Journal of Oil Palm Research Vol. 16 No. 2, December 2004, p. 121-128

SELECTING THE IDEAL OIL PALM: WHAT YOU SEE IS NOT NECESSARILY WHAT YOU GET!

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ABSTRACT

Yield is the most important selection trait for the ideal plant. Yield selection on single plants from segregating populations in the early selection cycle is unreliable because of unstable genotypes, low heritability and differential plant competitive abilities. Yield selection is best done in later cycles when sufficient quantities of the selected stable genotypes are available for replicated larger plot yield trials conducted over different locations and agronomic treatments. Breeding progress for yield in major crops has been generally slow at 1% -2% per year but nevertheless significant. Methods, e.g. *breeding, physiological, biotechnological, to improve selection efficiency and shorten the selection cycles are not likely to substantially reduce the cultivar development time because of the mandatory extended cycles of yield testing. A smaller erect canopied palm with high harvest index that can tolerate higher density planting would be the oil palm ideotype for efficient yield enhancement. Such cultivars are unlikely to be available for the next 15 years. Nevertheless, plantations should accelerate replanting as improved cultivars particularly with better oil content are continuously being produced, and coupled with the simultaneous implementation of improved agro-management practices, larger quantum yields can be achieved. Existing planted materials already have high genetic yield potential, and the onus lies with the agronomist and manager to implement the prescribed agro-management practices to achieve the yield potential of the site and thus, narrow the gap between potential and realized yields.*

Keywords: single plant selection, oil palm ideotype.

Date received: 22 September 2004; **Sent for revision:** 5 October 2004; **Received in final form:** 30 November 2004; **Accepted:** 1 December 2004.

INTRODUCTION

Selection or choice is closest to the heart of everyone. Everyone believes that he is the best selectionist, be it for fashion, food or friends. And we are not short of opinions from parents telling us how to select our partners or from our juniors, peers and superiors, on how to select the ideal rubber, cocoa or oil palm tree. This is good as everyone is actively thinking hard on the desirable attributes of an ideal partner or plant variety. Unfortunately, for some of the traits that matter, we can be dead wrong in our choice because of our bias or the desirable trait we seek may turn out to be more elusive than we think. Many animal breed and crop variety prize winners in agricultural/horticultural fairs do not make it to the market place because they are novelties and not commodities. And modern cultivars are usually smaller and less vigorous looking than their traditional counterparts. Why are these so?

The explanation boils down to two important concepts in plant and animal breeding, *i.e.* heritability and competitive ability.

HERITABILITY

The phenotype or the external expression of a trait is sum of its genotype or genetic constitution and the environmental influence, *i.e.* P = G + E. And the

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phenotypic differences or variance among a group of individuals is equal to the genetic variances and their different environmental influences, *i.e.* Vp = Vg + Ve. Heritabilty, h^2 = Vg/Vp, expresses the proportion of phenotype differences attributed to genetic differences.

If the heritability for a particular trait is high, *e.g.* dwarfism, fruit/flower/seed colour (*i.e.* qualitative traits), then there are no environmental differences, only genetic differences (*Figure 1*). The phenotype is the genotype and *what you see is what you get, i.e.* the trait transmits true to the next generation (sexual or asexual). The trait is usually under the control of one or few genes. Unfortunately, for most production/economic traits, *e.g.* yield, h^2 is usually very low because many genes are involved and environmental effects predominate. The phenotypic is thus not a reliable reflection of its genotype and progeny or clone testing, *i.e.* next generation testing, is mandatory to ascertain the genotype of the selected phenotype.

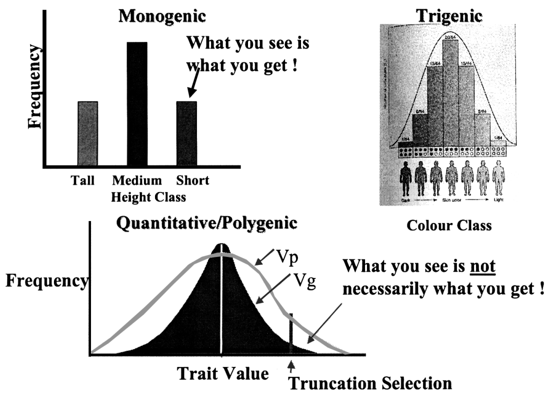

Figure 1. Trait inheritance.

