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Constraints to Expanded Food Production: A North American Perspective

John T. Pierce

Owen J. Furuseth

JOHN T. PIERCE* and OWEN J. FURUSETH**

Constraints to Expanded Food Production: A North American Perspective

Over the past twenty years estimates of the potential growth in food production systems and long-term adequacy of agricultural resources at the national and international scale have varied considerably. A review of current literature shows an enormous ambiguity, with some analysts warning that the potential for increased agricultural output in the near future is limited,[1] and others foreseeing abundant opportunities for continued agricultural expansion.[2] Different assumptions regarding the importance of technological change account for some of this variation but much of the difference can be traced to varying assumptions regarding the absence or presence of economic and environmental costs and ultimately the role of institutional, resource, and environmental constraints on the food production system. Despite the recognition that resource and environmental conditions pose some restriction on potential food production, the relative and cumulative impacts of these factors have received only cursory attention.

The primary focus of this article is an analysis and evaluation of resource and environmental constraints as they affect the long-term productive capacity of North American agriculture. These constraints have both natural and man-induced origins, which are often interconnected. Such factors as soil depth, thermal and moisture conditions, and quantity of arable land are critical natural resource limits in crop production, whereas loss of agricultural land to urbanization and climate modification are critical man-induced constraints. Additionally, many of the environmental constraints associated with the growth in food production, such as soil erosion and salinization, are man-induced. Consequently, it is the basic contention of this article that because so many of the constraints facing the food production system are man-induced, there is nothing inevitable about them. Inefficient and environmentally harmful resource

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*Department of Geography, Simon Fraser University, Burnaby, B.C.

**Department of Geography & Earth Sciences, University of North Carolina at Charlotte

1. U. S. DEP'T. AGRIC. NATIONAL AGRICULTURAL LANDS STUDY, FINAL REPORT (1981); W. FLETCHER & C. LITTLE, THE AMERICAN CROPLAND CRISIS (1982); Sampson, *Saving Agricultural Land: Environmental Issue of the 1980's,* 2 THE ENVIRONMENTALIST 332 (1982).

2. Castle, *Market Performance and the Adequacy of Agricultural Land* in THE CROPLAND CRISIS: MYTH OR REALITY? 231 (P. Crosson, ed. 1982); Fischel, *The Urbanization of Agricultural Land: A Review of the National Agricultural Lands Study,* 58 J. LAND ECON. 236 (1982); J. SIMON & H. KAHN, THE RESOURCEFUL EARTH (1984).

allocation has both its roots and solutions in society's institutions. Improvements in markets, pricing, research, and education affecting agricultural systems, as well as changes to the political and jurisdictional base, are all possible and feasible.

Our discussion begins with a brief overview of the factors and interrelationships which frame the adequacy of agricultural resources. This is followed by a ranking over time of the most significant resource and environmental issues in terms of their probable impact on the expansion of food production. Finally, the paper considers the importance of institutional factors in ameliorating the impact of resource and environmental constraints.

THE ADEQUACY ISSUE

The demand for food and fiber in relation to the productive capacity of an agricultural system ultimately determines the adequacy of the land resource base and the domestic "food security" of a nation, as demonstrated by Figure 1.[3] The productive capacity is a function of the growth in productivity and of existing and potential land resources. The quality and quantity of existing and potential reserves of cropland are, in turn, affected by three sets of constraints: institutional, resource, and environmental. If food and fiber demands can be met by the existing resource base, then economic and environmental costs are minimized and the supply of land is viewed as adequate. But if demand cannot be met because of resource limits, environmental degradation, or institutional barriers to the allocation of resources, then environmental and economic costs will increase and the adequacy issue will arise. It is the balance between the growth in demand for agricultural products and the growth in supply which determines the economic and environmental costs associated with increases in production.

Although land resources are an essential element in the adequacy formula, other production factors are equally critical. One author has noted that the adequacy of agricultural land resources "cannot be determined independently of the cost and productivity of land relative to the costs and productivities of other factors."[4] In the United States, for example, non-land factors such as labor and capital contribute approximately four times as much to the total value of agricultural production as does land.[5]

3. Food security refers to the capability of the agricultural system to meet society's expected food needs during the immediate and long-term future.

