BREEDING FOR INTERCROPS with special attention to beans for intercropping with maize

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Beans in eastern and southern Africa are mostly grown by small farmers who commonly use multiple cropping systems. In some areas, for example Rwanda and Burundi, land is increasingly scarce, so that improving the land productivity is more important than labour productivity. In addition, the many stresses to which crops are subjected cause farmers to diversify by planting more than one crop species together, and/or by using variety mixtures. Both these strategies reduce the risk of failure.

For a crop like beans, it is essential to take into account the social environment in which the new varieties will need to perform. Their acceptance or rejection will depend on how well they fit into the social as well as the physical environments. Since breeding takes some time, it is necessary to predict how the social environment will change. As farmers move from subsistence agriculture to marketing a larger proportion of their produce, so they tend to move away from intercropping and to the use of more uniform varieties. This trend can already be seen in some areas with access to urban markets, for example N. Kivu Zaire. However, the advantages of intercropping in terms of increased land productivity and reduced risk are not to be given up lightly, and sustainable improvements in productivity could be more readily achieved if new varieties were bred which were adapted to existing cropping systems.

A problem here is that the existing cropping systems are rather varied. Of course, the cropping system is not the only factor which varies significantly, since the environment is often not subject to much control by the small farmer. Breeding programmes typically generate a great deal of material, which is gradually reduced until one or very few varieties are finally released. These varieties need to be widely adapted if large scale seed production is to be worthwhile. Beans are rarely a very promising subject for large scale seed production. An alternative is to develop seed production in cooperatives of small farmers at a local level, and such small scale seed production would obviate the need for widely adapted varieties. Farmers could then become involved at an earlier stage in the process of selecting among the large genetic diversity in the breeding programme, and varieties could be selected which are more specifically adapted to their conditions, including their cropping systems.

In this paper I will consider some methodologies, with examples, for developing bean varieties specifically adapted to intercropping with maize.

Genotype x Cropping System Interactions and Heritability

Every breeding programme has to contend with genotype x environment interactions, and decisions have to be made with regard to the locations for breeding nurseries and the conditions of soil fertility and disease and pest control. The objective is to achieve the right balance between conditions which are representative of those found on farm, and at the same time uniform enough to allow reasonably reliable selection. The latter is a pre-condition for achieving a satisfactory heritability for the traits under selection. Cropping system is just another variable like the others mentioned above, and the question is whether variety selection is enhanced by including it or not. If there is a strong genotype x cropping system interaction for yield, there are two ways of dealing with this. One is to endeavour to explain the interaction in terms of other traits related to plant type, maturity, disease resistance etc., and then group the material under selection accordingly. This may reduce the interaction to a level at which selection can proceed in sole cropping. The other possibility is to select under intercropping. This is probably only worthwhile when the intercrop actually improves the efficiency of breeding, as in the case of climbing beans, where the maize provides cheap stakes and the heritability of yield is at least as high in the intercrop situation as in the sole crop (Pérez, 1982; Hopmans, 1983; Davis, Pérez and Hopmans, 1983; Zimmerman et al., 1984). Otherwise, early generation selection is better done in sole cropping, bearing in mind the traits required for the target cropping system/environment, and advanced lines should then be selected, preferably involving farmers in the selection of genotypes for testing in their cropping system/environment.

For bush beans, the interaction between genotypes and cropping systems (sole crop vs. maize intercrop) is usually slight, whereas for indeterminate beans the interaction is often highly significant (Roumen and Schellekens, 1984; Smith and Francis, 1986). When indeterminate beans are intercropped with different maize cultivars, on the other hand, the interaction is usually not significant. Therefore, having decided to breed for intercropping, it is probably not worthwhile trying to select the two crops simultaneously. In the case of beans, it is preferable to select a representative maize cultivar, which should ideally be relatively resistant to lodging and to other constraints like diseases. This is not to say that maize should not also be improved for intercropping with legumes (Woolley and Rodriguez, 1987). However, the interaction of maize cultivars with cropping systems is usually relatively slight, and if present can often be explained in terms of plant height and lodging susceptibility (Davis et al., 1986). Rather, the specific traits selected for in the maize breeding programme should be considered in the light of the target cropping system/environment. In particular, time to maturity, plant height, lodging resistance, standing ability after maturity (for relay), leaf width and internode length are all traits which affect the suitability of a maize cultivar for intercropping.

