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# Cultural Manipulation for Higher Yields

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## I. INTRODUCTION

By cultural manipulation we will mean, in a broad sense, everything a farmer might do to increase crop yields per hectare, after he decides what to plant and buys the seed. With this restriction we leave out the agricultural economist and the plant breeder. When we limit our interest to yields per hectare we introduce an element of area. This will include the crop canopy above the surface and the root system below it. Cultural manipulation also includes what the farmer might do to make best use of water, carbon dioxide, nitrogen, and essential mineral nutrients whether they occur naturally or otherwise. We will also include manipulations designed to make the most efficient use of radiant energy during the growing season. Finally, consideration of the length of the growing season introduces the concept of time as one of the objects of cultural manipulation.

This is a vast subject from which we cannot hope to do more than select a few interesting points to discuss. To review the literature we would have to start with the most ancient findings of archaeology when cultural practices were more the concern of priests than of agronomists. Last year a third to a half of the papers published in the area of agronomy would come within our definition so there is still some interest in the subject. Dr. Clements wrote a review in the Annual Review of Plant Physiology recently containing 284 literature citations, one of which I noticed was a review of climatic influences on crop growth that itself contained 10,000 citations. When we speak of cultural practices we are talking about something that is big business in the agricultural field.

## II. INTRASPECIFIC COMPETITION

I would like to start by referring to an experiment done in Lexington last summer for the prosaic purpose of evaluating 63 of the corn varieties (Zea Mays L.) most widely used in Kentucky. We will use it as a background to think together about whole plants growing in the field and about how they interact with each other and with their environment.

This corn was planted in a design described in Biometrics (1962) by John Nelder, now occupying the position at Rothampstead made famous by R. A. Fisher. In Kentucky we call it a wagon wheel design for reasons that are obvious when you see it. Each wagon wheel contains 21 4-row plots and all varieties are replicated three times, hence 9 wheels. The corn is planted in rows corresponding to the spokes of a wheel and the plants are set closer together in the row as we move toward the center of the wheel. Each plant is thus essentially in the center of a trapezoid that diminishes in area as we move toward the center of the wheel. The geometry stays constant, only the dimensions change. The planting rates go from 13,000 plants per hectare at the outside rim to a high of 107,000 plants per hectare at the last harvested radius.

A cross section of the planting design is almost a history of corn planting practices. On the outside rim the corn is planted almost like it was 40 years ago when Dr. Kiesselbach was doing such fine pioneering work with corn here at Lincoln and when almost all corn was open pollinated. The population, 13,000 plants per hectare, was close to the average rate used then and the yields are strikingly similar.

As we move toward the inside of the wheel we are progressing through 40 years of change in corn cultural practices. Near the center we reach the present and possibly even the future of corn cultural practices and problems. As planting rates change in our wheel so do the yields. The very best varieties yield 5,000 kg/ha on the outside radius and yields increase toward the center to as much as 15,000 kg/ha somewhere between the extremes of population studied.

Many feel that the major thrust of research toward higher corn yields should be to push the population higher and higher. As we do so the difficulties to be overcome change in nature. It is well to think of the problems of yield in terms of things that occur in the test tube and under the microscope, but it is in the competitive struggle among plants that any changes must operate and survive. It is for this reason that I want to spend some time talking about what happens to plants growing at various positions within our wheel.

As we move from the outside rim of the wheel toward the center, the yield per plant decreases in a very regular manner. Without bothering about a mathematical statement let us just say that if we plot the yield per plant as the ordinate against population per hectare as the abscissa on semilog paper we get a linear regression, a straight line that slopes downward (Duncan, 1958). From such a regression we can calculate the yield per unit of area at any rate of planting. The fact that the regression is linear indicates that there is a plant population at which a maximum yield per hectare would occur and we can of course estimate that maximum grain yield. This is why we plant our variety test in such a bizarre pattern. This is a good way to compare varieties. It lets us compare varieties on the basis of what each is capable of at its optimum population. It raises an interesting question about why the relationship between plant population and yield per plant should behave in such a beautifully mathematical manner, but this is outside the scope for this particular paper.

