INVITED CONTRIBUTION

Botanizing For Oil[1]

QUENTIN JONES[2]

Botanists specializing in fossil plants have long played an important if only a supporting role in the exploration for new oil deposits. The geologists have, and rightly so, played the lead in locating and developing new petroleum fields and the chemists have elaborated this raw material into a myriad of products which influence our every activity—and even the air we breathe! I am not here to plead for a larger role for botany in the oil industry nor even to review that role. Rather it is my purpose to report on another kind of search for oil that is taking place and one in which botanists have a principal role. As you have probably already surmised, the oil to which I am alluding is that found in plants and more specifically in seeds of plants. Actually, I should use the plural, *oils*, and should include as well as other plant constitutents of interest to modern agriculture and industry such as seed proteins and mucilages, plant fibers for paper pulp, and physiologically active compounds of interest to the pharmaceutical trade and to the insecticides field. Our objective is of course to bring the plant sources of these raw materials into our agriculture as successful new crops.

Why New Crops

You could quite legitimately ask: Why the interest in new crops? We certainly do not lack for food and fiber in this land of plenty and our industries appear to be adequately supplied with raw materials. Actually our agricultural abundance is presently providing the strongest impetus for new crops research. We need to find crops that can be grown on acres now contributing to our huge surpluses of wheat, feed grains, and cotton. Our present crop roster offers no possibilities for providing substitutes which will replace significant acreages of corn, wheat, or cotton without creating additional serious surpluses. The human stomach is largely inelastic so we cannot, in a reasonable time, eat our way out of grain surpluses nor can we profitably grow substitute food crops for these would only compete for existing markets and not create new ones. We are forced then to consider other ways of diverting surplus-producing acres. One way, we believe, is to develop entirely new crops with new or unusual raw material composition that will not compete with existing crop products and which will supply the needs of industry as our modern technology advances into new areas of product development. With this in mind, we must consider the relative proportions of various constituents found in plant material. Constituents present in major amounts offer the best opportunity for economic exploitation. Cellulose, mucilage, oils, and proteins are all to be found in major amounts in at least some plant materials. So the objectives we have selected for our new crops screening program are: seed oils with unusual fatty-acid composition (unlike our common vegetable oils, of which we have an abundance); seed proteins with superior amino acid balance for animal feeds; seed mucilages of the galacto-mannan type which are water soluble and have high viscosity in dilute solution for widespread industrial uses in emulsion stabilizers, suspending agents, binders, sizes, etc.; and stalk fibers with appropriate physical and chemical characteristics for paper and dissolving pulps.

---

[1]Invited address presented at the Fifty-First Annual Meeting of the Oklahoma Academy of Science, University of Tulsa, December 7, 1962.

[2]Botanist, New Crops Research Branch, Crops Research Division, USDA, Beltsville, Maryland.

Chances for Success

For several million years man has lived with virtually the same species of plants which comprise the world's flora today. Throughout this time he has experimented with the plants around him. Perhaps mostly by trial and error, but also through observation and deduction, motivated by hunger, cold, pain, fear and superstition, he has rather thoroughly screened the earth's flora for materials which could serve his ever increasing needs.

Some maintain that man has so thoroughly sampled the plants in his environment that there is little likelihood that useful new sources of at least major plant constituents will be found. In support of this contention they cite the fact that in historic time *not a single wild species has been brought under cultivation* to supply a raw material which had not previously been exploited from the species in the wild. Man has brought many crops into cultivation that had previously been exploited from natural stands and he has discovered and developed useful new constituents in old crops but he has so far not combined the discovery of a new source for a useful constituent with successful domestication of the source species.

There can be little doubt that man's search for useful products in the plant kingdom has been a thorough one. The cryptic constituents which he has discovered in plants and converted, often through complicated processing schedules, into useful products attest to the thoroughness of his screening. The principal caffeine beverages provide a good example. (Fig. 1) These are nine in number derived from as many species, distributed among six plant families and growing in widely separated regions of the world. Each of the ancient centers of agriculture and civilization had its own beverage plant. The obscure constituent common to all of them is the alkaloid, caffeine. It is believed that this cryptic substance was independently discovered at least *nine* times by prehistoric man.