Traits for Intercropping

a) Time to Maturity

Competition between two crop species can be reduced by maximising the temporal separation between their periods of flowering and seed development. This can be achieved by altering the relative planting dates, but this is limited by the length of the growing season. Otherwise, it can be achieved by selecting appropriately for earliness or lateness. However, it should be borne in mind that maturity differences have to be quite large to obtain the benefits of temporal separation. This can be achieved when there are large differences in photoperiod response (e.g. cowpeas intercropped with cereals in Nigeria, Steele and Mehre, 1980). Otherwise, breeding earlier cultivars may allow changes in relative planting dates. Woolley and Smith (1986) suggested using less leafy maize cultivars to permit the sowing of beans earlier in the relay system in Central America. The less leafy maize competes less for light, allowing the planting date of the beans to be advanced, meaning they are less liable to face end of season drought.

b) Plant Type

Above ground competition is controlled by the density and spatial arrangement of the crops, and by the plant type of each crop species. For maize, the most important traits are height, internode length and leaf width. For beans, node number, branching and climbing ability are the most important traits.

Maize genotypes with short internodes and broad leaves shade beans relatively more than genotypes with long internodes and narrow leaves. Tall maize genotypes generally shade understorey crops more (Davis and Garcia, 1983). The significance of the competition from maize depends on the density of planting, and the relative planting dates. If the maize is planted simultaneously with beans and the maize density is in the order of 40-60,000 plants/ha, then competition will be intense. In this situation, climbing beans usually compete better than bush. In much of Africa, however, it is common to find the maize density is rather low (10-20,000 plants/ ha). This situation is ideal for intercropping with bush or semi-climbing beans. If climbing beans are planted in relay with maize, then there will be very little competition and the most important characteristic of the maize is that its stem should resist the climbing beans for some time after the maize has passed maturity.

Beans vary enormously in their ability to climb. Indeterminate beans normally produce more nodes when presented with a support, and this response varies according to the genotype (Davis et al., 1984). Kretchmer et al. (1977) also found that certain genotypes of beans are stimulated to climb by a change in light quality of the sort expected to occur under a canopy of maize.

The ability to climb determines to a large extent the competitive ability of a bean variety (competitive ability defined as intercrop yield/sole crop yield), and this in turn is correlated with the maize yield reduction (Davis et al., 1986). It has also been found that relatively unbranced climbing genotypes of beans are more competitive (Davis and Garcia, 1987). In this situation, where maize and bean yields are negatively correlated, it is a good idea to group the breeding material by growth habit.

For cowpeas, the situation is somewhat similar. Wien and Smithson (1981) demonstrated significant interactions of genotypes by cropping systems, and found that plant size (vigour) in late pod fill was consistently correlated with seed yield in intercropping. They concluded that an initial screening could be made in sole crop, selecting for disease and insect resistance, and eliminating plants with low vigour and erect (bush) plant type.

c) Tolerance to Soil Constraints

There is much less known about below ground competition than above ground. Given that intercropping is widespread in relatively marginal conditions, varieties bred for intercropping should be as tolerant as possible of relevant soil constraints, such as drought, low soil phosphorus and Al toxicity. The legume component should be selected for efficient nodulation, so that it does not compete for ~~this~~ N ~~element~~ with the cereal, and contributes to soil fertility for the following crop.

The scope for complementarity between beans and maize below ground seems great, especially since beans can fix nitrogen. Indeed, the negative correlation between bean and maize yields is usually only found when competition is mainly for light. When soil factors become limiting beans do not usually reduce maize yield, and in fact there may be a slight positive effect (Davis et al., 1987). Below ground competition deserves more attention.

d) Disease and Pest Resistance

The incidence of certain diseases and pests may be reduced by intercropping (Altieri and Liebman, 1986). This may result in different priorities being set in a breeding programme for intercropping. If there is above ground competition between crop species, a disease or insect which attacks one species in the vegetative stage and reduces vigour will tend to give the competitive advantage to the other crop species. If, on the other hand, the attack occurs in the reproductive phase, there will probably be no compensatory effect. The combination of intercropping with genetic resistance is surely an attractive method of achieving sustainable disease and pest control. Related to this is the use of genetic mixtures which combine different resistance genes (Panse, 1988).

