Committee II
Agricultural Genetic Engineering
And Society

DRAFT--7/15/91
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GENETIC ENGINEERING NEW CROPS
FOR SOIL AND WATER RESOURCE CONSERVATION

by

Gerald Stanhill
Institute of Soils and Water, Volcani Center
Agricultural Research Organization
Ministry of Agriculture
Bet-Dagan, ISRAEL

The Eighteenth International Conference on the Unity of the Sciences
Seoul, Korea August 23-26, 1991

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G. Stanhill

'By avarice and selfishness, and a grovelling habit, from which none of us is free, of regarding the soil as property, or the means of acquiring property, chiefly, the landscape is degraded with us, and the farmer leads the meanest of lives. He knows Nature but as a robber.'

Walden: or Life in the Woods. 1854.

Why soil and water resources need to be conserved, or more precisely their lateral flows prevented, was explained by Thoreau over a century ago in the above quotation.

How genetically engineered new crops could help do so and what is the likelihood and need for such a development is the subject of this contribution.

New 'crops' have been taken to include grasses, trees and even aquatic vegetation since arable crops only cover one-tenth of the Earth's land surface and so less than a thirtieth of the total surface. Similarly, the conservation of resources other than soil and water have been considered as has the need to reduce pollution, both thermal and chemical.

DESIGNING DAISYWORLD

James Lovelock's notion of a world covered with daisies whose colour plays a major role in maintaining the atmospheres temperature within the narrow range suitable for life (Lovelock, 1989) is expanded in this section to list the desiderata for genetically engineered new crops so that they could conserve soil, water, fossil fuel and climatic resources, wild life diversity and reduce pollution. Ideotypes of some such crops designed to fit regional climate and soil retraints are then outlined.

Whatever the regional constraints the major crop characteristic needed for soil and water conservation is the provision of a year-round ground cover in a form which significantly reduces the exposure of the soil to wind and water erosion and at the same time enhances the infiltration of water into the soil and reduces biologically non-productive evaporation.

Additional environmentally important desiderata for new crops include the provision of a large and long-term sink for carbon to lessen the increasing concentration of CO_2 in the atmosphere and hence global warming. The carbon so fixed should be in decay resistant forms but growth-limiting nutrient elements should not be sequestered so that they can be recycled through the ecosystem. New tree crops for temperate zones whose timber resembled that of the tropical hard woods would do much to aid the conservation of tropical forests. For oceanic vegetation the carbon fixed should rapidly sink to the abyssal depths and so be removed from circulation.

Another general design requirement for new crops, except in cold regions, is a high reflectivity for non-photosyntheticlaly active solar radiation. This would also reduce atmospheric heating - the function of the white daisies in Lovelock's Daisy world. Such enhanced reflection would also, by reducing the crops energy load, reduce their water loss and so extend the growing season and reduce the need for irrigation in arid zones. Both changes would alleviate the problems of erosion and salinity.

Modifications to new crops which would reduce the need for the application of fossil- fuel based agrochemicals to promote and protect plant growth are also generally desirable. These include widening the range of symbotic bacteria and free-living algae to provide nitrogen fertilization to non-leguminous host crops. These changes would reduce the need for fossil fuel demanding and water resource polluting nitrogen fertilizers.

Many of the widely used pesticides have the same negative effects on the environment. Their use could be reduced by the genetic enhancement of the new crop plants physical and biochemical resistance to pests.

The design features outlined above are those generally desirable for all new crops. However, in practice a wide variety of new crops will be required, each intended for a specific region with its unique blend of climate, soil and human resources and requirements and environmental susceptibility.

To illustrate this range in a more specific fashion, the features, forms and functions of a variety of new crops will be considered along a transect ranging from the most arid desert environment to a midoceanic one.