## A. Cooperative Interaction

Instead let us first consider the general height relationship. The height of the corn plants increased with increasing plant population to a maximum and then the average height decreased again. This observation is in agreement with a more general statement by Yoda, Kira, and Hozumi (1957) who observed that "When plants are experimentally exposed to shade, there is usually found a certain light intensity at which the plant attains its maximum (height)"—There were relatively large differences in this among the varieties we tested but all increased in height with increase in mutual shading. First appearance of the tassel and anthesis were observed at about the same time in all populations within most varieties so we can infer that the length of time to attainment of maximum height was not much affected by mutual shading. Thus the taller plants must have elongated at a more rapid rate than the shorter ones.

This tendency of shaded plants to elongate more rapidly than unshaded ones was first reported by Hozumi, Koyama, and Kira (1955) as a result of their observations with corn. They noted that in closely spaced plants, the shorter plants had a higher elongation rate than the taller ones that were shading them. They gave the name "cooperative interaction" to this phenomenon because by reason of it the shorter plants tended to "catch up" in height with the taller ones. The results of this cooperative interaction were readily observable in the wagon wheels. The plant heights were more uniform at intermediate plant populations than at either the highest or lowest populations, and the difference in uniformity was statistically significant.

## B. Competitive Interaction

Kira and his associate, however, noted no such tendency for shorter plants to increase faster in weight. It was quite the opposite. Shaded plants, as one would expect, gain weight more slowly than less shaded ones. With corn the effect of height difference on gain in dry weight is closely related to plant density. By use of a modification of the computer simulation program mentioned earlier by Dr. R. S. Loomis (Chapter 3, this book) and using plant descriptions taken from experiments conducted by Williams and Loomis in California, I estimated the effect of difference in height on average daily photosynthesis of corn. A plant 10 cm shorter than those surrounding it would be deficient in the production of dry matter at low populations by about 20%, at high populations by almost 50%. If the difference in height is increased to 30 cm the deficiency in dry matter production would increase to 40 and 80%, respectively.

From this I think we can agree on several general propositions. One is that a corn plant shorter than its neighbors is at a considerable disadvantage. A second is that a difference in rate of elongation such as Kira described that could reduce the height difference would reduce the penalty imposed by overshadowing. A third obvious conclusion is that the higher the population of plants the more severe the penalty imposed by height difference. As we move to higher planting rates, height differences produce larger effects. Another observation by Kira and his associates that is a corollary of the first is that beyond some degree of shading, that produces a maximum height, further shading must result in shorter plants and hence slower elongation rates.

With these relationships in mind let us go back and slowly walk into our wagon wheel starting with our 1928-type plant populations. Here the plants are typically rather short and sturdy with several tillers, or suckers as grandfather called them. The plants are irregular in height and even more in yield of grain. The height irregularity is presumably due to genetic differences and the lack of enough competition to invoke Kira's cooperative interaction to hurry the shorter ones. The plants are irregular in grain yield per plant because some plants have one ear, some two, and some even three or four. In other low-population experiments we have observed that the top or first ear is remarkably uniform from plant to plant within a variety. The difference in yield from plant to plant seems to be due to differences among plants in whatever impulse or stimulant or absence of repression is needed to cause a second or third ear to form. Among varieties the higher yielding at these low populations were those capable of forming the largest or the most ears. This takes us back in memory to the old state fairs in the Cornbelt where the corn shows were the big attraction and the prizes went to the big well-filled ears. These were closely related to yield in the early 1900's. Another characteristic of our low-population corn I hadn't mentioned was that where our chemical weed control broke down, the weeds grew with astonishing vigor. It was easy to look at these and see why corn was cultivated three to five times in those days and checking was the popular way to plant it.

As we move through increasing plant populations we lose the tillers and most of the second ears and weeds are much less aggressive. The plants look uniform in height because of the cooperative interaction and they get taller and ear height increases. This is the 6,000 to 8,000 kg/ha yield level which is easily realized with adequate fertilization and rainfall or irrigation. This is the corn of the late 1940's and early 1950's. The main problems were fertility and water. No one worried much about row widths and barren plants weren't much of a problem. Unfortunately we did not put any of the old open-pollinated varieties in our wheels. I will do so next year and feel reasonably confident that we can get yields in excess of 6,000 kg/ha at these planting rates.