COMPETITIVE ABILITY

The crop community is a competitive environment in which individual plants compete among themselves for light, water and nutrients (*Figure 2*). Again the competition may arise from genetic and non-genetic (environmental) differences. Plants that are genetically vigorous growing, *i.e.*, tall, big canopied, strong rooting, are likely to outcompete their less vigorous neighbours. Competition can also arise from environmental reasons, *e.g.* microsite differences, differential management inputs. In both situations, competition effects tend to accentuate with time, *i.e.* the stronger gets stronger at the expense of the weaker.

Also individual plant selection is usually performed in a mixed stand or genetically segregating population situation while the developed variety is usually planted in a pure stand or genetically uniform population situation. Firstly,

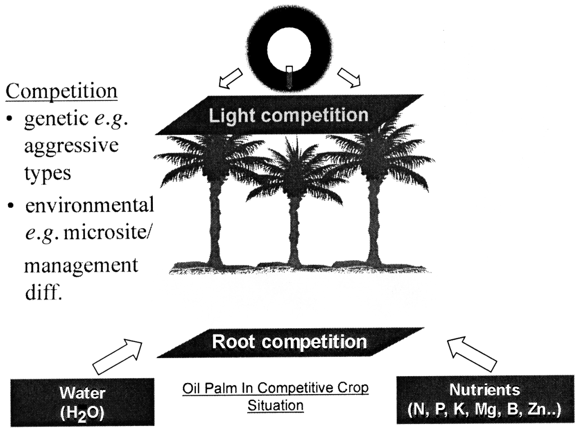

Figure 2. Competitive ability.

individual plant heritability for yield is generally very low in a genetically segregating stand situation due to the confounding effects of competition and environment (Allard, 1960; Simmonds, 1979; Bernado, 2002). Secondly, selection for yield in such a situation would tend to bias towards the more vigorous plants and against the weaker. The general experience in many crops is that yield of an individual plant in a mixed stand is poorly correlated to that of their sexual or clonal offsprings grown in a pure stand. Aggressive or vigorous genotypes do not make successful cultivars. Modern high yielding cultivars tend to be of smaller stature with an erectish canopy habit allowing them to be planted at a higher density being non-competitive and/or can withstand competitive stress (Peng *et al.*, 1999; Reynolds *et al.*, 1999; Tollenaar and Wu, 1999). On an individual plant basis, they may yield lower than the aggressive traditional varieties, but they convert a greater part of the light energy captured into the reproductive growth (yield) than to vegetative growth, *i.e.* better harvest index (HI). Modern cultivars thus achieve their high yields through high biomass production from higher stand and thus high biomass and/or high HI.

How are these concepts applied in actual breeding programmes?

SELECTION STRATEGIES IN BREEDING PROGRAMMES

A standard breeding programme involves the following stages (Caligari, 2003):

⇑ create genetic variability;
⇑ select among the variants; and
⇑ stabilize and multiply the selected genotype.

Inbreeding (self pollinated) Crops, *e.g.* Rice, Wheat

In inbreeding crops, maximum genetic variability is created in the F_2 of the cross between two selected unrelated inbred variety/lines (*Figure* 3). The F_3's are usually planted in non-replicated family rows (1-2). Single plant selection is done in F_2-F_3 focusing on more heritable traits, *e.g.* plant form, pest and disease resistance. Selection for yield per se is discouraged because of its low heritability, unstable genotype (heterozygosity) and confounding competition effects due to single plant or 1-2 row plantings (Allard, 1960; Simmonds, 1979).