4. Crosson, *The Cropland Crisis, Myth or Reality?*, THE CROPLAND CRISIS, MYTH OR REALITY? 3 (P. Crosson, ed. 1982).

5. STAFF OF SENATE COMM. ON AGRICULTURE, NUTRITION, AND FORESTRY, AGRICULTURAL LAND AVAILABILITY, 97TH CONG. 1ST SESS. [hereinafter cited as SENATE COMM. ON AGRIC.], Agricultural Land in National and Regional Economies 11, 28 (Huffman) (Comm. Print 1981).

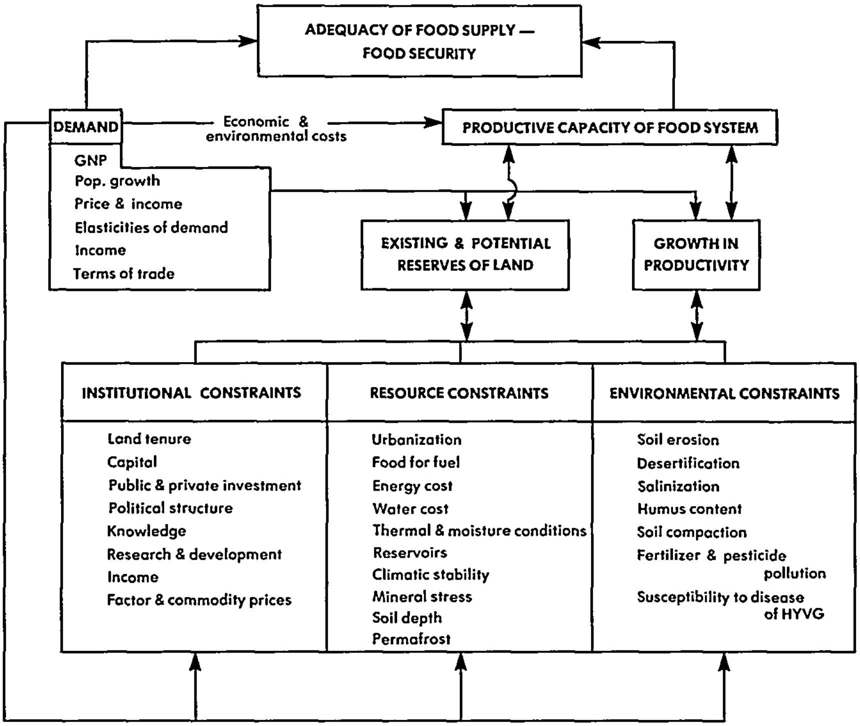

FIGURE 1. FACTORS AFFECTING ADEQUACY OF FOOD SUPPLY

Moreover, during the past thirty years, growth in agricultural productivity has been more important to expanding productive capacity than have additions to the cropland base. Therefore, changes in agricultural productivity have acted as a pivotal factor in the determination of the need for additional land resources.

There is no overwhelming evidence that either yields or total agricultural productivity has plateaued, but there is a growing recognition that land-substituting inputs such as fertilizers and high-yielding grains are losing their cost effectiveness, and the rate of growth in agricultural technology is slowing. Within this environment, the relative scarcity of land resources has become an important issue. One author argues "there is no simple way of projecting the cropland area for the remainder of the century, much less of assessing its adequacy."[6] Nevertheless, some per-

6. L. BROWN, THE WORLDWIDE LOSS OF CROPLAND 33 (1978).

spective into the adequacy of our cropland base and food production potential may be gained by comparing the interrelationships of the key components of food security, including demand or population growth, existing and potential reserves of land, and growth in productivity. In fact this has already been done in some detail for North America,[7] so that our task here is to provide a brief outline of the likely need for cropland continentally and globally.

The phenomenal growth in global food production during the last thirty years can be traced to the adoption of high-yielding grain varieties; the availability of cheap energy for use in irrigation, mechanization, and other fossil-fuel based technologies; favorable credit conditions; and relatively stable climatic regimes. Between 1950 and 1980, world cereal production increased by 126 percent due largely to an 80 percent increase in yields.[8] During the same period world population grew by 76 percent.[9] The resulting demographic and production trends have meant a 29 percent increase in the availability of grain per person, from 251 kilograms to 324 kilograms, with an accompanying 45 percent decrease in cultivated area per person.[10] However, these global figures mask considerable regional variation including the growth of North America as the major source of grain production for the world export market. Prior to World War II, North America accounted for 20 percent of net exports in grains; by 1980 this figure had more than quadrupled to 87 percent.[11] The significance of these figures lies not so much in their illumination of the past, but in their implications for the future.

