UNIVERSITEIT GENT

FACULTY OF BIOSCIENCE ENGINEERING

Plant Breeding

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Who am I ?

- 30 years active in breeding and breeding research

- Set-up of a **faba bean** breeding programme at UGent (1982)
- Civil servant variety testing and plant breeders' right (1984-1985)
- 1985-1996: active in a breeding company: breeding grasses (forage and amenity grasses), leguminous crops (white clover, faba bean),…….maize
- 40 varieties listed and commercialized in several European countries and CN
- Teaching Plant Breeding at UGent since 1996, breeding of tall fescue
- Member of CPVO Board of Appeal

What is plant breeding ?

- Several definitions
- Vavilov: "Evolution at the will of man"
- Changing the **phenotype** of plants to fulfill needs of mankind (or parts of mankind ?)

Since the needs are changing, phenotypes change accordingly: yield, quality, shelf life, storage life, …….

A never ending activity

Who is active in plant breeding ?

a) Universities - Research institutes ↘

b) Breeding companies

c) Research institutes associated with breeding companies

d) Participatory breeding

e) ‘Hobby’ breeders

Different goals:

Improve the world or earning money or both ?

Goal determines the breeding strategy !

How do plant breeders work ?

1) Selecting the right **phenotype**, meanwhile changing the genotype

   How ? Using genetic resources and combination breeding and (molecular) marker assisted selection

2) Selecting the right **genotype**, meanwhile changing the phenotype

   How ? Changing DNA or its expression : directed mutations, recombinant DNA techniques, …..

3) A combination of 1) and 2)

How do plant breeders work ?

Prof Coors (Univ of Wisconsin, Dept Agronomy) 2006

1. Form follows function : by selecting phenotypes, genotypes change accordingly

Darwinian view

Forward selection

2. Function follows form: selecting genotypes will produce the targeted phenotypes

Complete change of view

Backward selection

Trends in plant breeding ?

1. A) Concentration ! B) Time is money !

   Loss of genetic diversity and loss of (genetic) diversity in breeders…loss of attentiveness (see what happened in the past), desk breeders…

2. Stronger protection of new varieties

   Plant breeders' rights and DUS system and further on ?