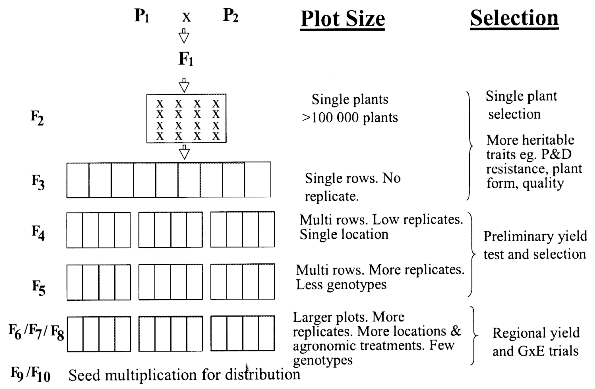

Figure 3. Self pollinated crop breeding: e.g. *rice.*

Preliminary yield selection usually begins in F_4 and F_5 with replicated multi-row plot trials with the availability of more planting materials and more stabilized genotypes. In F_7 to F_9, adaptability and agronomic requirement trials are conducted in larger plots replicated over environments with a few final line selections. The cultivar is officially released usually after F_{10} onwards after sufficient quantities of the stabilized genotype have been multiplied for commercial distribution. This translates to about six to 10 years for rice.

Outbreeding (cross-pollinated) Crops, *e.g.* Maize

Hybrid variety breeding in outbreeding crops starts of from crosses within each heterotic parental populations (*Figure* 4). F_2's are generated within each population. F_4-F_6's inbred lines are obtained from single plant and single row selection for the more heritable traits as for the inbreeding crops. Inter-population hybrid cross testing is performed with selected F_4-F_6 inbred lines. Heterotic hybrids are identified and the heterotic parents further purified and multiplied by selfing for commercial hybrid seed production.

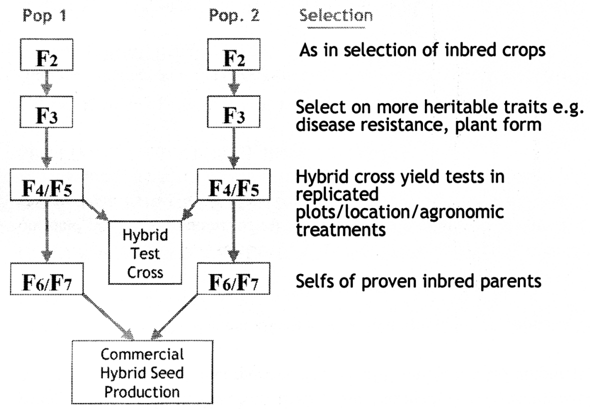

Figure 4. Hybrid (cross pollinated) crop breeding: e.g. *maize.*

Clonally Propagated Crops, *e.g.* Fruit Trees, Cassava, Sugar Cane, Rubber

Clonally propagated crops are perennial outbreeders and are highly genetically heterozygous and heterogeneous (Simmonds, 1979). A highly segregating F_1 population (equivalent to F_2 of inbred crop) can be achieved by crossing two unrelated clones. As they are generally intolerant to inbreeding, the best heterotic genotype is presumed to occur in this segregating population and the task is to be able to identify these individuals for commercial clonal propagation (*Figure* 5).

Again the strategy is to select weakly for yield and emphasize more heritable traits in the early clonal generations. Subsequent cycles of yield tests with increasing plot sizes, replications, locations and agronomic treatments are done with increasing availability of propagules of clones that survived selection at each cycle (Tan, 1987; Kawano *et al.*, 1998). The final selections are mass propagated for commercial distribution.