Another example of man's ingenuity, or luck, in discovering the hidden attributes of plant materials is provided by a second class of beverages—the alcoholic ones. It is not difficult to picture a situation leading to the discovery of fermentation of naturally occurring sugars by wild yeasts but imagining the discovery of processes for converting starch to sugar requires far more supposition. We can only wonder how ancient man discovered that saliva could be used to convert starch into sugar which in turn could be fermented to alcohol. (Fig. 1) Yet this process was independently discovered at least twice—once in Asia with rice as the starch source and once in the New World with maize or cassava as the starting material.

It is equally difficult to imagine how man discovered that when starch-rich seeds of cereals are in the process of germinating they are rich in enzymes which initiate the conversion of starch to simple sugars and thus provide a good medium for alcohol-forming yeasts. Evidence strongly suggests that this phenomenon was also independently discovered at least twice in man's history—in the Near East and in the Americas.

NEW APPROACHES AND OBJECTIVES IN PLANT SCREENING. Many more examples could be mustered to testify to the thoroughness of man's plant screening activities over the tens of thousands of years available to him. The evidence cannot be refuted but exception can be taken to the ultimate conclusions drawn from it. We can grant that man has, with the tools and knowledge available to him, rather completely sampled the world's plant resources. But the qualification, *with the tools and knowledge available to him,* is an all important one.

Caffeine Beverages

Beverage	Source	Family	Part Used	Area of Origin
Coffee	*Coffea* spp.	Rubiaceae	Seeds	N. E. Africa
Tea	*Thea sinensis*	Theaceae	Leaves	S. Asia
Cacao	*Theobroma cacao*	Sterculiaceae	Seeds	tropical America
Cola	*Cola nitida*	Sterculiaceae	Seeds	West Africa
Mate'	*Ilex paraguariensis*	Aquifoliaceae	Leaves	temperate S. Amer.
Cassine	*Ilex vomitoria*	Aquifoliaceae	Leaves	southern U.S. & Mexico
Yoco	*Paullinia yoco*	Sapindaceae	Bark	northwestern S. Amer.
Guarana	*Paullinia cupana*	Sapindaceae	Seeds	Brazil
Khat	*Catha edulis*	Celastraceae	Leaves	Arabia

Prehistoric Distribution of Methods
of Converting Starch to Sugar

	Near East	Asia	America
Germination	X		X
Salivation		X	X
Fermentation		X	X

Fig. 1. (Self-explanatory)

Fig. 2. Kenaf *(Hibiscus cannabinus)* in experimental planting in North Carolina. Yields of 5 tons of dry stalks per acre are not uncommon in test plots.

The development of modern science and technology in the last hundred years has provided man with tools and knowledge to probe much deeper into the complexities of the compositional attributes of his environment than has ever before been possible. This same advance in technological development has produced an ever increasing pressure for new and different raw materials to keep pace with changing industrial needs. Man in his plant screening activities has only begun to take advantage of the new approaches and new objectives borne of the industrial revolution. But a beginning has been made and the results already achieved give us confidence that the possibilities are excellent for finding many new useful properties of plants through the modern chemistry and technology of utilization research. Furthermore, we have every reason to believe that the many recent advances in the plant sciences, both basic and applied, can provide the know-how needed to develop crop sources of usable constituents discovered by utilization research. Mr. Wheeler McMillen of the National Farm Chemurgic Council puts it in more forceful language, and I quote: "I wish to express my unflagging astonishment at a particular blank area in human progress. It has long since been observed that civilization progresses like an army in conflict not along one broad and event front, but by advancing on one salient, while another stands still and awaits a suitable time to move forward.

"Without pausing to review all the history of human progress, it is enough to remark that most of us live in a state of amazement at the advances we are witnessing during our short share of this twentieth

Fig. 3. Sunn hemp *(Crotalaria juncea)* in Kansas. Plants in this experimental plot are about 12 feet tall.

century. We have seen the movies appear on the screen, and begin to talk, and bloom in color and now advance in three dimensions. We heard radio ride the atmospheric waves and now we see the unbelievable miracle of television. Some of us are alive today only because science reached into the soil and trained antibiotic substances to protect our health. We have watched as men ride the air over land and sea and go faster than the speed of sound. We have seen the power of the atom unleashed to commit incredible destruction, and now await its power to be harnessed to create wealth and happiness instead of death.