   Plant patents

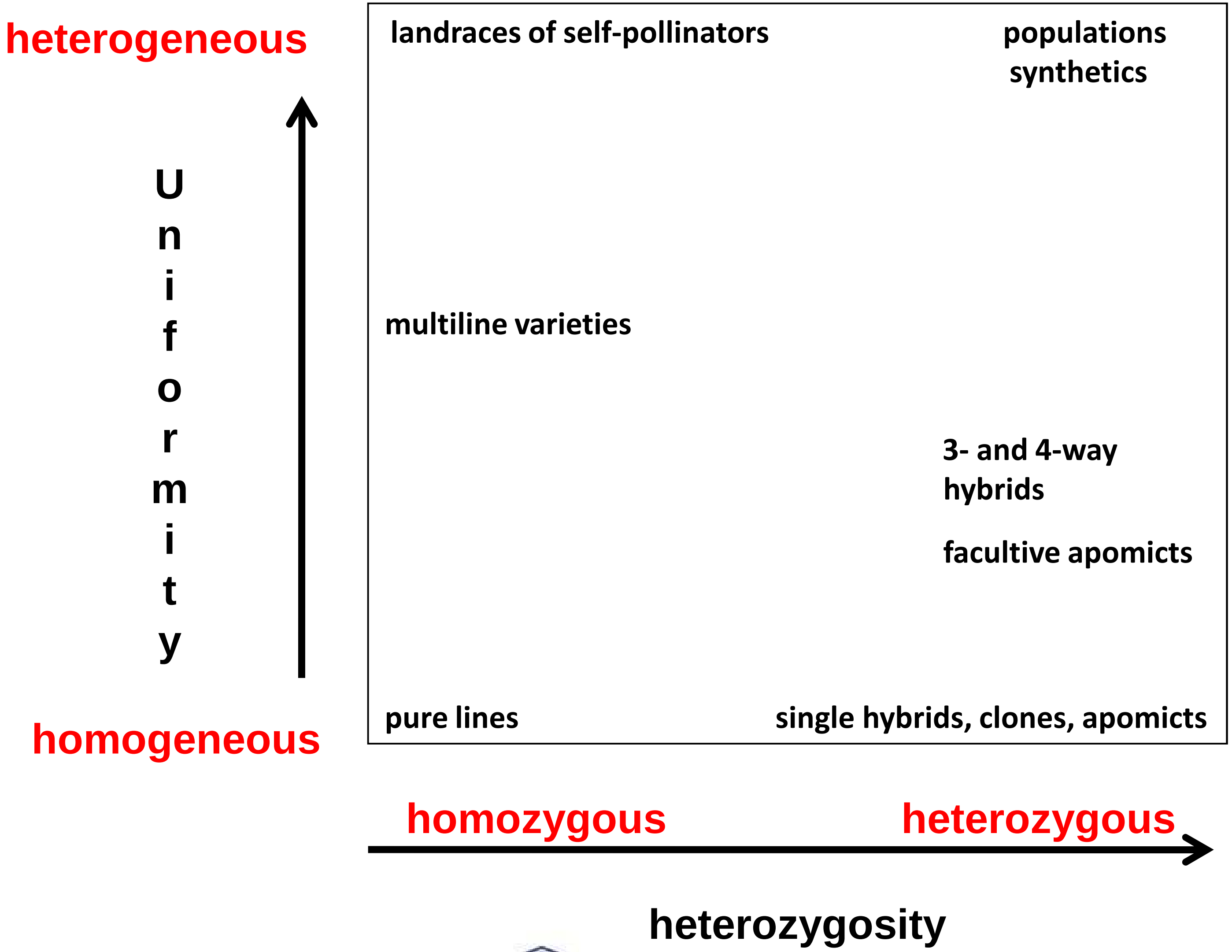
3. Reaction from organic agriculture: conservation varieties, no protection (patent = legal infertility)

What kind of varieties ?

1) Widely adapted ?
   Wanted by big companies: matter of costs

2) Regionally or locally adapted ?
   Copes better with G*E interaction;
   Popular in organic agriculture

Structure of the varieties



What if the variety is finished ?

Variety testing

Seed production

Marketing

Will plant breeders save the world ?

Approx 50% of progress in yield in the western world is owing to plant breeding; 50% to good agricultural practices. Recently the relative proportion of plant breeding is going up (rate of progress in agricultural practices is going down)

There is no such thing as classical breeding and modern breeding ! There is only "plant breeding"

Skills of plant breeders

- Attitude to work hard (….profile): listen well and don’t talk (to much)
- Think and study long before you start: know your crop, define the goal, design a strategy
- Work in the environment where the crop will grow (is not the lab !)
- Install good seed storage facilities
- Have attentiveness, select sharp if necessary
- Develop planning and efficiency skills, beware of the quality of all work
- Be aware of the constraints: money, labour, people
- Have an open mind but don’t change a programme quickly
- **Look for “disasters”: have always all your material in as many environments as possible**
- Do not give up (quickly)

Self-pollinating crops

Cross between 2 homozygous individuals:

From F1 on, heterozygosity diminishes with 50% per generation.

How long does it take to have a complete homozygous line ?

