Can We Break Present Barriers to Improvements in Sugarbeet Yields?

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Received for publication April 23, 1979

I am pleased to have the opportunity to share my thoughts with you about how to increase sucrose yields from the sugarbeet crop. Although my major research emphasis has been on the physiology of cereal and legume crops, I nevertheless have worked with sugarbeets enough to know that many of the same physiological principles apply to most of our major field crops.

I want to emphasize, at the outset, that regardless of the discipline one pursues in crop research, whether it be plant breeding, management, physiology, or processing, the successes we achieve in improving sucrose yields will depend heavily on the extent and effectiveness of our ability to communicate data and ideas about our research experiences. Evidence indicates that those research groups, regardless of size, that have the most free exchange of information accomplish more than do groups with common research interests, but who guard their ideas for whatever reasons.

My research has dealt with factors of photosynthetic efficiency, water-use-efficiency, and plant growth analysis of crops. At the outset of my program, I had visions about developing simple screening procedures that could be used by plant breeders to identify and select superior lines of certain crop species. With perhaps one exception, I have had little success with the development of efficient screening techniques. Nevertheless, through the process of communicating my research results about fundamental aspects of crop growth and development, I believe I have helped my plant breeder associates improve in their "minds eye" how a more ideal plant type should appear and how it should perform under field conditions.

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The breeder needs help from other researchers because he is responsible for making the first selections from heterozygous populations after parental crosses have been made. Thus, the more informed the plant breeder is about all basic and applied aspects of the crop, the more likely he is to make more intelligent selections from the heterozygous populations. Obviously then, it is the responsibility of resource people, e.g. plant pathologists, crop management specialists, processors, etc., to make sound observations about crop plants and then relay information and ideas to the plant breeder about methods to select superior plant types. Undoubtedly, the degree to which we assist the sugarbeet breeder in making better plant selections will be reflected in the progress we make toward increasing sucrose yields in sugarbeets.

The research topics I wish to address are seasonal growth patterns, morphology of plants and crop canopies, and endogenous physiological systems.

I will relate characteristics of some grain crops to illustrate how the sugarbeet plant and its management can be altered to improve its productivity. Although subjects such as disease resistance, pest management, tillage management, etc. play distinct roles in sugarbeet production, they will not be discussed because others can address their importance more effectively than I. I will use sugarbeets grown under irrigation as my model system since my experience with non-irrigated sugarbeet production is limited. However, many of the principles I relate will apply to both irrigated and non-irrigated production systems.

It is generally accepted that fall planted wheat has a greater potential for high yield than does spring planted wheat in most growing regions around the world. Also, in the cornbelt region of the midwestern U.S., corn planted in April will usually yield more than corn planted in May, and the corn planted in May will yield more than corn planted in June. Why? Because the fall wheat and the early planted corn exploit more of the growing season than do the late planted crops by developing a greater vegetative base plant. The larger vegetative base is then used to produce grain during a
longer period of time from anthesis, or heading, until physiological maturity of the seed. Thus, plant breeders have knowingly increased the effective growing season of these crops by developing winter or cold hardiness into the crops which enables the plants to survive and flourish in the environments in which they are grown. Although there are some exceptions, due to environmental interactions, there is a high and positive correlation between the duration of the grain filling period and potential for high grain yield in wheat and corn.

I believe the principle of using a longer grain-fill-duration in cereal crops can be utilized to increase sucrose production in sugarbeets. To increase the effective season of "sucrose accumulation" in sugarbeets, plant breeders should first select for high seed viability, rapid germination rate, and vigorous seedling growth in the early spring. Since most of the sugarbeet growing regions of the midwestern and western U.S. are characterized by cool, moist springs, often with a threat of late spring frosts, it behooves us to select beet genotypes that cope with these conditions. If we can accomplish in sugarbeets what the plant breeders have done to improve corn adaptation to harsh early spring conditions, we can enhance the vegetative base that is required to produce and store sucrose in the early development of the beet crop.

If sugarbeet varieties were developed that could establish and grow vigorously early in the spring, the next limiting factor to increasing "sucrose-fill-duration" is the length of time required for the hypocotyl and/or the storage root to initiate rapid expansion. As a corollary, I relate the stage of initial rapid root expansion in beets to anthesis, or heading, in cereal crops. Obviously, grain development begins after fertilization has taken place; if this process occurs very early and physiological maturity of the grain is later, the greater will be the opportunity to increase the number of days for grain filling. Likewise with sugarbeets; the earlier the process of sucrose storage is initiated and the longer it continues, the greater will be the chance for greater sucrose production because of an increase in the effective storage period during the growing season.
The hypocotyl test Dr. Doney described during this symposium should be of significant value as attempts are made to identify sugarbeet genotypes whose hypocotyls expand earliest in the spring.

When sugarbeet genotypes are developed that have roots expanding earlier, productivity can be further increased by selecting lines with the greatest capacity to produce photosynthate and store it as sucrose in the root of the plant. Dr. Snyder and colleagues reported on a technique that should prove useful to identify lines that partition greater amounts of their photosynthate to the root tissue. Hopefully, genotypes that shunt greater proportions of sucrose to the root in the early stages of root expansion will have the capacity to continue this favorable pattern of partitioning photosynthate throughout the growing season.

