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SEA CHANGE

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The term sea change has come to mean a profound and permanent change in the human psyche or in the terms and conditions of society. We're in the midst of a sea change - the most drastic and unsettling change in man's experience since he harnessed machines and power to transform raw materials into the infrastructure of an industrial society. The change underway is most unsettling because - as is the case with most changes - we know where we're been and where we are but not where we're going. The terms and conditions of the new society that will emerge in the most developed countries by the end of this century are still obscure. The bad news, then, is that the unsettled and uncertain "times" we are now experiencing will continue for some years. The good news is that a better society will emerge. Not all of us, of course, will concede that the new society is going to be better. The pull of the past - the known - is as imprinted in man as is the compulsion to move ahead. But, the latter is stronger, especially in the younger generations, and it will prevail as it always had.

Age of Information

Futurists characterize the emerging society - the third wave - as the age of information. It will transform the industrial society now fading as profoundly as the emergence of the industrial age transformed the rural society of the middle ages. Information and information processing systems will be the dominant forces in the shaping of the new society just as transportation and the factory shaped the industrial society. This does not mean that raw materials, shops, transportation nets and so on will become unimportant or less important than they are now. Rather, these ingredients in the human endeavor will no longer have the dominant influence on the terms and conditions of society. Huge pools of labor, for example, will no longer need to be concentrated around factory complexes. The new factories will be run by a few operators at the controls of integrated information processing systems. The work will be done by "smart" machines - the hands of the information system. The "system" software will still have to be generated and programmed by people - many people - but their physical proximity to the factory or even to each other will not be crucial.

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It's difficult to envision the new information based and sustained society. Will society have more leisure time because there will be less to do, or less leisure time because there will be more to do? There is no doubt that a huge corps of people will be required to develop and refine the software of the new society - 1600 man years were required to develop the software for the space shuttle, Colombia - and another huge corps will be needed to implement, monitor and service the systems - but surely not all of us. What will the rest of us do? There is the forecast that the service industry will escalate even faster than at present and become a major component of the new society. But, will it be as one wag put it, "like taking in each others laundry?"

Digital World

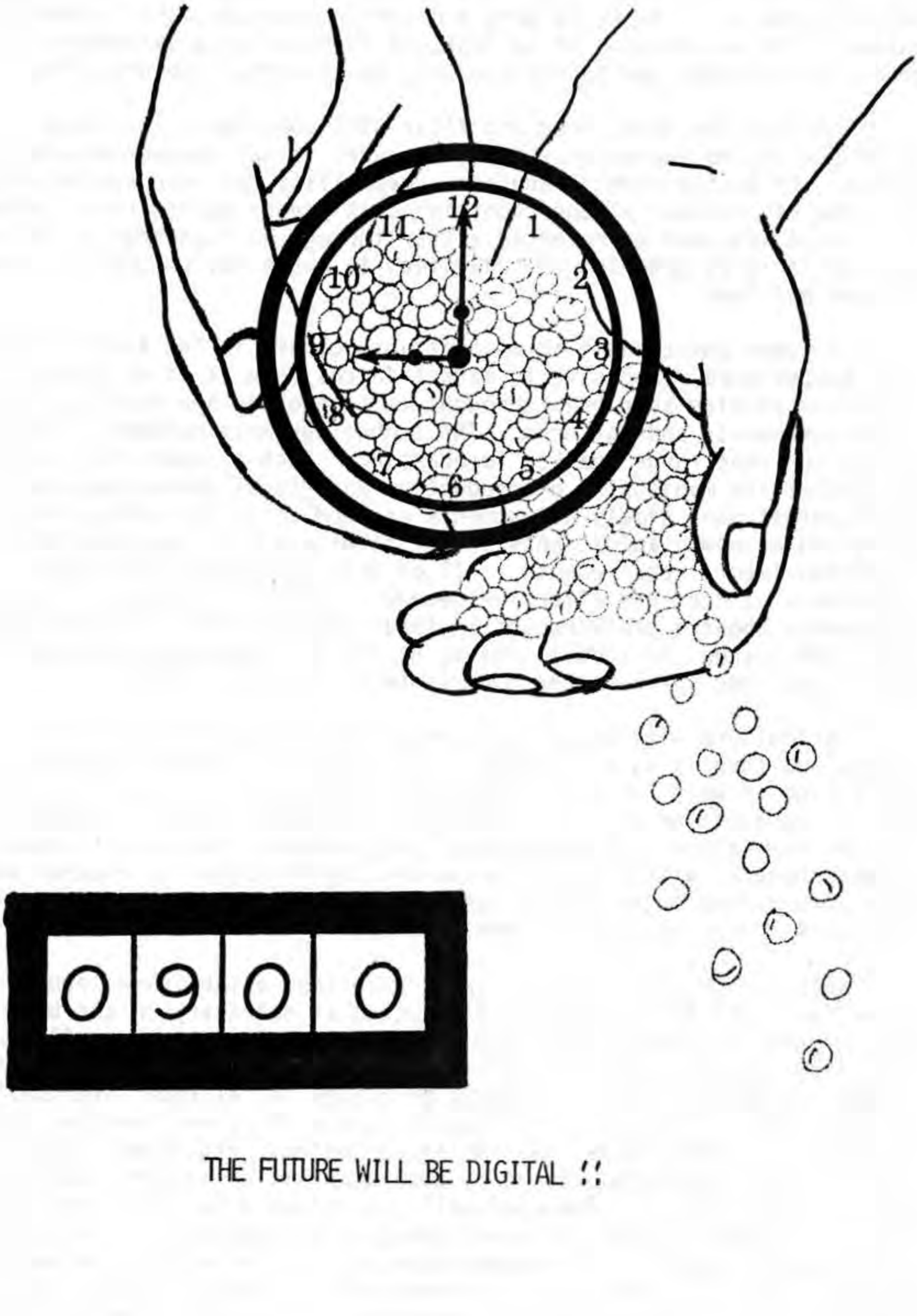
Some aspects of the new age are already evident. It will be digital. Already, youngsters with digital watches do not share the common concept of time as increments of 360^{o} - a circle. Such expressions as "a quarter to three", "half past nine" or the "sweep of time" have no meaning to them. Even now some cannot tell time from "regular" clocks and watches. I wonder if other concepts based on the movement and position of "indicating" needles within a "dial" will not also fade away. The concept of a half tank of gasoline, for example, derives mostly from the indicator or gauge which is divided into halves, quarters, etc. With a digital meter one has to focus directly on a quantity, e.g., 10.6 gal. and not on the portion or fraction of a whole. The necessity of making judgments in terms of specific values rather than in terms of fractions or portions will require considerable restructing in our way of thinking.