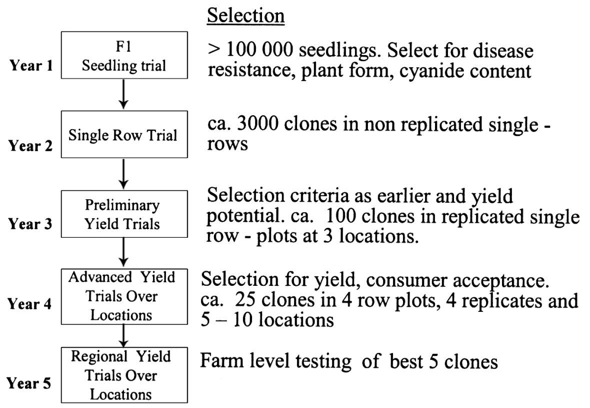

Figure 5. Clonal crop breeding: e.g. *cassava.*

Oil Palm

Hybrid seed breeding in oil palm essentially follows the procedure outlined for hybrid crops (Soh *et al.*, 2003a). Except that for a perennial tree crop, we cannot afford to inbreed for four to five generations (30-40 years) before hybrid progeny testing and subsequent hybrid seed production. Instead the parents are progeny-tested and selfed simultaneously at each cycle so that when the yield-test results are available, the selfed parents of the selected hybrids are ready to be used for commercial hybrid seed production (*Figure 6*). As most seed production programmes are based on less inbred parents, the resultant hybrid seeds tend to be still genetically variable as compared to, *e.g.* hybrid maize. This forms the basis of the interest and development of oil palm clones using tissue culture, basically to stabilize and multiply the selected genotype instead of using the inbred parent breeding approach (Hardon *et al.*, 1987; Soh *et al.*, 2003a).

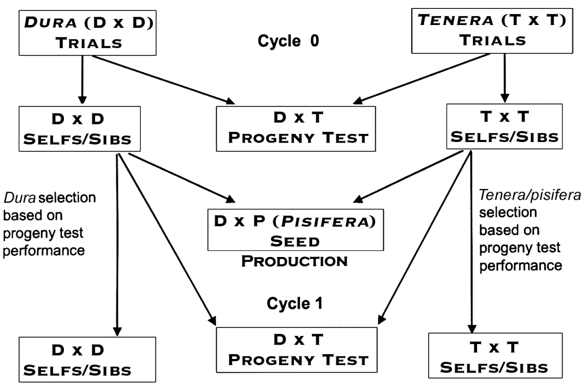

Figure 6. Oil palm breeding.

However, there is a persisting misconception that if we clone a high yielding palm from the hybrid family, we will capture its superior performance (Jones *et al.*, 1974; Khaw and Ng, 1997). In fact, the situation is not much different from that of the segregating F_1 population in clonal propagated crops. Due to the low heritability for yield and competition bias (Soh *et al.*, 2003b; Chan, 2004), cycles of clonal yield tests as done in cassava and rubber would be needed to establish the final clonal cultivar (Tan, 1987; Kawano *et al.*, 1998).

Should we use the approach outlined for clonal crops in oil palm? While we can clone and reclone oil palm, the efficiency of the technique in terms of clonal stability, *i.e.* minimal somaclonal variation and ease of mass propagation is still not foolproof although recent results are very encouraging (Wong *et al.*, 1999; Soh *et al.*, 2003a). In fact, the current breeding for hybrid seeds cum cloning the best hybrid plant approach may be the better strategy because with the strictly cloning approach, the selection limit is already set in the segregating F_1!

SELECTION TRAITS AND GENETIC IMPROVEMENT

A newly developed cultivar must meet both the agronomic requirements of the grower and the preference of the consumer. It is not surprising that the number of desirable traits under selection in most crop breeding programmes can be as high as 20 in oil palm and 50 in potato (*Table 1*). These would encompass agronomic traits, pest and disease resistances, quality traits and even aesthetic traits.

With the exception for yield (grain, bean, oil, sugar and latex), selection efficiency and genetic improvement for the other more heritable traits are usually good. In fact, it has been said that most of the genetic improvements made in the international cereal breeding programmes have been on pest and disease resistance, adaptability and quality than on yielding ability per se. Yield improvements in cereal crops have been estimated to be less than 5% per cycle or around 1%-2% per year. In oil palm, the estimated improvement is 12%-16% per cycle (eight to10 years) or a commendable 1.5% per year (Soh *et al.*, 2003a).