Proportion (p) of completely homozygous lines in segregating generations (g) issued from a cross between 2 homozygous individuals differing in n loci

$$p = \left[1 - \left(\frac{1}{2} \right)^{g} \right]^{n}$$

Proportion (p) of completely homozygous lines in segregating generations (g) issued from a cross between 2 homozygous individuals differing in n loci

F-generation	g	n		
		21	42	84
F4	3	0,06	0,004	
F5	4	0,26	0,07	0,004
F6	5	0,51	0,26	0,07
F7	6	0,72	0,52	0,27
F8	7			
F9	8			
F10	9	0,96	0,92	0,85

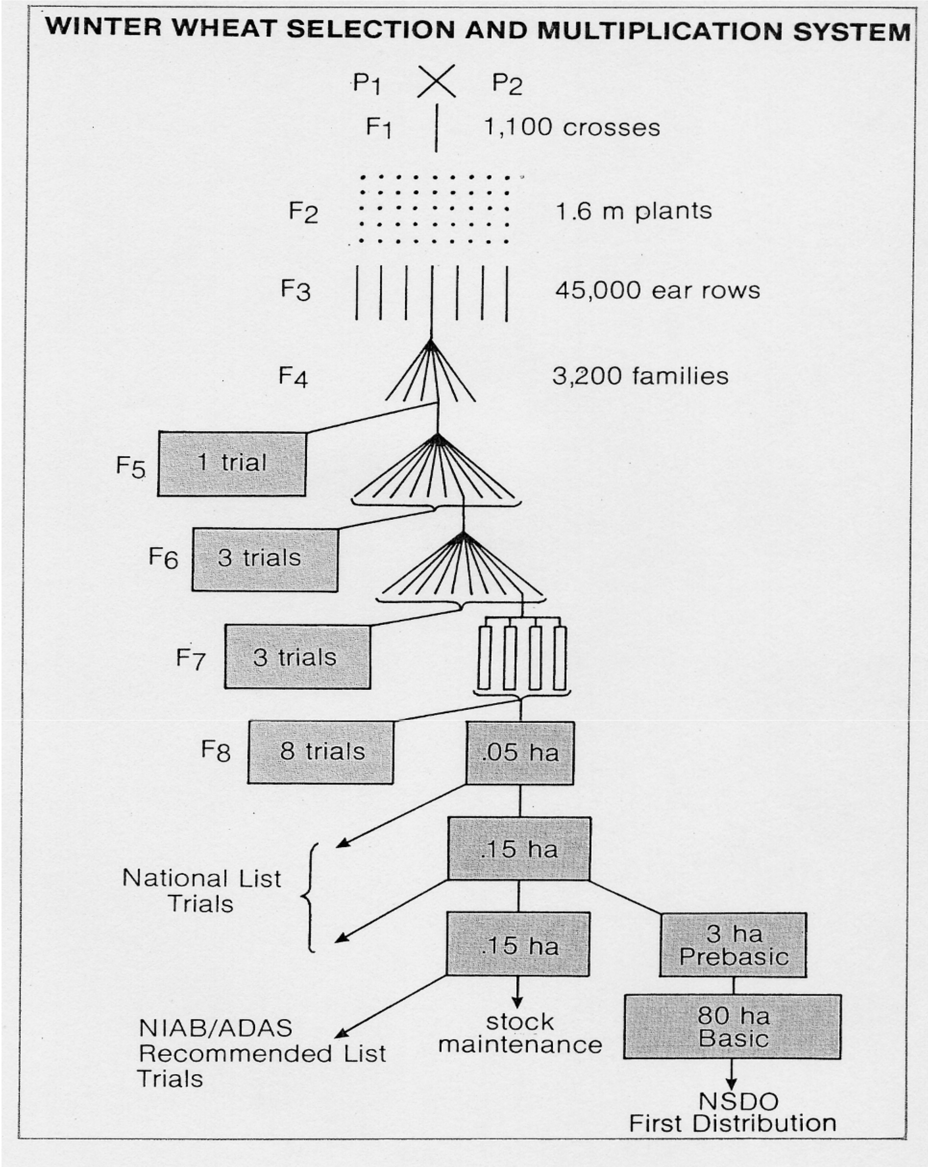
Proportion (p) completely homozygous lines in segregating generations (g) issued from a cross between 2 homozygous parents differing in n loci. Allard, 1999, p 178.