"But when it comes to plants where do we stand? What crops grow in the fields of this, the most advanced agricultural country in the world? Now ——, at the threshold of the atomic age, what species of plants do we plant and harvest? The species of the Stone Age!——In this salient we have not moved." End of quote. We are beginning to move. Results will not be quickly nor easily achieved. None of our present crops, we can be reasonably sure, attained an established niche in agriculture without at least decades of directed endeavor. Many others have failed to attain crop status perhaps more because of a lack of sustained research interest than a lack of economic potential in the species involved. A carefully planned program, based from the beginning on the best available information and with provisions for frequent refinements of evaluations of promising species as new information is brought to light, offers the best formula for success.

Some Promising Prospects

The Agricultural Research Service of the U. S. Department of Agriculture began a coordinated program in 1957 to evaluate heretofore uncultivated plants as potential new crop sources of raw materials having feed and industrial utility. This coordinated program represents a team effort by botanists, chemists, agronomists, engineers, and economists. All must play an effective role if the ultimate objective—new crops for the U.S. farmer—is to be achieved. Botanists undertake the background planning of what plant material should be collected, where it should be collected, and at what time of the year. They also accomplish the collecting of

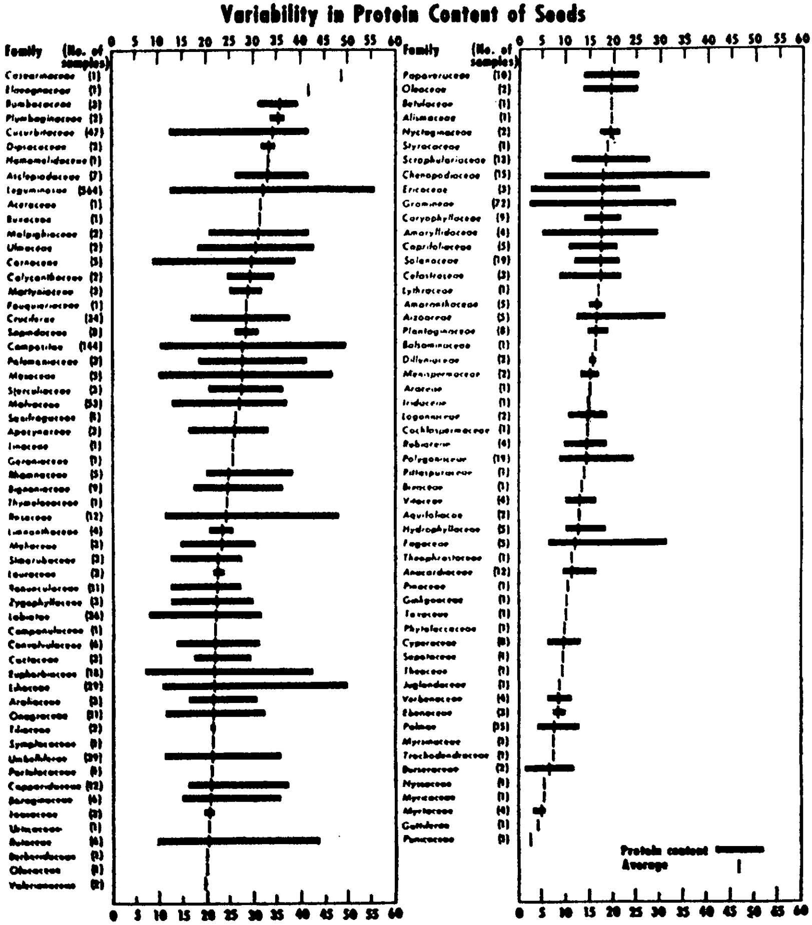

Fig. 4. (self-explanatory)

plant samples and provide identification of species collected. Samples go to the chemists for a preliminary screening or evaluation of total protein, oil, and gums in seed samples and of total fiber content and fiber dimensional characteristics of whole-plant samples. Species that appear promising from this initial evaluation are selected for more intensive investigation, both chemically and botanically. Additional samples of the selected species and samples of related species will be procured so that the chemists can delve more deeply into the characteristics of the constituent of interest and also determine its distribution within a group of related species.

If these more intensive studies confirm or enhance the initial appraisal, then the selected species will move into the next phase—crop developmental research on the source species and utilization research on the constituents of interest. At this time also, market opportunity studies will be undertaken by economists to determine economic feasibleness of the potential crop and its products. Agricultural engineers must enter the picture before the new crop reaches commercial status for there will usually be problems of harvesting and processing the crop.

