Chapter 8

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Physical Potentials for Crop Production

THERE CAN BE little doubt that a ceiling on total crop production will be reached sometime in the United States. Obviously this will occur when the population pressure is great; when all the land and water resources available to agriculture reach full development; and when natural limitations halt further improvements in technology and management practices. The question is: When will the ceiling be reached and at what level of production?

We can determine, within fair limits, the land and water resources available for expansion during the years between 1960 and 2000. We can also make certain assumptions as to population increases and eating habits, and use these to predict shifts in land use. But even for this brief period, it is exceedingly difficult to predict technological advances and the extent to which they may affect crop-production ceilings.

This chapter brings together published estimates of United States land and water resources available for development over the next few decades. It also points out some of the areas in our present technology that have possibilities for improvement, and some that appear to have approached their potential.

POSSIBILITIES FOR NEW CROPLAND

The total land resource of the United States, exclusive of Alaska and Hawaii, is 1903 million acres. Largely from this we must meet the food, feed and fiber needs of the nation regardless of whether the population is 180 million or 500 million. According to the 1954 U.S. Census of Agriculture, our total land resource is divided as follows: cropland, 460 million acres; open pasture and grazing land, 611 million acres; woodland and forest, 639 million; and all other uses, 193 million. Obviously, additional needs for cropland will have to be met by a shifting from the less intensive land uses.

Possibly as much as 110 million acres of our grassland and 105 million acres of woodland in continental United States are fairly well adapted for use in cropland rotations. Shifts between woodland and cropland are more difficult, time-consuming and expensive than shifts between grassland pasture and cropland.[1]

Of the 110 million acres of grassland suitable for cropland if plowed, drained and otherwise improved, about 12 million acres would make Class I land, 39 million, Class II, and 59 million, Class III (4). In these estimates, about 60 million acres of the grassland are on the Great Plains, 24 million acres in the Corn Belt and Lake States, 7 million in the Mississippi Delta, 5.5 million each in the Northeast and Appalachian areas, 3 million in the Southeast, and 5 million in the Mountain and Pacific States. Not all of these areas are equally suitable and, depending on the need for pastureland, as much as 50 percent might remain in grassland. Probably the most desirable are in the North Central States and the South, and the least desirable are in the Great Plains.

Of the 105 million acres of undeveloped land that could be changed from woodland to cropland as the need arises, about 8 million acres would become Class I land if cleared and properly cultivated. Another 34 million acres would develop into Class II land if simple erosion control and soil fertility practices were followed, and, with special erosion control and soil management practices, 63 million acres could be made into Class III land (4).

About 70 million acres of the undeveloped land lie in the Mississippi River Delta, Southeastern, and Appalachian states. Much of the best land is in the Mississippi River alluvial area of Louisiana, Mississippi, Arkansas and Missouri and requires clearing, draining and often flood control structures. Other undeveloped lands are scattered over much of the Southeast with the greatest concentrations in the Flatwoods, the Everglades and the southern alluvial plains (1, 6). These require clearing, draining, or both, and large amounts of fertilizer and lime. On sloping lands, erosion will be a problem. Tidal marshes, where rice production was once important, probably will be brought into production only as a last resort since they require diking and pump drainage, and many of the soils are of doubtful suitability.

About 12 million acres of cropland in the Northeast could be developed from abandoned farm and woodlands (4). Stone removal, clearing and drainage would be required most frequently.

[1] USDA. A 50-Year Look Aheaa at U. S. Agriculture. 20 pp. June, 1959. Processed.

Unfortunately, many of the better tracts are scattered and would be difficult to bring together into farm-size units.

The Lake States and Corn Belt have an estimated 12 million acres of potential cropland now in woods, cut-over areas and wet lands (4). Most of this acreage is in Minnesota, Wisconsin, Michigan and in fringe areas of the Corn Belt, and would require both clearing and draining. Very little suitable land is left for development in the Corn Belt proper.

The Southern Plain States have a potential of 9 million acres (4), about 3 million of which could be reclaimed by draining and breaking the Coastal Prairies of Texas. Most of the remainder could be salvaged by clearing brush, cedar and semi-arid woodland. The Northern Plains have a million-acre potential, and the Mountain States and Pacific States about one million, mostly in the Pacific Northwest. The latter does not include future irrigated lands and would result mostly from the clearing of woodlands and from draining and diking.