Another critical growth phase in sugarbeets occurs in the summer during the period of rapid sucrose accumulation in the root. Midsummer daytime temperatures often rise above optimum for the plants; therefore, either genotypes must be developed that adapt well to those conditions, or irrigation systems must be managed to minimize plant stress. Regardless of whether the crop is grown under rainfed or irrigated conditions, the less moisture and/or temperature stress they experience, the more vigorously they will grow and, thus, increase their potential for high yield.

Associated with the problems of moisture and temperature stress is the factor of nitrogen management in sugarbeet production. Generally, present recommendations for nitrogen suggest relatively heavy applications during early and mid-seasons, with allowance for significant reductions in the soil NO_3-level in late summer and fall. Evidence from past research has indicated this reduction in the level of soil N is necessary to increase the sucrose level in the storage root, thus enhancing sugar yields per unit area of land.
If present sugarbeet varieties require a "ripening off" period to increase sucrose concentration induced by reduced levels of soil N in the fall, I propose it is because our present varieties have been developed in plots using this type of nitrogen regime. I suggest that we would have beet genotypes that would grow with greater vigor for a longer period during the season and, thus, have the potential to store more sucrose if initial selections of superior sugarbeet genotypes were made under a system available whereby soil N was not significantly reduced in late summer or fall. Therefore, if plant breeders could select plants that partitioned their photosynthate more favorably to the root and with less concomitant leaf development but with more rings in the root, sucrose yields could be increased by lengthening the duration of sucrose accumulation and storage in the later summer and fall periods.

Selection of new sugarbeet varieties that simultaneously increase the number of days of effective sucrose storage in the root and more favorably partition photosynthate to the root, would likely result in an increase in the leaf (source) photosynthesis of the plants as a result of increase in the carbohydrate sink in the root.

Although a sugarbeet genotype with a superior rate of leaf photosynthesis might be identified at sometime in the future, it is likely that increasing the sink strength for sucrose in the beet root will be a more efficient way to enhance total photosynthesis in the crop.

In addition to the need for research mentioned above, efforts should be made to select plant types, or management systems, that optimize photosynthetic productivity throughout the growing season. There is a great need to capitalize on interactions with crop management systems. The need for a testing system that would provide a means to measure genotype X environment interactions led me to the development of a chamber-type, gas-exchange system for field plots (1). The system consists of plastic covered chambers that can be placed over plots early in the growing season, with four or five subsequent moves to similar plots during the season. The dynamic aspects of plant growth and development can be monitored and related to various
measurements of the plant-soil-atmosphere environment that may be recorded in addition to the photosynthetic rates and transpiration rates of the plants under study.

The field chamber system provides a basis for a holistic approach to research which will produce more complete and meaningful answers to fundamental questions we now have about crop canopy design, photosynthesis, plant water relations, light utilization, etc., and how they interact under field conditions. Results from these field chamber systems can also be used to test crop growth models such as those developed by Dr. Loomis for sugarbeet growth and development.

In conclusion, if we are to move off the sucrose yield plateau in sugarbeet production, we must seek new and innovative methods to accomplish the task. Many, if not most, yield increases that have been achieved in seed crops have been accomplished by increasing the period of effective storage of carbohydrate in the seed. Through cooperative efforts, sugarbeet researchers can focus their research on methods to lengthen the duration of sucrose accumulation in sugarbeets and, thus, break the yield barriers that currently exist.

LITERATURE CITED

SUMMARY

When Watson and Crick first structurally analyzed the DNA molecule and came up with a structural arrangement of the hereditary material, it wasn't a sudden breakthrough but an integration of many pieces of information. The information had already been available for some time; it was just putting each piece and each bit of information in the right perspective. Most breakthroughs happen this way; i.e., by building piece upon piece, brick upon brick until the whole structure can be visualized.

In times past, we have witnessed numerous methods that were going to revolutionize plant breeding such as mutation breeding, quantitative genetics, nitrate reductase activity, photosynthetic efficiency, mitochondrial complementation, etc. Each one has had something to add to our knowledge and to our set of tools in plant breeding, but none have proved to be a panacea. We must learn how to use them to build the proper structure.

The growth processes are a complicated series of functions and processes all going on at the same time interacting with each other in supply, demand, and feedback equilibrium. These papers have presented us with an overview of the growth functions that hold promise as plant breeding tools (in sugarbeets). These are by no means a list of all the functions. The growth processes have been reviewed, and only those with the greatest potential have been presented. This does not say, however, that as our understanding of the physiology of the plant is increased there will not be additional important and useful growth processes.

As a plant breeder, I am often discouraged at the slow progress we are making. Sometimes it seems as if we are going around in circles. We select and test, and select and test, and seem to make very little improvement. There are pressures on us to more rapidly and efficiently develop higher yielding and more productive hybrids. In light of our present progress and the needs of the world today, we need to look at these new approaches very carefully. They need to be evaluated and developed to the point of practical use.
The speakers have presented us with many suggestions and questions that are thought provoking and certainly deserve our attention. Some of these suggested potential selection criteria are new and novel, while some are the refinement of old techniques. Some might be useful by themselves while, at the same time, they would be more effective combined in an index with other techniques, and some may be ineffective or too expensive or time consuming. In any event, we now have at our disposal some potentially powerful new tools. The proper development, integration, and use of these tools may be the foundation for new breakthroughs in sugarbeets.