Selection and Yield Evaluation

Single plant selection of beans and other legumes is normally best done in sole crop. An exception to this is climbing beans, where it may be simpler and cheaper to plant with maize (one bean plant to one maize plant).

Early generation evaluation of progeny is also usually better done in sole crop. However, climbing beans are readily evaluated with maize, and early generation yield trials have been found to be effective (Davis et al., 1983). The efficiency of these can be increased by using hill plots (Roman, 1987). In Colombia, single hills consisting of two maize plants and two beans plants, spaced 0.92 m apart on the square, with four repetitions, were found to give satisfactory yield estimations which correlated well with yields from normal plots. The amount of seed required is very low, and the plot size is very small, allowing large numbers to be handled in a small area. Hill plots are also attractive in that the maize has been found to lodge significantly less when planted in this way than in rows (Davis and Garcia, 1987). If the conditions on the experiment station are insufficiently representative of the target areas, hill plots could also be used for testing relatively large numbers of lines on farm without taking up too much space.

For advanced trials, larger plots must be used than for sole cropping. Beans are usually an understorey crop and the effect of shading must be considered. This would apply to beans under maize or sorghum, and even more so to beans under bananas, a common cropping system in Central Africa. Light penetrates from the edge of a small plot and this can improve the yield of the understorey crop, leading to an overestimate of the Land Equivalent Ratio (LER), and especially overestimating the yield of the less competitive varieties (Davis et al., 1981). The LER is defined as the ratio of the intercrop and sole crop yields of the beans plus the same ratio for maize. With tall maize (>2.5 m) it is preferable to discard 1 m at either end of the plot for yield measurements, while 50 cm is sufficient with short maize (<2 m).

If there is a significant competitive effect of one crop on the other, and this varies according to the variety, it is not enough to select only on the basis of the yield of one crop. The LER, while estimating the efficiency of the intercrops relative to the sole crops, is not an adequate selection criterion for a breeding programme since it is based on ratios, not on absolute values. An alternative is to select on the basis of income, by multiplying the yield of each crop by the price. Costs of production are unlikely to vary significantly for different varieties. However, the price of the product may vary if the market class of the varieties differs considerably. If this is the case, it is preferable to group the varieties by market class. The price ratio can be used to calculate an 'equivalent yield' (Davis et al., 1987). For example, if the price of beans is three times the price of maize, then bean equivalent yield is calculated by dividing the maize yield by three and adding it to the bean yield.

If there is a strong correlation between the yields of the two crops, varieties might be selected which show a significant positive deviation from regression (Davis and Garcia, 1983). These are varieties which yield well and yet interfere relatively less with the other crop species.

Harvest index is sometimes worth studying in conjunction with grain yield. Bean harvest index is normally reduced by competition from maize, but the amount of the reduction varies widely from one genotype to another (Davis et al., 1984). Where the breeding programme aims to improve efficiency of the intercrop, harvest index may be a valid selection criterion.

Farmer Participation

The complexity of cropping systems and the need for new varieties to fit existing cropping systems, or to provide the opportunity for changing the cropping systems in a way which is compatible with farmers' goals, mean that it is important to involve farmers in the breeding programme. Visits of groups of farmers, especially those who already are considered experts in their region, to the experiment station, can provide valuable insights to guide the breeding programme. Farmers expressing most interest in particular groups of breeding materials, advanced lines, or agronomic practices, will probably be the cooperators most interested in testing those materials or practices on their farms. Plans for on farm trials can be developed through joint farmer - researcher discussion, and this is especially relevant for cropping systems research.

In Rwanda, it has been found that 94% of poor farmers buy seed each season, compared with 23% of wealthy farmers. Most of the time farmers buy their seed from their neighbours (Sperling, 1988). Having identified the right varieties for multiple cropping, methods of stimulating local seed production need to be developed. Intercropping itself may be one way of producing cleaner seed.

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