TABLE 1. SELECTION TRAITS IN CROPS

	Potato	Rubber	Oil Palm
Field	Early growth & vigor P&D resistance Tuber yield, shape, color, size Resistance to mechanical damage	Growth & vigour P&D & wind resistance Latex yield Plugging index Brown bast	Palm form, height, girth Bunch yield, number, weight Bunch & fruit forms Oil content, Kernel content
Qualit.	Flesh colour, texture, Cooking, frying quality Glycoalkaloid content	Dry rubber content, protein content	Fatty acid composition Carotene content vitamin E content

IMPROVING BREEDING AND SELECTION EFFICIENCY

Reduction in Selection Cycle/Breeding Time

Since the early days of development of the scientific basis of modern crop breeding, breeders have been seeking ways to shorten the selection cycle and expedite the breeding progress. Successful methods developed include:

⇑ early yield testing of families instead of individuals to identify families with best

prospects of providing good candidates for breeding improvement;
- ⥣ use of dihaploids to expedite development of superior inbred lines;
- ⥣ single seed descent and moving breeding materials across climatic zones for rapid generation turnover; and
- ⥣ cloning in out-breeding perennial tree crops, (*e.g.* oil palm, cacao) can shorten the cycle time.

Some of these methods have been tried in the oil palm.

Ideotype Breeding

As yield selection improvement is so inefficient and cumbersome, can we not define a plant type with morpho-phsiological traits that are more efficient in yield enhancement, for us to select, instead of yield per se (Rasmusson, 1991)? As in other major crops, this approach has been advocated and attempted in oil palm (Breure and Corley, 1983; Breure, 1986; Henson, 1992, Smith, 1993).

The crop physiological components of the oil palm productivity are given in *Figure 7,* and can be expressed in the following equation:

$$Y = S * f * e * p$$

i.e. yield (Y) is a function of the light energy (S); interception by the canopy with efficiency (f); conversion of the energy captured to dry matter with efficiency (e), and partitioning of dry matter produced into the crop with efficiency (p). Proposals and attempts to breed for high efficiency plants with better light capture, higher photosynthetic rate, higher leaf area ratio, better conversion efficiency, reduced respiratory loss, change from C3 to C4 pathway and improved HI (Evans and Fischer, 1999; Loomis and Amthor, 1999) have been made. Many of these traits have been identified retrospectively from new high yielding cultivars. However, when these traits were applied actively in actual breeding programmes the results have been disappointing.

The probable reasons are:
- ⥣ many of the measurements and selections were made on individual plants that may not apply in a uniform crop situation;
- ⥣ some of the parameters were derived parameters from yield or dry matter and were thus biased by dependencies or autocorrelations (Chang and Rao, 1989); and
- ⥣ yield is a final product of a complex set of physiological processes both at the plant and the crop levels and it would be naive to believe that just by altering one component, one would get a significant increase in yield. An increase in one component would result in a bottleneck in another in an otherwise equilibrium system.

A classic example is the New Plant Type (NPT) programme of IRRI (Peng *et al.*, 1999). In the late 1980s, they identified that the high unproductive tillering, high LAR and small panicle (small sink) plant type of the semi-dwarf indica rice was the cause of its stagnating yield. Simulation studies showed a 25% yield increase with a new plant type with lower