One interesting perception of the new society is that it will be relatively immobile. There will be no need for transport of information in the form of a person. Rather, it will be transported and transferred electronically between persons and/or information processing systems without the need for travel. Already teleconferencing brings people "together" for discussions and meetings in every sense except the physical.

What will agriculture be like in the information age? While we can be sure it will continue to be important, it will surely change. For the information age will transform the biology of agriculture as much - if not more - than it is transforming the physical components of our environment.

Agriculture in Transition

Surely it is a paradox to attempt to peer into the future of agriculture, which implies progression, at a time when it is entering a period of retrogression (situation as of mid-1983). Surpluses, distressed commodity prices, production cut-backs - agriculture has been



THE FUTURE WILL BE DIGITAL !!

down this avenue before! But, the present retrogression, damaging and demoralizing as it is to farmers and agri-businesses, will affect only output. The progression of agriculture in terms of advancements in production systems and technology will go on without interruption.

The need for food, feed and fiber will continue to increase as the world population increases. Need, however, is not synonomous with demand. Effective demand requires a capability for procurement which is at a low ebb in many of the countries that import agricultural products. This situation must be reversed either through an "upswing" in the world economy, or a re-ordering of priorities in countries chronically short of food and feed.

It seems inescapable to me that agriculture in the future must and will become more responsive to market forces than it is at present. This will require some breakthroughs in technology and revisions in trade agreements and patterns. The technology most needed is a capability for long range weather forecasting. Such a capability combined with satellite monitoring of production and "local production problems" would permit more timely adjustments of production in surplus producing areas and economic adjustments in deficient areas in accord with "probable" food/feed import requirements. All of this would make for a better congruence of need and effective demand. Over-all, however, I'm more optimistic about a breakthrough in long range weather forecasting than about the changes in social orders, political structures and human nature required for a better congruence of need and demand.

Agriculture will become much more highly information oriented and controlled than it is at present. The inflow of information amd its organization in ways needed for decision making will be continuous. Indeed, much of the decision making will be done by the information systems themselves - automatically, so to speak. The mix of crops a farmer produces will be based on market, meterological, resource and cost information organized and programmed to identify the economically optimal mix for the season, area, and specific farm.

Once the cropping mix and areas have been established, production operations will be scheduled and adjusted as necessary on the basis of the outputs of computerized crop models. Base data on the soil types, fertility status, subsoil moisture, facilities and other more-or-less "fixed" resources of the farm will be placed in "storage" and updated periodically. "Variable" data inputs such as kind and variety, area, soil and air temperature, soil moisture content, and other climatic data will be continuously monitored by data acquisition systems and collated with the base data. A computer will crunch and digest the data and "output" a periodically adjusted schedule for operations from planting time through harvest. Some operations such as irrigation (permanent system) will be automatically accomplished. Insects, diseases and weed populations will be monitored by the farmer or hired consultants and the data fed into the computer program. The output will "tell" the farmer (or consultant) when and what kind of control measures need to be implemented. Throughout the production season, the program will provide the farmer-producer with an estimate of gross and net returns depending on the crop status at the time the estimates are made. An information system of this sort will greatly increase the efficiency of production and permit the farmer to maximize profits.

The trend to minimum or no-tillage production systems will continue and accelerate because of general recognition that soil is an essentially non-renewable resource that must be conserved, and breakthroughs in seeding technology and pest management. The reduced use of energy for production will greatly improve efficiency and returns on investment.

Aquaculture will become a major enterprise especially in the Southern coastal states. Catfish farming is already an on-going enterprise. It will expand and shrimp and crawfish farming will come on line in just a few years. Enterprises such as aquacultures will provide alternatives for production planning that are presently not available, as well as satisfy a growing demand for high protein, "non-fattening" foods.

