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STUDIES ON COMPETITION BETWEEN ASSOCIATED BEAN AND MAIZE CROPS

E. Ann Clark

RESUME

Associated cropping is characterized by the growing of two or more crops on the same land area during the same time interval. It is commonly observed that individual crop yields are less in association than in monoculture. However as it is possible to produce combined crop yields that are both more diverse and often more stable and higher than in monocultures over comparable land areas, associated cropping has had a strong traditional appeal to small- and medium-sized farm operators.

The degree of interaction and subsequent yield reduction between the associated crops depends in part on the temporal overlap in their growth cycles. Physical differences between associated crops such as height and leaf display, rooting volume and relative population densities also determine whether the interaction will be equal or unequal, with one crop clearly dominant.

In the studies summarized in this report, crop-to-crop interaction was maximized by simultaneous, high-density plantings of both crops. The height difference between the bean and maize, and the variation in the height parameter among growth habits produced crop-to-crop interactions ranging from near-equal to plainly *dominant-suppressed*. This latitude in

degree of crop interaction was focused toward realization of the following objectives:

I. BEAN BREEDING

A. To compare the growth and developmental responses of the different bean growth habits in monoculture and associated with maize.

B. To relate plant growth responses to resultant grain yield in both cultural systems.

C. To evaluate the possibility of a genotype x cultural system interaction in the yield response.

II. BEAN PHYSIOLOGY

A. To test three basic hypotheses accounting for the effect of associated maize on beans,

1. Spatial competition for resources
2. Temporal competition for resources
3. Microclimate modification.

B. To examine a postulated bean effect on maize growth and yield.

Four growth cycles were employed during the interval between July 1977 and December 1978. The breeding objectives - an extension of the pioneering studies of Drs. Charles Francis and Carlos Flor - were addressed in the first season with the remaining three seasons primarily oriented toward the physiological questions.

BEAN BREEDING

In the first season 40 bean varieties, 10 in each of the four growth habits, were grown both in monoculture and in association with maize (H207). Due to contamination from seed-borne virus, 19 varieties were rendered unusable and had to be removed from the field. Maize lodging occurred at 77 days, damaging the canopy structure and subsequent performance of the type III and IV varieties such that the yield data were confounded with the state of maturity at the time of lodging and could not be clearly interpreted. Thus of the original 40 varieties, eight type II varieties (which had reached harvest maturity at the time of the maize lodging) survived to produce usable data.

Within the type II varieties, the following trends were observed:

1. Wide ranges of phenotypic variability existed in all measured parameters.

2. Branch parameters were more strongly affected by the associated maize than were main stem parameters.

3. Strong relations existed between yield and seed color and between yield and percentage branch-borne yield.

4. Yield-determining parameters varied with cultural system:

MONOCULTURE	ASSOCIATION
No. of main stem pods	No. of seeds/main stem pod
Hundred Seed Weight	Hundred Seed Weight
Harvest Index.	

5. Due to diverse strategies of yield-component compensation among bean varieties, no single parameter accounted well for yield, although most produced highly significant relations.

6. In simple correlation analyses, the parameter with the highest R^2 values (total plant dry weight at final harvest) accounted for 74% of the yield variation in association but only 35% in monoculture. This could suggest that yield was more closely related to total dry weight when light was more limiting.

7. Varietal yield rankings in monoculture were essentially identical to those in association, indicating no genotype x cultural system interaction.

BEAN PHYSIOLOGY

A. Spatial Competition

The first of the physiological studies was designed to separate and quantify spatial competition for resources into two levels - those of root and of shoot competition. However, we were unable to realize these objectives due to violations of critical assumptions in the design and to the high fertility level of soils at CIAT (Palmira). Consequently, revised objectives were generated consistent with the type of data that had been collected.

