change with the resultant drop in seed yield per unit area.

Mixed stand studies

As in pure population where the density stress intensifies the expression of small differences between individuals so also in mixed populations the stress may exaggerate and exploit interspecific differences. De Wit's replacement series has been effective in mixed cultures where the competing species are similar in size and growth habit (Harper and McNaughton, 1962; Ramakrishnan, 1970). However, Van den Bergh and Elberse (1970) have been able to bring out the interference effect of two species of differing growth habit by appropriately varying the ratio of seed numbers in the replacement series and calculating relative yield total (RYT) values and relative replacement rate of species. In the present study where the two competing species are of divergent size, varied densities and proportions of the two in mixtures have effectively brought out the reciprocal effects.

Increase in interspecific effect from the weed resulted in an adverse effect on survival and yield of maize. The mortality of *E. colona* due to interference from maize was much more than that observed at corresponding densities in pure stands. This could partly be due to the larger plant size of the crop causing shading effect on the weed. At very high crop densities the survival was practically absent and even the few that survived were very weak and remained depauperate. The yield of maize decreased significantly due to increasing interference from *E. colona* and this decrease was more marked in the less fertile soil. This is due to intensified competition for limited mobile ions in a less fertile soil more so for a higher plant population. While at lower weed densities maize yielded best in NPK altered soil at high weed densities the effect of fertilizer was neutralized by density stress, with the result that the yield was much the same in all the altered soils. In mixtures with maize in nutrient rich soils, the yield/m^2 of *E. colona* decreased steadily with increase in its own density unlike in pure stands. In low fertility soil dry weight yield/m^2 at first improved and then declined at 1,600 plants/m^2. This is a consequence of the severe mortality of the weed partly due to increase in its own density and partly due to interference from maize. Further, the seed yield response of the weed per unit area in low and high nutrient soil showed a steady decline with increase in weed density indicating that yield response for dry matter production and seed production could be different in mixed cultures too, due to differential allocation of assimilates.

Whereas simultaneous introduction of the two species into the mixtures itself resulted in significant interaction between the two, the time of introduction into the mixture had a great bearing in yield response of the two competitors. Where *E. colona* had an initial advantage in time over maize, the latter did not suffer any significant reduction in dry weight yield compared to that in simultaneous introduction which was different from what was observed in wheat and *Cynodon dactylon* (Ramakrishnan and Kumar, 1971 *b*). However, the adverse effect of the early introduction of the weed on the crop was observed in seed number per cob. Where *E. colona* was introduced later into the mixture, the individuals of it responded by complete mortality.

Removal of the weed at different stages of growth of the crop showed that interference from the former to the crop is a continued risk throughout the life cycle and that longer the period of association between the two competing species greater the damage caused to ultimate crop yield. Even a shorter period of association between the crop and the weed resulted in ultimate reduction in crop yield particularly at higher weed densities.

In this study of weed-crop interaction, the two competing species had not only divergent growth habit but also showed different ecologic behaviour. The present studies have shown differences with regard to mortality in pure stands wherein maize was comparatively more susceptible compared to *E. colona*. The dry matter production was also more sensitive to density stress in the case of maize compared to *E. colona*. In mixed cultures, while the influences are reciprocal, the effect of the crop on the weed was much greater than the reverse effect. This is particularly due to differences in size and growth form of the two competing species. The design of the experiments was such that the reciprocal effects were brought out clearly as is evident from the preceding account. Whereas the effect of the weed on the crop could be primarily due to competition for nutrients, the reverse effect could be due to shading of the weed by the crop.

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REFERENCES

Harper, J. L. and Gagic, D., Experimental studies on the mortality and plasticity of a weed, *Weed Res.* 1 91–104 (1961).

Ramakrishnan, P. S. and Kumar, S., Mortality, plasticity and productivity of interfering model populations of maize and *Cynodon dactylon* (L.). Pers. *J. Indian Bot. Soc.* 50 321–331 (1971 *a*).

Ramakrishnan, P. S. and Kumar, S., Productivit and plasticity of wheat and *Cynodon dactylon* (L.) Pers. in pure and mixed stands. *J. Appl. Ecol.* 8 85–98 (1971 *b*).

Donald, C. M., Competition among pasture plants. *Adv. Agron.* **15** 1–118 (1963).

Kapoor, P. and Ramakrishnan, P. S., Studies on crop-legume behaviour in pure and mixed stands, *Agro-Ecosystems* 2 61–74, 1975.

Ramakrishnan, P. S., Ecology of *Echinochloa colonum* Link., *Proc. Indian Acad. Sci.* **53 B** 73–90 (1960).

Kapoor, P. and Ramakrishnan, P. S., Soil factors influencing the distribution of ecotype populations in *Echinochloa colonum* (L.) Link. (Gramineae). *Bot. J. Linn. Soc.* **69** 65–78 (1974).

Piper, C. S., *Soil and Plant Analysis.* Interscience, New York (1944).

Snell, F. D. and Shell, C. T., *Colorimetric Methods of Analysis.* Vol. II, D. Van Nostrand Co., Inc., New York (1949).

Harper, J. L., A Darwinian approach to plant ecology. *J. Ecol.* **55** 247–270 (1967).

Ramakrishnan, P. S., A comparative study of productivity in monocultures of species of varied ecological characteristics. In *Tropical Ecology Emphasizing Organic Production.* (ed. P. M. Golley and F. B. Golley), Athens, Georgia, 121–135 (1972).

Ramakrishnan, P. S., Individual behaviour of some legumes in monocultures related to growth rate. *Proc. Indian Acad. Sci.* **48** 212–221 (1973).

Sukatchev, Y. N., *Plant Communities* (in Russian) Moscow (1928).

Yoda, K., Kira, T., Hozumi, H. and Kira, H., Self-thinning in overcrowded pure stands under cultivated and natural conditions. *J. Biol.* Osaka City Univ. **14** 107–129 (1963).

White, J. and Harper, J. L. Correlated changes in plant size and number in plant populations. *J. Ecol.* **58** 467–485 (1970).

Kira, T., Ogawa, H. and Sagazaki, N., Intraspecific competition among higher plants. I. Competition-density-yield relationship in regularly dispersed populations. *J. Inst. Polytech.. Osaka City* (1953).

Harper, J. L., The nature and consequence of interference amongst plants. *Proc. XIth Int. Conf. Genet.* pp 465–481 (1964).

Eddowes, M., Physiological studies on competition in *Zea mays* L. II. Effect of competition among maize plants, *J. Agric. Sci.* **72** 195–202 (1969).

Bradshaw, A. D., Evolutionary significance of phenotypic plasticity in plants. *Adv. Genet.* **13** 115–155 (1965).

Harper, J. L. and McNaughton, I. H., The comparative biology of closely related species living in the same area. VII. Interference between individuals in pure and mixed populations of *Papaver* species, *New Phytol.* **61** 175–188 (1962).

Ramakrishnan, P. S., Nutritional requirements of the edaphic ecotypes in *Melilotus alba* Medic. III. Interference between the calcareous and acidic populations in the two soil types, *New Phytol.* **69** 81–86 (1970).

Van den Bergh, J. P. and Elberre, W., The yield of monocultures and mixtures of two grass species differing in growth habit, *J. Appl. Ecol.* 7 311–320 (1970).