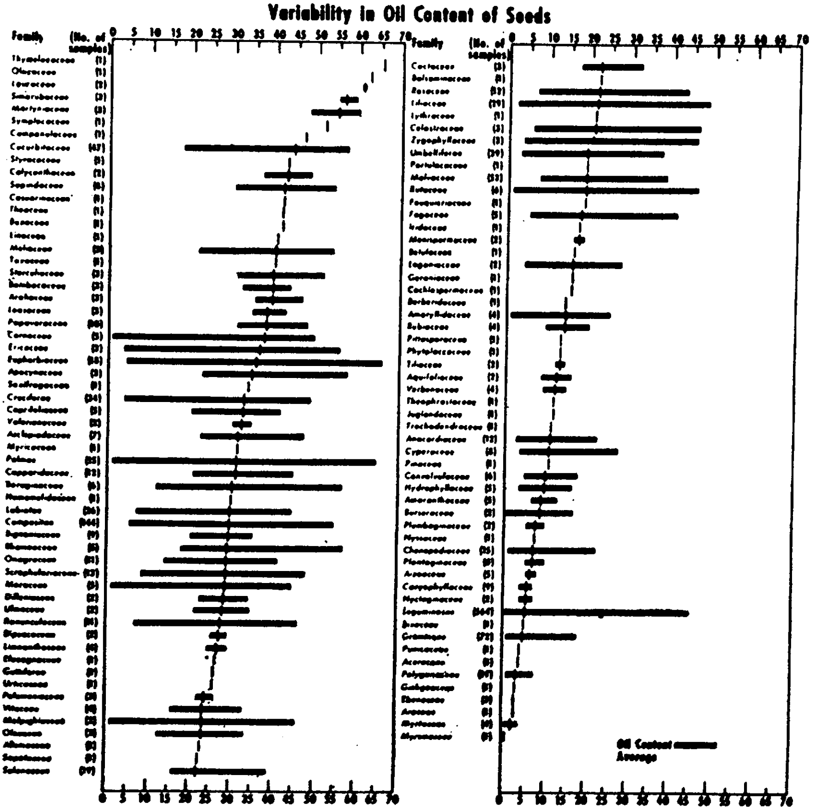

Fig. 5. (self-explanatory)

At present we have new crop prospects at all levels in this progressive sequence—from preliminary promising leads to developmental stages approaching commercialization. Let us look at some of these so you may judge for yourself as to whether or not the search for new crops is a promising one.

Annual Pulp Crops. Something over 33 *million tons* of paper of all kinds is now consumed annually in the U. S. and the rate of increasing consumption is exceeding that of population growth. In the past wood has supplied practically all of the raw materials needed by this giant industry. It is questionable whether future needs can always be met in this way. Increasingly heavy demands are being placed upon our forests by recreational, conservational and other needs. Indications are that the chances are good for finding and developing annual crops which are technologically suitable for processing into various paper products or dissolving pulps and which have sufficient yield per acre to place them on a favorable competitive basis with established crops.

General requirements for a species to be considered as a potential source of paper pulp are: 1) high annual yield of cellulose per acre, 2) desirable chemical composition of pulp, 3) desirable physical dimensions of pulp fibers. Beyond these general requirements a host of specific factors become involved depending upon the ultimate product to be made from the pulp and the pulping methods to be employed.

Among those revealed by the screening program thus far to have high potential are: kenaf *(Hibiscus cannabinus)* (Fig. 2); sunn hemp *(Crotalaria juncea)* (Fig. 3); sorghum *(Sorghum vulgare)*, and sesbania *(Sesbania* sp.) These prospective annual pulp crops are now undergoing developmental research in crop production and in pulping tests.

Fig. 6. Harvesting experimental planting of *Crambe abyssinica* in Texas with conventional grain combine.

New Oilseeds. Screening for superior sources of seed proteins and for unusual seed oils go hand-in-hand. Such a program is a major activity in USDA's new crops work and results indicate this to be one of the most fertile areas of plant resources investigations. The objective is to find *new* or *unusual* kinds of oils that will not compete with our present abundant vegetable oils like soybean, cottonseed, peanut, and corn, and to find seed meals high in protein with nutritionally superior amino acid balance. We have now screened over 3,500 samples representing about 2,500 species from a wide spectrum of the seed plants.

