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Harvest index and evoluation of major food crop cultivars in the tropics

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Summary

Relative importance of harvest index (I) and total biomass yield (B) to economic yield (Y) was assessed in several food crops at different levels of environmental productivity. Importance of B is generally higher in low than high yielding environments, while that of I is higher in high than low yielding environments. In some crops B is important throughout different yield levels while in others I is important even in low yielding environments.

Past efforts by anonymous farmers have consummated a good part of genetic improvement of crop yields through improvement in B. Many venerable land cultivars of grain crops, adapted to unimproved, limited-input cultural conditions, evolved through this process. The same process may not have thoroughly exhausted the yield improvement opportunity through improving I. Success in yield improvement by modern breeding has been limited mainly to high-input cultural conditions characterized by higher soil fertility and irrigation mainly through improvement in I. Varietal improvement possibility for less productive environments is discussed.

Introduction

One of man's greatest achievements has been the domestication and improvement of crop species. Nearly all the major food crops have been domesticated in the tropics or adjacent areas. Variation of cultural practices coevolved with each crop species in its center of origin and diversification. Consequently, the variation in crop germplasm and cultural practice in the tropics is enormous.

The majority of arable land in the tropics is characterized by poor soil nutrient status and irregular water supply. It is in this environment that crop species have been domesticated and venerable cultivars have evolved. It is also under these environmental conditions that a significant proportion of tropical agricultural production will continue to take place.

Agricultural advances in the temperate countries constitute a recent and a small chapter in the history of domestication and evolution of crop production. The basic characteristics of crop technology developed for temperate areas are the establishment of high input cultural conditions for maximum crop productivity and the creation of crop genotypes which give the highest yields under such environments. There are cases of success following this strategy in the tropics also. Yet, the important portion of tropical farm lands are so low in soil fertility and deficient and unreliable in water sup-

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ply that the cost of soil amendment and irrigation is often prohibitve. Adjusting genetic potential of the crop to available environmental productivity is one new, inevitable trend in tropical crop breeding (Kawano & Jennings, 1983).

The yield of food crops is genetically improved through the improvement of either total biomass yield (B) or harvest index (I) or both. I is the proportion of economic yield (Y) to the B of the crop. B represents the crop's accumulated photosynthesis while I represents the efficiency of the crop to convert photosynthesized products into an economocally valuable form.

In this paper, based on numerous varietal trials, relative importance of I and B to Y is assessed in several crops not only under productive but also under less productive environments. Combined with inter-genotypic competition studies, evolutionary background of tropical crop cultivars is inferred. Possibility of varietal improvement for less productive environments is also discussed.

Description of field experiments

Varietal yield trial

1. Rice

Twenty five genotypes (cultivars and breeding lines) of different plant types were evaluated in yield trials under 11 different cultural conditions at Lambayeque, Peru. The 11 cultural conditions included different nitrogen applications, spacings, and planting methods (transplanting, row seedings, broadcasting).

Each experiment had 4 replications and the genotypes were randomized in each replication. Grain yield data came from the central 4 m^2 area after eliminating border plants and were adjusted to 14% moisture content. Total plant weight and harvest index were calculated from a 50 × 50 cm plot on the basis of 0% moisture content for straw and grain. Root weight was ignored from the calculations.

2. Cassava

Twenty to 230 genotypes (cultivars, germplasm accessions and hybrid clones) of different plant type were evaluated in yield trials with 2 or 4 replications under 12 different cultural conditions. The 12 cultural conditions included 6 planting in different seasons at CIAT headquarters in Cali, Valle, 3 plantings at Caribia, Magdalena, and 3 plantings at Carimagua, all in Colombia, S. America.

Harvest was one year after planting. Data on root yield, total plant weight, and harvest index came from sampling of 9 plants (9 m^2) at the center of each plot after eliminating 2 rows of borders. Root yield and total plant weight were expressed on a fresh weight basis.

CIAT, Caribia, and Carimagua represent high, intermediate and low yielding environments, respectively, for casssava production.

Competition study

1. Rice

The same 25 genotypes as in the yield trials were mix-planted with the cultivar 'IR 8' at Lambayeque. Each genotype and IR 8 were planted alternatively in rows of 20 cm separation. Grain yield data of each genotype were compared with the grain yield of the same genotype in monoculture. Competitive ability of each genotype was expressed as: (grain yield in mixed population)/(grain yield in monoculture). The experimental plots received the recommended level of fertilizer application and the planting was made with the recommended plant spacing.