By the end of this century, world population is expected to grow by two billion, to a total of at least 6.2 billion.[12] Some have argued that this projected increase, combined with projected increases in per capita incomes, could almost double the demand for food. While this demand will undoubtedly be expressed in many forms, cereals production will clearly play a dominant role since it already represents 75 percent of food consumed and 66 percent of the arable land base.[13]

Assuming the continued importance of cereals, how will the increased demand through higher population levels affect cropland requirements? If population expands by the projected 40 percent and if per capita availability of grains, 324 kilograms per year, is to remain the same, then

7. Pierce & Furuseth, *Assessing the Adequacy of North American Agricultural Land Resources*, 14 GEOFORUM 413 (1983).
8. Brown, *World Population Growth, Soil Erosion, and Food Security*, 214 SCI. 995 (1981).
9. *Id.*
10. *Id.*
11. *Id.* at 998.
12. UNITED NATIONS, WORLD POPULATION PROSPECTS AS ASSESSED IN 1980 (1981).
13. Schaffer, *Insuring Man's Food Supplies by Developing New Land and Preserving Cultivated Land*, 16 APPLIED GEOG. & DEV. 7 (1980).

production will also have to increase by a proportionate amount. Let us also suppose that productivity levels remain constant at 1.89 metric tons per hectare.[14] In that case, by the year 2000 the production of cereals would need to reach 2009 million metric tons, requiring 1063 million hectares of cropland. This translates into a 40 percent rise in land resources from 758 million hectares. Increasing yield to two metric tons per hectare reduces the required area, but still necessitates a 33 percent increase in farmland, or 1004 million hectares. If we assume that cereal production's share of the arable land base will remain constant, 66 percent, then the total arable land base of the world will have to increase from its present level of 1.4 billion hectares to 1.6 billion hectares. Moreover, a doubling of demand for cereals under constant productivity would increase the cropland requirements another 1.4 billion hectares, an area equivalent to the present arable land base.

With these potential land requirements in mind, the question emerges, how much additional cropland is there? Estimates vary from 3.2 billion hectares[15] to 4.2 billion hectares.[16] Some analysts believe that North America alone could more than double its cropped area.[17] However, recent resource inventories and land evaluations reveal that North America contains comparatively little potential for cropland expansion. Canada, at most, has 5 million hectares, and the United States between 25 and 40 million hectares.[18] Both nations have the flexibility to increase their cropland reserves. The most likely sources for growth in new cropland would be a shift in land out of pasture and summer fallow, or an enlargement of the area under double cropping.[19]

While the physical capability to expand agricultural output exists, the economic costs of expanding the productive capacity of the system are likely to be formidable. In Canada, a 77 to 100 percent projected increase in cereal production by the year 2000 would necessitate a 21 to 57 percent real price increase.[20] Even these increases are conservative estimates, because they were premised upon high rates of gain in productivity and the use of most of Western Canada's summer fallow land. The United States Department of Agriculture's National-Interregional Agricultural Projections model estimates 20 percent real price increases by the year 2000 if production increases by 66 percent. More conservative projections

14. BROWN, *supra* note 8.

15. PRESIDENT'S SCIENCE ADVISORY COMM., THE WORLD FOOD PROBLEM (1967).

16. Revelle, *The Resources Available for Agriculture*, FOOD AND AGRICULTURE 113 (1976).

17. *Id.*

18. Pierce & Furuseth, *supra* note 7.

19. Boxley, Agricultural Lands: Prospects for Expansion (paper presented at the Annual Meeting of the Association of American Geographers, Washington, D.C., 1984).