The "automation" of agricultural production and decision-making will not be unique. Rather, it will be in the stream of general automation of most production operations. While many new jobs will be created to service the new agriculture, the displacement of jobs will be greater, and add to the general trend, already well underway, of un-and under-employment of the available workforce. The problem of a growing surplus of workers will have to be solved in some way by politicians, socialists, and economic planners.

Perhaps, the greatest changes in agriculture will be in the crops (and animals) produced. Advances in scientific knowledge and technology in just the past 15 years have laid a base for revolutionary changes in plants and animals and in the purposes for which they can be produced.

Traditional Crop Improvement

The crops that man cultivates for food, feed, fiber, shelter and industrial products have been obtained in three basic ways: by introduction, selection, and hybridization (crossing). Put another way, man has taken advantage of the "natural" variation among and within plant species to introduce, select and "mold" crops suitable for his needs.

Introduction was probably the first method used by man to obtain crops for cultivation. Indeed, agriculture began with man's discovery that he could take wild food plants and produce them under "cultivation" in an area of his own choice. Thus, the first crops were "wild" species "introduced" by man into a primitive farming system. Since different tribes undoubtedly took different species and/or "natural varieties" into their agriculture, it was not long - palentologically speaking - before tribes were also introducing crops they had seen under cultivation by other tribes. The exchange of crops and varieties increased as civilizations rose, territorial states developed, and methods of transportation advanced. Every advance in transportation increased the "area" from which crops could be introduced.

The historical intercontinental travels during the great age of exploration beginning in the 14th century brought man into contact with many crops completely unknown to him (the voyager or visitor, but not, of course, unknown to the persons visited). New world crops such as maize and potatoes were introduced into "old world" agriculture, while "old world" crops such as wheat were introduced into the new world. As the pace of exploration and colonization increased, so also did the introduction and exchange of crops. The rubber tree, for example, is a native of Brazil, but came to be mostly cultivated in Asia.

Even in the present "era", introduction has been and remains an important means of obtaining new crops for cultivation. Soybeans were introduced into the U.S. many years ago, but burst forth as a major crop only in the last 30 years.

While the introduction of plant species (i.e., new crops rather than new varieties of crops) was probably of greatest importance until the close of the age of exploration (end of 18th century), the introduction of new crop varieties (or lines) has been of greatest importance during the past 100 years or so. The "new" varieties of lines are variant populations of a species that have developed naturally or through selection and crossing by man.

Man probably began selection, the second method of crop improvement, soon after he first took (introduced) plant species under cultivation. He selected types from the "variability" in the species cultivated which he perceived to be most desirable for his needs. Or, he might have gone back to the wild populations of the species and selected variants more desirable then the ones he originally selected. Since selection within a crop species was practiced by the farmers in thousands of villages, numerous varieties were developed, each "fitted" to the local soil resources, climatic conditions, and social customs. Until only a few years ago, hundreds of local rice varieties were grown in the Southern U.S.

The effectiveness of selection as a mean of improving crops, however, is dependent on the degree of genetic variability within the population in which selection is practiced. The possibilities for improvement soon diminish - especially in self-pollinated species - unless new populations to select from are continuously introduced. Even then, possibilities are limited because one is forced to select a plant(s) which "naturally" possesses the best combination of desirable traits.

Hybridization or crossing, the third basic method of crop improvement, extends the possibilities for crop improvement. One can select two or more plants, each with a set of desirable characteristics, and combine the good traits into "one" plant through a series of crosses and selections among the progeny, which stabilize the recombination of traits sufficiently so that the novel plants can be propagated by seed.

The major improvements in crops during the past 70 years or so have been achieved through hybridization. In the case of corn and sorghum, very significant improvements have taken place through exploitation of the phenomenon of hybrid vigor.

Exploitation of the science of genetics - and associated plant sciences - by plant breeders has tremendously improved the productivity and quality of crops. A good portion of the current effects of plant breeders, however, has to be devoted to maintaining productivity and quality against the ravages of diseases, insects and other crop pests. "Traditional" plant breeding is also a rather slow process. Development of a new variety takes many years and a lot of money. In many cases, the variety development process falls behind the development of the pests so that yields are eroded for some years before a resistant variety is released. The extensive use by plant breeders of tropical winter season nurseries and greenhouses represent fairly successful efforts to speed up the variety development process, but it is still slow.

The basic limitation in current variety improvement technology, however, is not time. Rather, it is imposed by the variation within crop species that can be exploited for the development of even more superior varieties. Unfortunately, the natural variability that has evolved within the population of many species is being continuously decreased by disturbances in regions where the greatest natural variability exists. New varieties introduced into or developed for a region usually mean the disappearance of local varieties. Extension of cultivation into the centers of origin of crop species, where greatest diversity exists, results in the loss of the "wild" members of the population.

Although extensive collections of the genetic diversity within species have been made and are preserved in "genetic banks", much has been lost forever. Even if all the diversity that naturally evolved within a species could be assembled, efforts to improve crops would still be limited by the extent of that diversity. Recombinations of characteristics from different species is difficult to impossible because of sexual barriers to promiscuity.

The new biotechnology rapidly surfacing has awesome possibilities in the arena of species and variety improvement - possibilities that were almost unthinkable even 10 years ago.

New Biotechnology

Is it just coincidence that the third wave - the information age - generated in imprints on silicon wafers is being joined by the tidal force of breakthroughs into the genetic code - the ultimate information system? Coincidence or not, the exploitation of the two information "systems" is changing not only the way man does things, but how he feels and thinks about them.