2. Cassava

Twenty genotypes, which were included in all the cassava yield trials, were mix-planted with a germplasm accession M Col 638 at CIAT. Each genotype and M Col 638 were alternated in rows of 1 m separation. Root yield data of each genotype were compared to root yield of the same genotype in monoculture. Competitive ability of each genotype was expressed as: (root yield in mixed plot)/(root yield in monoculture). The experiment was carried out at CIAT.

All the experiments for rice were carried out from 1970 to 1972 and those for cassava from 1975 to 1981. The detailed descriptions of genotypes used, experimental methods and characteristics of experimental sites are available in previous papers (rice: Kawano et al., 1974; cassava: Kawano et al., 1978; Kawano & Thung, 1982).

Results and analysis

Relative importance of harvest index and total biomass yield to economic yield

To assess relative contributions of harvest index (I) and total biomass yield (B, which is total plants weight) to economic yield (Y, equal to grain yield or root yield), two statistics are compared. One is the simple correlation coefficient between Y and B or I and the other is the relative size of variance of B or I compared to that of Y. In the latter case, the calculation was made by converting all the variables to a logarithmic scale. Since Y is mathematically related to I and B, correlation coefficients do not stand conventional statistical test for significance. However, comparison among different correlation coefficients gives information about the relative strength of the relationship. These measures are presented at different levels of environmental productivity (Table 1 and 2). Environmental productivity is given by the total average yield of each yield trial.

In rice, the relationship between Y and B was very close in low yielding environments, but it was much less in high yielding environments (Table 1 and Fig. 1). The importance of I, on the contrary, was greater under high than low yielding environments (Fig. 2). Thus, B was more important than I in less productive environments, while the situation was reversed in more productive environments.

In cassava, the importance of I was high throughout all the locations and yield levels (Table 2, Fig. 3). The relative importance of B tended to be greater in low than in high yield environments.

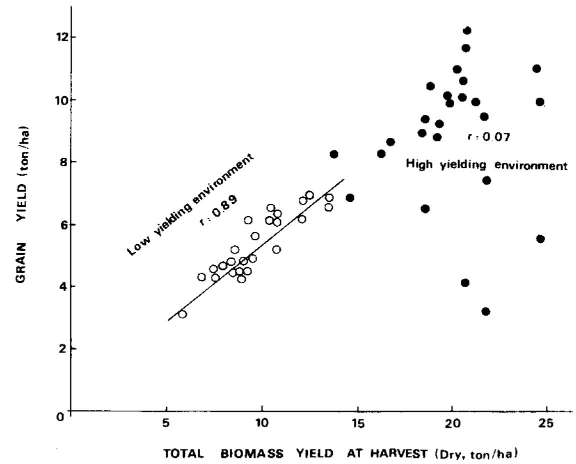

Fig. 1. Relationship between total biomass yield and grain yield of rice under low and high yield environments.

Behavior of yield characters in genetic mixture

In the rice experiments the competitive ability of each genotype was positively correlated with weight of the same genotype in monoculture ($r = 0.62^{**}$) and negatively correlated with I ($r = -0.69^{**}$). Grain weight of each genotype in the competition plot was highly correlated with Y of the same genotype in monoculture in the low yielding environment, but it was not correlated with Y in

Table 1. Relationship of total biomass yield (B) or harvest index (I) with rice grain yield (Y) under diverse environmental conditions

Average grain yield of experiment (t/ha)	r_{YB}	V_B/V_Y	r_{YI}	V_I/V_Y
5.3	0.89	0.99	0.22	0.38
7.4	0.89	1.06	0.18	0.41
7.8	0.68	0.69	0.72	0.69
8.0	0.54	0.84	0.59	0.68
8.1	0.57	0.97	0.29	0.57
8.1	0.23	0.81	0.53	0.67
8.8	0.07	0.46	0.80	0.91
9.1	0.24	0.39	0.82	0.67
9.2	0.24	0.81	0.76	0.97
9.3	0.10	0.56	0.74	0.65
9.6	0.07	0.73	0.89	1.18

r: Correlation coefficient.
V/V : Relative size of variance of B or I to that of Y (variables were converted to logarithmic scale).