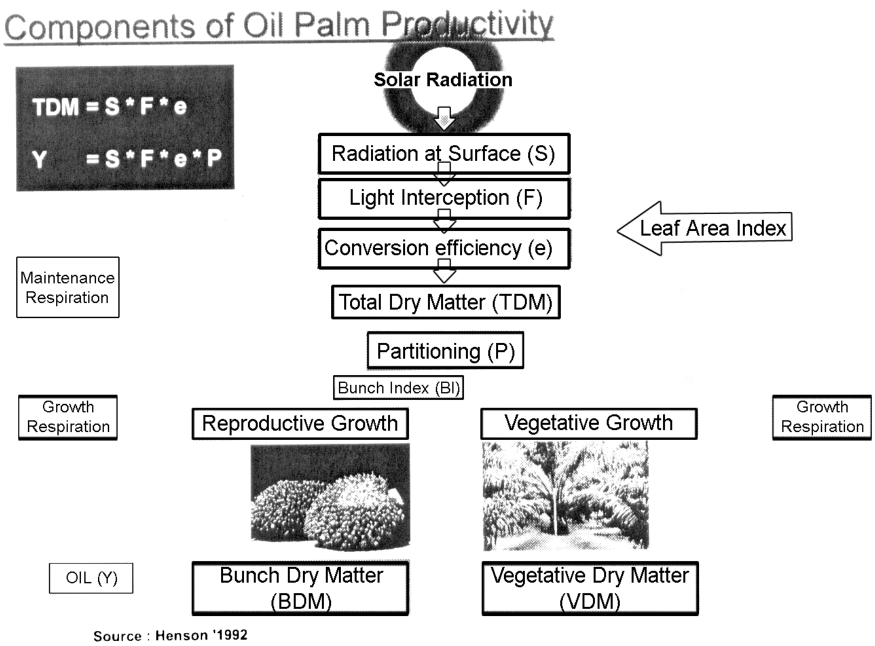

Figure 7. Oil palm productivity.

leaf area, reduced tillering and a larger panicle. Unfortunately, the yield of the bred NPT variety turned out to be otherwise because of poor grain filling.

That being said, from retrospective studies, the common features of current high yielding crop cultivars are high biomass production from high density plantings and/or high (HI).

Biotechnology

In recent years, biotechnology has been touted as the solution to the slow progress from conventional breeding. Biotechnology can assist breeding in all the three stages:

- ⥣ transgene technology can broaden and expedite creation of genetic variability;
- ⥣ molecular markers can expedite selection and improve its efficiency; and
- ⥣ tissue culture/micropropagation can fix the desirable genotype and multiply it for commercial production.

While not denying their potentials, there are constraints in the applications of these technologies. Currently, only major genes or highly heritable traits work well in transgenics and marker assisted selection (MAS). The transgene may not be stably incorporated and expressed or disrupt the host genotype and breeding is still needed to clean up and fix it. In the tissue culture system, the transgene may be silenced or somaclonal variants may be induced, *e.g.* mantled fruit in oil palm.

Yield testing in the field under various environmental and agronomic conditions is mandatory for successful cultivar development. This is the most tedious and time-consuming stage in the breeding programme. As such, all the methods designed to shorten the breeding cycle are unlikely to reduce cultivar development time substantially.

CONCLUSION

Highly heritable traits derived from one or few genes, *e.g.* quality traits, pest and disease resistance, are readily and efficiently selected in breeding programmes. Selection for yield per se based on single or few plants is discouraged in the early cycles of the breeding programme because of its unstable genotype, low heritability and bias from differences in competitive abilities among the segregating genotypes. Selection for yield is usually postponed till the later generations when sufficient propagules of the stabilized genotype are available for replicated plot yield tests in cycles of increasing plot sizes and replications including tests over different environments and agronomic treatments before the final confirmation of a few genotypes as new cultivars.

Breeding improvement in yield for most major crops has been very modest yet significant at about 1%-2% per year. For oil palm, it has been 12%-16% per eight to10 years or about 1.5% per year. With the cloning option in oil palm, the quantum improvement would not be much changed except that the time might be shortened by a couple of years (*Figure 8*). Biotechnological tools can assist in the introduction and introgression of novel and