Only two varieties (P566 and P364), representing two distinct growth habits (Types II and IV, resp.) were used because of the complexity of the treatment design and the resultant land and labor requirements. The treatment design was a factorial of three levels each of root (soil variables) and shoot (light)competition. Maize population (H210 at 20,000, 40,000 and 60,000 pl/ha) was the root variable and canopy structure (open, erect and closed, defined by bending the maize plants with bamboo slats) was the shoot variable. Anticipating effects of maize population (the root variable) on light interception (the shoot variable), light energy was quantified using the OZALID paper method. Accurate interpretation of yield differences however, required the assumption that canopy structure would not influence maize root demand. Thus, bean yield differences at a given population across canopy structures, could be interpreted as directly attributable to light.

This assumption was invalidated by observed differences in maize yield (and presumably nutrient demand) at a given population, with canopy structure. Comparison with monoculture maize controls indicated that most of the difference resulted from the bending process itself. However, in the type IV associations additional effects were exerted by the beans, further reducing the maize yields. Thus, the assumption of constant root level competition at a given population was unverifiable.

However, assuming that root level competition in the naturally rich and heavily fertilized (380 kg/ha of 10-30-10) soil of CIAT was negligible anyway, we may consider the maize population and canopy treatments simply as modifying the penetration of light to the associated beans. The response of yield-related variables to shading at the various naturally-imposed levels can thus be assessed. The form of the light response (convex, concave, threshold) indicates the sensitivity of each parameter to integrated light availability over the whole season, the limiting resource under these cultural conditions. This information could be incorporated in breeding objectives to compensate for the most responsive parameters.

As light availability to the bean varies, so also does light interception by the maize, implying a shifting in the balance of light use between the two crops. Thus, we can visualize the entire treatment matrix as controlling the balance of light availability between the two associated crops. From this perspective, we can compare the various systems for resultant productivity.

Using total plant dry weight at final harvest as an integrative index of light availability over the entire season, the following conclusions were drawn:

1. Most yield component parameters were closely related to total dry weight and by assumption, to light availability over the season.

2. Type II responses were generally more clearly defined by light energy than were those of the Type IV variety. This may reflect the homogeneous shading of the low-lying Type II canopy versus the heterogeneous shading imposed on the more vertically oriented climbing canopy.

3. The Type II variety responded more strongly in harvest index, hundred seed weight and number of seeds/pod than did the Type IV variety, while the pod number responses were nearly identical.

4. Bean and maize grain yields showed a strong, negative relation over all treatments and specifically, within each canopy type. The slope of the relation was increasingly negative as canopy structure closed, as light became progressively more limiting.

5. Type IV associated systems consistently yielded more total protein (kg/ha) than did Type II systems, both of which produced more than monoculture maize at its highest (optimum) population.

6. Five of the Type II and three of the Type IV associations equaled or exceeded protein production in their respective typical associations (maize at 40,000 pl/ha, normally entwined). These findings suggest that productivity can be increased by redistribution of the limiting resource - light energy - between the bean and maize crops.

B. Temporal Competition.

The dynamics of resource acquisition were studied in the third season, comparing growth habits II and IV (represented again by P566 and P364, resp.) in monoculture and in association with maize (Suwan-1).

Maize growth was also analyzed by comparing the associated maizes with monocultures at comparable (40,000 pl/ha) and optimum (55,000 pl/ha) populations. Due to technical difficulties in the previous trial, light energy measurements were repeated, using another modification of the OZALID paper technique.

Dynamic or time-varying changes in both dry weight and nutrient (N, P and K) accumulation were measured in weekly harvests, starting at 26 days from planting. Numeric (node, raceme and pod (>5 cm) numbers), dry weight partitioning and leaf area parameters were measured and dry weight components were analyzed for nitrogen, phosphorous and potassium concentration at weekly intervals.

It is intended to use growth analysis methodology (calculating growth rates, relative growth rates, in both energy and in nutrients) to define the timing and magnitude of resource acquisition. Although analyses are incomplete, preliminary findings include:

1. Significant differences in light availability (over the interval from 50 to 75 days) existed between bean monocultures and associations (of both types), between the monoculture maize populations and between the two growth habits.

