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ΠΡΟΕΔΡΙΑ ΛΟΥΚΑ ΜΟΥΣΟΥΛΟΥ

ΓΕΩΠΟΝΙΑ.— **Advances in plant breeding methodology,** by Academician *J. Papadakis* *.

ABSTRACT

The great difficulty in plant breeding is to evaluate mother plants and progenies, for productivity. Because of soil heterogeneity and variation of climatic conditions from year to year, we are obliged to carry out extensive trials during several years, before reaching a conclusion, and our decisions to continue or exclude progenies each year are based on inadequate data. Moreover to carry out so extensive trials is expensive and much seed is required; therefore we try only a small number of progenies, and the probability to encounter the outstanding combination of genes, that may exist in the material, with which we are working, are minimal. Still more important, competition favours aggressive, not productive, biotypes, and deceives us; instead of selecting for productivity, we select for aggressivity; the yields of lines or plots are distorted by competition (interference).

The paper discusses the mechanism of plant competition, a very important process, that is virtually ignored in plant breeding. Living roots excrete toxins; because of that plants tend to extend their roots, there is a lineal relation between the space occupied by the roots of a plant and its yield, there is antagonism between aggressivity and productivity, natural selection favours aggressive biotypes, and instead of selecting for productivity we select for aggressivity.

The remedy is to carry out our trials in pots, located in the open air, with 1 only plant in each pot. Competition is excluded, the space occupied by the roots of each plant is precisely fixed, and selection of both progenies and mother plants is done on a safer base. Moreover extensive experiments can be carried out with very little seed; and each mother plant gives sufficient seed, to carry out as extensive experiments, as we want. Instead of sowing in pots, we may sow in sufficiently distant hills to avoid competition;

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more than 50cm in the case of wheat, more than 1^m in that of maize; in the case of trees we may use relatively small distances, separating plots with ditches sufficiently deep to avoid the passage of roots.

Both methods have been used in the Institute of Thessaloniki, Greece, and it is with these methods, that the author has bred, 38290, wheat variety, that was leading in all Greece, during 20 years.

The application of these methods in different cases, the design and analysis of experiments in hills, ways to avoid competition between plots, the importance of crop physiology for the breeder, the wide adaptation of good varieties, the advantages of carrying out plant breeding on a world wide basis, the history of plant domestication and breeding, are also discussed.

I. INTRODUCTION

While the number of plant breeding institutions is great in the world the apparition of a variety, that is really better, and produces a great impact in agricultural practice, as it has happened, with the english wheats of 19th century, those of Farrer, Saunders, Strampelli, Borlaugh, Mentana and 38290 in Greece, the rices of the International Rice Institute, etc., is a rare phenomenon, that happens once in many years, in one or another part of the world. However while breeding for productivity is so difficult, breeding for resistance to diseases, or quality, is usually successful and rapid.

Several authors have tried to justify such situation, saying that a plateau has been reached; but such opinion has been proved false by the green revolution. Sheleski (1967) says, that he has visited leading wheat breeders in the URSS, Sweden, Denmark, Germany, the Netherlands, France, England, USA, Canada, and he has been amazed at the variation, that exists between institutions in methods of breeding for yield. Fasoulas (1983) says, that plant breeding methodology has virtually remained stagnant since the middle of 19th century. It is evident, that something is wrong in plant breeding theory and methodology, and fundamental advances are needed.

In several previous papers (Papadakis 1931a, 1935a, 1935b, 1937c, 1940, 1981) I have presented the one plant par pot or hill methods, that permit an efficient and rapid evaluation of both individual plants and progenies. The object of this communication is to propose further advances in these methods, and plant breeding methodology as as whole.

II. THE MECHANISM OF PLANT COMPETITION
NATURAL VERSUS ARTIFICIAL SELECTION

Misunderstanding of the mechanism of plant competition is the chief cause of present stagnation in plant breeding; 70 years ago Pickering (1917) has shown, that living roots excrete toxins, that are injurious not only to neighbour plants, but also to the plant, which secreted them. And such excretion has been confirmed by the author (Papadakis 1941) with more advanced methods.

Because of this secretion, in the space occupied by living roots of a plant, another plant cannot extend its roots; it is a fact of common observation, that a dense crop is the more sure way to avoid weed invasion. For the same reason the relation between available space and plant yield is lineal; if in a square meter instead of 100 plants we have only 10, the yield per plant is 10 times higher (experiments of the International Rice Institute, annual report 1964) and experiments with whatever crop all over the world; if in a bottle with nutritive solution, instead of 1 plant we grow 2 or 3 the yield per plant is 2 or 3 times lower (Papadakis 1941, 1949); when plants are grown in containers, the yield increases with the volume of the container (Papadakis 1941, 1949). Some authors (Blackman and Wilson 1951 and others) tried to explain these facts by competition for light (mutual shading); but after several decades of almost universal acceptation such theory has been abandonned; plants compete for soil space, very rarely for light (see fig. 1).

We should take into consideration, that plants cannot hit or kill one another; the only weapon they have in their struggle for survivance is impeding the invasion of their space by the roots of other plants with Pickering toxins; moreover the leachates of leaves of some plants have analogous effects (allelopathy). Moreover plants cannot migrate, when the soil in which they live is exhausted; they live in the same soil during all their life; the same soil is used by one or another plant during millenia. It is obvious that plants have the capacity to limit their own growth, with Pickering toxins, etc.

Since the principal weapon, that plants use in their struggle for survivance, limits their own growth, there is antagonism between aggressivity and productivity (yield per unit of space). And natural selection selects aggressive but little producing genotypes (Papadakis 1940a).