The foregoing shifts have been estimated on the physical potential of the land, without thought as to economic feasibility or desirability. The recent report of the Select Committee on National Water Resources, U.S. Senate, cites an estimated need of only 35 million acres of additional land from this source by the year 2000 when projected on the medium population level of 329 million (3).

Alaska now has 20,000 acres of cleared land and 3 million additional acres are thought to be physically suited for cultivation. Practically all of this acreage would have to be cleared and some would require drainage.

About 11 million acres of additional land can be irrigated in the western states (2). The largest development would come in the Upper Missouri River Basin and in the Western Gulf area of Texas. The new irrigation projects would be on lands now used largely for dry farming or grazing.

LOSSES OF CROPLAND

Partially offsetting the possible gains of new croplands are losses of lands to nonagricultural uses and to soil erosion, and the shifting of unsuited cropland to less intensive uses. Urban, industrial, and recreation development, new roads, airports, reservoirs and flood control areas require agricultural lands in ever-increasing amounts. Recently, the average rate of absorption into nonagricultural uses has been about 1.5 million acres per year of which about 25 percent came from cropland and about 15 percent from pasture. Under assumptions of medium population growth from 1960 to 2000, special nonfarm uses are expected to require another 81 million acres of which 20 to 25 percent might come from cropland, and 75 to 80 percent from woodland, pasture and other land (3).

Although the rate of loss of cropland from erosion has been reduced tremendously through application of soil conservation practices, land is still being lost at an estimated rate of 400,000 acres per year. With continuing emphasis on conservation and steady improvement of conservation practices, the rate of loss should decline appreciably in the future. However, about 50 million acres of cultivated land should be shifted either out of cultivation or into less intensive cultivation. Another 50 million acres should be subjected to more effective erosion control practices (3).

EXPANSION OF IRRIGATION

Overcoming all moisture deficits through irrigation is not in the picture. We have definite limitations on the amount of good-quality water available to agriculture. Not all lands are suitable for irrigation, and both available water and suitable land for irrigation are not always found together.

In a normal year, the U.S. averages 30 inches of precipitation. About 21 inches is used in evapotranspiration. The remainder, 9 inches, is returned to streams. About two-thirds of the streamflow occurs during flood periods and less than one-third is available over the majority of the year. By storage and regulation of release, it is thought possible to provide a future constant availability of about 5 inches of the total precipitation. Half of this is required for navigation and waste disposal, leaving about 2.5 inches for irrigation, industrial and domestic uses. Presently we are using about 0.9 inch for all of these, of which about 0.4 inch goes for irrigation. While such average figures are not too meaningful, they do illustrate that definite limitations exist on the amounts of water available for irrigation.

Industrial and domestic use undoubtedly will continue to require more water as the population increases. With industry reaping per-gallon returns for water fifty times that of irrigation, there is little to stop further commercial use of water.

Possibilities for increased irrigation are much greater in the East than in the West. The 17 western states receive about 28 percent of the total water supply (350 billion gallons per day) in the nation. About two-thirds is concentrated in the Pacific

Northwest where a large portion returns to the ocean. This leaves roughly 120 bgd, of which about 85 bgd of the total available are being used. The East, in contrast, has about 225 bgd with a current use of 80 bgd (2).

Not all water is suitable for irrigation. Brackish waters along the tidal inlets of the seacoasts, some western rivers, and many wells, may contain soluble salts in excess of what is safe to apply on the land.

Pollutants from industries, nuclear reactors, drainage ditches and sewage may also render streams unsuitable for irrigation, particularly during periods of low flow. Ground-water supplies may be polluted, also.

Probably less than 15 percent of the potential croplands of the United States are suitable for irrigation. Soils in arid regions having a combination of restricted drainage and high content of soluble salts and alkali are poor irrigation risks. Steep lands cannot be irrigated effectively, and extremely sandy soils retain too little water to justify irrigation except for certain high per-acre-return crops grown in areas of favorable climate. As a rule, only Class I, II or III lands are considered suitable for irrigation.

About 18 million acres of unirrigated land remain in the 17 western states, and about 29 million acres in the East, which conceivably could be irrigated if necessary. Full expansion of irrigation, however, is likely to come slowly and, because of high costs involved, only in response to population pressures. By 1980, assuming a medium potential for irrigation, it has been estimated that an increase of about 4.7 million acres for the West and 2.5 million acres for the East would occur. By the year 2000, using the same assumptions, the increase would be 11.2 million acres for the West and 4.7 million acres for the East (3).