Figs. 4 and 5 graphically present the variability in protein and oil content among 113 families, with the average for each family indicated by a vertical line through the bar. High extreme for each family is of more portent to the screening program than is the average value. The Leguminosae, for example, have a very low average oil content (Fig. 5), but occasional species of the family have seed sufficiently high in oil to recommend continued screening in this family. The Gramineae, on the other hand, which have about the same average oil content as the Leguminosae, do not offer the promise of an occasional species with interestingly high seed-oil content.

Oil content, in general, is considerably more variable than protein content within a family. Nearly twice as many families are prospective sources of 35% oil seeds as are prospective sources of 35% protein seeds. In 35 families it is probable that additional species that have combined oil and protein value exceeding 70% of total seed constituents will be found.

Of the 56 families highest in average oil content, 40 are also among the 56 highest in average protein content. This does not mean that protein content is positively correlated with oil content in a given species. It does mean that families that provide good hunting for oil-rich seeds are also likely to yield protein-rich seeds. From this data we see that of those families represented by 10 or more samples and appearing in the upper half of both Figs. 4 and 5, the Capparidaceae, Compositae, Cruciferae, Cucurbitaceae, Euphorbiaceae, Labiatae, Onagraceae, and Ranunculaceae appear to offer outstanding promise as sources of new oilseeds. Fortunately, these families are well represented by herbaceous members that are native to temperate areas and from which it should be possible to select or develop plant forms suitable for commercial, mechanized production.

Selected examples of new oilseed prospects that were discovered in the USDA screening program and which are now undergoing developmental research are:

Crambe abyssinica (Cruciferae) (Fig. 6); 40% oil in the seed; 60% of oil is erucic acid (C_{22}) which has industrial promise in synthetic rubber additives, plastics, synthetic fibers, special greases and other lubricants, and detergents.

Vernonia anthelmintica (Compositae) (Fig. 7); 25-30% oil in the seed; 70% of the oil is epoxy-oleic acid. Epoxy acids are now produced at considerable cost by epoxiding soybean oil and animal fats. Here we have a naturally-occurring epoxy acid, present in major amounts. Potential uses: plasticizers, surface coatings, chemical derivatives, etc.

Limnanthes spp. (Limnanthaceae) (Fig. 8) Seed contains 25-30% oil which is more than 95% fatty acids of chain lengths greater than C_{18}. This oil can be easily converted to liquid or solid waxes.