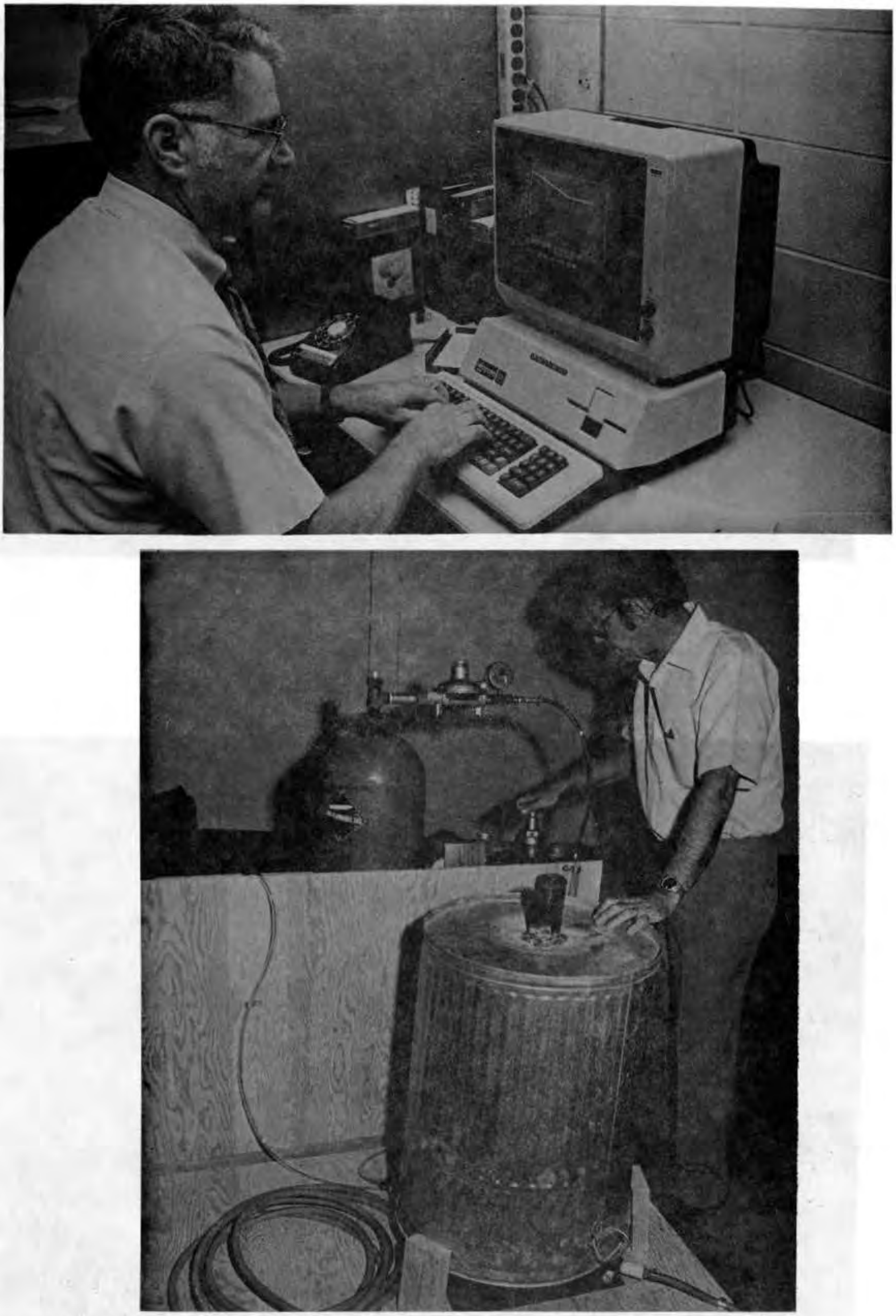
The new biotechnology being developed and positioned for exploitataion is based one way or another on progressively deeper insights into genes, gene expression and control, and the associated physiology of differentiation. The technologies arising out of these insights provides the means to do things only dreamers dreamed about a few decades ago.