2. The growth habits differed in vegetative/reproductive strategies in both cultural systems,

a. While the Type II response to resource limitation (ie: maize competition) was an early restriction in node generation and thus, in potential vegetative growth, the Type IV variety persisted in generating a nodal structure equal to that in monoculture.

b. The late-generated nodes in the associated Type IV variety did not contribute to either leaf area expansion or to pod retention and quickly senesced.

c. The Type IV variety exhibited an exploitative habit in both cultural systems, generating many more excess nodes than did the Type II variety. At final harvest, the type IV variety had lost 35 and 30% of its maximum node number (in association and monoculture) versus 18 and 17% in the Type II variety.

While representing excessive vegetative growth under the controlled conditions of this trial, this character might enhance the yield stability of the Type IV growth habit in periodically stressful environments. For example, if early-set pods aborted due to water stress or insect attack, this compensatory flexibility could permit recovery.

3. Nitrogen concentration was not consistently affected by cultural system but the Type II variety generally showed lower vegetative and higher reproductive nitrogen concentrations than the Type IV variety.

4. Due to differences in dry weight accumulation, monoculture beans accumulated more above-ground plant nitrogen than did associated beans but the habits did not differ in total nitrogen accumulation in either system.

5. By 82 days (using the 68 day values for the Type II beans which had already been harvested), the associated systems (maize and bean combined) had accumulated 10 and 19% (Types II and IV, resp.) more nitrogen than had their respective bean monocultures (these calculations assume no nitrogen transfer between bean and maize between 68 and 82 days).

6. Maize growth was affected by both types of associated beans starting at 33 days, the Type IV bean exerting an addition influence at 47 days, coinciding with the onset of measurable pod growth.

7. Maize yields in association differed significantly from those in monoculture. However, the monoculture maizes did not differ significantly, nor did the two associated maizes.

8. The labor allocation (by type of activity and by personnel) is presented for this trial, indicating the magnitude of time and effort expended in this sort of growth analysis study (planted area = 0.45 ha). This information may be useful in planning future work.

C. <u>Microclimate Modification</u>.

The presence of a taller crop growing in association with an underlying crop could affect more than simply the availability of photosynthetic energy to the shorter crop. Incident light energy directly affects plant temperature with secondary effects on metabolic activity, plant water status and plant development. In the opposite direction, the loss of thermal energy, thermal re-radiation, while a component of day-time energy relations is the dominant factor in the night-time energy budget. Thermal re-radiation determines plant and air temperature at night and thus affects factors ranging from plant development to the duration of dew-fall, which can affect disease dynamics. Thus, the presence of overhanging maize leaves and stalks would influence the diurnal energy budget in diverse and potentially significant forms.

Secondly, the overhanging maize crop would restrict air movement directly above the bean crop. Wind-generated turbulent transport is the mixing process by which energy and water vapor are lifted from and CO_2 brought down to the crop surface during the daytime. Limitations in turbulent transport could then affect crop temperature and CO_2 availability particularly in bright sunshine when the maize (a C_4 crop) would be photosynthesizing most actively.

It is possible then to envision theoretically plausible modifications to the bean microclimate deriving from the associated maize. The fourth and final experiment is designed to measure light energy penetration, plant temperature and water relations to determine if the above postulated effects are quantitatively meaningful.

The relative distribution of bean and maize leaf area in both vertical and horizontal strata, affects both microclimate and light competition between the two crops. Thus a harvesting system was developed to permit comparison of the spatial display of leaf area in associations and monocultures of bean and maize.

This trial is currently in progress.

TABLE . YIELD AND YIELD-RELATED PARAMETERS IN TYPE II BEANS GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE (H-207).