## C. Plant Uniformity and Barrenness

As one moves to higher populations still we encounter the problems of the present and get a look at those of the future. Plant heights become less uniform because our cooperative interaction no longer operates. All of the plants are shaded to nearly their maximum height and hence their maximum rate of elongation. A plant that germinates slowly or is slow in getting started is soon shaded beyond its maximum elongation rate. In consequence it grows more slowly than its neighbors. It is soon even more heavily shaded and hence grows more slowly still. It is thus suppressed and becomes a starved, spindly, barren plant.

By doing everything possible to insure uniformity one could probably avoid such suppressed plants, but only up to a point. When the maximum-height shading is reached for all plants the equilibrium becomes unstable. Some plants must be suppressed. As stated by two famous Nebraskans, Clements and Weaver (1929), in their description of an experiment with sunflowers (Helianthus annuus L.), "in a crowded population a difference in height of as little as a millimeter could be decisive if it enabled one plant to get its leaf over its neighbors."

We have stressed the competition for light, but an equally deadly competition must be going on under the soil. Shaded plants have an increased shoot/root ratio. The more shaded plant invests a decreased part of its resources in roots so its root system is smaller and shallower than its more favored neighbors. Moisture or fertility stress can only add to the relative disadvantage and increase the probability of of suppression. The nature of this double competition has been shown in many experiments, but possibly never more clearly than by Donald (1958) in his experiments in the 1950's.

In the 63 varieties we observed, these suppressed plants were almost invariably barren. The ears formed contained only a few scattered kernels if any at all. More interesting was the fact that only plants that would be classified as suppressed by competition were barren. This might not have been the case under more normal field conditions where more reasons for barrenness might exist. In our plots there was ample pollen over a long period of time because of the numbet of varieties planted together. We also had a very favorable growing season with supplemental irrigation but I feel that the competitive interactions I have described are one of the important causes of barrenness in high-population corn. It has received surprisingly little attention in the agronomic literature.

Barren plants are one of today's serious problems in seeking higher yields and it is one not likely to get less important. A barren stalk intercepting light and using water and nutrients but giving nothing in return cannot but reduce grain yield. It should be pointed out, however, that grain yield in corn reaches a maximum and then declines as population continues to increase whether there are barren stalks or not. The effect of barren plants is to cause the yield maximum to occur at a lower plant population and to accelerate the rate of decrease in yield as populations continue to increase. As might be expected barrenness increases with stress.

It would have been interesting to see what some of the old open-pollinated varieties would have done at these much higher plant populations. Undoubtedly the increased variability among plants would have meant increasing numbers of plants would have been suppressed and hence barren. From this point of view it seems obvious that one advantage of hybrid corn varieties is uniformity that permits higher plant populations. The greater uniformity of single-cross varieties might be one factor in their yield potential.

Dr. Donald has written recently (1968) about the possibility of increasing plant yields by the breeding of crop ideotypes, defined as plants with model characteristics known to influence photosynthesis, growth, and grain production. One basic characteristic he notes is that ideal plants should have weak competitive ability. By this he means they should have characteristics that enable them to make the best possible use of their share of the environment without encroaching on environment allocated to neighboring plants. We will return again to this thoughtful observation but we can see in the tendency of corn plants to elongate when shaded the survival of a trait that in more primitive ancestors represented the thrust of green blades above competitors. In a field of crop plants where all plants have equal value the tendency to try to crowd out neighboring plants is highly undesirable.

In addition to mutual shading this elongation increases plant and ear height and decreases stalk strength. Both make the plant more likely to lodge. It has the less obvious effect of increasing the tendency to suppress individual plants at high plant populations. Elongation at a more rapid rate in response to shading may provide the mechanism for a certain improvement in height uniformity but this is small compensation for the additional stresses it imposes. The fact that there is relatively large variation in this tendency to elongate among varieties we have observed indicates that there is genetic variability for breeders to work with and probably that progress is already being made.

## D. Planting Patterns

Our observations have stressed the potential loss of yield caused by lack of uniformity and the need for increased uniformity as plant populations increase. Some preventable causes of nonuniformity are obvious. Seeds should be uniform in germination time and should be planted uniformly.