Yield benefits from irrigation vary with the water deficit encountered in the soils during the growing season. In arid regions, practically no crop production can be obtained without irrigation. Crop-production increases that can be attributed to irrigation, decline from West to East as the amount of effective precipitation increases. In humid regions, both yield benefits and acreages irrigated vary more or less directly to the frequency and intensity of droughts and the time of their occurrence. Irrigation of corn, pasture, cotton and tobacco is highest during drought years and drought cycles, and declines considerably during years of ample or near-ample rainfall. Irrigation of rice remains constant from year to year and that of vegetables and speciality crops remains fairly constant.

LAND IMPROVEMENT THROUGH DRAINAGE

Removal of excess water from croplands and prevention of overland flow markedly affect crop production potentials. About one-fifth of our present cropland either has been brought into production or has been greatly improved through drainage. Drainage also goes hand-in-hand with development of successful irrigation projects in the West. The full potential to be realized from drainage, however, has not been reached on existing croplands, and many of the new croplands of the future will require extensive drainage.

In 1950, 102,688,000 acres were in organized public drainage enterprises in 40 states, of which four-fifths, or 82 million acres, were improved. Some 15 million acres in enterprises were still too wet for cultivation, and crop losses were frequent on an additional 10 million acres. In addition to the organized enterprises, an estimated 50 million acres have been drained by individuals (5).

Improvements in present cropland drainage can be brought about largely through rehabilitation of existing drainage systems at comparatively low costs. Improved yield potentials and more efficient operation can be achieved through such things as combinations of surface and subsurface drainage systems; more effective spacing and depth placement of tiles or moles, and improvement of outlets and lateral systems; drying out of potholes; adjustments of rates of water removal to crop and soil needs; improved maintenance and functioning of installed drains and drainage channels; adjustment of water tables to prevent subsidence on peat and muck soils; and removal of unneeded field ditches and spoil banks. Also, greater efficiency would result from coordination of piecemeal drainage systems and incorporation of larger acreages into community drainage enterprises.

No accurate data exists on the exact amount of undeveloped wetlands that can or should be drained in the United States. According to Wooten (5), there are some 50 million acres of wet and overflow lands which would be suitable for agricultural development if adequate drainage were provided. Of the 50 million acres of inadequately drained land, 60 percent is in organized drainage enterprises. Approximately 30 million acres are in partial cultivation and 20 million are undeveloped. The recent estimates and projections made for the Select Committee show that 10.1 million acres of grassland, and 24.7 million acres in forest which might eventually be shifted to cropland, would require drainage (3).

There seems to be little question that drainage will be a major factor in increasing our agricultural potential. Undoubtedly drainage improvements on present croplands will be continued. In response to increasing population pressures, new or improved drainage systems will expand first into grasslands and gradually into the better forest lands. Other wetlands, such as the inland and coastal marshes and swamps, which are also important wildlife habitats, will probably receive drainage only as a last resort. In western irrigation projects on new lands, however, drainage is a necessary complement to the successful application of water.

Real possibilities exist for reducing costs of drainage and for improving the design and effectiveness of drainage systems. Plastic-lined mole drains equipped with grade-control devices are now in advanced stages of development and offer considerable promise for greatly reducing the cost of internal drainage. Improvements are being made in design of surface removal of water. Use of electrical resistance networks, combined with better understanding of soil properties as related to water movement into and through the soil, promise to take much of the guesswork out of designing drainage systems. Much research, however, still remains to be done.

CONSERVATION AND EFFICIENT USE OF WATER

As was indicated earlier, water is a major limiting factor in crop production, and there are definite limitations on the amount available to agriculture. The only alternative to moisture shortages is moisture conservation. Fortunately, there are tremendous possibilities for moisture conservation. They fall into three main categories: (1) conserving runoff water for irrigation, (2) getting more water into the soil moisture reservoir and (3) obtaining more efficient utilization of the available moisture stored in the soil.

Water conservation for irrigation can be achieved through increased use of dams and regulated release, increasing underground storage by artificial means, reduction of conveyance losses through canal lining systems, control of phreatophytes, increased re-use or recycling of waste waters, improved management of watersheds to regulate water yield, reduction of pollutants, prevention of salt intrusion, reduction of siltation of reservoirs and the like. Full exploitation of these measures can go far in increasing the water supplies available to agriculture, particularly in the western states.

There are possibilities, although seemingly remote, for supplementing water supplies through artificial induction of precipitation, processing of sea or brackish waters, and control of evaporation from free water surfaces by chemical means.