This antagonism has been proved experimentally by the author (Papa-

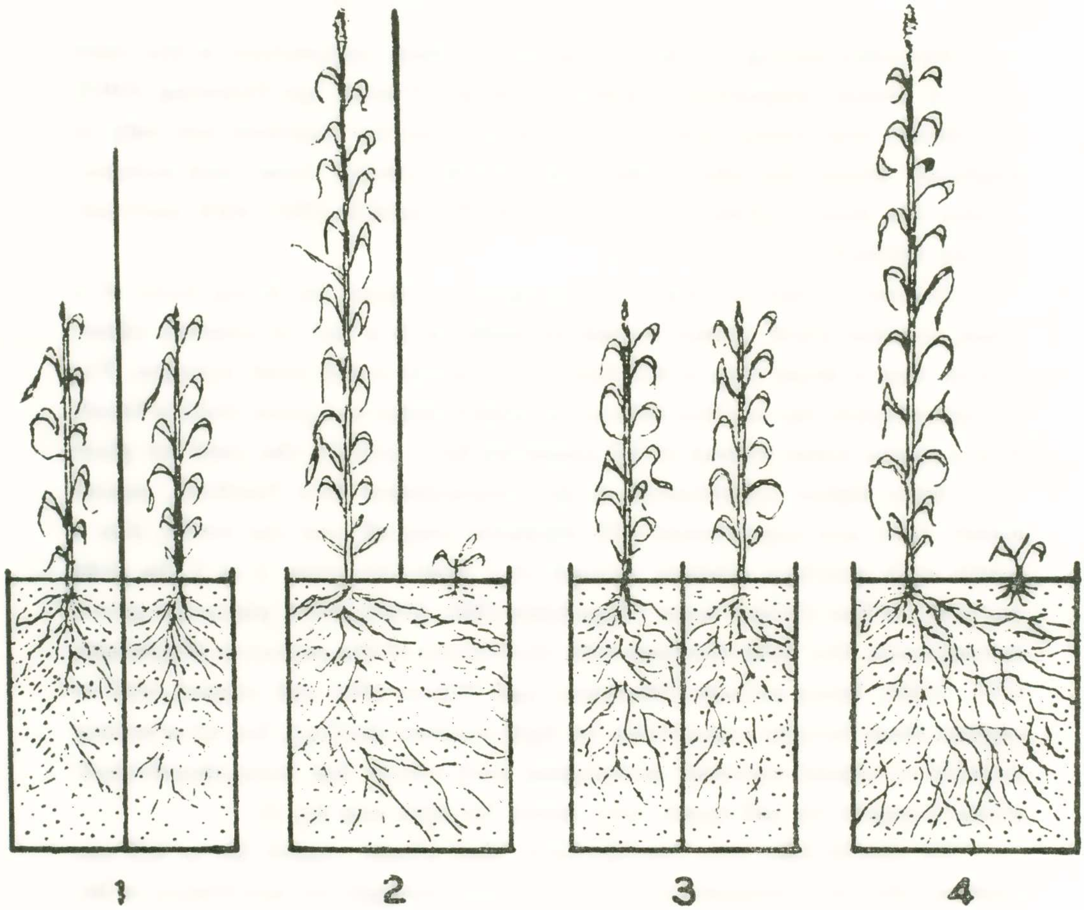

Fig. 1. Experiment to show, that root competition is much more important than mutual shading. In pots 1 and 3 soil is divided with a partition, that impides root passage. In pots 1 and 2 an opaque partition impedes mutual shading. Two plants are sown in each pot, but the left plant is sown earlier. In pots 1 and 3, where root competition is impeded, the plant sown later grows normally, and after a certain time its size does not differ appreciably from that of the plant sown earlier. In pots 2 and 4 the plant sown later encounters the soil occupied by the roots of the left plant, and it cannot grow, it often dies; on the contrary the left plant, having double soil at its disposal grows much better than the left plant of pots 1 and 3. The partition that impedes mutual shading, does not influence appreciably plant growth. (Papadakis 1977).

dakis 1937b). We have grown mixed several wheat varieties, and we determined the increase or decrease of their proportion in the mixture at harvest; the same varieties were grown not mixed in the same experimental field, with many repetitions of each one. The experiment has been repeated several times with different mixtures in the Institute of Thessaloniki and its substations. Varieties, that sown alone gave the higher yield, have often decreased in the mixture; and varieties that sown alone gave lower yields have often dominated in the mixture. Moreover the author (Papadakis 1940) has shown, that some wheats till abundantly, but many of these tillers do not produce ears, and yield is low; on the contrary other wheats produce few tillers, but almost all produce ears, and yield is higher. The first named varieties do not respond well to fertilizers, while those which tiller little respond better. Early tillering helps to occupy rapidly soil, and impedes growth of neighbour plants; it contributes to aggressivity.

Since there is antagonism between aggressivity and productivity, the opinion, that local species and varieties are preferable, is erroneous; they may be better adapted to some adversities (diseases, frosts, aluminium, salinity, alcalinity, etc.); but they usually lack productivity. And in fact the majority of crops and varieties grown in each country are of foreign origin. Maize, potato, sunflower, Phaseolus, tomato, etc. are important crops in Europe; but they are of American origin. Hevea is very important in southeast Asia, but it has been introduced from Brasil. On the other hand in North and South America wheat, barley, oats, sugar cane, coffee, the great majority of fruit and vegetable crops, alfalfa, almost all the grasses and legumes sown in artificial prairies have been introduced from the old world. Practically all crops grown in Australia have been introduced from other continents.

And the same happens with varieties. The introduction of English wheats in France, Germany, etc. has been highly successful in the 19th century. Marquis, a Canadian wheat, has been successful in United States. Mentana, created in Italy by Strampelli, gave excellent results in Greece. The wheats created by Borlaugh in Mexico have produced the "green revolution" in India, Pakistan, and other countries. The same hybrids of maize, the same varieties of sugar beet, apple, peach and other fruits and vegetables are grown in many parts of the world. Almost all the varieties actually grown, in relatively developed countries have been created with artificial selection. Good varieties are difficult to obtain, but they have great adaptability.

III. CROP ECOLOGY AND PLANT BREEDING

Another cause of stagnation is that plant breeders are competent in genetics, many of them in phytopathology, but very few in crop ecology. There is not doubt, that plant breeding is application of genetics; but we know still so little about the inheritance of the characters, which determine plant response to environment and consequently yield, that the breeder does not apply but elementary principles of plant breeding. The task of the plant breeder is chiefly ecological. He should first have a clear idea, what is the type of plant he is aiming at. The introduction in trials of foreign varieties should be preceded by a crop ecologic study of their performance abroad and probabilities of success in the new environment; trials should be done under several environments, some of them extreme, and decision should be based, not only on average yields and their standard deviation from place to place, as it is usually done, but on an ecological discussion of the results, including growth observations. Otherwise we risk to exclude varieties that are valuable, or recommend others that fail in practice.

Successful breeders had all a clear idea or the type of plant, they are aiming at. The Vilmorins were searching early wheats, resistant to lodging; Saunders early wheats, than ripen before the arrival of first frosts; Farrer early wheats, that avoid rusts and drought; Borlaugh dwarf wheats, which are productive; the International Rice Institute dwarf rices. Breeding for resistance to diseases and quality is generally successful, because the breeder has a concrete target, and efficient methods to test individual plants and progenies.

The introduction of Canberra and Mentana wheats in Greece has been preceded by an ecological study (Papadakis 1923); the experiments have been carried out in several stations; and they permitted me to formulate conclusions after 2 years only. I am always recommending to carry out trials under several, often extreme, environments (Papadakis 1931b). I have even proposed wheat breeding on an international basis (Papadakis 1931a); Borlaugh began such trials in the sixties; the International Rice Institute and other institutions followed the example later. Moreover since the fifties Borlaugh was growing two generations each year, one in the lowlands, and the other in the highlands, under very different conditions. Successful breeders were always carrying trials under very different conditions.

It is true, that the data, on which the breeder should base his decisions (yields and growth observations during many years in many stations, corresponding climatic and other data, disease resistance and quality tests, etc.) are so numerous, that their manipulation is difficult and time consuming. In the Institute of Thessaloniki we were spending more than 15 days each year with the chiefs of sections and substations, to discuss the results in 14 hours meetings. But now all these data can be stored in a computer, which gives you instantly the data you need; and the same computer does previously the stalistical analysis of the data; but the computer should help the breeder, not decide for him.

IV. BRIEF HISTORY OF PLANT DOMESTICATION AND PLANT BREEDING CAUSES OF SUCCESS AND FAILURE

Plant domestication is plant breeding. And the primitive man has been very successful in it. Still now, after more than 6 millenia, mankind obtains more than 80% of its food, measured in calories, from 5 plants, 3 from the Old World, wheat, rice and sorghum, and 2 from the Americas, maize and potato. And they have been selected from more than 200,000 species of plants. And in more than 6,000 years no other species of such importance has been added. The great majority of oil, fruit and vegetable plants have been domesticated at that time.

We have no information how agriculture has been invented, and plant domestication has been carried out by the primitive man. But the following version (Papadakis 1960) seems probable. Man has observed, that when an olive or other useful tree grows isolated, not surrounded by other plants, yields much better; and he began to kill the plants that were growing near the useful one; in this way the field, in which stunted olive trees were growing was transformed to an olive grove. And the same happened with other plants; agriculture began with weeding, plantation has been invented later. The domestication of cereals may have begun in a slightly different way. Primitive men were collecting cereal grains, and storing them in their huts; some of these grains were falling in the soil arround the hut, germinating, and producing plants, that because of their isolation were yielding exceptionally well. Such observation conduced the primitive man to try sowing. But only the seeds, that by chance were falling in a space not occupied by other plants were giving plants; and they were yielding grain only when they were not surrounded by other plants. He concluded, that before sowing it is necessary to eliminate all the plants, that occupy the soil; and during growth, it is also necessary to eliminate all those, that invade it later. Agriculture is a struggle against undesirable plants. That explains why agriculture has been born in the deserts, and other regions with scanty vegetation; the struggle against it is there easier; a desert land without vegetation can be sown without tillage, when inundated.

I should add, that the primitive man has certainly observed, that a few plants, when protected from weeds are sufficient to obtain the higher yield in a certain area; consequently and to economize seed, that was scarse, he was sowing thinly. But later he observed that a dense sowing defends itself better against weeds; he had also more seed at his disposal. So that selection — domestication is selection — was taking place between isolated, not competing to one another, plants, and it was based on productivity. While later, when crops were sown more dense, selection, when done, was between competing plants, and thus distorted by aggressivity. Moreover natural selection within densely sown crops was favouring less productive genotypes. All that explains why the primitive man has been so successful, and the following generations much less.