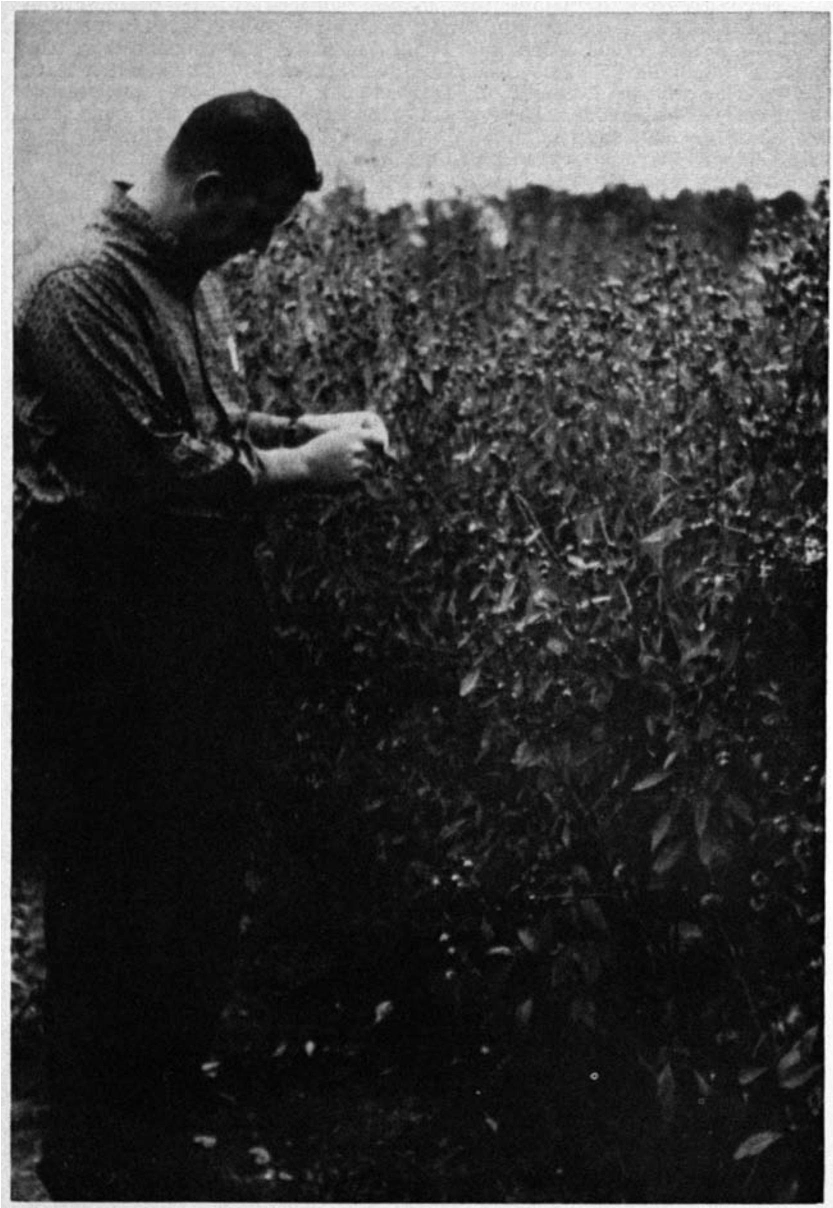

Fig. 7. Indian ironweed *(Vernonia anthelmintica)* in experimental plot in North Carolina. Seed shattering is a serious problem with this potential oilseed crop.

Fig. 8. Meadowfoam *(Limanthes douglasii)*. All members of this native North American genus have long-chain fatty acids in their seed oils. Such oils can be chemically converted to waxes.

Fig. 9. Yellow-top *(Lesquerella fendleri)*. The Lesquerellas are native to southwestern United States and northern Mexico. A number of the species are heavy seeders and all so far examined have unusual seed oils of industrial interest.

Lesquerella spp. (Cruciferae) (Fig. 9) 25-40% oil in the seed; 50-70% hydroxy acids in the oil. Native annuals, biennials, and perennials of our Southwest and northern Mexico. The unusual hydroxy dienoic acids found in the seed oils of members of this genus have a great deal of industrial potential in plastic foams, resins, high temperature lubricants, surface coatings. This may someday be a commercial crop in Oklahoma on lands now producing wheat and other small grains.

Seed Mucilages. Seeds that contain minimal amounts of oil and protein and no starch are likely places to look for endosperm mucilages. Water soluble carbohydrate gums (here synonymous with mucilages) of the galacto-mannan types have large and expanding industrial markets. Of the natural plant gums available the U. S. imports about 40 million pounds annually, consisting chiefly of gum arabic, tragacanth, karaya, and locust bean gum. We now produce about 10% of the guar *(Cyamopsis tetragonoloba)* gum used in this country. The rest is imported from India and Pakistan. The cereal starches, used industrially to the extent of more than a billion pounds a year, may be considered as gums since they form thick pastes in water. However, for many applications starches are used not because of especially desirable characteristics but because they are cheap, readily available, and perform acceptably. Such a product continually carries the risk of replacement by superior materials, possibly of non-agricultural origin. Availability of superior natural gums from new crop sources would aid in preserving these markets for agriculture.

Sufficient screening for seed gums has been accomplished to indicate that the legume family is the only promising source of gums of the galacto-mannan type. Of outstanding promise are species of *Crotalaria, Cassia, Astragalus,* and *Sphinctospermum.* Most of these contain more gum in their seeds than do guar and carob bean, presently in commercial production.

ACKNOWLEDGMENTS

The author wishes to thank Dr. W. T. Fike, Department of Field Crops, North Carolina State College, Raleigh, for the use of photographs appearing as Fig. 2, Fig. 7, and Fig. 8; Dr. G. A. White of the New Crops Research Branch, ARS, Beltsville, Md., for Fig. 3 and Fig. 6; Dr. A. S. Barclay also of the New Crops Research Branch for Fig. 9; and the Industrial Crops Laboratory, Northern Utilization Research and Development Division, ARS, Peoria, Ill., for the graphs in Figures 4 and 5.