NEW CROPS FOR THE PROTECTION OF A RANGE OF ENVIRONMENTS

Each form and function of the possible new crops discussed in this section can be found individually in the existing flora. This fact, combined with the assumption that the techniques of molecular biology will eventually allow the genes carrying the desired, individual characteristics to be identified, transferred and combined into viable new crops, provides the justification for the speculations which follow.

Warm deserts Such regions, according to Kophen's clarification, occupy one-sixth of the Earth's land surface. The major conservation role for plant cover in these regions is to prevent the severe soil erosion to which they are subject. Wind storms, common to such areas, lift vast quantities of soil into the atmosphere, causing major changes in its radiative and thermal characteristics (Joseph and Wolfson, 1975) before being deposited, sometimes thousands of kms from their source, often causing further environmental damage. Another cause of large scale erosion in hot desert lands are the rare but intense rainstorms.

To provide protection against soil erosion any plant cover must be capable of surviving these wind and rainstorms as well as the long and variable periods of aridity and extreme ranges of temperature.

Man-caused destruction of desert plant covers would be considerably reduced if they provided directly for the needs of their increasing populations. In developed countries plant cover enhances the value of deserts for recreational and housing needs and these can often compete with alternative land use such as irrigated cropping and livestock production. In the developing world, desert populations require their flora to provide fuel, food and if possible, gainful employment if they are to conserve rather than degrade the vegetative cover.

The wide range of existing plants which can maintain a protective perennial ground cover in warm deserts have in common special modifications to reduce water loss to the atmosphere.

These include water proof cuticles often covered with hairs and spines which increase the boundary layer resistance to water vapor diffusion. Within the leaves or pseudo leaves, stomata are few, small and often sunken to increase diffusive resistance. Many desert plants plants have the Crassulacean Acid Mechanism (CAM) which reduces water loss by reversing normal stomatal behavior - opening at night to temporarily absorb CO_2 which is then fixed photosynthetically by day when the stomata are closed. The transpiration loss per unit dry matter gain of CAM plants averages one-third of most tropical crop plants with their C_4 metabolism and one-sixth of the average for temperate crops with C_3 metabolisms (Stanhill, 1986). Expressed per unit rainfall depth the annual dry matter productivity of 5 CAM spps was found to average 1.6 g m^{-2} per mm, similar to that of a range of agronomic crops but twice the average for 8 non-succulent desert spps (Nobel, 1988).

A common adaptation of desert perennials associated with their special surface features is a high reflectivity of solar radiation particularly in the non-photosynthetically active near infrared portion of the spectrum (Billings and Morris, 1951; Ehleringer, 1980).

The architecture of desert plant associations is such as to maximize internal trapping of the radiation reflected by individual plant tissue causing a low reflectivity of the ground cover as a whole. Some scientists (Charney, 1975; Otterman et al., 1975) have argued that baring of the highly reflective desert surface by denudation of the darker vegetative cover inhibits rainfall and so enhances desertification. The mechanism invoked to explain this biofeedback is that denuded desert surfaces have a higher radiative loss because of their greater reflectivity and surface temperature. This net radiative cooling leads to subsidence of the air column which inhibits convective precipitation.

The Saguaro 'forest', which at one time covered much of the Sonoran desert in the southwest of North America provides a striking example of a productive and protective desert plant association (Steenbergh and Lowe, 1983). Consisting of many CAM species this dense ground cover achieved a large, long-living biomass which supported a wealth of animal life and the Papago and Pima Indian tribes. During this century overgrazing by introduced cattle, urban housing development and uncontrolled recreational motor traffic has denuded much of the vegetation.

How could new crops be genetically engineered to be more resistant to human overexploitation than the native flora which has evolved in the desert?

One possibility is by significantly increasing the value of the vegetative products so that they could not only pay for establishment and maintenance, but also receive protection as a valuable source of income, rather as the Myrhh and Frankincense trees of the South Arabian desert were protected for thousands of years.