Replenishment of the soil moisture reservoir through encouraging water intake and reducing runoff offers more potential in subhumid and humid regions than does irrigation. Replenishment can be achieved mainly through adoption or improvement of known practices. These include surface mulches, cropping systems designed to increase the intake rate, contour cultivation to hold the water on the land longer, strip cropping, graded terraces and water spreading. The effectiveness of these practices will vary with soil and climatic conditions and with the character of the individual rainstorms. However, they often improve the soil moisture situation materially.

Certainly the inefficient moisture-conserving practice of summer fallow in dry farming areas will be displaced by other more efficient practices. Usually only one-quarter of the rainfall that falls during the fallow season is stored in the soil for future use. Since there are about 25 million acres of cultivated summer fallow, this would add considerably to our land resources.

Exciting possibilities exist for more efficient use of soil moisture. It has been variously demonstrated that 40 percent or more of the water used in crop production is evaporated from the soil surface, which is much higher than originally thought. Although evaporation can be suppressed in experiments by covering the soil surface with a thin layer of plastic, practical field measures present many problems. Since heat from the sun converts liquid water into vapor in the evaporation process, evaporation suppression becomes largely a matter of diverting the heat from the evaporation process. Possibilities for reducing surface evaporation thus rest primarily in providing more thorough shading of the soil surface by the growing plants and in arranging the row directions and the geometry of the plants so there is a minimum of solar energy to be dissipated in evaporation at the soil surface. Evaporation suppression probably will be practical only on soils having a sufficiently high water holding capacity to store sizeable amounts of moisture. Also, sufficient precipitation is required to fill or nearly fill the soil reservoir. The Midwest would most closely meet these criteria.

Possibilities also may exist for reducing water losses from transpiration by spraying plants with wax-like chemicals. However, since evaporation is a major means of cooling the atmosphere around the growing plant, transpiration control would encourage heat build-up which in turn might increase respiration and tend to offset over-all yield gains. On the other hand, dissipating heat through air turbulence brought about by controlling the arrangement of crop plants in the field, or by limiting this treatment to crops that make their major growth during the cooler portions of the growing season, might offer real promise.

Anything that increases the dry matter production of a crop increases its water efficiency. Fertilizers are particularly effective in this respect. In fact, the efficiency of water use may be doubled. Increasing plant populations, utilizing more of the growing season through early planting and later maturity, encouraging rapid initial growth and substituting high yielding for low yielding crop varieties will all improve efficiency.

Weeds are extravagant users of water and greatly reduce the amount of water available for crop growth. Ragweed, for example, takes three times as much water as corn to produce an equal amount of dry matter. With the rapidly advancing technology of weed control through herbicides in combination with weed-free seed and cultivation, adequate control measures should be no problem in the long-term future.

INCREASED USE OF FERTILIZERS AND LIME

Fertilizers and lime play a very great role in the maintenance and improvement of the productive potential of agricultural lands. Before the advent of fertilizers and lime, our early agriculture was marked with abandonment of exhausted land. About 20 percent of the increase in farm output since 1940 has been attributed to fertilizers. We are now applying 7.4 million tons of primary plant nutrients of which 2.6 million tons are nitrogen, 2.6 are available phosphate and 2.2 are potash.

Considerable evidence indicates that we have not yet exploited the full potentials of fertilizers as a crop producing factor. Fertilizer use on most agricultural lands in the United States is modest in comparison with other progressive countries having highly developed or intensive agricultures. This is brought out in Table 8.1. As pressures on our agricultural lands approach those of western Europe, there is good reason to believe that fertilizer use on our better croplands where moisture is not a critical factor will also approximate that of western Europe. However on drylands and lands of lower productive potentials, fertilizer use will stabilize at lower levels.

Although we are short on utilizing the full potential of fertilizers in over-all crop production, this situation does not apply equally for all crops or for all areas of the country. As shown in Table 8.2, the high cash-return crops approach or exceed the

Table 8.1. Average Rates of Fertilizer Application ($N + P_2O_5 + K_2O$) Per Acre of Agricultural Land[a] in 1957 for Selected Countries

Country or region	Lbs. per acre
Japan	190
Belgium	182
Netherlands	177
Formosa	129
Norway	126
West Germany	122
Denmark	107
United Kingdom	47
France	46
U.S.A.	12.5
Central America	6.5
South America	1.0
Africa	0.7

[a] Agricultural land includes arable, tree crops, permanent meadows and pastures.