In the 19th century a few English agriculturists, encountered wheat plants, that grown isolated, were very productive; a plant cannot produce so much unless isolated. They miltiplied these plants, some of them proved really productive, and the English wheats, that have been so successful not only in England, but in the continent, have been bred. However these wheats were lacking aggressivity, and when grown by farmers, who were not cultivating well their lands, were suffering from weeds, and giving lower yields than the older varieties.

In the middle of 19th century Louis de Vilmorin introduced selection according to the quality and characteristics of the progeny. Many breeders, selecting for quality created superior varieties of sugar beet, vegetables, fruits and flowers, while the scientific establishment, influenced by the ideas, that acquired characters are inhetited, and that natural selection produces the best genotypes for each environment, were abstaining from breeding. It is characteristic, that while Louis de Vilmorin, in its communication to the French Academy of Sciences, is saying that he obtained sugar beet with selection, 60 yeras later outstanding authors were affirming, that the result had been obtained by growing the plants in a favourable environment.

After the rediscovery or Mendel's laws or heredity in 1900, crossing began to be used extensively. But very few breeders, the Vilmorins in France, Farrer in Australia, Saunders in Canada, Strampelli in Italy, Borlaugh in Mexico, the author in Greece, etc. have obtained varieties, that had a real impact on agriculture. Excellent results have been obtained in maize with heterosis. However at the beginning the scientific establishment had not understood the practical possibilities of the method. And it is Wallace, a practical man, who introduced it in practice. Now the method is also applied in other species.

V. EXPERIMENTS IN POTS, THE ONE PLANT PER POT METHOD

The great difficulty in plant breeding is to evaluate individual plants, progenies, etc. for productivity. We have efficient methods to evaluate resistance to several diseases and quality of many crops; and breeding for them has given phenomenal and rapid results. But we have not efficient methods to evaluate productivity. Because of soil heterogeneity each treatment should be repeated several times in each experimental field. Moreover competition between border lines of plots obliges to use plots several meters wide. And because of the variation of soil and climatic conditions from land to land, and in the same land from year to year, the experiment should be repeated in many places, during many years. Therefore the number of genotypes that can be tested is very limited. Moreover to test a genotype we need many kilos of seed.

To overcome these difficulties I decided in the Institute of Thessaloniki to complement field experiments with experiments in pots. And since 1929 we were carrying out experiments in more than 10,000 containers (see fig. 2 and 3).

Pot experiments have many advantages. There is not competition between pots, and relative yields are not distorted. We can do in the same place experiments with very little seed under very different conditions. In the Institute of Thessaloniki each variety, etc. was sown in shallow (40cm), deep (80cm), fertilized, no fertilized, early sown, late sown pots, filled with 3 different soils; and the ecological discussion of the results obtained under so varied conditions was permitting to detect rapidly the best varieties, progentes, etc.

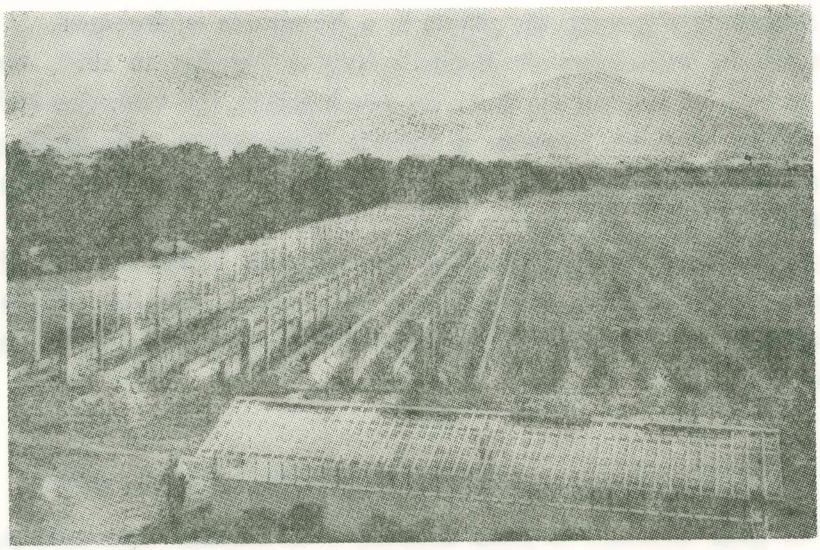

Fig. 2. Pot experiments in the Institute of Plant Breeding of Thessaloniki, Greece (Papadakis 1935a).

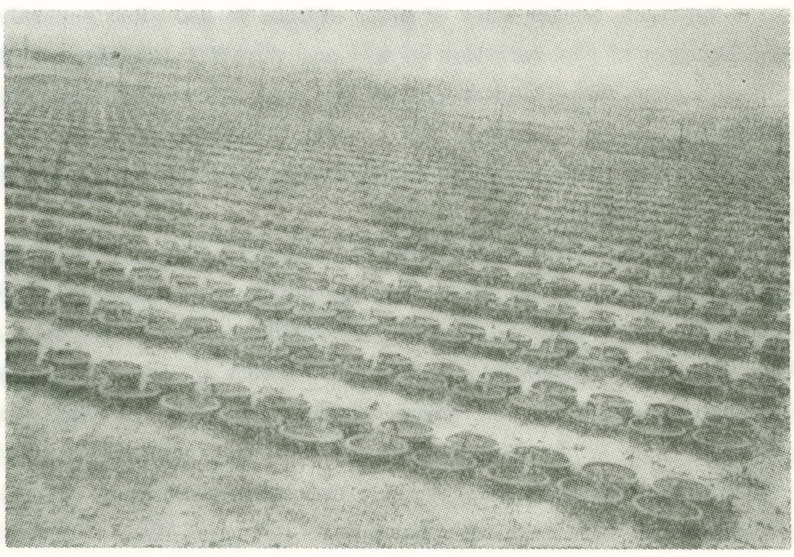

Fig. 3. Buried in soil pots in the Institute of Plant Breeding of Thessaloniki, Greece (Papadakis 1935a).

The results proved, that while the classification of varieties according to their yield varies considerably from year to year, and many years are necessary to reach a conclusion, such classification was varying little in pots from year to year (see fig. 4). Moreover (Papadakis 1935a) it is risky to base decisions on one only year field experiments, as the breeder is obliged to do, selecting or discarding progenies, etc.; the correlation between the relative yields of wheat varieties in 1 year (3 sowings) experiments in the field and 5 years experiments in the same field was only 0.714 in our experiments, varying from 0.283 to 0.874. On the contrary the correlation between 1 year experiments in pots (factorial 2 dates of sowing, humid-dry, shallow-deep) and 5 years experiments *in the field* was 0.968, varying from 0.730 to 0.999; therefore it is much safer to base decisions on 1 year pot experiments; all the correlations mentioned are positive. However one variety, 3491, gave repeatedly lower relative yields in pots; but this variety is aggressive, when mixed with other varieties, it dominates in the mixture (Papadakis 1937b), and may be favoured by competition between border lines in plot experiments; moreover it is susceptible to frosts and the pots were not buried.

Soil day temperatures are higher in not buried pots, and may be they should not be used for crops growing in summer. They consume more water; even "dry" pots were receiving some irrigation. Irrigation was regulated to maintain pot weight constant at two levels, one for dry and the other for humid pots. Periodically some pots of each category were weighted; in the meantime irrigations were decided taking into consideration tank evaporation; but all irrigations were giving the same quantity or water; it is their frequency that was regulated.

Roots can grow out of the bottom, penetrate in soil, and increase space and yield; that is why pots with no perforated bottom are preferable. Pots are placed in open air, and may receive too much rain in humid climates; to avoid that they may have a cover with a hole for the passage of stems.

At the beginning we were using pot esperiments to try varieties and promising progenies. But since 1934 we were also using them for the selestion of individual plants; each pot was sown with 2 seeds, and after germination 1 only plant is left.

Concerning size, the diameter was 12 - 25cm.; big pots with 1 plant give much seed, and this is a serious advantage; error per pot is also lower; but they are more expensive. In the case of maize, bigger pots are used.