	Generations ($g = 0$ in F_1 and $g = 13$ in F_{14})												
Loci	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}
1	0.50	0.25	0.88	0.94	0.97	0.98	0.99	—	—	—	—	—	—
2	0.25	0.56	0.77	0.88	0.94	0.97	0.98	0.99	—	—	—	—	—
3	0.125	0.42	0.70	0.77	0.91	0.95	0.98	0.99	—	—	—	—	—
5	0.0313	0.24	0.51	0.72	0.85	0.92	0.96	0.98	0.99	—	—	—	—
10	—	0.06	0.26	0.52	0.77	0.85	0.92	0.96	0.98	0.99	—	—	—
20	—	—	0.07	0.28	0.53	0.73	0.86	0.92	0.96	0.96	0.99	—	—
50	—	—	—	0.04	0.20	0.46	0.68	0.82	0.90	0.95	0.98	0.99	—
100	—	—	—	—	0.04	0.20	0.46	0.68	0.82	0.90	0.95	0.98	0.99
150	—	—	—	—	0.01	0.05	0.31	0.56	0.74	0.86	0.93	0.97	0.99

— Indicates frequency < 0.01 or > 0.99.

Pedigree method

PBI,
Cambridge, UK
19eighties



Single seed descent method

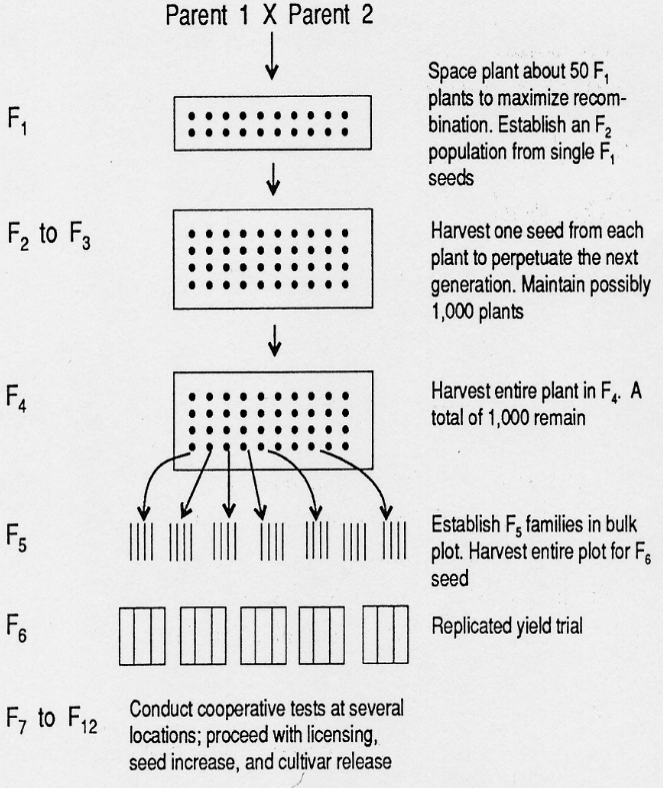


Figure 11.1 Schematic presentation of the single-seed-descent method initially presented by Goulden (1939) and reintroduced by Brim (1966) as a modified pedigree system. During the F_2 to F_4 or F_5 generations, one seed from every plant is used to plant the next generation. When the desired level of inbreeding is attained, each plant is used to establish a family to aid in selection and to produce sufficient seed for subsequent generation yield trials.

Like any plant breeding system, the classical single-seed-descent method can be modified to suit specific crops, circumstances, or objectives. The single-seed-descent method has been used extensively with soybeans and cereals and is starting to be used in tomato, lettuce, and safflower breeding programs. An attractive feature of the single-seed-descent method is the time and space saved in reaching homozygosity.