High value products from desert crops are likely to be found among the many complex secondary metabolites produced by the native flora of arid zones. These include a range of oils and waxes, fragrances, colors and flavors, drugs and precessors for the pharmaceutical industry. Hopefully, genetic engineering would increase the yield of such products, improve their qualtiy and widen their range.

However, the market for such high value products is limited and extensive areas of desert are unlikely to be replanted with such crops. A much greater demand for desert vegetation is for grazing purposes and examples of revegetation for this purpose exist. Large areas of deteriorated rangelands in Coahuila, Mexico, have been planted with a spineless Opun tia spp. a CAM plant, for controlled cattle grazing (Medina, Acana and De La Cruz, 1988).

Experienced gained in these plantations stressed the need for protection against overgrazing by cattle in the first dew years of establishment. Here genetic engineering might enable the palatability of the vegetation to vary with age so as to deter overgrazing.

The exploitation of desert vegetation by animal spps ecologically more suited to the desert environment and less damaging to their plant cover than cattle, is outside the scope of this paper as is the ranching of game animals in these areas; both of these possibilities could prove to be an economically feasible way of conserving the desert's soil and water resources.

Semi-arid rangelands Approximately half of the earth's land surface is rangeland and some 135 milion people, about 20 percent of the world's population, base their economies and societies on rangeland resources. Approximately threequarters of this area has been classified as at least moderately degraded, more than half of this land lies in the semi-arid regions. Such semi-arid rangeland supports most of the world's estimated 3 billion head of domestic livestock and produces most of the meat consumed by humans (Anon, 1990).

Rangeland degradation results from the removal of its perennial vegetation cover which normally protects the underlying soil from erosion.

In the more humid areas, the ground cover was removed to convert large areas of range to annual cropping. Many of the world's classical 'dust-bowls' resulted from this change in land use, some Asian examples of rangeland degradation following conversion to cropping, are very old; most, as those in North America, are recent and occurred during the 'colonial expansion period' of agriculture which started in the middle of the last century.

The conversion of the more productive, humid rangelands to cropland has a second negative 'multiplier' effect on the more fragile and often neighboring arid rangelands. By displacing the cattle and human populations dependent on them from the more robust humid to the more sparsely vegetated arid lands, the danger to the latter of overgrazing is increased.

The degradation of rangelands has had an additional environmental impact by contributing to the increased CO_2 concentration in the atmosphere. It has been estimated that all the changes in land use between 1850 and 1985 have transferred 115±25 G tonnes of Carbon from the terrestrial to the atmospheric pool of Carbon; this can be compared with the 195±20 Gt C released by burning fossil fuel in the same period (Watson et al., 1990). Although the contribution to this total attributable to the loss of rangeland vegetation cannot be precisely known, the area and density of the climax range vegetation in the now cropped regions of semi-arid rangelands suggest that it was considerable.

The creation by genetic engineering of new crops more suitable for semi-arid regions could do much to reverse the negative environmental effects of their 'opening-up' for dryland cropping. An increase in their productivity could lead to a drawdown in the carbon dioxide concentration of the atmosphere, first to be stored in an increased biomass, later and more permanently in an increased soil organic matter content. A year-round productive ground cover could also supply cattle fodder and perhaps grazing so relieving the pressure on the more arid and less productive rangelands unsuitable for cropping.

A primary requirement for semi-arid grain crops is that they be perennial, providing year-round protection against soil erosion. This would also result in greater productivity, because of the longer period for growth. A second desiderata for the new crops is that they incorporate the C_3 pathway which confers a greater dry matter production per unit water loss, compared with the C_4 pathway of the wheat and barley crops widely grown in these regions today. A third desirable characteristic in new crops, is that they host symbiotic bacteria in their root systems capable of fixing atmospheric nitrogen. In years of above-average, non-limiting rainfall, this would remove a very important yield limitation while avoiding the cost and environmental risks of applying unnecessary amounts of nitrogen fertilizers.