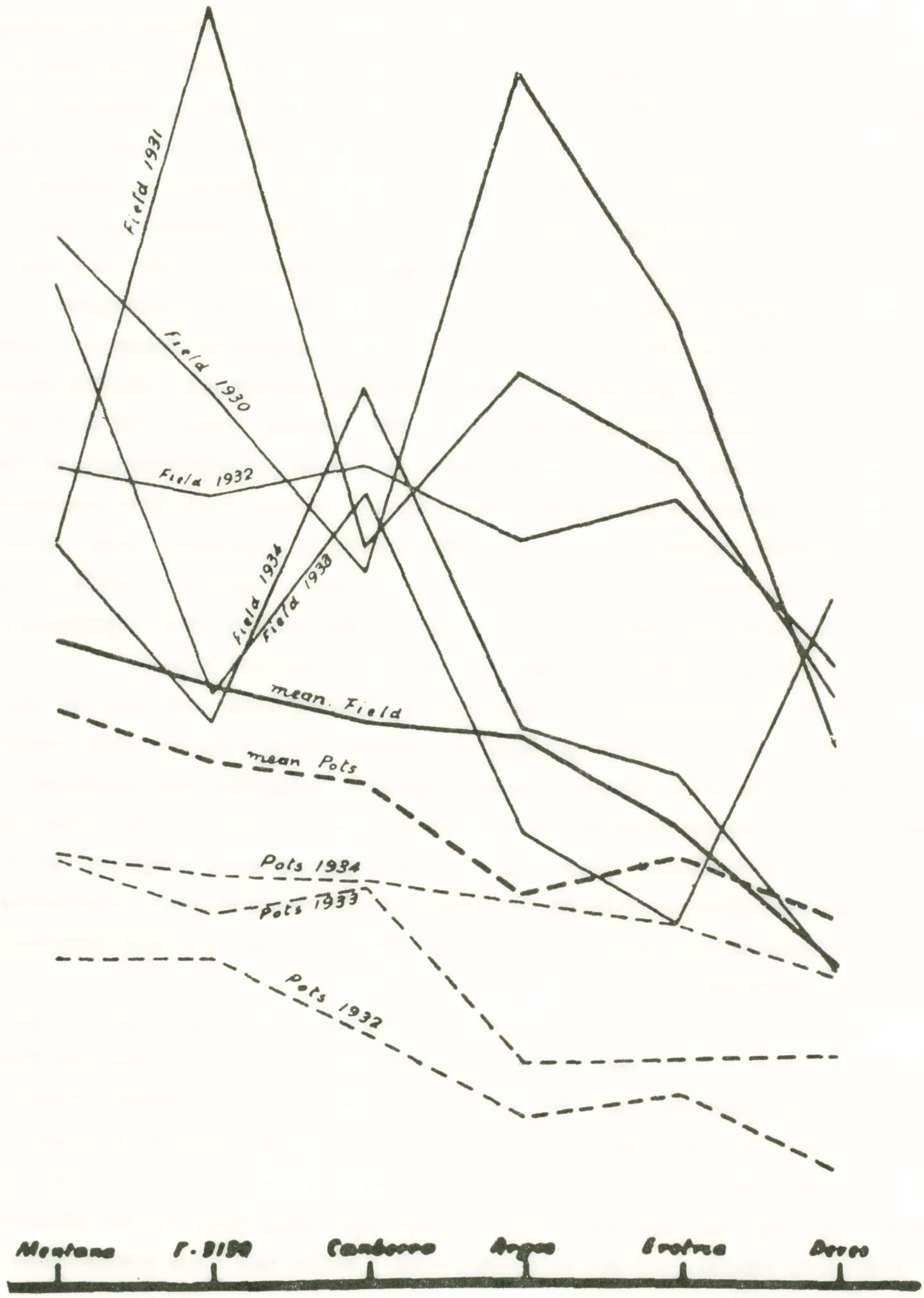

Fig. 4. Relative yields of wheat varieties in pot and 2m wide plots experiments. In the long run (mean Field, mean Pots) the varieties are classified in the same way. But classification according to field experiments varies enormously from year to year, making unsafe the decisions that the breeder is obliged to take each year. On the contrary in pots the classification of varieties varies less from year to year, and the risk to take a wrong decision is less.

In spite of their advantages we do not preconize (Papadakis 1935a) the abandonment of plot trials. As soon as we have sufficient seed, we complement pot trials with plot trials.

VI. THE ONE PLANT PER HILL METHOD

As stated in II, the yield of a plant increases lineally with the space occupied by its roots. In a field such space varies enormously from plant to plant for accidental causes. Moreover aggressive genotypes robe space to their neighbours. So that when we select a plant in a field the probability to select a productive genotype is minimal.

For the same reason the space between two rows is not equally shared between them. This fact is long ago known by plant breeders, and it has been called "interference"; it distorts the results of the experiments in rows or not sufficiently wide plots, making selection for productivity very difficult.

Moreover soil heterogeneity obliges to use many repetitions. But many repetitions of wide plots require much seed. Selection for productivity is postergated; in the mean time the segregating population is grown with small distances between plants, and competition eliminates the productive genotypes. Moreover few genotypes can be included in plot experiments in several places with many repetitions in each one. And the probability to encounter a productive genotype is minimal.

To overcome these difficulties I introduced in the Institute of Thessaloniki the 1 plant per hill method (Papadakis 1935b, 1937c). The distance between plants was 50cm in the case of wheat. Yield per ha was 2.3 to 7.5 times lower than with usual sowing; that shows, that hills were far from using all available space, and competition between plants was minimal, if any; 2 - 3 seeds were sown per hill, but 1 plant was left; weeds were carefully controlled. Ten to twenty thousand hills were sown each year in the Institute and its substations. Standard deviation of the yields of the same genotype from hill to hill varied from 40% to 101%, average 71%, while in the case of plots, in the same soil, it varied from 25% to 80%, average 27%; so that to have equal precision we need 1.6 to 41.0 times more repetitions in hills than in 2.00 × 12.50m plots (Papadakis 1937c). But 300 or more times less seed is required.

Experiments in the same soils (Papadakis 1935b, 1937c) have shown, good agreement between experiments in hills and in plots 2m wide, in the classification of varieties according to their yield. But wheat hills are more attacked by frosts and Puccinia graminis; they produce much more tillers and ripen later; soil between hills is moister; that favours some varieties at expenses of others; it seems that varieties, that tiller abundantly take better advantage of abundant space. Kiesselbach et al (1917) have observed, that plump seed is preferable, when sowing thinly. For all these reasons we cannot replace plot experiments with hill experiments; as soon as we have sufficient seed of a promising progeny, we include it in plot trials with sufficiently wide plots, continuing those in pots and hills. But selection of individual plants and progenies, that we cannot yet include in plot trials, should be done with the 1 plant per pot or hill method, which also ensures rapid multiplication; selected hills give more than thousand seeds.

In the case of maize the distance between hills should be 1m. or more. In the case of trees instead of increasing the distance it is preferable to delimit the space occupied by each tree, with ditches sufficiently deep to avoid the passage of roots; in this way competition is excluded, and small distances between trees can be used. Naturally what is essential is to exclude competition; distances between hills of 15cm, that some authors have tried, are obviously insufficient, even in the case of wheat.

VII. DESIGN AND ANALYSIS OF 1 PLANT PER HILL TRIALS

In the Institute of Thessaloniki I was using a square design. In the seventies Fasoulas introduced the honeycomb (hexagon) design. For reasons of convenience a systematic distribution is usually adopted, but the repetitions of each progeny should be well distributed in all the field; and the 4 or 6 hills that are adjacent to each hill are sown with seeds of 4 or 6 different progenies. Since the object of the trial is not only to select progenies, but also individuals (hills) within each progeny, it is essential to determine as precisely as possible the yield of each hill, adjusted for soil heterogeneity. To obtain that the yield of each hill is adjusted on the basis of presumed productivity of the 4 or 6 adjacent hills (Papadakis 1937a, 1940, 1970, 1984). If y is the yield of a hill, and $\bar{y}$ the average yield of the progeny sown in it, in all the field, $d = y - \bar{y}$ is an index of productivity of each hill; and the yield of each hill is adjusted, by substracting the average d of the 4 or 6 adjacent hills. Adjustment is reiterated 2 or 3 times. Gaps and abnormal hills are determined, but the number of gaps should not exceed 10% of the number of hills, because it is also due to genetic differences between hills of the same progeny.