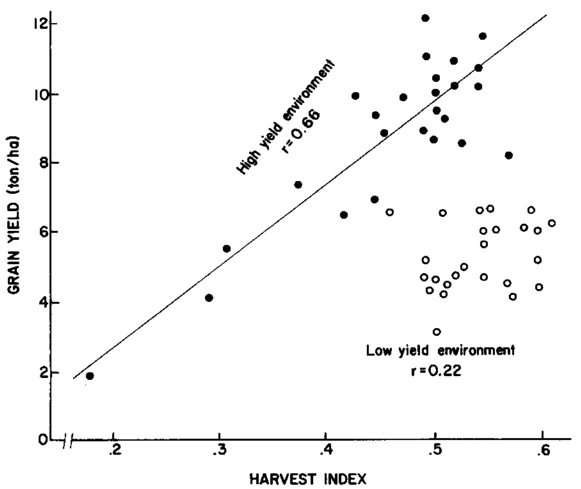

Fig. 2. Relationship between harvest index and grain yield of rice under low and high yield environments.

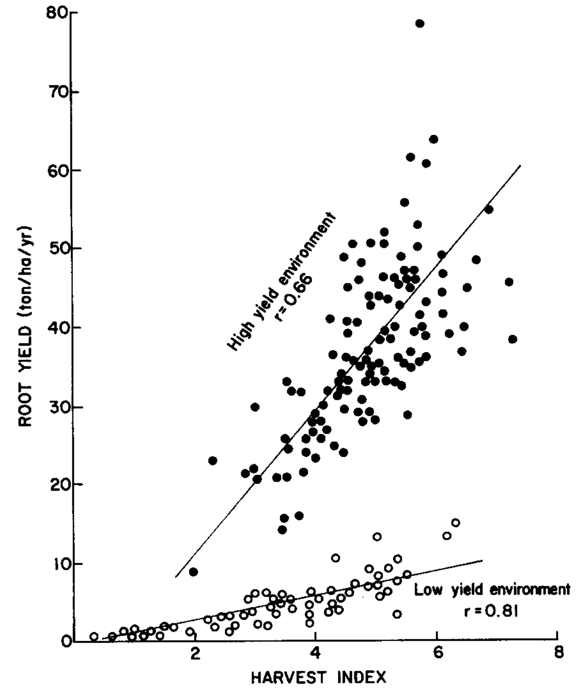

Fig. 3. Relationship between harvest index and root yield of cassava under high (at CIAT – Palmira) and low (at Carimagua) yield environments.

the high yielding environment (Fig. 4). On the contrary, harvest index of each genotype in the competition plot was highly correlated with Y of the same genotype in monoculture in the high yielding environment, but it was not correlated with Y in the low yielding environment (Fig. 5). Thus, for individual plant selection in segregating populations, selection through harvest index would be more efficient than through grain yield itself if the selection target is high grain yield in high yielding environments. When the selection target is high grain yield in low yielding environments, selection by grain yield itself would be highly efficient. If plantings of genetically mixed rice populations are made simply by planting the seeds from the previous harvest, highly competitive genotypes with high yielding ability in low yielding environments,

Table 2. Relationship of total biomass yield (B) or harvest index (I) with cassava root yield (Y) under diverse environmental conditions

Location	Average root yield of experiment (t/ha)	r_{YB}	V_B/V_Y	r_{YI}	V_I/V_Y
Carimagua	4.9	0.84	0.53	0.81	0.62
Carimagua	15.3	0.93	0.75	0.69	0.41
Carimagua	19.1	0.89	0.71	0.77	0.64
Caribia	24.1	0.79	0.74	0.58	0.71
Caribia	27.3	0.81	0.44	0.85	0.69
Caribia	29.8	0.82	0.76	0.71	0.50
CIAT	26.3	0.24	0.04	0.84	0.96
CIAT	27.8	0.41	0.32	0.82	0.91
CIAT	28.6	0.54	0.25	0.92	1.04
CIAT	30.4	0.55	0.48	0.76	0.82
CIAT	37.2	0.77	0.67	0.66	0.71
CIAT	42.1	0.53	0.40	0.78	0.77

r: Correlation coefficient.
V/V: Relative size of variance of B or I to that of Y (variables were converted to logarithmic scale).