In drier-than-average years when rainfall is insufficient for an economically worth harvesting grain yield, the new crops' vegetation could be used for grazing and fodder production, reducing the overgrazing pressures on the more arid rangelands in drought years. The development of symbiotic mycorhizal fungi aiding the crop roots' ability to absorb phosphates, could remove another yield-limiting factor in a number of arid soils which have low phosphate availabilities.

Temperate croplands The characteristics needed in new crops designed for temperate regions differ markedly from those previously discussed. Greater production is not required in the developed world whereas the need, and possibility, of paying for a reduction in environmental pollution is.

In Western Europe, for example, the cost of subsidizing the European Community's agriculture constitutes two-thirds of the European community's budget and the insensitive use of nitrogen fertilizer and pesticide have given rise to a number of the regions environmental problems.

It is important, therefore, that any new crops intended for this region should be able to produce economic yields without the need for intensive applications of agrochemicals. A reduction in their rate of application is needed to safeguard the producers and consumers of the food as well as the environment.

Genetic engineering techniques are being used on a wide scale in an effort to produce pest-resistant crop plants and Hall et al. (1990) have recently reviewed the opportunities currently available for introducing bioactive compounds in new, transgenic plants in order to confer resistance to herbicides, insects, viruses and pathogens, as well as for other purposes.

Although this approach would not necessarily reduce the quantities of herbicides used for weed control, it could lessen the need for chemical sprays to protect crops against pathogens and insect pests and virus vectors.

Other applications of genetic engineering under development are environmental protection against frost damage. By introducing genes encoding bacterial proteins which have been found to act as very effective ice nucleation agents (Lindow et al., 1978) into the epidermis of crop plants, chilling protection could be conferred by inducing extra - rather than intra - cellular freezing.

Genetic engineering is being used in attempts to modify the functional and nutritional propterties of seed storage proteins, in particular to improve the breadmaking qualities of certain temperate climate wheat varieties as well as those of other grain crops which are currently not suitable for breadmaking.

Finally, the development of transgenic plants, capable of producing significant amounts of pharmacologically active materials, provides an example of the opportunities that may emerge for new, non-food crops (Hiatt, Cafferkey and Bowdish, 1989).

A second and different requirement is for new crops in the marginal and generally more humid parts of the temperate regions. Food crops are unlikely to be required; this according to the results of an analysis which suggests that European agriculture is entering a long era of agricultural contraction (van der Woude, 1990). The abandonment of marginal areas of temperate cropland is, of course, by no means a phenomenon confined to Europe and many examples can be found in the northeastern parts of the USA.

Contraction of temperate region cropping would be accelerated if the potential for increased crop productivity in semi-arid regions previously discussed came about. Similarly, a reduction in the need for food imports from temperate cropland would follow the improved productivity of the colder marginal areas predicted to result from global warming; this is expected to be especially pronounced and beneficial in the high northern latitudes (Parry, Carter and Kinijn, 1988).

The major plant product imported to Europe is timber and its large-scale production in the marginal areas of the temperate zone could be environmentally beneficial in a number of respects. Possibily the most important could be to reduce the import of timber from tropical forests. By conserving the immense biological resources of these regions, aptly described by G.C. Evans as 'mankind's sack of uncut diamonds', the genetic potential for engineering new flora and fauna, as well as for more conventional exploitation, could be preserved for future generations.

The conservation of the tropical moist forests, and their restoration is apparently not possible, is environmentally important for additional reasons. These include the disproportionately large role they play in the global carbon and water balance and the disasterous effects of their clearing on downstream regions through erosion and flooding.

Genetic engineering could help conserve tropical forests if new temperate tree crops could be produced whose timbers could substitute for the highly priced luxury tropical woods. Today, such woods are only available from the few remaining such trees, sparsely distributed in the very heterogeneous tropical forests. The sale of these woods is an important economic motive for tropical deforestation.