A more subtle influence on uniformity is in the pattern of planting. In our wheels each plant was in the center of a trapezoid, almost as well separated from neighboring plants as possible for a given planting rate. This deferred competition among plants for light as well as for underground factors as long as possible. At critically high planting rates any lack of uniform plant distribution would mean localized high density areas where plants would be shaded past the point of instability at which some plants must be suppressed no matter how uniform the initial conditions. The adverse effect of any lack of uniformity would be accentuated.

This at least partially explains the current interest in narrow rows. As one decreases the distance between rows to some point, for a given plant population, the distribution of plants becomes more uniform. Our experiments have shown that the higher the plant population the greater the yield advantage of narrower rows. This is the usual conclusion from such experiments.

The high planting rates necessary for higher yields in the future thus require more uniform planting patterns. The best planting pattern for any plant can be shown by rather rigorous mathematics to be equilateral or hexagonal as you choose to look at it. We might assume, therefore, that planting patterns of the future will tend toward this one. The present interest in narrower rows may be taken as a part of this trend. The problem of developing planting equipment that will place seed in a hexagonal pattern does not seem to me to be insuperable. A square pattern is almost as good and this was the common pattern for many years although the spacing was far too wide.

Dr. Daynard and I have also shown by convincing mathematics with the aid of our computer that the worst way to distribute seed within a given area is with multiple seed hills. Quite a number of early experiments compared such hills with row plantings at the same population and usually showed small yield differences in favor of the rows. These were done at far lower than what we now consider high populations. At high rates the differences in favor of the row plantings are quite a bit higher as we learned in a small unpublished experiment 2 years ago. This is not to say that disease or insect control or other considerations might not favor other planting patterns but theory favors the hexagonal design.

## E. Tillering

The disturbing fact is that tillering plants such as wheat [*Triticum* (*aestivum* L.) sp.] or rice (*Oryza sativa* L.) are essentially plants growing in multiple-plant hills which is, according to our computer, the worst way. Using somewhat different reasoning, Dr. Donald has selected as his ideotype for wheat a single-culm variety. This is not to say that a tillering plant might not have advantages in specific localities. Dr. Donald mentions the very obvious advantage of a tillering rice plant for Japanese conditions where the individual plants are usually set by hand. Scientists at the International Maize and Wheat Improvement Center in Mexico are interested in the development of a strongly tillering variety of corn which may have great advantage under some conditions. What I am asserting, with Dr. Donald, is that highest yields under very favorable conditions, will probably result from nontillering plants. It is again a matter of plant geometry and of our ability to control it.

## F. Leaf Area Index

In summary of this discussion of the problems associated with the best use of space we may ask the question as to why high planting rates are required for high yields and if there is no limit to planting rates. If there is a limit, what determines it? The answer goes back, in part, to some of the points made by Dr. R. S. Loomis (see Chapter 4, this book) and his computer in describing the architecture of plant canopies. Higher plant populations are needed with a plant like corn in order to have high leaf area indices (LAI). Without high LAI values, the useful light cannot be intercepted at efficiently low levels of illumination. There is a limit to this, however, that is set by the leaf angles involved.

With flat horizontal leaves a high LAI is a disadvantage because of excessive self shading. As leaf angle increases so can LAI. The rate of planting required for maximum canopy photosynthetic rate and presumably yield with a given phenotype is set by the leaf area per plant and the angle or aspect of the leaves. There are obviously other considerations but these are fundamental and limiting.

We can think about this in terms of Dr. Donald's idea that the ideal plant should be as noncompetitive as possible. With near vertical leaves it is possible for a plant to intercept light at low levels of illumination and hence more efficiently as far as the use of radiant energy is concerned. With such leaves the shading of neighboring plants is minimal. High yielding crops come from plants that are pacifists; that concentrate on productivity and minimize rivalry.

In this context, a soybean plant (Glycine max L.) might be a good example of a plant with reprehensible social behavior. It has a bush habit of growth that tends toward overshadowing neighboring plants. For many varieties the leaves are large, relatively flat and placed close together. They thus intercept both direct sunlight and skylight at inefficiently high levels of illumination instead of dividing the light flux among many more leaves.