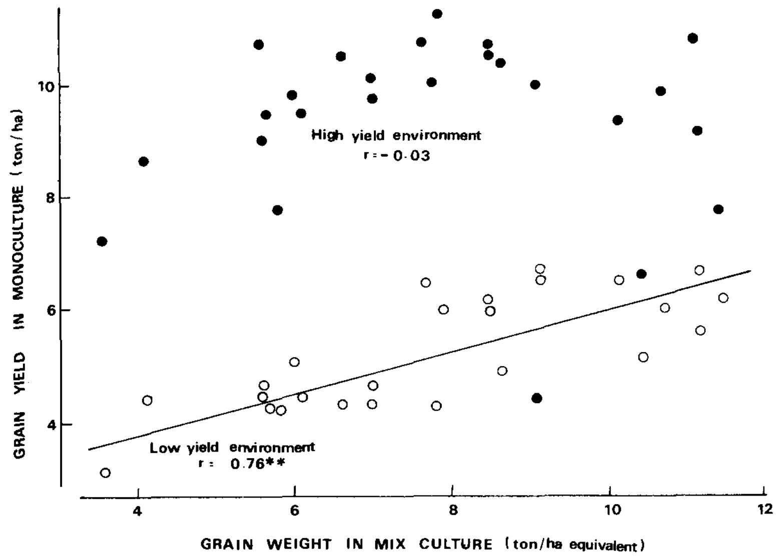

Fig. 4. Relationship between grain yield in mix culture and that in monoculture (under low and high yield environments of the same rice genotype).

but not necessarily as such in high yielding environments would result after many cycles of plantings.

In cassava the competitive ability of each genotype was highly correlated with stem and leaf weight of the same genotype in monoculture (r = 0.81**) and it was negative correlated with I of the same genotype in monoculture (r = −0.86**). Since in cassava I is highly important to Y, competitive ability was negatively correlated with Y in monoculture (r = −0.70**). Stem and leaf weight in competition plot was negatively correlated with Y in monoculture (r = −0.54**). Root weight in competition plot was correlated with Y of the same genotype in monoculture (r = 0.57**). However, harvest index in the competition plot was more closely correlated with Y in monoculture (r = 0.91**). Thus, selection through harvest index would be more efficient than through root weight itself when the selection target is high root yield in monoculture. If plantings of genetically mixed cassava populations are made simply by using available stem cuttings without respect to harvest index and root yield, highly competitive genotypes but of low yielding ability would dominate after several cycles of plantings.

Table 3. Relative importance of harvest index and total biomass yield in major food crops under low and high yielding environments

	Yield limiting factor in	
	Low yielding environment	High yielding environment
Cassava	I, B	I
Rice, Wheat, Barley Oat, Groundnut	B	I
Maize	B	B, I
Field bean, Soybean	B	B

B: Total biomass yield.
I: Harvest index.
References: Cassava (Kawano & Thung, 1982; Kawano & Jennings, 1983); Rice (Kawano et al., 1974; Kawano & Jennings, 1983); Wheat (Syme, 1970; McEwan, 1973; Donald & Hamblin, 1976); Barley (Singh, 1971); Oat (Sims, 1963); Groundnut (Duncan et al., 1978); Maize (Yamaguchi, 1974), Field bean (CIAT, 1977, 1978); Soybean (Buzzell & Buttery, 1977).

Discussion

Tropical food crops may be grouped according to the relative importance of harvest index (I) and total biomass yield (B) to economic yield (Y). The

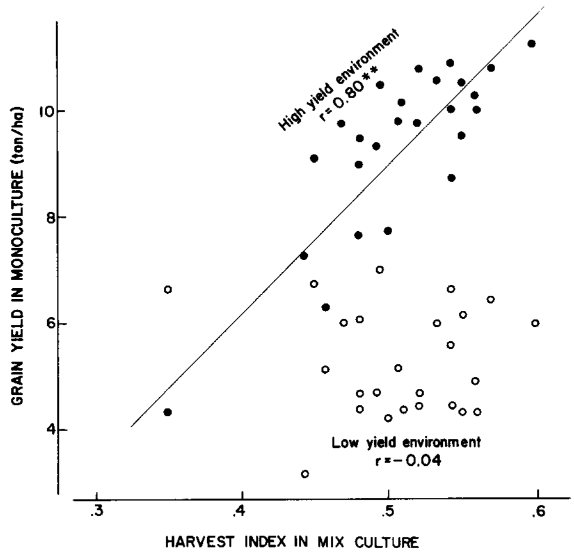

Fig. 5. Relationship between harvest index in mix culture and grain yield in monoculture (under low and high yield environments of the same genotype).

first group, exemplified by cassava, includes crops in which I holds a universal importance to Y over a wide range of environmental conditions.