<u>Arctic tundra</u> The patchy mantle of low vegetation, mainly grasses, sedges and dwarf shrubs which covers the vast frozen plain, making up one-tenth of the Earth's land surface, is well-adapted to conserve its soil and water resources. The below-ground part of this vegetation is an order of

magnitude greater than that growing above the surface and more than 90% of its annual growth eventually finds its way into the large organic component of the soil where it is preserved by low temperatures and high water tables.

Although today there is neither environmental need nor economic possibility of replacing the tundra's existing plant cover with genetically engineered new crops, global warming on the scale predicted to occur in the high northern latitudes, could change this picture in the next century.

The greater temperature will probably increase the contribution that this area makes to the global Carbon exchange adding to the fluxes of both carbon dioxide and methane to the atmosphere (Watson et al., 1990). This increase could be significant as approximately a third of the Carbon in the Earth's biomass is contained within the soils of the high, northern latitudes (Bolin, 1986; Kohlmaier, Janacek and Kinderman, 1989).

The speed and magnitude of the temperature increase predicted for the Arctic makes it unlikely that natural selection or acclimation will enable the existing vegetation to adapt to the changing climate sufficiently quickly to avoid severe environmental damage. Should increased temperatures and carbon fluxes from the exposed, thawing Tundra soils materialize on the scale anticipated, then human intervention to reestablish a plant cover with new crops, genetically engineered to protect the soil and atmosphere, might be justified.

It would seem likely that any new crops designed for this purpose would be modified forms of evergreen forest spps now growing in the Boreal forest or taiga zone, which lies to the south as it has been estimated that this vegetation would eventually colonise 42% of the tundra area, as a result of climatic changes following a doubling of the atmosphere's concentration of CO_2 (Shugart et al., 1986).

Presently neither tundra nor taiga vegetation are of economic importance; presumably their modification to yield harvestable products would be a neccessary, if not sufficient, incentive for engineering new crops for this region.

Oceanic phytoplankton The primary reason for considering the modification of ocean vegetation by genetic engineering is, as was the case for arctic tundra, the possibility that new crops of phytoplankton could significantly moderate global climate change. Two mechanisms which could enhance the 'daisy-world' effects of this vegetation will be considered.

The first is by an increase in their rates of photosynthesis to remove Carbon from the atmosphere and sequester it in the deep ocean, so taking it out of circulation. It has been estimated that increasing the rate of aquatic photosynthesis by one percent would decrease the equilibrium CO_2 concentration in the atmosphere by 0.5 to 2.5%, i.e. by 2-7 ppmv, with a time lag of only a few years (Viecelli, 1984). This reduction would more than compensate for some three years increase in the CO_2 concentration of the atmosphere, resulting from the current combined effects of the combustion of fossil fuels and land use changes, including deforestation.

Another desirable characteristic of new phytoplankton crops would be an increase in the fraction of their photosynthetically fixed carbon which sinks beneath the active surface layers of the ocean. Currently 10% of the total aquatic primary productivity, estimated at 40 x 10^{15} g C yr^{-1}, sinks below the surface layer and 1% is deposited on the ocean floor, largely in the form of faecel pellets (De Vooys, 1979). Thus, an increase in oceanic primary productivity and deep deposition of Carbon should lead to an increase in secondary production and hence, in the amount of fish and other sea food harvested.

The feasability of introducing new and more productive phytoplankton cultivars is increased by the fact that primary production is as unevenly distributed over the oceans as it is over the land surfaces. Modification of the oceans flora would have the greatest effect in the colder areas of the seas where updwelling currents ensure a plentiful and non-limiting supply of nutrients.