## III. NO-TILLAGE PLANTING

Let us continue by considering the underground environment and to some extent the use of water. In Kentucky and adjoining states there is considerable interest in a cultural method called "no-tillage." It is an awkward term to use in writing or speaking but no better one has evolved as yet. This year there were almost 40,000 ha (100,000 acres) planted in Kentucky by this method and more will be planted next year. What has brought it to the front is a better approach to an ancient problem, the control of weeds. The fact that weeds are easier to control in corn than in other crops probably explains why it is in wider use in this crop than others.

Under this concept the grass sod or other ground cover is killed with herbicide mixtures and a 5-cm-wide (2-inch) seedbed prepared with a fluted coulter. Seeds are placed in this strip with only slightly modified planters. Results haven't been free of problems but there is solid reason for encouragement and for thinking it is much more than a passing agricultural fad. One that is most exciting to me is that our corn so planted has shown less wilting under moisture stress than corn in adjoining plots prepared conventionally. Apparently less water is lost from the soil during preparation, during the time when corn is too small to shade the soil surface, and possibly even after this when most visible radiation is being intercepted. There is a favorable effect on infiltration of rainfall also which may be a factor. At any rate, yields for no-tillage corn in Kentucky are as good as conventional tillage under very favorable conditions and consistently higher when there is moisture stress.

While in Davis, California, I audited a class in tropical agriculture taught by Dr. W. A. Williams in which he discussed a comparable planting system in the steep hills of a remote part of Brazil. Here the farmer applied an ancient herbicide, fire, by burning the brush. He then planted his no-tillage corn—by a touch with the tip of his machete that made a mark just large enough to allow him to insert and cover a grain of corn. The farmer didn't know anything about scientific agriculture but he knew that the less he disturbed the surface of the soil the fewer weeds he would have. The process may sound a bit crude but it may embody the fundamental principles of the best cultural manipulation of soil for the future.

As we think about no-tillage systems and see how well they work we must ask the question, why do we plow in the first place? Observations of no-tillage systems suggest to me that what we refer to as soil preparation has little to do with improving the environment for root development. Corn yields without plowing are just as good, usually better, and sometimes quite a bit better than with conventional tillage. Apparently in our part of the country the major reason for plowing is to control weeds. Dr. deWit has told about similar results with crops other than corn in Holland, so it isn't too local a conclusion. A huge tractor pulling four or five bottom plows is a lot of machinery just to kill weeds.

## A. Rooting Patterns

One of our exciting observations about no-tillage is that crops seem to improve with successive cropping. Dr. deWit has told me that this seemed to be the case over a 6-year experience in Holland, and he proposes to look under the soil surface to see if there might be some progressive change in rooting habits. It is not unreasonable to think that with time in undisturbed soil there are increased numbers of passages into deeper layers of the soil attributable to old root channels, insect holes, animal burrows, etc. These channels are, to a considerable degree, structured so that roots following them would be led downward, and most such openings would have some degree of permanence. Plowing presumably interrupts and destroys such channels and substitutes for them a non-structured and less permanent porosity.

I can make almost any statements about roots growing in the soil without much fear of contradiction because we know so little about them. They are too hard to dig up. Probably Dr. Weaver and his students here at Nebraska have done more than anyone else to try to find out about roots growing in soil but there is much more we need to know to evaluate the need for plowing.

If I have inspired any of you to take a closer look at roots in the soil, don't go very deeply into it without reading a little paper on root sampling techniques by E. T. Newman (1966) on work done at Duke University. I found out about it from Dr. Torsell, one of Dr. R. O. Slatyer's associates who has used the methods described. It is a real breakthrough in a way to study a difficult subject.

## B. Future of No-Tillage

The present interest in and development of no-tillage methods has come from a basic new agricultural tool, modern chemical herbicides. The possibilities for the future depend on further development and perfection of agents for the control of weeds. It is still too early to do away with our tractors and plows and sell stock in companies that manufacture agricultural implements. The ideal herbicide hasn't been developed yet and our techniques for using them will probably seem unbelievably crude as seen through our grandchildren's eyes.

If by remote sensing from airplanes high above the earth we can distinguish between wheat and oats (Avena sativa L.) it should be possible to build a herbicide applicator that can locate and identify general classes of weeds. With such a tool we can apply the best herbicide to control each class of weeds and none at all where no weeds are growing. This will increase effectiveness, decrease cost, and minimize the danger of undesirable contamination of soil and crops.