20. These estimates of increased prices have been adjusted so as to discount the effect of inflation. AGRICULTURE CANADA, CHALLENGE FOR GROWTH, AN AGRI-FOOD STRATEGY FOR CANADA (1981).

estimate an additional 25.9 million hectares of land will be needed in the United States by 2010.[21]

The most critical element linking all of these cost estimates is that they are predicated on a future relatively free of major resource, environmental, and institutional constraints. The estimates fail to consider any environmental or social costs resulting, for example, from the growth in derived demand for agricultural land resources. The failure to account for or internalize these costs severely underestimates the real costs borne by society and raises serious questions regarding the value of the estimates for planning purposes.[22]

RESOURCE AND ENVIRONMENTAL CONSTRAINTS

Land Degradation

Land degradation including wind and water erosion, salinization and soil compaction, is clearly the most critical constraint facing North American agricultural productivity. In the United States, the Department of Agriculture (USDA) estimates that on non-federally owned lands about 6.5 billion tons of soil are displaced annually.[23] This is the equivalent of 17.5 million hectares losing a 1-inch layer of soil. During the last 200 years, one-third of the topsoil on United States cropland has been lost as a consequence of human-induced degradation. This translates into a 10 to 15 percent decrease in production potential.[24]

The full impacts of land degradation, and especially erosion, must be measured in both off-site and on-site terms if the real costs of the phenomenon are to be understood. The off-site damages of erosion are physically evidenced in clogged roadside ditches, degraded air quality, and sediment choked waterways. There is considerable effort and cost required to remedy these impacts. A 1982 study by the United States Congressional Office of Technology Assessment (OTA), for example, estimated that off-site erosion in the United States annually costs $60 million for dredging and $25 million for water treatment.[25] More importantly, these costs are

21. Plaut, *Urban Expansion and the Loss of Farmland in the United States: Implications for the Future*, 62 AM. J. AGRIC. ECON. 537 (1980).

22. P. CROSSON & S. BRUBAKER, RESOURCE AND ENVIRONMENTAL EFFECTS OF U.S. AGRICULTURE (1982). This is contingent in their view on real price increases of between 25 and 30 percent.

23. U.S. GENERAL ACCOUNTING OFFICE GAO/RCED-84-48, AGRICULTURE'S SOIL CONSERVATION PROGRAMS MISS FULL POTENTIAL IN THE FIGHT AGAINST SOIL EROSION (1983) [hereinafter cited as GAO].

24. Pimentel, Terhune, Dyson-Hudson, Rochereau, Samis, Smith, Denman, Reifschneider & Shepard, *Land Degradation Effects on Food and Energy Resources*, 194 SCI. 149 (1976). Production potential refers to the physical output that could have been achieved given current technology but in the absence of eroded topsoil.

25. Reported in GAO, *supra* note 23, at 8.

expected to increase in the near future as larger quantities of agriculturally marginal and more erosion-prone land are cultivated and agricultural cropping patterns change. Projections for the years 1977–2010 from Iowa State University's Center for Agriculture and Rural Development (CARD), based on a sediment delivery model, indicate a doubling of the amount of sediment delivered to U.S. waterways during the next twenty-five years.[26]

Less apparent than the off-site damage but more significant to future agricultural development is the on-site damage that erosion can have on the productivity of cropland and rangeland through the loss of plant nutrients, and a reduction in rooting depth, soil nutrients, and water retention capacity. The difficulty in trying to develop large-scale estimates of the impacts to soil productivity caused by erosion is that technology masks these costs in the short-term. Even if excessive erosion does not immediately affect crop yields, it requires farmers to apply larger quantities of additional costly inputs, including inorganic fertilizers, hybrid seeds, irrigation, and lime to substitute for soil loss. The OTA estimates, for example, that American farmers currently spend between $1 and $4 billion a year to replenish lost soil nutrients.[27]

An equally serious problem in defining on-site impacts is that a relationship between erosion and productivity can only be quantified for one soil, in one place, and for one given climatic condition. Therefore, the relationship observed in one situation may or may not occur elsewhere as a consequence of changes in the variables. In an effort to quantify the impact of soil erosion on future American agricultural productivity, while considering this restriction, the USDA has developed a broadly based yield-soil loss simulation model. The data employed in the model were derived from over one thousand county soil surveys in twenty-one water resource regions. Using this framework, the researchers estimated that if the current level of erosion is allowed to continue on the 117.5 million hectares included in the model, erosion would cause a reduction of productive capacity equivalent to the loss of 9.3 million hectares of cropland or eight percent of the total base area.[28]