Simmonds and Smartt, 1999

Bulk method

Simmonds and Smartt, 1999

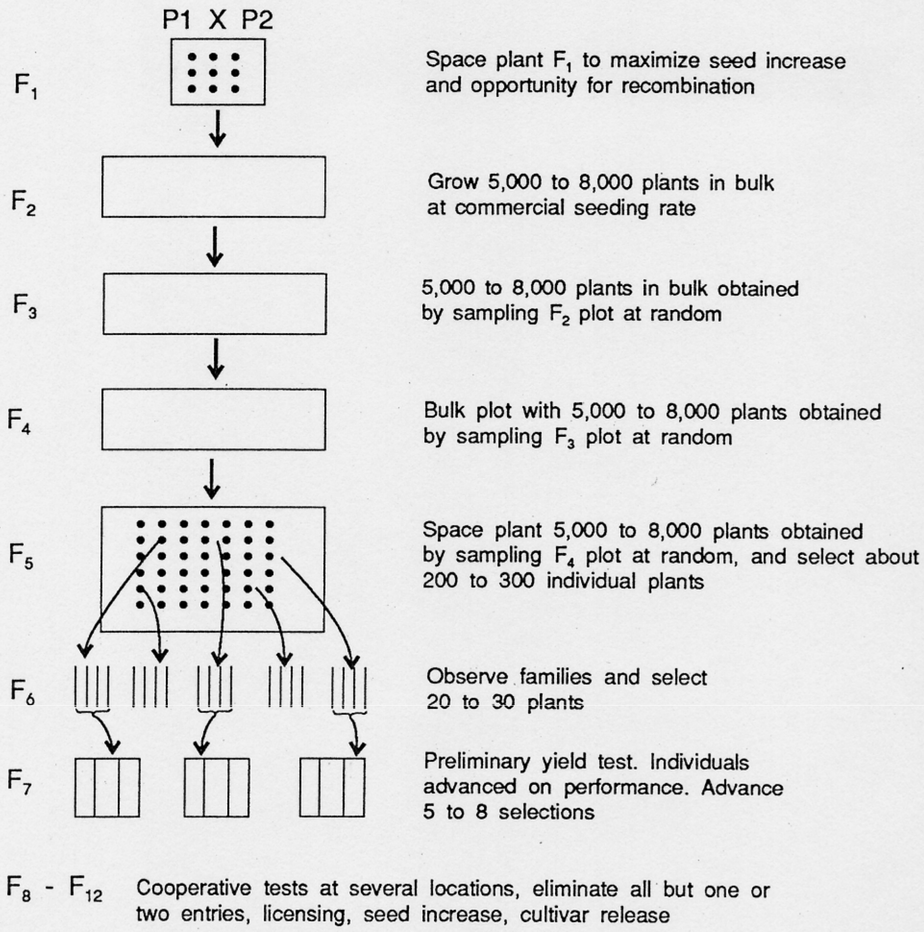


Figure 9.1 The bulk method of plant breeding outlined in this diagram has been adapted to handle extremely large volumes of breeding materials in an inexpensive way and to take advantage of natural selection. Pedigree selection can be practiced among homozygous plants in the population to produce a cultivar. The Swedish plant breeder Nilsson-Ehle used the bulk system in 1908 to screen winter wheat progeny for high yield and winter hardiness (Newman, 1912).

Homozygous lines can be produced with minimum effort and expense, but caution must be exercised to sample adequately each generation to ensure that genetic variability is not reduced. Natural selection operating in the population may modify gene frequency in an undesirable direction.

The bulk system may be used to screen segregating progeny for winter hardiness following a spring x winter hybridization program, for general or horizontal disease resistance, and for grain yield.