A second modification of oceanic vegetation that could enhance their role in modifying global climate change would be to increase their rates of emission of reduced sulfur gases, principally dimethyl sulfide - $(CH_3)_2S$. The soluble aerosols produced by these gases are a major source of cloud condensation nuclei in the clean maritime air masses characteristic of the mid-ocean environment. It has been suggested (Charlson et al., 1987; Bates, Charlson and Ganman, 1987) that this biological control of oceanic cloud cover could play an important regulatory role in global warming through increased reflection of solar radiation, and hence lowered sea surface temperatures. This suggestion is supported by the changes in the rate of production of sulfur gases which have been detected in Antarctic ice cores and are correlated with the major climate changes which occurred over the last 160,000 years (Peel, 1991).

A recent simple model calculation (Foley, Taylor and Ghan, 1991) indicates that present rates of production of $(CH_3)_2S$ by photoplankton and their grazing zooplankton limits this climate feedback effect to 7%. It also demonstrates the potential importance of changes in the rate of sulfur metabolism by oceanic phytoplankton, or the inclusion of other metabolic pathways, producing gases with similar cloud promoting properties.

THE POSSIBILITIES AND PROBABILITIES OF GENETICALLY ENGINEERING NEW CROPS TO PROTECT THE ENVIRONMENT

> 'You begin to see that it is possible to transplant tissue from one part of an animal to another, to alter its chemical reactions and methods of growth, to modify the articulation of its limbs, and indeed to change it in its most intimate structure.'
>
> The Island of Dr. Moreau. 1896

Speculations of the possiblities offered by the combination of desirable characteristics from different spps into new animals and plants are neither new or confined to science fiction of the type quoted above (Wells, 1896). It is interesting that these authors, together with those of the medieval books of monsters (Jacob, 1976/77) and today's opponents of genetic engineering (Collmer, 1991), all stress the dangers of transgenic creation. The reasons why in the past neither natural nor man-directed selection were capable of realizing these possibilities or releasing the dangers, have been discussed by Jacob (1976/77).

The fact that genetic engineering is now capable of creating new, transgenic living material is indisputable. It is evidenced dramatically by the existence of both plants and pigs containing human genes (Collmer, 1991; Stafford and Fowler, 1991).

Such accomplishments do not however mean that the production of the environmentally protective new crops discussed is merely a question of time. Formidable technological and economical barriers to their realization exist and it is by no means certain that these can be overcome. It is even less certain that if they can be they will be.

The technological difficulties still to be solved can be seen in the slow progress that has been made in attempts to transfer two of the important crop characteristics discussed. One is the three different photosynthetic pathways found in CAM, C_4 and C_3 plants. The other is the ability of plants belonging to the Leguminosae family to host symbiotically nitrogen fixing bacteria within their root systems.

For almost two decades intensive efforts have been made to transfer these characteristics by several large research teams at various national and international research centers, although there has been much progress in understanding these processes, there are no signs of field applications as yet.

One reason is their complexity. Each system of carbon metabolism, for example, involves a major complex of enzymatic, organelle, and cellular specializations, each of which in turn involves many groups of gene sequences. The identification and mapping of the locations of genes on chloroplast chromosomes has occupied some two dozen research groups around the world for a number of years. Even when the sites of all of the controlling genes have been identified, the problem of moving the genes into the double membraned chloroplasts, the site of photosynthesis, remains.

An important general consideration that should be borne in mind when considering the possibilities of genetically engineering new crops is that there is nearly always a biological price to be paid for the desirable characteristics.

In the case of bacterial fixation of atmospheric nitrogen this is the energy for the process which the host plant has to supply. This is the reason why yields of leguminous crops are usually below those of comparable crops receiving nitrogen fertilizer and why high value leguminous crops often receive fertilizer applications. A summary of a workshop devoted to the energetics of biological nitrogen fixation (Anon, 1982) concluded that these were approximately the same as for industrial fixation.

Another example is provided by the CAM plants. Their avoidance of water loss, achieved by the night-time opening of stomata and CO_2 absorption by organic acids, later to be released for day-time fixation in photosynthesis, is an energy demanding process. This reduces the absolute levels of net carbon fixation and hence the yields of CAM crops. Thus the high water use efficiency of these plants is at the expense of their solar radiation conversion efficiency.