Another USDA estimate, derived by a linear extrapolation of current rates of erosion, using a 1.01 billion tons loss in excess of two tons per hectare, projects a much higher loss in productivity.[29] The combined effect of water and wind erosion on cropland is estimated to produce a .5 million "hectare-equivalent" loss annually. Consequently, over the next fifty years up to 25 million hectare-equivalents could be lost, assuming the 1977

26. CROSSON, *supra* note 4, at 186.
27. GAO, *supra* note 23, at 8.
28. Pimentel, *supra* note 24.
29. *Id.*

erosion rate is continued.[30] Using a different approach, it has been estimated that if 1977 rates of erosion continued for the next 100 years, then yields could be expected to decline by 5 to 10 percent.[31] These estimates would change if the cropland base were expanded to accommodate more marginal land. In this regard, it has been estimated that the cropland base would have to expand by 24 to 28 million hectares under conditions of high demand, high input prices, and slow pace of technological change.[32] Cropland erosion, in turn, would be 80 percent above 1977 levels.

In a recent review of productivity effects of cropland erosion, it is concluded that as long as the area cropped remains constant, the effect on production costs of 1977 rates of erosion over the next 100 years would "continue to be small relative to the effects of rising demand, input prices, and technological advance."[33]

While the American concern for soil degradation is focused primarily on erosion, the Canadian perspective is broader. Both wind and water erosion are viewed as serious concerns, but the consequences of acidification and salinity are considered as important.[34] Unlike the United States, in Canada there have been no nationwide efforts to assess the magnitude and to evaluate the impact of land degradation. A very general picture of land degradation has been provided by Agriculture Canada, based upon a review of geographically disparate and often highly specialized studies of land degradation.[35] Estimates of water and wind erosion vary considerably by region, depending upon slope, soil conditions, crop type, and frequency and intensity of rainfall. In western Canada, erosion rates are very high. This is especially the case in those areas practicing summer fallow methods rather than continuous cropping methods. Summer fallowing is also associated with the problem of dryland salinity. Through saline seep, water charged with naturally occurring salts moves downward and laterally to discharge areas, and leads to an accumulation of salts detrimental to most crops. In Saskatchewan, Canada's major wheat producing province, 1.6 million hectares of cropland are affected by saline seep. The area of saline soils is increasing at approximately one percent per annum.[36] The total impact upon yields of these and other

30. Hectare-equivalents provide a general measure of the comparable number of hectares that are lost in production through declines in output. If yields decrease by ten percent in an area of one thousand hectares, this would be equal to one hundred hectare-equivalents.

31. Larson, Pierce & Dowdy, *The Threat of Soil Erosion to Long-Term Crop Production*, 219 SCI. 458 (1983).

32. CROSSON & BRUBAKER, *supra* note 22.

33. P. CROSSON & A. STOUT, PRODUCTIVITY EFFECTS OF CROPLAND EROSION IN THE UNITED STATES 66 (1983).

34. F. BENTLEY, AGRICULTURAL LAND AND CANADA'S FUTURE (1981).

35. D. COOTE, J. DUMANSKI & J. RAMSEY, AN ASSESSMENT OF THE DEGRADATION OF AGRICULTURAL LANDS IN CANADA (1980).

36. Rennie, *The Drop in Soil Productivity: Who Will Pay the Price?* in ARABLE LAND: THE APPROPRIATE USE OF A SCARCE RESOURCE 9 (Centre for Human Settlements, University of British Columbia 1978).

sources of soil degradation such as soil compaction and acidification are difficult to predict. Land degradation has contributed to an estimated 40 percent decrease in yield potential.[37]

Most recent estimates suggest that the total soil loss from wind and water erosion in the Canadian prairies is approximately 277 million tons per year.[38] This is equivalent to a yearly yield reduction of 71,600 tons of wheat. Using the annual rate of loss in production, it is calculated that in the sixty-five years during which prairie soils have been farmed the area has lost approximately 14 percent of total crop production averaged for the years 1969–1978. Interestingly, although the lost production has been offset by increased fertilizer use and the use of improved technology, "the recovery of yield is dependent on good growing conditions and will probably be limited to approximately 85 percent of potential yields."[39]