The bulk method is not practical for developing high-yielding dwarf genotypes in crops in which dwarf and semi-dwarf stature are desired because such plants are noncompetitors in a population heterogeneous for plant height. The bulk system might be useful for screening dwarf plants in a

Figure 5-52

SCHÉMA DE SÉLECTION GÉNÉALOGIQUE DIFFÉRÉE APRÈS HYBRIDATION *(BULK METHOD)*

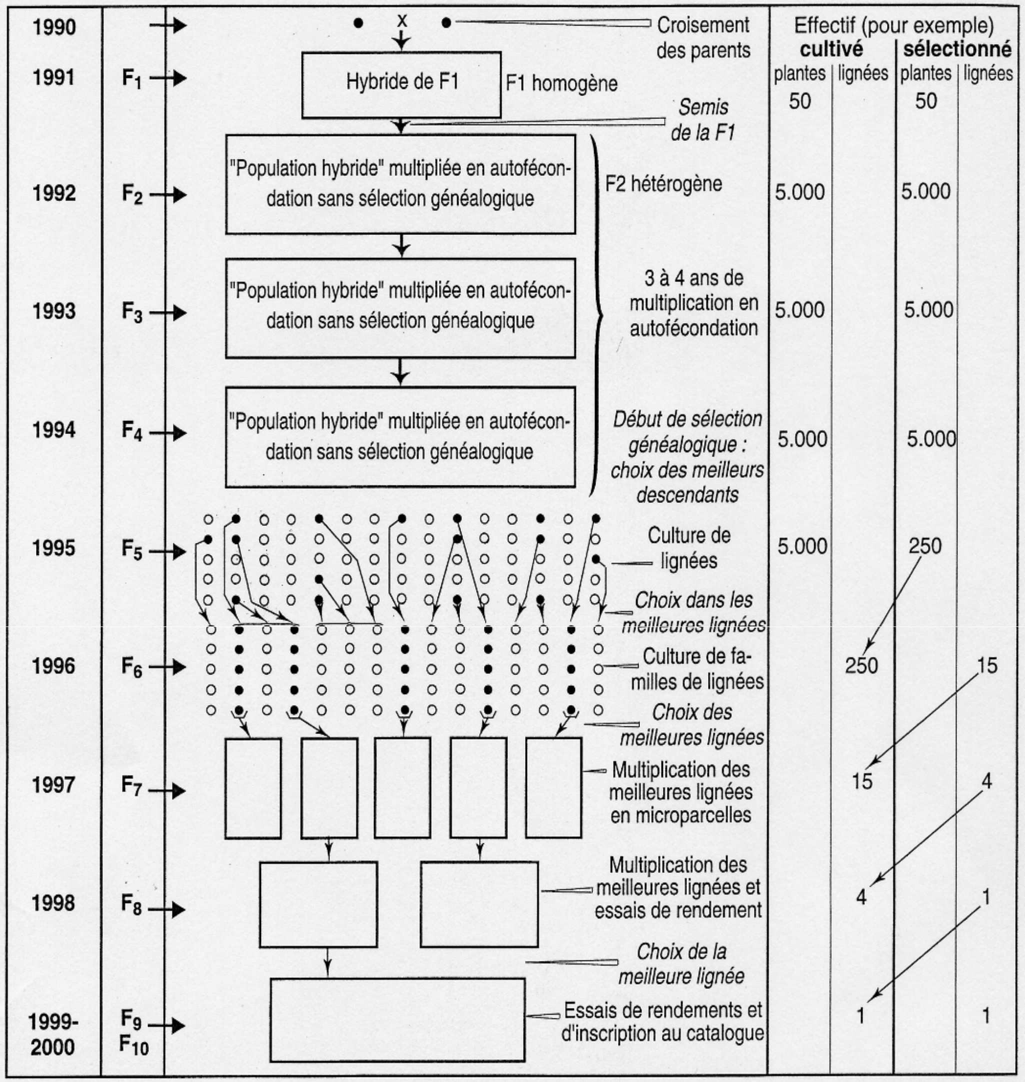
(D'après Yves Hervé, Techniques Agricoles Sélection Végétale N° 2341 - 1991)

La différence par rapport à la méthode précédente (Sélection généalogique directe après hybridation, planche 5-51) est que l'on multiplie durant quelques années, en autofécondation, les hybrides de F1.

Ces autofécondations ont l'avantage de **mettre à l'état homozygote** les caractères intéressants, mais récessifs.

Ces caractères peuvent alors s'extérioriser en devenant homozygotes.