Plant Copies

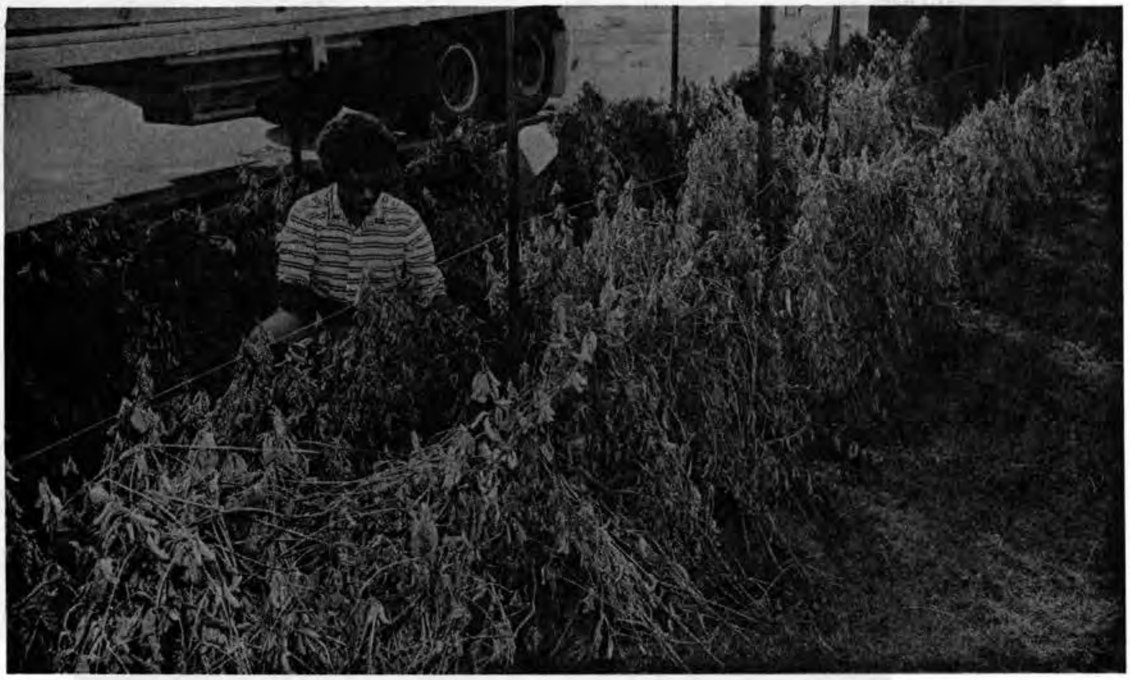
Variants arise (or are identified) in plant species with such desirable characteristics that man would like to propagate them; and, he has. Since the variants often do not breed true from seed (like does not always beget like), the desirable variants are cloned, i.e., copies are produced through stem cuttings, division, buds, and so on. These processes are used for propagation of crops such as fruits, ornamentals, sugar cane, potatoes (white and sweet), cassava, bananas, and even the hybrid bermudagrasses, which being triploid don't even produce seed! Traditional vegetative propagation, however, has limitations; it is laborious and expensive. Thus, traditional vegetative propagation has been primarily used for long-lived species - such as fruits, nuts, and roses - and for species that cannot be propagated -or propagated easily - by seed such as potatoes, cassava, and bananas. A further limitation of traditional vegetative propagation is that a substantial portion of the produce is "consumed" in replanting, i.e., sugar cane and potatoes.

An important component of the new biotechnology of plants has to do with non-traditional methods of vegetative propagation or cloning. A bit of tissue is taken from a plant and cultured in a broth of nutrients and hormones (tissue culture). The cells of the tissue divide and form a mass of callus tissue which can be maintained by periodic sub-division and transfer to fresh "broth." The foregoing is not too difficult. The difficulty arises in inducing the cells in the culture to regenerate a new plant. Regeneration has been sucessfully accomplished for a substantial number of species from wheat to tobacco. Many orchids and ferns are now commercially propagated by tissue culture techniques. The seedlings developed are copies (more-or-less) of the plant from which the tissue was originally taken. Thus, the sexual process, which reshuffles traits, is by-passed.

A most interesting version of tissue culture cloning is a process called <u>somatic embryogenesis</u>. In this process, tissue from young embryos, floral stalks, or very young leaves (in some cases) is cultured



High tech does not always a computer make. Sometimes high tech is spawned in a garbage can!!



The key to weathering resistance and other improvements may be an improved seed covering.

and induced to form somatic embryos identical in structure to the embryos in true seed. The somatic embryos can then be dispersed and induced to germinate and develop into a plant. Plants produced through the somatic embryogenesis process are genetically uniform and normal, which is not always the case with plants regenerated by other tissue culture methods.

The implications of somatic embryogenesis are truly awesome. If the somatic embryos formed are physiologically similar to those in seed, methods for dehydrating them to a low moisture content (as happens to seed embryos during maturation) can probably be developed. The next step would be to encapsulate a somatic embryo with an adequate food supply, thus, producing "cultured" seed. Theoretically billions of somatic embryos - hence, potential cultured seed - can be produced in the laboratory independently of season. As an alternative to encapsulation for planting, hydrated somatic embryos could possibly be "fluid sown" with modifications in already developed fluid gel sowing systems.

The important feature of tissue culture propagation of plants is the act of cloning - making copies. This means that a superior plant, regardless of how true breeding (homozygous) it is or is not (heterozygous), could be duplicated in enormous numbers for planting. It would not have to "breed" true since no further "breeding" would be involved. It may be that some of the hybrid crops such as hybrid rice and hybrid cotton which are proving to be so difficult to develop commercially because of pollen transfer problems will eventually be commercially developed not through improvements in pollen transfer but through somatic embryogenesis.

When one considers what has already been accomplished in just a few years, the question is not if but when practical applications will issue forth (some already have). What will the "seed industry" of the future be like? I can't really envision what it will be like, but I'm sure it will be very different from what it is today. And, its new outline will begin to take form before the end of this century!! As a traditional seed technologist, I can only seek comfort in the high probability that quality assurance and control techniques will be just as important in the future as they are now, and that there will still be concern about "germination", "vigor", storage, and varietal purity.