The second group, represented by rice, includes crops in which I is more important in high yielding environments, while B is more important in low yielding environments. In crops such as wheat (Syme, 1970; McEwan, 1973; Donald & Hamblin, 1976), barley (Singh, 1971), oat (Sims, 1963), and penut (Duncan et al., 1978), I is more important in high yielding environment. With these crops it is at present difficult to analyze which factor is more important under low yielding conditions because very limited attention has been given to the genetic aspect of yield factors in less productive environments. However, these crops would likely fall into the same category as rice.

In tropical maize, Y is highly correlated with B regardless of planting densities, while I is equally important to Y only at high planting densities (Yamaguchi, 1974). Maize may compose the next group in which B is important over a wide range of environmental conditions and I is important only in highly productive environments.

In field bean (*Phaseolus vulgaris*) Y is highly correlated with B while it is not with I (CIAT, 1975, 1978). Similarly, in soybean, I is not an important factor to grain yield (Buzzell and Buttery, 1977). These results were obtained from comparatively well managed fields, receiving adequate fertilizer application, irrigation, and weed and pest control. Thus, these represent relatively high yielding environments. In these crops also, very limited research has been conducted for low yielding environments. Since in other crops relative importance of B to Y tends to be greater in low than in high yielding environments, it would be likely that in field beans and soybean B is important to Y also in low yielding environments. Thus, field bean and soybean belong to the group in which B is important over a wide range of environmental conditions (Table 3).

Intergenotypic competition occurs essentially through competition for light interception (Kawano & Tanaka, 1967; Jennings & Aquino, 1968); thus, genotypes with large B are expected to be strong competitors because of the larger resourses allocated to stem and leaf expansion, while those with high I are expected to be weak competitors because of the fewer resources allocated to stem and leaves.

In field bean, competitive ability is positively correlated with B and Y is highly correlated with B (CIAT, 1977). In maize, competitive ability is positively correlated with Y (Kanneberg & Hunter, 1972). In rice competitive ability is positively correlated with Y in less productive environments through its close correlation with B.

Improvement of grain crops might have started through improvement in I at its earliest stage of domestication. Soon the improvement must have passed to the next stage in which the main improvement was through improved B under relatively low yielding environments. Bulk population methods of crop breeding are characterized by leaving genetically mixed populations to natural selection, in which genotypes with higher competitive ability have a comparative advantage. Farmers' efforts over thousands of years with food crops is a large-scale bulk population breeding program. This process, undoubtedly helped by the general direction of natural selection, produced many venerable land cultivars of grain crops which perform well in their accustomed cultural conditions of comparatively low productivity. It is only after the accomplishment in this step that the improvement for higher yielding environments took place through improved I at the expense of competitive ability against the general direction on natural selection.

In cassava and its wild relatives, bulked roots are not an indispensable plant organ for reproduction because seeds and stems are the means of reproduction. Evolution of cassava cultivars must have occurred largely through the improvement in I because I must have been very low when the improvement started. The yield improvement has been attained at the expense of competitive ability.

Early success of the rice breeding program at IRRI and the wheat breeding program at CIMMYT is the result of the definition of the strategy that to ensure maximum progress in a relatively short time, work should be concentrated in high yielding environments, defined by irrigation and fertilizer application, and the selection for high I types, characterized by short stems, erect leaves, and photoperiod non-sensitivity (Tanaka et al., 1967; Chandler, 1969).

Selection by I had not been a major part of farmers' practice. Thus, the main secret in the success story of the breeding program mentioned above lies in the finding of a plant character which is relevantly related to the selection target and has not been exploited in the farmers' practice of bulk population breeding. Hence, use of I in cassava selection is a relevant approach and significant yield improvement may be expected even for less productive conditions resulting from low-input cultural practices.

In situations where B is the yield limiting factor, modern efforts to improve yield levels may be only a tiny extension of what the farmers have been doing for thousands of years. Consequently, a quantum jump in yield selection is not likely to occur because the farmers may have done most of the work already and traditional cultivars may be the answer. One approach that farmers may not have exhausted, however, is the use of wide and multiple crosses among varied germplasm sources. This may lead to a moderate increase and a better stability of yield, rendered by the increased B and improved tolerance to adverse conditions.

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