In central and eastern Canada, water erosion is also an important concern. For wide-row crops such as corn and beans, maximum erosion rates vary from 5 tons per hectare annually on level ground to 7.5 tons per hectare on moderately sloping ground. Despite the high rate of soil loss in Ontario and the relatively shallow depth of soils, comparatively little concern has been expressed by government agencies.[40] The problems of eastern Canada include relatively high levels of atmospheric pollutant fallout—acid rain, soil erosion, compaction, and subsidence. The sources of man-induced acidification in eastern Canada's soils are acid rain, 40 percent, and fertilizer, 60 percent.[41] While the precise effects of acidification on Canadian agricultural productivity are not documented, data for the northeastern United States indicate that diminished crop yields, up to 50 percent for selected vegetable crops, and changes in agricultural cropping patterns result from increased acid rain.[42]

Competition for Agricultural Land

There is a measure of agreement that land alienation has increased during the past twenty-five years, although there is little consensus beyond this starting point. Research estimates of the quantity, quality, and intensity of land consumed vary considerably as do the spatial and temporal scales, sampling frameworks, definitions, and general coverage. Not surprisingly, projections of future rates of land conversion display similar vicissitudes.

The most widely cited source of cropland alienation information is the *Potential Cropland Study*, prepared by the Soil Conservation Service.[43]

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37. BENTLEY, *supra* note 34, at 13.
38. PRAIRIE FARM REHABILITATION ADMINISTRATION, LAND DEGRADATION AND SOIL CONSERVATION ISSUES ON THE CANADIAN PRAIRIES (1983).
39. *Id.* at 112.
40. COOTE, DUMANSKI & RAMSEY, *supra* note 35.
41. *Id.*
42. *Id.*
43. U.S. SOIL CONSERVATION SERVICE (SCS), POTENTIAL CROPLAND STUDY (1977).

The study reported that between 1967 and 1975, 2.18 million hectares of cropland were converted to urban, built-up, transportation, and water uses, or an average annual conversion rate of 272,500 hectares. These figures have been disputed by some researchers,[44] while supported by others.[45] More conservative estimates suggest that the annual rate of conversion of cropland is around 183,400 hectares.[46] The most recent estimates of urban and built-up uses in the United States support these more conservative estimates.[47] Urban and built-up areas within the United States currently appear to be in order of 19 million hectares, compared to the 1977 estimates of 26 million hectares.[48]

The importance of competition from urban and built-up land uses as a constraint is expected to decline during the mid and long-term time horizon. This lessening is a result of the near completion of the interstate highway system, the slowdown in reservoir development, and the slowing of population growth in the United States. As a consequence of these factors, the need for agricultural land is expected to be less, relative to demand for agricultural land during the past fifteen years.

Currently, there is no comparable research on the impact of urban growth and built-up land uses in Canada. Two studies have, however, documented the quantity, quality, and intensity of land lost to urban development for cities over 25,000 between 1966 and 1976.[49] The average annual conversion was 14,940 hectares, with the rate of loss declining during the last half of the period.[50] While the Canadian rate of conversion is, in purely quantitative terms, smaller than the American rate, the loss in qualitative terms is far more serious. Proportionally, much of Canada's best agricultural resources lie within the shadow of Canadian urban centers.[51] Consequently, the net loss in agricultural output to urbanization is far more important in Canada than in the United States, and it remains a serious constraint in the short and mid-term future.

Energy

Energy impacts the agricultural system in three ways: on-farm impact of higher energy costs; exploitation of agricultural land and water for

44. Fischel, *supra* note 2, at 238; Simon & Sudman, *How Much Farmland is Being Converted to Urban Use?*, 7 INTER. REG. SCI. REV. 257, 258 (1982).

45. Douring, Chicoine & Braden, *Evaluating Agricultural Land Use Change in Illinois*, 37 J. SOIL WATER CONS. 259, 261 (1982).

46. Spaulding & Heady, *Future Uses of Agricultural Land for Non-Agricultural Purpose*, 32 J. SOIL & WATER CONS. 88 (1977).

47. Boxley, *supra* note 19.

48. *Id.*

49. ENVIRONMENT CANADA, RURAL TO URBAN LAND CONVERSION (Occ. Paper No. 16) (1977); ENVIRONMENT CANADA, THE URBANIZATION OF RURAL LAND IN CANADA 1966-1971 AND 1971-1976, (Land Use in Canada Series No. 20) (1981).