The analysis is naturally time consuming. Moreover observations are

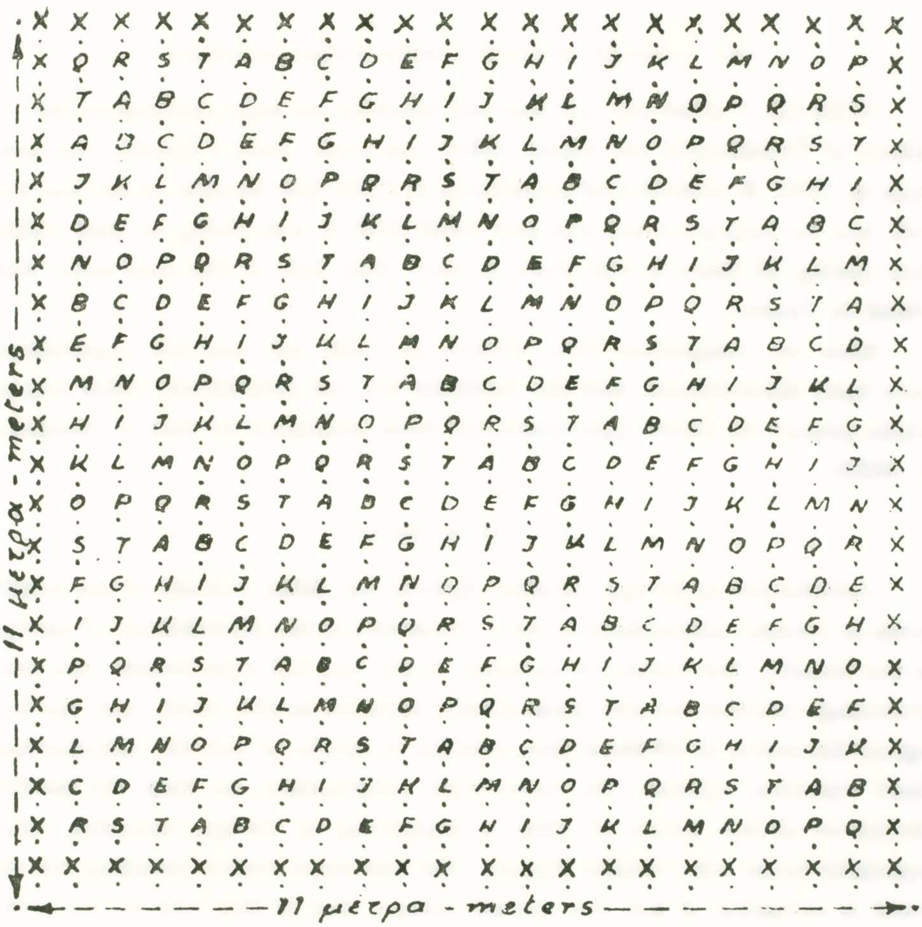

Fig. 5. Plant breeding experiments in hills; 20 varieties with 20 repetitions (Papadakis 1935b).

taken during growth; the same progenies are tried in pots, and eventually plots, in several places; there are also the results of previous years, tests of resistance, quality, etc. To take into consideration all that is time consuming and troublesome. But now it is sufficient to feed the computer with the data, it does the analysis and gives you immediately all the information on each progeny, variety, etc.

Since each selected plant gives usually more than thousand seeds, the number of repetitions, which varies from progeny to progeny, is very great, more than 25, sometimes more than 100.

VIII. RESULTS OBTAINED WITH THESE METHODS

With the 1 plant per pot and hill methods we have selected in the Institute of Thessaloniki the wheat 38290; the cross, Rieti x Quality, has been done in 1934; it entered seed production in 1942; but because of the war and civil war its multiplication was slow until 1950; it was giving so high yields, that during 20 years it was sown in more than half of the area sown with wheat in Greece.

After my emigration from Greece, in 1946, pot and hill experiments have been discontinued. But the Institute has not created any other wheat, whose impact on Greek agriculture has been analogous to that of Mentana, or 38290.

IX. APPLICATIONS

Introduction of foreign varieties, hybrids, etc. After a study of the results given in foreign environments, and a discussion of the probabilities of success in the country, the variety is included in pot and hill experiments; the most promising varieties are also immediately included in plot trials; and the ecological discussion of all these data permits to decide, or not, the introduction. Good varieties, hybrids, etc. have wide adaptability; so that the breeder should be always aware of what is happening in foreign countries, more especially those with similar climate. For the same reason breeding for the world is advisable· it has also the advantage, that in this way we have two generations per year.

Selection in autogamous populations. The 1 plant per pot or hill methods permit to select more efficiently individual plants, and test more rapidly their progenies.

Selection after cross. The seed produced by F_1 is sown in numerous pots and hills; the best are selected, and the seed of each one of them is included in pot and hill trials. The best progenies are selected, and within them the best pots or hills; but exceptional pots or hills belonging to inferior progenies are also selected. And so on the following years.

This method is chiefly used in self-pollinated species. In cross-pollinated crops the individual plants we select have already been crossed with other plants, and give a genetically heterogeneous progeny. To overcome the difficulty we may self-fertilize the selected plants; but self-fertilization should often be done before harvest, when we do not yet know the yield of the plant; moreover the operation may modify the yield of the plant. So that in many cases selection of individual plants cannot be accurate; trials are chiefly done to evaluate progenies.

However the selection of plants, that open pollinated give a high yielding progeny, gives often good results. And we may combine the two methods. We omit self-fertilization during the first years of selection; then we self-fertilize the plants we select; and finally, when the object of selection is to maintain the productivity of the population, we continue the selection, without self fertilizing the individual plants we select. The same methods can be used to improve populations of cross-pollinated crops.

Testing combinating ability. Each combination is sown in numerous pots and hills; and the combining ability is evaluated. Well known hybrids are included in the trials.

Mixtures of pure lines. Theoretically a mixture is less exposed to a fortuitous adversity than a pure line; and it may be advisable to grow populations. However in my experiments (Papadakis 1947b) the mixtures used have always given lower yields than the average yield of the varieties mixed, sown separately. Moreover natural selection may reduce gradually the productivity of the mixture. We owe test sufficiently the mixture, before recommending it; grow separately each pure line, and prepare with them the certified seed.

Maintaining the productivity of populations. Natural selection increases aggressivity and reduces productivity. We may avoid that by selecting the best plants and progenies with the 1 plant per pot or hill methods.

Selection in plants with asexual reproduction. Each clone is sown in many pots and/or hills; the best plants are selected. In the case of big plants the hills should be separated with sufficiently deep ditches, to avoid the passage of roots.