Unique Combinations

The advent and development of the science of genetics in this century has enabled man to make dramatic improvements in the crops he produces for feed, fiber, shelter, and industrial uses. Desirable traits identified in the population of a crop species are systematically transferred and accumulated in a plant(s) by plant breeders through a series of crosses and selections. The traits accumulated are then "stabilized" over several generations by control of pollination and further selection. Eventually a new variety is developed which at its best represents a new and powerful combination of traits important in crop production, or at its "least" represents simply a "novel" combination of traits. In either case, the new variety is molded from traits that are manifested in the population of plants that make up the species. New traits are not developed; rather they are only combined in new ways in a unique sub-population - the new variety.

In their efforts to develop improved crop varieties, plant breeders have been limited to the "pool" of traits that has evolved in the species, or - put another way - to the genetic variability within the species. A substantial part of the genetic variability within crop species that has been sampled (and which has not been irrevocably lost) is "stored" in genetic "banks". Plant breeders constantly search through and/or review the genetic diversity represented in germplasm collections for traits they perceive to be important, e.g., resistance to a disease or herbicide. If the traits they seek are not in the collected germplasm, there are only a few alternatives: an exploration can be mounted to search for yet uncollected "wild" types that have the desired trait(s); mutation breeding can be used to attempt to extend the range of genetic variability available; interspecific crosses - such as wheat and rye (triticale) - usually followed by doubling of the chromosome, and other manipulations of "ploidy", or chromosome number, can be attempted. Despite a few successes, none of the alternatives mentioned have proven to be very efficient and effective in the development of new crop varieties (or new crops).

Aspects of the new biotechnology now under development have the potential for introducing "foreign" traits into a species, thus, permitting development of plants with traits that did not evolve in the population, or even totally new plant types.

Plant species are usually isolated from other species by barriers to sexual crossing. These barriers are beginning to be by-passed in one area of the next biotechnology. In cell cultures, enzymes are used to "dissolve" the walls of cells and release the living protoplast held together only by the cell membrane. In some instances, plants have been regenerated from these "naked" protoplasts. When protoplasts from different species can be caused to fuse - as has been done in some cases - a hybrid cell is produced from which a somatic hybrid plant might be (and has been) regenerated. Somatic hybridization of plants combined with tissue culture cloning techniques could produce totally new plants combining (it is hoped) the desirable traits of two sexually incompatible species.

Another area of the new biotechnology - widely publicized - is concerned with the transfer of specific genes or gene sets from one species to another. In some cases the species are as disparate as bacteria and plants, or as seemingly closely related as rats and mice. The procedures used are termed recombinant DNA technology. Recombinant DNA technology has been successfully used to develop bacterial strains that produce insulin and interferon. Just a few weeks ago (early 1983) Monsanto announced that its scientists had successfully transferred a genetic trait from a bacterium (resistance to an antibiotic) to plant cells. The genetic trait was expressed in the plant cells which exhibited resistance to the antibiotic. While there is little apparent practical value in a culture of antibiotic resistant plant cells, or even to an antibiotic resistant plant regenerated from such cells, the implications of this accomplishment are as awesome - if not more so - than those of somatic embryogensis.

Man has almost in his grasp a new technology to engineer plant (and animal) species to his specifications far, far beyond the limits imposed by sexuality and the sexual process on "traditional" plant breeding technology. The prospects of the new biotechnology are as unsettling as they are exciting.

Likely Prospects

One does not have to belabor his mind with visions of monster plants to visualize some traits which if introduced into certain crop varieties, would revolutionize agriculture. Successful transfer of the nitrogen fixation symbiotic mechanism from legumes to cereals, for example, would diminish or eliminate the need for nitrogen fertilization. The impact of a development of this type on cereal production, expecially in the developing countries, would be enormous, and world grain trading would be drastically altered. Yet, the cereal varieties with nitrogen fixing mechanisms would not be very different from the varieties we produce today - no one except specialists really notices the nodules on soybean roots! But, nitrogen fixing cereals would represent a giant advance in agriculture.

Similarly, transfers of other traits (i.e., single gene "breeding") such as enhanced photosynthetic efficiency, disease and insect resistance, resistance to herbicides, tolerance to drought (or cold) and salinity, and so on, which cannot be accomplished through sexual crossing, might be achieved by recombinant DNA technology. Trait transfers of this type would not necessarily elevate yield potential, but they could circumvent environmental factors that reduce yield which is almost as good. The first successes of the recombinant DNA technology in crop agriculture are likely to be of the sorts described - revolutionary but not dramatic. The monster plants are much further in the future.

Traditional plant breeding technology will not disappear for some time. The new biotechnology will simply provide a means to achieve things that cannot presently be achieved. Other aspects of the new technology will greatly speed up the "work" of breeding, e.g., microspore derived haploids and "instant homozygosity", organelle transplants (cytoplasmic hybrids).

The possibilities laid out are more than that - they are high probabilities. They won't be realized tomorrow or even in the 80s, but the pay-off should be well underway by the end of this century. If it's not, a lot of investors will be wailing at the wall.

Seed As A Delivery System

Seeds are the reservoir and carrier of the genetic complement of plants from one generation to the next. The "make-up" of the genetic complement is established at the time of fertilization (sexual) and begins interacting with the environment during germination (and even before) to control and determine the growth, development and physiological characteristics of plants. The seed is remarkably well designed for its important roles. It is miniaturized and very portable, highly resistant to environmental stresses (e.g., cold, heat), relatively long-lived and fitted with a regulatory system(s) (dormancy) that contributes to longevity and distributes germination over time.