Variety	Seed Color	YIELD (Kg/ha, 14%)			PERCENTAGE BRANCH - BORNE YIELD	
		Monoc.	Assocn.	% Yield Reduction	Monocult.	Assocn.
High-Yield Group						
P566	black	1974	824	58	20	1
P675	black	1847	756	59	38	6
P488	black	1828	632	65	37	5
P 17	brown	1786	652	63	61	21
$\overline{X}$		1859	718	61	39	8
Low-Yield Group						
P756	white	1690	531	69	55	29
P643	white	1637	428	74	64	5
P524	tan	1378	558	60	76	24
P402	tan	1262	550	56	60	19
$\overline{X}$		1492	517	65	64	19
High-Yield vs. Low-Yield		***	***			

TABLE . COMPARISON OF YIELD-RELATED PARAMETERS IN TYPE II BEAN VARIETIES (high-vs.low-yield group) GROWN IN MONOCULTURE AND IN ASSOCIATION WITH MAIZE (H-207).

CHARACTER	ASSOCIATION	MONOCULTURE
POD NUMBER		
-Main stem	ns	(+) ***
-Branch	ns	(-) ***
Total	ns	ns
SEEDS/POD		
-Main stem	***	ns
-Branch	ns	ns
HUNDRED SEED WEIGHT	***	***
SEED WEIGHT		
-Main stem	***	***
-Branch	ns	***
TOTAL DRY WEIGHT	*	*
HARVEST INDEX	ns	*

TABLE . SIMPLE LINEAR CORRELATIONS BETWEEN BEAN YIELD AND YIELD-RELATED PARAMETERS (r-values, over eight type II varieties).

PARAMETER	ASSOCIATION	MONOCULTURE	COMBINED SET
POD NUMBER			
Main Stem	0.68***	0.56***	
Branch	-0.15 ns	-0.17 ns	
Total	0.57***	0.23 ns	
SEEDS/POD			
Main Stem	0.58***	0.53***	
Branch	-	0.39*	
HUNDRED SEED WT.	0.53***	0.35*	0.61***
TOTAL DRY WEIGHT	0.86***	0.59***	0.93***
STRUCTURAL DRY WT.	0.78***	0.08 ns	0.81***
HARVEST INDEX	0.29 ns	0.61***	0.52***

TABLE . PRODUCTION OF PROTEIN (KG/HA)* IN ASSOCIATED AND MONOCULTURE SYSTEMS OF TYPE II BEANS (P566) AND MAIZE (H210).

CANOPY TYPE	MAIZE+ POPN.	PROTEIN: SYSTEM BEAN	PROTEIN: SYSTEM MAIZE	PROTEIN: SYSTEM TOTAL	BEAN AS % OF TOTAL	EXPRESSED RELATIVE TO: MAIZE MAXIMUM	EXPRESSED RELATIVE TO: TYPICAL ASSOCIATION
OPEN	20,000	348	210	557	62	126	105
	40,000	276	310	586	47	132	110
	60,000	252	390	642	39	145	121
ERECT	20,000	245	284	529	46	119	100
	→ 40,000	169	362	531	32	120	100
	60,000	113	472	585	19	132	110
CLOSED	20,000	262	210	471	56	106	89
	40,000	130	310	441	29	100	83
	60,000	70	390	460	15	104	87

*calculated 8% of maize and 25% of bean grain dry weight.
+in pl/ha.

TABLE . PRODUCTION OF PROTEIN (KG/HA)* IN ASSOCIATED AND MONOCULTURE SYSTEMS OF TYPE IV BEANS (P364) AND MAIZE (H210).

CANOPY TYPE	MAIZE POPN.	PROTEIN: SYSTEM BEAN	MAIZE	TOTAL	BEAN AS % OF TOTAL	EXPRESSED RELATIVE TO: MAIZE MAXIMUM	TYPICAL ASSOCIATION
OPEN	20,000	588	80	668	88	151	103
	40,000	560	150	710	79	160	110
	60,000	504	170	675	75	152	104
ERECT	20,000	495	148	643	77	145	99
	40,000	345	267	612	56	138	95
	60,000	300	314	613	49	139	95
CLOSED	20,000	476	80	556	86	126	86
	40,000	347	150	497	70	112	77
	60,000	277	170	447	62	101	69
TYPICAL	40,000	238	408	646	37	146	100

*calculated as 8% of maize and 25% of bean grain dry weight.