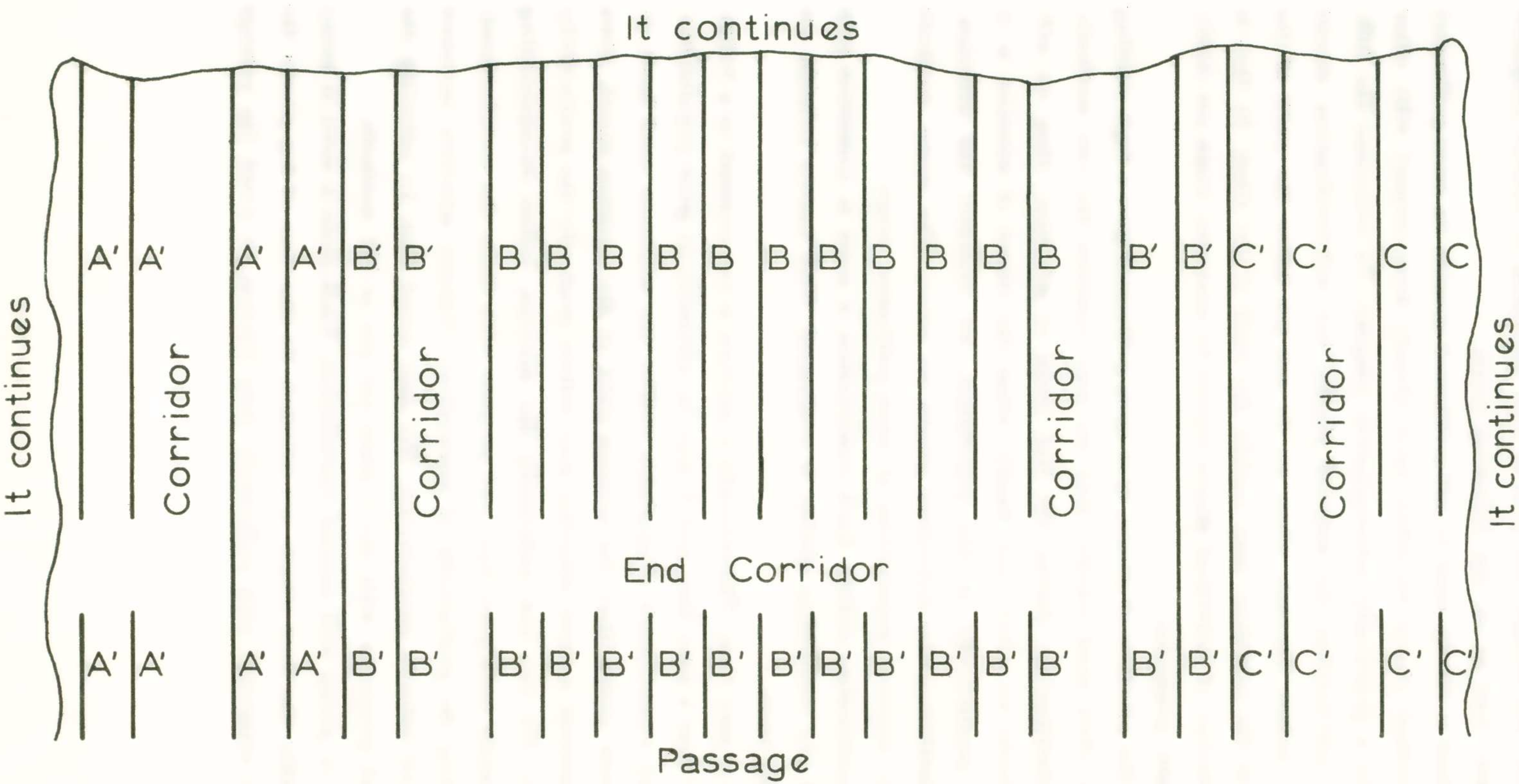

Fig. 6. Method to minimize competition between plots (interference). Each plot contains, 15 rows, of which 11 only are "operative" (their grain is included in the yield of the plot). Border rows, A^1, B^1, C^1, are separated from operative rows, A, B, C, with a corridor wider than that separating operative rows. A similar corridor limits operative rows at their two ends; their continuation after the end corridor is not operative. Border rows are not eliminated before ripening. Sowing can be done mechanically, or the furrows, in which the seeds are sown are open mechanically. The end corridors can be opened after sowing. A, B, C are the varieties sown in each row.

Εἰκ. 6. Μέθοδος γιὰ νὰ ἐλαττωθεῖ ὁ συναγωνισμὸς μεταξὺ τεμαχίων.

X. WARNING

The number of combinations, that may result from a cross, or exist in a population of a cross-pollinated species, is enormous; and to encounter the best of them is very difficult; we should try a number of progenies as great as possible. And to carry out so extensive trials a numerous lower personnel is necessary. In the Institute of Thessaloniki the scientific staff were few in number, but the lower staff were very numerous.

However many plant breeding institutions resemble armies, with sufficient officers, but very few soldiers. And an army cannot win the war, without soldiers.

XI. PLOT SEPARATION

To reduce competition (interference) between plots their operative width should not be less than 2m. To facilitate operations and avoid mistakes, border lines (those whose grain is not included in the yield of the plot) are separated from "operative" lines with a relatively wide corridor (30cm, when the distance between operative lines is 17cm, se fig. 6). Sowing can be done mechanically.

ΠΕΡΙΛΗΨΗ

ΤΕΛΕΙΟΠΟΙΗΣΕΙΣ ΣΤΗ ΜΕΘΟΔΟΛΟΓΙΑ ΚΑΛΛΙΤΕΡΕΥΣΕΩΣ ΦΥΤΩΝ

Ἡ μεγαλύτερη δυσκολία στὴν καλλιτέρευση τῶν φυτῶν εἶναι ἡ ἀξιολόγηση τῶν φυτῶν-μητέρων καὶ τῶν ἀπογόνων των (progenies), ἀπὸ ἀπόψεως παραγωγικότητος. Ἐπειδὴ τὸ ἔδαφος εἶναι ἀνομοιόμορφο, καὶ οἱ κλιματικὲς συνθῆκες διαφέρουν ἀπὸ χρόνο σὲ χρόνο, εἴμεθα ὑποχρεωμένοι νὰ κάνουμε ἐκτεταμένες δοκιμὲς ἐπὶ πολλὰ χρόνια, πρὶν καταλήξουμε σὲ συμπεράσματα. Καὶ οἱ ἀποφάσεις, ποὺ παίρνομε κάθε χρόνο, νὰ διατηρήσομε ἢ ἀπομακρύνομε ἀπὸ τὴν ἐπιλογὴ οἰκογένειες, βασίζεται σὲ ἀνεπαρκῆ δεδομένα. Ἐπὶ πλέον ἡ ἐκτέλεση τόσο ἐκτεταμένων πειραμάτων εἶναι δαπανηρή, καὶ χρειάζεται πολὺς σπόρος. Γιὰ τοὺς λόγους αὐτοὺς δοκιμάζομε μικρὸ ἀριθμὸ οἰκογενειῶν (progenies) καὶ ἡ πιθανότητα νὰ βροῦμε τὸν ἐξαιρετικὸ συνδυασμὸ γονιδίων, ποὺ μπορεῖ νὰ ὑπάρχει στὸ ὑλικὸ μὲ τὸ ὁποῖο ἐργαζόμεθα, εἶναι ἐλαχίστη. Ἀκόμη σπουδαιότερο, ὁ συναγωνισμὸς εὐνοεῖ τὰ ἐπιθετικά, ἀλλὰ μὴ παραγωγικὰ βιότυπα. Καὶ ἀντὶ νὰ διαλέγουμε τὰ πιὸ παραγωγικὰ διαλέγομε τὰ πιὸ

ἐπιθετικά. Οἱ ἀποδόσεις τῶν γραμμῶν καὶ τεμαχίων διαστρεβλώνονται ἐπίσης ἀπὸ τὸ συναγωνισμὸ (interference).

Στὴν ἀνακοίνωση συζητεῖται ὁ μηχανισμὸς τοῦ ἀνταγωνισμοῦ μεταξὺ φυτῶν, ἕνα φαινόμενο μεγάλης σημασίας, ποὺ σχεδὸν ἀγνοεῖται στὴν καλλιτέρευση τῶν φυτῶν. Οἱ ζωντανὲς ρίζες ἐκκρίνουν τοξίνες. Γιὰ τὸ λόγο αὐτὸ τὰ φυτὰ ἔχουν τὴν τάση νὰ ἐπεκτείνουν τὸ ριζικό τους σύστημα καὶ ὑπάρχει γραμμικὴ σχέση μεραξὺ τοῦ χώρου ποὺ κατέχουν οἱ ρίζες ἑνὸς φυτοῦ καὶ τῆς ἀπόδοσής του. Γιὰ τὸν ἴδιο λόγο ὑπάρχει ἀνταγωνισμὸς μεταξὺ ἐπιθετικότητος καὶ παραγωγικότητος. Ἡ φυσικὴ διαλογὴ εὐνοεῖ τὰ ἐπιθετικὰ βιότυπα, καὶ ἀντὶ γιὰ παραγωγικότητα, διαλέγομε γιὰ ἐπιθετικότητα.

Ἡ λύση εἶναι νὰ κάνομε τὶς δοκιμὲς μας σὲ δοχεῖα, τοποθετημένα στὸ ὕπαιθρο, μὲ ἕνα μόνο φυτὸ κατὰ δοχεῖο. Μὲ τὸν τρόπο αὐτὸ ἀποκλείομε τὸ συναγωνισμό, ὁ χῶρος ποὺ κατέχουν οἱ ρίζες κάθε φυτοῦ καθορίζεται μὲ ἀκρίβεια, καὶ ἡ ἐπιλογὴ φυτῶν μητέρων καὶ οἰκογενειῶν (progenies) βασίζεται σὲ ἀσφαλέστερα δεδομένα. Ἐπὶ πλέον μποροῦμε νὰ κάνουμε ἐκτεταμένα πειράματα μὲ πολὺ λίγο σπόρο. Κάθε φυτὸ-μητέρα δίνει ἀρκετὸ σπόρο, γιὰ νὰ κάνομε ὅλα τὰ πειράματα ποὺ θέλομε.