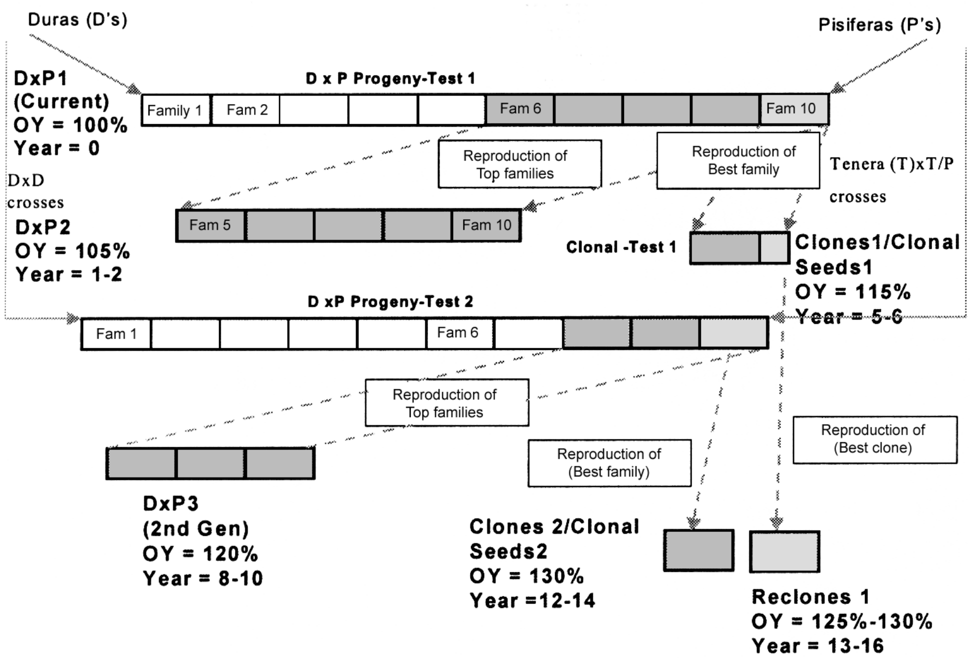

Figure 8. Expected breeding and cloning progress for oil yield (OY).

enhanced product traits. They generally work best with highly heritable traits. With poorly heritable production traits *e.g.* yield, molecular markers and quantitative trait loci (QTL) could only account for a very small percentage the yield variation (Bernado, 2000). The biggest stumbling block in the development of reliable markers is usually the very imprecise measurement of yield (Soh *et al*., 1990).

It cannot be denied that biotechnological tools will continue to be improved towards better breeding and selection efficiency for yield. High yielding cultivars are often sought as the solution to the large gap between the genetic yield potential (GYP) and realized yield, *e.g.* oil palm GYP = 12-18 t ha^{-1} yr^{-1} oil versus 4.5-5 t ha^{-1} yr^{-1} national, mature field average (*Figure 9*). Of the ideotype traits examined, it appears that the best approach to improve yield in the oil palm, as in other crops, is to select for smaller palms with more erect canopies that can tolerate high density planting to achieve high biomass production (>44 t ha^{-1} yr^{-1}) and with high HI particularly from high oil to bunch ratio (>30%). Such materials presumably with larger quantum leaps in yield, however, are unlikely to be available within the next 15 years and even if they are available now, with current rates of replanting of less than 5%, their impact on national yields will not be felt within the next 10 years. Nevertheless, plantations should accelerate replanting as improved hybrid seeds and clones particularly with better oil extraction would continuously be produced and coupled with the implementation of improved agro-management practices right from the start, yield improvement of 20%-30% is achievable.

Currently planted materials already have yield potentials as field yields exceeding 40 t have frequently been reported (Goh *et al*., 2002). Such yields that represent the confluence of genotype, agro-management and environmental conditions occur infrequently and in small fields and it is unrealistic to insist on such yield targets for every field. The site yield potential (SYP) that has allowed for limitations due to site factors is an achievable target with the correct agro-management inputs (Kee *et al.,* 1998). Yields of 30-35 t are close to the SYP's for most fields planted on reasonably suitable areas and should be the more realistic targets. Coupled with extraction rates of about 22%-23% reported for more recent plantings, oil yields of 6.5-7.5 t ha^{-1} are achievable, thus enabling the industry to break out from its stagnating yield syndrome.

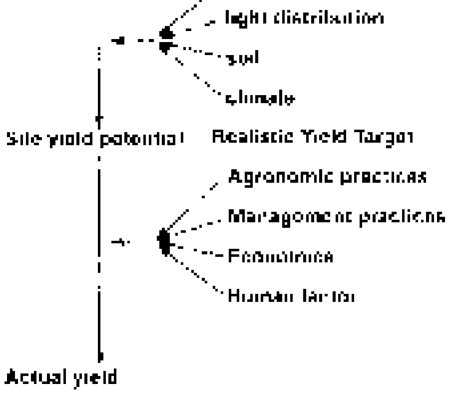

Figure 9. Genetic yield potential, site potential and realizable yield.

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to Advanced Agriecological Research Sdn Bhd and its principals, Boustead Holdings Bhd and Kuala Lumpur Kepong Bhd for permission to publish this paper.

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