A third example which has received much attention is the possible cost of effective control of disease and insect attacks by biochemicals produced by the plant, often at enhanced rates in reaction to pest attacks (Harborne, 1990). It has been suggested, although not demonstrated, that these materials could be more dangerous to those eating the plants than the residues of chemical pesticides substituting for them (Ames, 1983).

But the major reason why the possibility that new crops for land, water and air conservation will be produced by genetic engineering is a remote one is not because of the scientific difficulties involved. Rather it is due to the lack of markets which could justify the high costs of research and development.

This economic limitation is clearly seen from current trends in both genetic engineering and the adoption of solutions currently available to solve environmental problems.

The private sector is the major source of capital for research and development for transgenic crops and the amounts needed and the risks involved are such that the only ventures undertaken which can be expected to yield large and rapid returns.

After some 25 years of research and development the first transgenic crops to reach the field application stage are those incorporating herbicide resistant genes. This application is of course confined to intensive, high-value crop production and its development was sponsored by a number of the larger agrochemical enterprises. Thus, this investment will be recouped not only from the increased sale of herbicides, but also by sales of the new genetic material via subsidiary seed firms. This first, major application of genetic engineering may well add to, rather than reduce, the environmental problems caused by intensive crop production.

Other genetic engineering developments very close to stage of field application are new crops which contain genes conferring resistance to virus attacks (Grumet, 1990), a range of new colours and shapes for some ornamental crops and tomato fruits with prolonged shelf-lives obtained by genes inhibiting the decay processes.

All these applications are confined to high value crops and the returns on the investments will be achieved through the sale of the genetic material. Report that a major effort involving over a dozen scientists is being devoted to the development of a blue rose, even if apocryphal, highlights this trend in genetic engineering.

Bioindustrial exploitation of genetically engineered plant material, as in cell culture systems, are confined, by their cost of production as well as of development, to even higher value products, in particular, pharmaceutical materials. (Stafford and Fowler, 1991).

The opportunities and dangers which these trends in biotechnology represent for the developing countries of the world have recently been reviewed (Sasson, 1989). It is noteworthy that this very extensive text does not include any reference to environmental applications.

The low probability that genetically engineered crops will be used for conservation is also suggested by the very limited application that has been made of the wide spectrum of solutions currently available, this because of their cost and lack of economic incentives.

Many effective methods for soil and water conservation have been developed since the dust bowl incidents of the 1930's, especially for the fragile semi-arid lands. An extensive literature, whcih includes scientific journals, is devoted to these methods.

Agrochemical pollution can be eliminated or at least much reduced by a wide range of well documented methods. In the developed world nitrogen fertilization can be replaced, by including legumes in crop rotations, and by the increased use of farmyard manure, with minimal reductions in yield. The use of chemical pesticides can be replaced by a variety of crop protection methods (Unwin, 1990).

Evidence that adequate crop yields can be obtained without the use of any agrochemicals whatsoever is provided by an analysis of more than 205 scientific comparisons of yields obtained in 'organic' and conventional production systems. The mean yield from 26 crops and two livestock products, milk and eggs, produced by the organic methods was 0.91 of that produced by conventional systems (Stanhill, 1990).

CONCLUSIONS

Despite the potential of genetic engineering to produce new crops to conserve land, air and water resources, discussed in the first half of this presentation, there are many reasons, given in the second half, to indicate that this potential is unlikely to be realized.

Even if the scale of the global environmental crisis is such as to mobilize the sums needed to develop new crops and establish them on the scale needed for environmental protection, it is doubtful whether such a program could be implemented within the time required.

Fortunately in such a case a number of well established, but currently unused conservation methods are available for agricultural and rangeland areas.

This is not so for the high northern latitudes and the mid oceans. Because of the lack of conservation methods suitable for these globally important regions, research to produce environmentally protective vegetation for these areas could be justified.

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