Planting and fertilizing through masses of organic debris on the surface poses challenging problems. Thus far fertilization has been almost disappointingly simple. Surface application of all nutrients seems to be entirely adequate on the soils we have worked with. Surely this cannot be generally true.

Planting equipment seems crude and awkward for the task. We are still chained to cultivated-field thinking. We must get our engineers to spend some time meditating on the Brazilian farmer tapping the soil with the tip of his machete and dropping the seed into the wound. The need is for a tool that will deposit the seed under the soil with a pecking motion like the beak of a bird, not a device that will prepare even a 5-cm-wide strip down which a conventional planter can be dragged.

Many problems remain to be solved. One interesting one our experimenters ran into in Kentucky was with field mice. When they cultivated a narrow strip and planted seed in an old bluegrass sod they made a mouse freeway studded with refreshment stands. Some plots had to be replanted three times. They also made more than one hurried call for the entomologist to look at insects they had never before recognized as corn pests. It we can send men around the moon, however, we can probably solve problems like these in some way.

I should point out here that results from one state, Indiana, do not agree with other states which have worked with no-till corn. What I have presented is a majority report. The fact that there might be a minority opinion is added reason to learn more about the basic principles involved. Differences in results suggest differences among soils or climates or methods that affect the results.

I haven't mentioned the most obvious reason for interest in no-tillage methods. As we have been made more aware at this conference by Dr. J. G. Harrar's address, there is urgent need for more food production. No-till methods could allow us to bring millions of hectares of sloping land into permanent row cropping thus effectively increasing the acreage available for production of human food. This possibility should give powerful motivation for study of no-till methods.

Research should proceed in steps. The first is to confirm our observations and to be sure of our facts. This is about where we are in no-tillage. The second step is to develop hypotheses to explain what we observe and to reconcile apparent discrepancies. The third step is to design experiments to test our hypotheses. When our hypotheses survive to evolve into theories and stronger we can begin to feel that we understand the problems. This is where we would like to be with no-tillage and as rapidly as possible.

## IV. UTILIZATION OF THE GROWING SEASON

The last of our elements of cultural manipulation is time, by which is meant the procedures we may use to make fullest use of the growing season. This is not exclusively a temperate zone problem. Even in the tropics there are often factors that make some part of the year a more desirable growing season than others.

Agronomists in Nebraska do not have the same problems we have in Kentucky with corn. Here they plant early varieties as soon as they can in the spring and spend the summer hoping they will mature before it snows. In Kentucky if we plant corn early it will be mature and dead by the last of August. With really early varieties it will be dead sooner. There is often a month or more of fairly good growing season left unused. The farther south one goes in the United States the more corn growing weather is wasted. Our problem is how to translate the unused season into higher yields. Later varieties grow taller and silk later but there seems to be little increase in the filling time during which grain is produced.

### A. Ideotypes

To state the problem in Dr. Donald's terms, we are looking for an ideotype that will be short and hence early with erect leaves and that would have several or very large ears on every stalk. It would silk and tassel early and would spend the remaining growing season filling the kernels pollinated earlier. The time from silking to maturity would not be affected by temperature. With such varieties a farmer could buy seed to suit his planting time and the length of his growing season, and corn yields would increase with the growing time available. The ideal ideotype for high yields would germinate quickly in cool soils and grow off rapidly at low and variable spring temperatures.

Presently we probably sacrifice yield by seeking varieties that mature early enough to dry in the warmer days of fall. It would be better, as far as yield is concerned, to develop varieties with longer filling periods that would mature later. There are other ways of drying corn after harvest than by using solar radiation. Our only energy for growth comes from the sun. We should use as much of it as possible for producing grain, and develop ideotypes that will make full use of it.

### B. Double Cropping

Another method for extending the growing season is by using the cooler part of the year to produce crops that do well at lower temperatures and follow or precede them with crops that flourish during the warmer part of the season. Alert farmers in our area are experimenting with various plans for double cropping to accomplish this and our plant breeders are developing early maturing small grains to fit into such plans. Only recently I heard of one of our farmers trying to develop a cornplanter to fit under his combine in order to put no-till corn in the clean ground behind the cutter bar to be covered by the straw falling behind the combine. Farmers are alert and thinking along these lines everywhere and they are developing methods that we agronomists must help them with. Another idea that is coming into use is the seeding of small grains in standing soybeans and corn with airplanes. I am sure the birds approve of this, but seeding rates are increased enough to feed them and get satisfactory stands. Yields are as good as, or better than, with conventional seeding. Any improvement in yield probably comes about because earlier seeding is possible rather than because of the method used.