Source: H. J. Page, "Trends in fertilizer consumption in relation to world food supply." Outlook in Agriculture, 2(5):203-12. 1959.

average fertilizer use reported for the leading fertilizer using countries. Also, we are closer to meeting the potentials of fertilizer use in the Southeast and Northeast than in other humid or irrigated areas of the country.

Considerable potential still remains for increased fertilizer use on the grain crops and hay and cropland pasture. Also, there would appear little question that the entire cropland acreage, except possibly in the more arid dry-farming areas, will eventually receive fertilizer. Fertilizer use probably will not increase equally for all three of the major nutrients. Greater quantities of nitrogen are needed by crops on most soils, and its use should increase accordingly.

While fertilizer use has increased greatly in the United States in recent years, the same does not apply for lime. Acid soils remain notoriously underlimed, and this situation must be corrected before we can realize full potentials of crop production.

Current use of lime in the United States averages about 20 million tons annually. This level of lime consumption is sufficient only to offset lime depletions through leaching and crop removal. For example, assuming a 250 pound per acre annual loss from an estimated 170 million acres of harvested cropland in the humid regions, this would amount to about 21 million tons. In addition to normal losses, many farm soils have accumulated

Table 8.2. Estimated Use of Principal Plant Nutrients by Crops and Regions, 1954

Crop or region	Acreage fertilized	Av. rate of $N + P_2O_5 + K_2O$ per fertilized acre
	(Percent)	(Pounds)
Tobacco	97	298
Potatoes	78	277
Vegetables	63	209
Fruits	58	151
Sugar crops	91	118
Cotton	58	105
Corn	60	80
Wheat	28	64
Oats and barley	30	65
Hay and cropland pasture	10	81
ALL CROPS		
Northeast	43	126
Lake States	29	73
Corn Belt	39	82
Appalachian	44	119
Southeast	69	112
Mississippi Delta	48	79
Southern Plains	13	59
Northern Plains	11	41
Mountain	13	70
Pacific	34	57
U.S.	30	79

Source: Fertilizer Used on Crops and Pastures in the United States — 1954 Estimates. Stat. Bul. 216. USDA, ARS, Aug., 1957.

residual acidity as a result of inadequate liming in the past, and others, particularly those in permanent pasture, have never been limed. A 1950 U.S. Department of Agriculture survey of conservation needs indicated that annual use should approach 80 million tons and that some 556 million tons would be required to reduce acidity to a level conducive to good crop production.

New lands and grasslands shifted to croplands will require large initial applications of fertilizer and lime. Soils of many of these lands, particularly in the East, are inherently very acid, and low in phosphorus and potassium.

Recovery of fertilizer nutrients by plants is alarmingly inefficient. Seldom over half of the nitrogen, 10 percent of the phosphorus and half of the potassium applied is recovered by crops. Certainly more efficient ways will be found someday to provide crops with the nutrients they require. Marked improvements in the efficient use of fertilizers, however, do not seem to be forthcoming in the immediate future.

MORE PRODUCTIVE CROPS

Crop breeding has been one of the more important and fastest moving ways to increase the productive potential of crops. Costs to the farmer are small, largely in the price of the seed, and adoption of improved varieties is rapid and widespread.[2] Increased yield and greater stability of production has resulted for many crops when improved varieties are combined with good practices. Crop breeding also has permitted establishment of disease and insect resistance, expansion of the area of adaptation of certain crops, adaption to mechanization and improvement of quality.

Commercial use of first generation hybrids has been successfully applied to corn, sorghum and a number of vegetable crops. First usage of commercial hybrids usually accounts for an initial yield increase of 20 to 25 percent over open pollinated varieties. Improvements and refinements over a period of years, as in the case of corn, further increase the yield potential about 15 percent. Hybrid grain sorghums are expected to follow the same pattern of improvement as corn. Present yield improvements for hybrid sorghum are reported to range from 20 to 30 percent and about 75 percent of grain sorghum is now hybrid.

Utilization of commercial hybrids may be realized in other crops. Hybrid alfalfa is a possibility, although present hybrids outyield open pollinated varieties by only 10 percent. In the South, hybrid cattail millet has come on the market within the last year (1959), and hybrid Pensacola Bahiagrass should be on the market within a few years, followed by a hybrid Starr millet and hybrid Sudan grass. One by one, cross-pollinated crops appear to be yielding to hybridization although many problems face the plant breeder. Hybrid cotton, for example, has failed so far because of the difficulty of producing hybrid seeds on a commercial scale.