TABLE . TRANSMISSION OF LIGHT ENERGY IN MONOCULTURES AND ASSOCIATIONS OF MAIZE (Suwan-1) AND BEAN (P566, TYPE II and P364, TYPE IV) AT 50 TO 75 DAYS.

Source	df	SS	MS	F
Block (day)	6	9,039	1506	8.15 **
Treatment	10	35,315	3513	19.1 ***
CONTRASTS:				
Mono. II vs. Assoc. II	1	14,821		80.3 ***
Mono. IV vs. Assoc. IV	1	1,222		6.6 *
Mono. Maize, 40,000 vs. 55,000 pl/ha	1	2,681		14.5 **
Type II vs. Type IV	1	3,253		17.6 **
Bean Treatments vs. Mono maizes	1	10,838		58.7 ***
Level 1 vs. Level 2*	1	1,481		8.0 **
Residual	4	1,019	255	1.4 ns
Error	60	11,081	184.7	

* Level 1 = 105 cm. above ground
Level 2 = 135 cm. above ground

TABLE . BEAN YIELD (KG/HA, 14% MOISTURE) AND TOTAL ABOVEGROUND NITROGEN ACCUMULATION IN MONOCULTURES AND ASSOCIATIONS OF BEAN AND MAIZE.*

CULTIVAR	CULTURAL SYSTEM	YIELD	NITROGEN (g/m^2) BEAN	MAIZE	TOTAL
P566 (Type II)	MONOCULTURE	2364	13.5		13.5
	ASSOCIATION	925	5.3	9.7	14.9
P364 (Type IV)	MONOCULTURE	3023	13.5		13.5
	ASSOCIATION	1065	5.9	10.2	16.1
Maize (Suwan-1)	MONOCULTURE				
	40,000 pl/ha			12.8	12.8
	55,000 pl/ha			12.7	12.7

*measured at time of maximum accumulation in beans, 68 days (Type II) and 82 days (Type IV) and at the time of bean harvest in maize (82 days).

TABLE . COMPARISONS AMONG MAIZE (Suwan-1) GRAIN YIELDS REALIZED IN MONOCULTURE (at two populations) AND IN ASSOCIATION WITH BEANS (of growth habits II and IV).

Cultural System:	Yield Kg/ha, 16%	Matrix A *** C_1	ns C_2	ns C_3	Matrix B ** C_4	*** C_5	ns.
ASSOCIATION							
Type II (P566)	3561	1	0	1	0	-1	
Type IV (P364)	3109	1	0	-1	1	-1	
MONOCULTURE							
40,000 pl/ha	4051	-1	1	0	-1	-1	
55,000 pl/ha	4565	-1	-1	0	0	3	

Source	df	SS	MS	F	
TREATMENT	3	12,865,730	4,288,577	6.26 *	
Matrix A					
C_1	1	10,315,338	10,315,338	15.05	***
C_2	1	1,437,360	1,437,360	2.10	ns.
C_3	1	1,113,032	1,113,032	1.62	ns.
Matrix B					
C_4	1	4,836,050	4,836,050	7.06	**
C_5	1	8,027,034	8,027,034	11.71	***
residual	1	2,646	2,646	ns.	
ERROR	9	6,167,107	685,234		

TABLE . DISTRIBUTION OF WORK IN TRIAL 7821, BY TYPE OF ACTIVITY AND PERSONNEL

	TYPE OF ACTIVITY											
	Field (47%)								Lab. (53%)			
	Planting	Trellis construction	Thinning	Applications *	Weeding	Entwining	Field harvest	Other	Lab. processing	Leaf area	Wiley milling	Light measurement
Man-hours	88	110	54	112	57	45	58	64	430	69	154	24
Percentage of total	7	9	4	9	5	4	5	5	34	5	12	2

* Includes irrigations

1265 TOTAL HOURS WORKED

22% (277h) me

6% (72h) field operations (irrigations)

72% (916h) workers of Agronomia Frijol voluble