## V. FUTURE RESEARCH

Work to improve plant yields through cultural manipulation is probably the most ancient form of agricultural research, but there is still room for improvement. As one new and powerful tool we have the modern digital computer whose speed and memory capacity permit the simulation of complex plant and environment situations. We can begin to fit what we know about the parts of the system together like pieces of a giant puzzle to make model systems we can manipulate in the computer. With such models we can test our ideas in seconds instead of years and without having to worry about droughts and floods and all the other accidents that happen to field experiments. In such models we can test the plant ideotypes Dr. Donald mentions without ever having to produce a seed. We can design plants for specific situations and turn the blueprints over to the plant breeders. We are well on the way toward this.

The greatest present obstacle standing in the way of rapid progress in the development of simulation or systems analysis methods in the agricultural sciences is lack of any way to publish results or methods. Fortran programs make dull reading to the uninitiated and explaining them takes more space than is usually allowed in journals. A further difficulty is that most agricultural journals are frozen to the idea that publishable data comes from physical experiments rather than from sound logic and transistor hookups. As a result there is little opportunity for those working in simulation to exchange ideas. Neither is there an opportunity to show agricultural scientists generally that simulation with modern computers has tremendous potential for solving many complex agronomic problems. Such new scientific developments call for imaginative new ideas in publication.

By whatever the method, the general need in agronomy is more mathematics to aid us in generalizing complex problems. There is no other way we can gain clear understanding of the real nature of the difficult problems involved in cultural manipulation for higher yields. We have improved yields through the centuries by trail and error methods, however, and we can probably continue to make stumbling progress by the same methods. We can attain our ends more rapidly and more surely, however, if our experiments are guided by a higher level of understanding.

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# 14...DISCUSSION

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In sugarcane fields (Saccharum officinarum L.) maximum yields are more nearly obtainable when the requirements of the crop are diagnosed and satisfied while the crop grows and all negative factors are neutralized as much as possible prior to the start of the crop. In order that the requirements of the crop be met as they develop, samples of leaf sheaths and blades are collected every 35 days starting at 2-3 months of age and continuing until harvest. All the samples are analyzed for tissue moisture, N, K, and total sugars of the sheaths. Normal levels of sheath moisture and leaf nitrogen for each cane variety for each age are a matter of calculation. Within 48-72 hours after a sampling, the actual levels are obtained, plotted on the log, and, when compared with the "normal," appropriate action can be taken.

Intensive analytical work during the period of maximum growth gives data on all the essential elements, major and minor and $SiO_2$. Three consecutive samples are so analyzed. Soil pH is also determined for each station. These data provide all the information needed with which to start off the next crop, i.e., not only to provide adequate nutrients but just as important to eliminate toxicities—particularly those associated with poorly aerated, poorly drained acid soils: ferrous iron, aluminum, nickel, excessive amounts of the minor elements, particularly Mn, Zn, and Cu. Crop log data at times are fortified with root data covering the potentially toxic elements. Calcium metasilicate, calcium carbonate, calcium sulfate, or magnesium oxide may be called for and each would be applied at the start of the next plant crop and worked into the soil with deep plowing, discing and/or rotovating.

On irrigated plantations, the moisture regime is checked at each analysis and adjustments made if necessary. Maintaining high tissue moisture levels is a primary requirement for maximum yields. On unirrigated plantations below normal moisture levels during adequate rainfall and fertilization may call for a change in soil preparation techniques.

Blossoming of sugar cane can be completely prevented by imposing a mild moisture stress onto the crop. Withholding one water application between August 4 and September 8 will drop the tissue moisture level to stress levels and prevent flowering.