Ensuite, la méthode "Bulk" se déroule de la même manière.



Modified pedigree-bulk selection as applied in bread wheat breeding programmes at CIMMYT, anno 2003.

F_1 : Pair crosses, if necessary additional backcrosses

F_2 : 2000 plants per F_1, planted as spaced plants. Positive visual selection; **seed harvest per selected plant.**

F_3 : Ear to row. 3 rows with a length of 2 m per ear (looks as a mini-plot); seed density: 100 kg/ha, which comes close to what farmers apply in their fields. Having 3 densely planted rows simulates a interplant competition effect. 10-15 plants are selected within the central row: 1 ear per plant is harvested and all **seed is bulked.**
The seed is calibrated and the biggest seeds are prepared for F_4.

F_4 and F_5 : Idem as F_3.

F_6 : Analogously as F_3; 5-10 plants are selected (1 ear/plant): **seed is harvested per plant.**

F_7 : Establishment of small plots, the best plots are harvested and **seed is bulked.**

These seeds are sent to the mega-environments all over the world.

CIMMYT applies the modified pedigree-bulk selection method to breed for arid enviroments: shuttle breeding.

F_2 : **Spaced plants in an optimal environment** (irrigation, fertilizers,…); artificial inoculation with rust spores (in a genetically broad sprectrum); selection of elite plants (representing the yield potential).

F_3 : As F_3 here above; but **without irrigation.**

F_4 : Idem as F_3 but again in **optimal conditions**

F_5-F_6 : As F_3 : **without irrigation**

F_7-F_8 : **Yield trials simultaneously both in optimal and arid conditions: only selections that perform well in both environments are selected for further work**.

Doubled haploids – DH's for quick fixation

1. Androgenesis (anther culture, microspore culture): oilseed rape, barley, (wheat)

2. Gynogenesis

‘Composite cross’ populations

A **composite cross population** is a population composed with the crossing products of many (well planned) pair crosses.

F_1-seeds are bulked and segregation is allowed to take place in **different** environments, resulting in very different populations, well adapted to the environments in which they were developed

Comparing (1) pure line varieties, (2) evolving mixtures and (3) composite cross populations

Experiment in USA with barley

Mechanical mixtures, initially composed of varieties bred by PS lose their genetic diversity with progressing generations owing to the increasing dominance of a few or even 1 particular variety, showing the highest competitive advantage.

In **generation 45**, the **CCV (composite cross variety)** still was genetically diverse, i..e no dominance of a few or a single genotype. At that moment the following experiment was conducted with 4 different entries (1) a number of commercial elite varieties were tested as pure varieties and (2) in a mechanical mixture and compared to (3) 8 lines taken from the CCV, tested as pure lines and (4) tested as a mechanical mixture.

Two out of the 8 CCV lines were performing as well as the best commercial varieties, 3 of the CCV lines performed less (but not significantly different from the top). The mixture of the commercial varieties did not outperform significantly the mean of its components, but the mixture of CCV lines definitely outperformed the mean of its components.

The scientists explain the superiortiy of the surviving genotypes in a composite cross as the results of a ***superior 'ecological combining ability'*****,** *allowing them to perform well under competitive circumstances, because they have been created under such circumstances.*

This (and other similar) experiments prove :

(1) The existence of natural selection for an 'ecological combining ability' in populations (consisting of different genotypes)

AND

(2) that the surviving genotypes also perform outstandingly as pure lines.

What if crops are both cross- and self-fertilizers ?

Theoretically one can develop (inbred) lines or synthetics.

Lines can be grown as pure lines or mechanically mixed.

Synthetics can take advantage of some heterosis which makes them theoretically better than lines.

Ghaouti (2009) studied the performance of lines, mixtures of lines and synthetics in *Vicia faba* in organic farming in Germany.

If G*L(ocation) interaction is greater than the other components of the G*E interaction,
topsynthetics offer better opportunities than top lines.

Maintenance breeding

Soltner, 1996