Ἀντὶ νὰ σπείρομε σὲ δοχεῖα μποροῦμε νὰ σπείρομε σὲ ὄρχους μὲ τέτοια ἀπόσταση ἀπὸ φυτὸ σὲ φυτό, ὥστε νὰ ἀποφεύγεται ὁ συναγωνισμός: περισσότερο ἀπὸ 50 έκ. γιὰ τὸ σιτάρι, περισσότερο ἀπὸ 1 μ. γιὰ τὸν ἀραβόσιτο. Γιὰ τὰ δένδρα οἱ ἀποστάσεις μποροῦν νὰ εἶναι μικρές, χωρίζοντας τὰ τεμάχια μὲ χαντάκια ἀρκετὰ βαθιὰ ὥστε νὰ ἀποκλείεται τὸ πέρασμα τῶν ριζῶν.

Καὶ οἱ δυὸ μέθοδοι χρησιμοποιήθηκαν στὸ Ἰνστιτοῦτο Καλλιτερεύσεως Φυτῶν Θεσσαλονίκης καὶ μὲ αὐτὲς δημιουργήσαμε τὸ στάρι 38290, ποὺ εἶχε τόση ἐπιτυχία καὶ ἦταν ἡ καλλίτερη ποικιλία ἐπὶ 20 χρόνια.

Στὴν ἀνακοίνωση συζητεῖται ἐπίσης ἡ ἐφαρμογὴ αὐτῶν τῶν μεθόδων σὲ διάφορες περιπτώσεις ὁ σχεδιασμὸς καὶ ἀνάλυση τῶν πειραμάτων σὲ ὄρχους, τρόποι νὰ ἀποφεύγουμε τὸν συναγωνισμὸ ὅταν τὰ πειράματα γίνονται σὲ τεμάχια, ἡ σημασία τῆς γεωργικῆς οἰκολογίας (crop physiology) γιὰ τὸν καλλιτερευτὴ (breeder), ἡ εὐρεία προσαρμογὴ τῶν καλῶν ποικιλιῶν, τὰ πλεονεκτήματα νὰ γίνεται ἡ καλλιτέρευση σὲ παγκόσμια βάση, ἡ ἱστορία τοῦ ἐξευγενισμοῦ τῶν καλλιεργουμένων φυτῶν καὶ τῆς καλλιτερεύσεώς των, κλπ.

Μετὰ τὸ τέλος τῆς ἀνακοινώσεως, ὁ Ἀκαδημαϊκὸς κ. **Ἰ. Ξανθάκης** λαμβάνει τὸν λόγο καὶ παρατηρεῖ τὰ ἑξῆς:

Νομίζω ὅτι τὸ πρόβλημα ποὺ πρέπει νὰ μᾶς ἀπασχολεῖ δὲν εἶναι τόσο ἡ αὔξηση τῆς παραγωγῆς ὅσο ἡ βελτίωση τῆς ποιότητος. Ὁ καλλιεργήσιμος χῶρος τῆς χώρας μας εἶναι περιορισμένος καὶ ὡς ἐκ τούτου θέτει ἕνα ὅριο στὴν παραγωγὴ ποὺ δὲν μᾶς ἐπιτρέπει νὰ συναγωνισθοῦμεν μὲ τὸν παράγοντα αὐτὸ ἄλλες μεγαλύτερες χῶρες ἀπὸ μᾶς, Ἰταλία, Γαλλία, Ἱσπανία, Καλιφόρνια κλπ. Μέχρι πρὸ ὀλίγων ἐτῶν εἴχαμε ἕνα πλεονέκτημα ἔναντι τῶν λοιπῶν χωρῶν, τὴν πρωϊμότητα τῶν προϊόντων σὲ ὁρισμένα εἴδη. Ὁ παράγων αὐτὸς ὅμως ἐξέλιπε μὲ τὴν ἐγκατάσταση τῶν ποικίλων θερμοκηπίων, συνεπῶς ὡς ἀνταγωνιστικὸς παράγων γιὰ μᾶς παραμένει μόνον ἡ ποιότης ἀπὸ ἀπόψεως ἐμφανίσεως καὶ κυρίως γεύσεως. Τὸ πρῶτο δὲν εἶναι δύσκολο νὰ τὸ ἀποκτήσομε· τὸ δεύτερο θὰ ἀπαιτήσει ἰδιαίτερη φροντίδα. Χρειάζονται λεπτομερεῖς καὶ ἐκτεταμένες ἔρευνες γιὰ τὴν ἀκριβῆ γνώση τῶν καλλιεργήσιμων ἐδαφῶν (ἐδαφολογία) καθὼς καὶ τῶν ποικίλων κλιματολογικῶν συνθηκῶν. Ἡ Ἑλλάς, κύριε Πρόεδρε, ἀπὸ τὴν ἄποψη μικροκλιματολογίας εἶναι στὴν πραγματικότητα πολλὲς Ἑλλάδες, πρέπει νὰ τὸ γνωρίζομε καλά, γιὰ νὰ ἐπιτύχομε τὴν ἀπαιτούμενη βελτίωση τῶν προϊόντων της.

Ἔπειτα ὁ Ἀκαδημαϊκὸς κ. **Θεμιστοκλῆς Διαννελίδης** συμπληρώνει, λέγοντας τὰ ἑξῆς:

Ἡ μεθοδολογία ποὺ ἐφαρμόσατε, κ. Παπαδάκη, γιὰ τὴν καλλιτέρευση φυτῶν ἀπὸ τοῦ 1929, διὰ τὰ σιτηρὰ εἶχε ἐξαιρετικὰ ἀποτελέσματα, ἰδιαίτερα στὴν παραγωγὴ σιτηρῶν στὴν Ἑλλάδα. Στὰ πρὸ τοῦ 1939 χρόνια αὐξήθηκε ἡ παραγωγὴ σίτου, ἡ ὁποία ἦταν ἐλλιπής, ὥστε νὰ ὑπερκαλυφθοῦν οἱ ἀνάγκες τῆς χώρας. Αἱ μέθοδοι ποὺ ἐφαρμόσατε περιορίσθηκαν μόνον σὲ φυτὰ μεγάλης καλλιεργείας, ὅπως ὁ σίτος, ἢ ἐπεξετάθηκαν καὶ σὲ φυτὰ ὄχι μεγάλης καλλιεργείας ἀλλὰ μεγάλης σημασίας καὶ ἀξίας;

Εἰς τὰ λεχθέντα ὑπὸ τοῦ κ. Ξανθάκη, θὰ προσθέσω, ὅτι θεμελιώδη σημασία γιὰ τὴν ποιότητα τῶν γεωργικῶν καὶ δενδροκομικῶν προϊόντων ἔχει ἡ ὑπερβολικὴ χρήση χημικῶν λιπασμάτων, ἀκόμη δὲ καὶ τὰ χρησιμοποιούμενα φυτοφάρμακα. Εὔκολα τὸ διαπιστώνει κανεὶς ἀπὸ τὴν μειονεκτοῦσα γεύση φρούτων.

Ἀπάντηση τοῦ κ. **Ἰωάννου Παπαδάκη** στὸν κ. **Ἰωάννη Ξανθάκη**

Ἡ ἀνακοίνωση ἀναφέρεται στὶς μεθόδους ἀξιολογήσεως φυτῶν μητέρων καὶ οἰκογενειῶν ἀπὸ ἀπόψεως ἀποδόσεως. Τὸ ζήτημα τῆς ποιότητος ἔχει βέβαια μεγίστη σημασία. Καὶ ἡ καλλιτέρευση τῶν φυτῶν ἀπὸ ἀπόψεως ποιότητος εἶναι σχετικῶς εὔκολη καὶ γρήγορη, ὅταν ὑπάρχουν μέθοδοι, ποὺ ἐπιτρέπουν νὰ ἀξιολογηθεῖ γρήγορα μεγάλος ἀριθμὸς φυτῶν καὶ οἰκογενειῶν. Παράδειγμα ἡ δημιουργία ζαχαροτεύτλων καὶ ζαχαροκαλάμου μὲ μεγάλη περιεκτικότητα σὲ ζάχαρη, ἡλιάνθου μὲ μεγάλη περιεκτικότητα σὲ λάδι, κλπ., φρούτων καὶ λαχανικῶν μὲ πολὺ ὡραία παρουσία, ἀνθέων πολὺ ὡραίων, κλπ. Ἀλλὰ ὁ κ. Ξανθάκης ἐννοεῖ ἀσφαλῶς πραγματικὴ βελτίωση, ἀπὸ ἀπόψεως γεύσης καὶ ὑγιεινῆς. Σχετικὰ μὲ αὐτὸ ὑπάρχουν μεγάλες δυσκολίες. Δὲν ξέρουμε ἀκόμη σὲ τί ὀφείλεται ἡ καλὴ γεύση, καὶ δὲν ἔχομε μεθόδους, ποὺ ἐπιτρέπουν νὰ ἀξιολογήσομε γρήγορα πολλὰ φυτὰ καὶ οἰκογένειες. Χωρὶς αὐτὸ ἡ καλλιτέρευση δὲν μπορεῖ νὰ προχωρήσει.