The last 6 or 7 months of the 2-year cycle crop are given over to deliberate ripening of the crop. Weekly samples of sheath tissue are taken and moisture analyses are made. At the start of the period, tissue moisture should be high—82-84%. And on the day of harvest the level should be 73% which is usually achieved in a series of drought impositions, at first light but progressively more severe. With each drop in tissue moisture, growth is reduced and carbohydrates accumulate. When water is again applied, tissue moisture rises but never to the previous high levels. In this way a very orderly ripening is effected.

In pineapple culture, according to Dr. Wallace Sanford, efforts have been expended to broaden the time of fruit ripening and harvest. If the crops were allowed to differentiate naturally, they would peak at the same time resulting in crowding the canneries for a very short time. To lengthen the harvest and processing, early fruiting is induced by aqueous application of such growth regulators as ethylene, acetylene, sodium naphthalene acetic acid (SNA), and by beta-hydroxyethylhydrazine. Depending on temperature and sunlight, the time of fruit development from induction varies from 6-7 months. With rather precise knowledge for each area and field the canning period is broadened and peak performance is maintained.

Experimentally, flowering has been delayed with SNA if used in large amount but some bad side effects may ensue. Application of beta-naphthoxy-acetic acid or SNA in large amounts 6 to 8 weeks before expected harvest will increase fruit weight by as much as a half-pound and delay harvest 1 to 2 weeks. Moisture levels of the fruits are raised but there is a lowering of sugars, acids, and pigments.

In Hawaii, the flowering of the daylength indifferent lychee (Litchi chinensis) is very uncertain. Work done by Dr. Shigeru Nakata however points up the effective control measures. Although cold nights (14.0-15.6C) during the September to January induction period assures profuse blossoming, as demonstrated in controlled chambers, rarely are our temperatures that low. Abundant carbohydrate accumulation is associated with flower induction. This condition can be induced by imposing a drought either through the cessation of irrigation or by covering of the soil with clear polyethylene sheets. It can also be accomplished by girdling either a branch or the whole trunk, overcoming in this way to some extent at least the tendency toward biennial bearing.

Shipments of papaya (Carica papaya L.) to the mainland United States, an expanding business, are beset by three main problems: fruit fly, fruit rot and a short shelf life. Vapor heat or ethylene dibromide fumigation are approved quarantine treatments for the fly. The latter as worked out by USDA and University of Hawaii researchers is the more commonly used method, but this has no controlling effect on the storage decay. A hot water dip (49C for 20 min.) to control the decay worked out by Professor E. K. Akamine is now combined with fumigation as the common treatment for air as well as marine shipments.

Low dosage gamma irradiation (not yet cleared for commercial use) combined with the hot water dip, effectively controls the rot as well as the fruit fly and extends the shelf life 3 to 4 days by delaying *ripening and senescence. Another* 2 days can be gained by shipping fruit so treated under low oxygen refrigeration.

# 14... DISCUSSION

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I would like to use three examples to focus your attention on one part of the plant which, except for Dr. Duncan's paper, has received very little attention at this conference—the root. Increasing crop density must include increased root density. Pitman (1962) has a particular example of the effect of root density. The roots of winter wheat are aligned along the geomagnetic lines of force, and so if the rows are also aligned this way, interactions of roots from different plants are greater than if the rows cross the lines of force. There were effects on yield and on the date of heading, presumably because of competition for water.

As Dr. Duncan has indicated, explaining the results of no-tillage planting or transplanting also requires consideration of the roots. A procedure similar to the one he described from South America can also be seen in North America; it is used to transplant tree seedlings in British Columbia. To protect the roots and lower stem from damage during the transplanting procedure, Walters (1968) has developed a mechanized procedure involving the planting of seed, germination and growth of tree seedlings in plastic bullets. After transplanting, the bullet splits open under the pressure of continued plant growth.

In the type of statistical wheel that Dr. Duncan used, the gas composition of the soil would change from the outside to the inside, and it would be affected by whether green manure or inorganic fertilizer was used. An effect that these factors may have on the microflora has been shown by Pentland Friesen (1967). She has shown that the weight of Armillaria mellea can be doubled by a continual supply of 50 ppm ethanol. More recently, she has found that methoxylated lignin degradation products, again at the part per million level, control the production of rhizomorphs. The rhizomorphs are important in the pathology of Armillaria. This fungus, therefore, would be greatly stimulated by high levels of biological activity in the soil, leading to the availability of alcohol and other organic products.

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