Potentialities seem more limited for improvement in yields of self-pollinated crops that have already been tested intensively, such as small grains. The dwarf wheats, however, seem to be establishing a higher yield plateau in the Northwest. Shorter straw in crops such as dwarf wheat, dwarf sorghum and dwarf internode castors makes them adaptable to higher rates of nitrogen fertilizer application.

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[2] Material reported here was obtained largely through discussions with Dr. Martin G. Weiss, Crops Research Division, ARS, USDA.

Progress in forage crop breeding, with few exceptions, has lagged behind accomplishments with several other crops. As research effort is increased, however, considerable advance in yield potentials of forage crops appears likely.

Breeding for disease resistance does much to maintain yields, although higher yield potentials usually are not established. Oat breeders have successfully evaded serious onslaughts of different races of crown and stem rust through a continuing program of developing new disease-resistant strains. There is hope, too, of introducing a broad-type of disease resistance into oat varieties that now exist in the wild species, _Avena strigosa_. Bacterial wilt, which virtually eliminated alfalfa from long rotations, was conquered by the resistant varieties such as Ranger, Buffalo and Vernal. Continuing success in the general area of disease resistance is expected.

Real advances have been made, and are likely to continue, in adapting crops to different climatic areas. There has been development of varieties of soybeans, for example, which permit the crop to be grown successfully in Minnesota and other northern areas. Grain sorghum breeding for earliness and laxness of head (to evade molding) is progressing. This will aid adaptation to more northern conditions.

IMPROVEMENTS IN FARM MECHANIZATION

Farm mechanization also must be considered in any evaluation of future potentials of crop production. We have all seen the effects of mechanization upon our agricultural economy. Replacement of animal power alone released an estimated 82 million acres of land which was used almost exclusively to produce feed for horses and mules. While such a far-reaching revolution in agriculture is unlikely to occur again, there are nevertheless continuing improvements and inventions which affect crop production.

Mechanization improvements[3] can be expected largely through perfection of machines that will permit more timely tilling of the soil and harvesting of crops, better and more effective methods for applying pesticide chemicals, less loss of crops during the harvest operation, manipulation of the soil in a manner to improve the soil environment for crop production and improved mechanical means for reducing erosion and water runoff.

Looking at the future on a crop basis, there seems to be little opportunity for much further improvement in the mechanization

[3] Material reported here was obtained largely through discussions with Dr. Walter M. Carleton, Agricultural Engineering Research Division, ARS, USDA.

of grain crops. Man-hours required for their harvest already have reached a low level beyond which further advances can only be small. Greatest and most far-reaching possibilities lie in the mechanization of forage-crop harvesting and processing. We now have high yielding, coarse grasses which will produce 8 to 10 tons of dry matter per acre if properly fertilized. Such grasses are difficult to harvest and preserve in a palatable state. As machines are developed to harvest coarse vegetation, cure and process into pellet or wafer form, the forage processing will become simplified, the crop will be more palatable to livestock and the actual amount of useable animal food per acre will be high. High yielding forages effectively processed can result in drastic changes in the grassland economy, particularly in warmer climates, and higher per-acre returns can be expected on lands that are not suitable for cropland because of their erosion hazard.

OTHER ASPECTS

My discussion has been limited to only a few of the factors that contribute to the crop production potential. Many others contribute mightily, for example, insect control, soil microorganisms, nematocides, plant disease control and utilization of crops by livestock.

In any case, however, the truly major advances in the agricultural technology of the future are likely to result from new scientific breakthroughs rather than from a slow accumulation of minor improvements. There is ample evidence to support this thesis. Hybrid vigor in plants, the farm tractor that made possible replacement of animal power, selective chemical herbicides and the organic insecticides — all resulted from major breakthroughs. None of these could have been predicted in advance.

That additional major discoveries will be made, and at an accelerated rate, seems without question. Science is the new frontier which we have hardly started to exploit. Rapid basic discoveries in physics and other fields open the way to discoveries in the biological fields. Scientists are becoming better trained, the organized research approach is replacing the lone worker and greater effort is being placed on fundamental lines of research that will produce major advances.

Furthermore, it must be recognized that the strength of our present agriculture lies in our ability to combine practices and technological improvements and thereby achieve production levels that would be otherwise impossible.

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