Ἄλλη δυσκολία εἶναι, ὅτι γιὰ νὰ παραδεχθεῖ ὁ παραγωγὸς μιὰ ποικιλία ποὺ δίνει καλλίτερη ποιότητα, ἀλλὰ τὴν ἴδια ἢ μικρότερη ἀπόδοση ἀπὸ ἐκείνη ποὺ καλλιεργεῖ, πρέπει ἡ τιμὴ ποὺ πληρώνεται στὸν παραγωγὸ νὰ εἶναι αἰσθητῶς ἀνώτερη. Τὸ ἐμπόριο τὶς νέες ποικιλίες τὶς πληρώνει στὴν ἀρχὴ φθηνότερα, ἕως ὅτου τὶς συνηθίσει ὁ καταναλωτής. Ἐνδιαφέρεται περισσότερο γιὰ τὴν παρουσία, τὴν ἀντοχὴ στὶς μεταφορές, τὴ διατήρηση σὲ ψυγεῖο κλπ. Καὶ ἀπ' αὐτὴ τὴν ἄποψη ἔγιναν μεγάλες πρόοδοι στὴ Χώρα μας.

Τὰ φροῦτα καὶ λαχανικὰ ποὺ βρίσκομε σήμερα, εἶναι πιὸ εὐπαρουσίαστα, πιὸ σύμφωνα μὲ τὰ εὐρωπαϊκὰ γοῦστα, ἀπὸ πρίν. Ἴσως σὲ ὁρισμένες περιπτώσεις νὰ εἶναι λιγότερο νόστιμα. Αὐτὸ πρέπει νὰ ἐρευνηθεῖ, καὶ τότε θὰ εἶναι δυνατὸν νὰ διορθωθεῖ.

Ὅπως εἶπε ὁ κ. Ξανθάκης, ἡ ποιότητα ἐξαρτᾶται πολὺ ἀπ' τὶς κλιματικὲς καὶ ἐδαφολογικὲς συνθῆκες, εἶναι πολλὲς φορὲς ζήτημα μικροκλίματος, μικροπεριβάλλοντος (land type). Τὸ ἴδιο ἄλλωστε συμβαίνει μὲ τὴν ἀπόδοση. Γιὰ τὸ λόγο αὐτὸ ἡ οἰκολογικὴ μελέτη τῆς Χώρας, μὲ τὴν κλασσικὴ ἔννοια τοῦ ὅρου «οἰκολογία», εἶναι πολὺ σπουδαία. Στὴν ἀνακοίνωσή μου τῆς 17ης Ἰανουαρίου, «Τὸ Γεωργικὸ Κλίμα τῆς Ἑλλάδος», ἔδωσα τὶς κλιματικὲς παραμέτρους 97 ἑλληνικῶν σταθμῶν, μὲ μεθόδους ποὺ ἐπιτρέπουν τὴ σύγκριση μὲ χιλιάδες σταθμοὺς ἀπὸ ὅλον τὸν κόσμο. Μὲ τὴν βάση αὐτὴ καὶ λαμβάνοντας ὑπ' ὄψιν τὶς διαφορὲς ὑψομέτρου, προσανατολιαμοῦ, ἀναγλύφου, καὶ τὴν «συμπεριφορὰ» τῶν καλλιεργειῶν, ὄχι μονάχα ἐκείνης ποὺ μᾶς ἐνδιαφέρει ἀλλὰ ὅλων, μποροῦμε νὰ χαρακτηρίσουμε ὁποιοδήποτε ἑλληνικὸ μικροκλίμα. Γιὰ τὰ ἐδάφη πρέπει νὰ σημειώσουμε ὅτι χάρη στὶς ἁρμόδιες ὑπηρεσίες καὶ τὸ 'Ινστιτοῦτο «Νικόλαος Κανελλόπουλος», ἔχομε σήμερα ἀρκετὰ στοιχεῖα.

Καὶ σὲ μιὰ ἀνακοίνωση, ποὺ θὰ κάμω προσεχῶς, θὰ δώσω τὰ βασικὰ χαρακτηριστικὰ τῶν ἑλληνικῶν ἐδαφῶν. Μὲ τίς βάσεις αὐτὲς μποροῦμε νὰ χαρακτηρίσομε ἱκανοποιητικὰ τὰ μικροπεριβάλλοντα (land type). Καὶ οἱ τοπικὲς ὑπηρεσίες θὰ μποροῦν νὰ τὰ μελετήσουν μὲ ἀκρίβεια.

'Απάντηση τοῦ κ. **'Ιωάννου Παπαδάκη** στὸν κ. **Θεμιστοκλῆ Διαννελίδη**

Τὶς μεθόδους δοχείων καὶ ὅρχων τὶς ἐφάρμοσα στὸ στάρι, καὶ ἄλλα μικρὰ σιτηρὰ (κριθάρι, βρώμη). 'Αλλὰ ἀπὸ 10 περίπου ἐτῶν ὁ καθηγητὴς Φασούλας τὶς ἐφαρμόζει στὸ καλαμπόκι, ζαχαρότευτλο, βαμβάκι, κλπ. "Αλλοι "Ελληνες καὶ ξένοι, τὶς ἐφάρμοσαν ἐσχάτως σὲ ἄλλα φυτά. Γιὰ μεγάλα φυτὰ χρειάζονται βέβαια μεγαλύτερα δοχεῖα, 50 ἑκ. διάμετρο π.χ. γιὰ τὸ καλαμπόκι. Καὶ μεγαλύτερες ἀποστάσεις μεταξὺ ὅρχων, 120 ἑκατοστὰ π.χ. γιὰ τὸ καλαμπόκι.

Προκειμένου γιὰ δένδρα δοχεῖα μὲ διάμετρο 1 ἢ λίγων μέτρων εἶναι, φαίνεται, ἀρκετά. Παρουσιάζουν τὸ πλεονέκτημα ὅτι ἐπιταχύνεται ἡ καρποφορία. 'Επίσης οἱ ἀποστάσεις μεταξὺ δένδρων μπορεῖ νὰ εἶναι μικρότερες ἀπὸ τὶς συνηθισμένες. 'Αλλὰ ὁ ἐδαφικὸς χῶρος, ποὺ καταλαμβάνουν οἱ ρίζες κάθε δένδρου (ὅρχοι) πρέπει νὰ ὁροθετεῖται μὲ ἀκρίβεια, μὲ χαντάκια ἀρκετὰ βαθιά, ὥστε νὰ μὴν περνοῦν οἱ ρίζες.

"Οπως εἶπε ὁ κ. Διανελλίδης, πολλοὶ ὑποστηρίζουν, ὅτι τὰ λιπάσματα καὶ ἰδιαίτερα τὸ ἄζωτο, αὐξάνουν μὲν τὶς ἀποδόσεις, ἀλλὰ ὑποβιβάζουν τὴν ποιότητα (γεύση κυρίως). 'Αλλὰ ὅπως εἶπα, δὲν ξέρομε ἀκόμη σὲ τί ὀφείλεται ἡ ποιότητα καὶ δὲν ἔχομε μεθόδους ἀξιολογήσεως ἀπ' αὐτὴ τὴν ἄποψη. Χρειάζεται πολλὴ ἔρευνα, γιὰ νὰ δοῦμε πρῶτα πρῶτα τὶ συμβαίνει.

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