Increasingly, the seed is also being perceived and used as a convenient carrier of "applied" materials for the purpose of protecting the seed and developing plant against pests, influencing the growth and development of the plant, and/or modifying the environment in the vicinity of the seed in desirable ways.

The practice of applying chemicals to seed to protect them against seed rotting microorganisms and destructive insects in the seed bed has been well established for many years. It has also been long and well established that certain seed transmitted diseases can be effectively and efficiently controlled by chemicals applied to the seed, or other treatments (e.g., hot water soaks) of the seed. With the exception of seed applied innoculants, however, seed have been used as carriers of materials for other purposes only in relatively recent years.

The advent of systemic fungicides and insecticides, i.e., chemicals that are "taken" into the seedling/plant, greatly expanded the potential role of the seed as a carrier of efficacious materials. Presently, systemic insecticides and fungicides are applied to seed for the control of insects and diseases that attack the seedling and young plant. Some of the newer materials provide essentially season-long protection against certain diseases. Since application of a chemical to seed is an extremely economical way to protect plants against pests, this method is likely to be heavily exploited in the future. Very powerful chemicals active at the very low dosages that can be efficiently carried by seed are providing a new dimension to plant protection.

Seed are increasingly being used to carry micronutrients essential for proper growth and development of plants for plantings in soils deficient in one or more of the micronutrients. Molybdenum is applied to soybean seed to improve growth and yield of the crop on certain acid soils. Interestingly, soybean seed produced on soils with good molybdenum status frequently carry enough molybdenum "internally" for planting in molybdenum deficient soils. Boron, zinc and several other micronutrients are also being applied to seed to "carry" them into deficient soils.

Use of seed as the carrier of materials that function in weed control systems is among the recent innovations in "seed treatment." Several herbicide "safeners" have been developed which when applied to seed alter the physiology of the seed/seedling in such ways that they permit the control of certain weeds in crops by specific herbicides that would control the crop as well as the weeds in the absence of the safener applied to the crop seed. Further development of the herbicide safener concept should lead to effective control systems for major weed pests that are closely related to crop plants, e.g., red rice in rice, shattercane in sorghum. Another approach in the weed control area is to use the seed to carry an herbicide for control of weeds in the vicinity of the emerging seedlings.

The use of crop seed as carriers for materials operative in weed control systems is just getting underway. The potential (profits, etc.) of such systems is so great that rapid and maximum exploitation of the several alternatives is assured. In addition to the "safening" and "carrier" systems mentioned above, the alternative of development of crop varieties by conventional breeding or DNA recombinant biotechnology that are resistant to a specific broad spectrum herbicide is especially attractive. A high tech company active in both varietal development and agri-chemicals could then market seed of good varieties along with the specific herbicide for control of weeds in the crop - maybe all weeds. There is no doubt that many of the large chemical companies now active in the varietal development and seed business have this sort of goal (among others) in mind.

Seeds can be used to carry chemicals which when taken into the seed or emerging seedling, alter or modify germination, growth and development. A dormancy-breaking chemical is now being applied to peanut seed to overcome any residual dormancy and thus permit more rapid and uniform emergence. Treatments of this type could be used (and are needed) for other crops ranging from lettuce to pasture grasses. Other types of chemicals such as regulators of growth and development - even male sexual sterilants for hybrid seed production - could conceivably be applied to seed. The kinds of modifications needed are unlikely to be produced by any one chemical. Combinations of chemical will be required, but this will not present a major problem in most cases. A lot of materials can be loaded on seed with modern coating technology.

Regulating Emergence

The percentage and uniformity of crop seed emergence is largely determined by interactions among properties of the seed and seed bed, i.e., microenvironment. The pertinent seed properties are well known: inheritance (genotype), vigor or degree of deterioration, mechanical damage, and infestations with certain fungi and bacteria. We know somewhat less about the seed bed microenvironmental factors that influence emergence, and still less about their interactions with the seed properties. But, research in these areas is increasing rapidly so that baseline knowledge is sufficient for speculation on the sorts of systems that likely will be developed to improve and regulate crop emergence.

Several systems have already been developed and evaluated with limited to good success. Seed coatings are applied to the earlier maturing parental line planted for hybrid seed production to delay emergence so that the pollen shedding and female receptivity are synchronized. An alternate procedure which is widely practiced is to plant the earlier maturing line later, but this is troublesome and the weather is not always cooperative. Further developments of emergence delaying treatments or coatings will greatly facilitate the production of hybrid seed.

Some years ago a patent was granted to Canadian workers on a seed coating system to permit planting of normally spring sown crops the previous fall. The advantage of such a system is obvious. Unfavorable weather in the spring often delays planting beyond the timeframe for best yield. Planting during some favorable weather slot in the fall with emergence at the appropriate time in the spring would, therefore, be highly advantageous. These ideas, however, are a good example of beautiful theory but difficult application. Microencapsulation technology and polymer chemistry are well enough advanced to devise seed coating systems that would, for example, be impermeable to water (thus preventing germination) until the seed bed temperature and moisture rise to certain levels. The problem is that these conditions might occur -in the South at least - several times between November and mid-April, the average-sowing season for the earliest planted crop. Emergence of fall or winter planted cotton, rice, soybeans, etc., in late February or early March rather than mid-April or later would, of course, be disastrous. Some more dependable "triggers" than soil temperature and moisture need to be "thought of" to permit effective regulation of the time of germination and emergence of seed - something as predictable and stable as the stomach acidity and temperature that trigger the timed release of medicine, or the "acid acting on a copper wire" trigger used for time bombs. The only really stable environmental components I can think of are photoperiod (day length) and the phases of the moon - but I don't believe they would be very effective triggers for release of emergence regulating systems. So, its back to the drawing board. The best possibility would appear to be some sort of germination inhibition system (applied chemical) that would "breakdown" and permit germination in a way analogous to the breaking of bud dormancy in fruit trees - it wouldn't be perfect but maybe good enough. Another possibility is a chemical inhibition system with an antidote flown on at the appropriate time, but it might be rather expensive. While all of this might read like "pipe dreams," I'm convinced that effective systems for regulating the time of seed germination and emergence will be developed before the end of the present century - in less than 17 years. Before then several systems for improving emergence in a less dramatic way will be developed.

Protection Under Too Dry - Too Wet Conditions

The two most important factors influencing germination and emergence are moisture supply and temperature. Seed are often planted in relatively dry soil in anticipation of a rain. If the soil moisture supply is inadequate for germination and the anticipated rain is delayed too long, the seed rot. Protectant fungicides prolong the time the seed retain their capacity to germinate under such conditions but frequently not long enough. Seed moisture content increases - but not high enough for germination - and this combined with a warm seed bed temperature produces a sort of accelerated aging effect which causes rapid deterioration of the seed. Some hydrophobic (water resistant) coatings combined with a protectant fungicide can extend the period seed retain germination capability in "dry soil" to 14 days or longer. It is likely that other hydrophobic coatings not yet evaluated will be even more effective. Interestingly, hydrophobic coatings on seed also "protect" them in saturated soil for a few days in the event that a heavy rain occurs during or soon after planting. There is also some evidence that emergence is improved by slowing down the rate of water absorption in less than water-logged soil conditions by use of hydrophobic coatings.

Alternatively, other evidence suggests that certain chemicals (inhibitors of biochemical reactions) applied to seed reduce the rate of deterioration under too dry and too wet soil conditions. Combined with a protectant fungicide, such chemicals might be even more effective than hydrophobic coatings and much simpler to apply - just apply with the seed protectant fungicide.

Multiple Coatings

Treatments/coatings of the general types mentioned above are being researched. The developments that arise out of these researches will be very compatible with those "envisioned" earlier. The "new seed" will have a tremendous potential for yield under temperature and moisture stress. But, this potential will be realized only if the seed emerge uniformly to the target density, weeds are controlled and some diseases for which no inherent resistance has been "build in" are also controlled. Thus, seed companies will take every measure possible to assure good performance - and farmers will insist on these measures because the seed will be expensive. The seed will be treated and coated with herbicide safeners. several fungicides, micronutrients depending on the area, deterioration inhibitors, hormones that extend the range of temperature within which the seed germinate, hydrophobic materials to control the like "pipe dreams," I'm convinced that effective systems for regulating the time of seed germination and emergence will be developed before the end of the present century - in less than 17 years. Before then several systems for improving emergence in a less dramatic way will be developed.

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The most recent development in the pregermination/priming area is fluid or gel sowing. Seed are pregerminated or primed and then sown in a fluid or gel medium. The technology is well advanced although much remains to be done to establish the best system for each kind of seed. The fluid or gel sowing systems provide moisture as well as serving as a carrier or delivery medium for pregerminated or primed seed and various other materials added to stimulate seedling growth, protect against soil microorganisms, and modify the seed bed, e.g., anticrusting agents.

Although pregermination and priming treatments have been most used for vegetable seed, the "idea" is equally applicable to crop seed. Imbibitional injury which is a problem in soybeans and chilling injury during imbibition which is a problem in corn, soybeans, and cotton could be largely overcome by sowing primed or pregerminated seed. Uniformity of emergence could also be improved and this might be more important than we realize at the present time. There is substantial evidence that plants produced by early emerging seedlings produce the greatest yield. Late emerging seedlings are often unproductive and act as weeds.

Final Thoughts

In this paper, I have tried to take a look ahead into what some aspects of agriculture might be like by 1990, 2000 and thereafter. I do not claim clairvoyance, and my visions are certainly not any clearer than those of others. Indeed, they might be clouded with over optimism. Many of my colleagues "see" some of same things I "see", but much further in the future. I hope their timetable is correct because we could do with a bit more time than I think we have to make the necessary adjustments.

Of this I'm sure: agriculture in the future will be much more "scientific" and less of an "art" than it is now; there will be fewer farmers (or production units) and their inputs will be supplied by a relatively small number of high-tech companies; varieties of major crops, for example, will be almost wholly developed by private companies. Thus, there will be a great shrinkage in the number of seed companies most of which are presently producing seed of publicly developed varieties. Seed certification and seed control procedures will have to adjust to the new emerging situation, and their importance will inevitably diminish. The spillover from these and other changes in agriculture will also affect the roles of the agricultural extension services and the agricultural experiment stations.

Coming to grips with change is among the most difficult and unsettling adjustments we have to make. Yet, failure to come to grips with change is even more unsettling and the difficulties are multiplied. Our adjustment to the new agriculture has been too long deferred. It must begin now.