50. *Id.*

51. V. NEIMANIS, CANADA'S CITIES AND THEIR SURROUNDING LAND RESOURCES (Canada Land Inventory Rep. No. 15) (1979).

energy development; and the use of agricultural land for energy production.[52] While these impacts are discrete, they are also interrelated.[53] Thus, a sharp rise in petroleum prices, reflecting greater scarcity, could result in a triggering of all three consequences.

The on-farm impact of increasing energy prices on Canadian and American agricultural production has been a serious concern since the 1973–74 oil embargo. This concern arises from the energy intensive character of our agricultural system. Each of the three major physiological needs (food, water, and protection) in plant and animal husbandry is increasingly satisfied by energy intensive management systems and production inputs.[54] Despite fears that higher energy prices would disrupt agricultural output, economic analyses in the United States have shown that higher real prices for energy and petroleum-based inputs are not likely to depress agricultural production nor sharply increase food and fiber costs.[55] Instead, the most likely impact would be a modest shift in agricultural land use. One analysis suggests that a doubling in energy prices would bring a 22 percent drop in irrigated land in the United States, and a slight drop in nitrogen fertilizer and pesticide use.[56]

Canadian policy analysts are less sanguine. Rising petroleum-based agricultural inputs costs are viewed as a threat to the full development of Canada's agricultural resources. Although direct energy input represents a small value, roughly six percent of the final product, the successful development of the Canadian agricultural industry is a product of relatively cheap direct and indirect energy supplies.[57] Without significant reserves of land as in the United States, the rise in relative prices for essential inputs will make resource substitution difficult. Despite the fact that no quantitative analysis is provided, one federal government report warns that price increases for energy, energy embodied inputs, and transportation related costs are constraints on increasing agricultural output.[58]

A second consequence of higher energy prices is the exploitation of agricultural land and water for energy development. The major concern is the surface or strip mining of coal on agricultural land, with a secondary issue revolving around the diversion of water resources to coal and petroleum mining requirements. This type of energy concern is not shared by both nations; it is an American concern. Currently, 606,000 hectares

52. SENATE COMM. ON AGRIC., *supra* note 5, Competition for Agricultural Land to the Year 2000 103 (Boxley) (Comm. Print 1981).

53. *Id.*

54. C. Benbrook & A. Hildebaugh, The Economic and Environmental Consequences of Agricultural Land Conversion, (National Agricultural Lands Study Tech. Paper XIV) (1982).

55. *Id.*

56. D. DVOSKIN & E. HEADY, U.S. AGRICULTURAL PRODUCTION UNDER LIMITED ENERGY SUPPLIES, HIGH ENERGY PRICES, AND EXPANDING AGRICULTURAL EXPORTS (Iowa St. Univ. Center for Agric. & Rural Dev. ((CARD)), CARD Rep. No. 69, 1976).

57. Furniss, *Energy Demands of Agriculture,* 13 CAN. FARM ECON. 8 (1978).

58. AGRICULTURE CANADA, *supra* note 20.

of land in the United States are disturbed by surface coal mining.[59] If United States Department of Energy goals for increasing domestic coal production are reached, an additional 121,000 to 404,000 hectares would be stripped by surface mining by 2000, with another 606,000 to 808,000 hectares lost permanently to more than 800 new coal and nuclear power plants and related facilities.[60] Much of the land used for strip mining would be reclaimed for productive use.[61] Nonetheless, in any single year between now and 2000, approximately 229,500 hectares will be either in coal production or undergoing reclamation.[62]

The major impacts of surface mining include the short-term loss in agricultural output, the permanent loss in productivity associated with the reduced agricultural capability of reclaimed lands, and the water quality problems associated with surface mining. Some analysts warn that the latter problem may be the most serious because of the lack of cost-effective technology to cleanup mine related water pollution.[63]

Water diversions for energy production, usually considered to mean shale oil and coal mining, would also seem unimportant to agricultural production, at least if viewed individually. Research examining water requirements for energy mining operations in various portions of the Rocky Mountain region reached similar conclusions.[64] Energy development would cause minor disruptions in some localized areas, but not affect large-scale agricultural output to any serious degree.[65] The OTA, for example, concluded that the "effects on the farming industry should be small, especially compared with the effects of competition for labor and the purchase of farmlands for municipal growth."[66]

A final impact of higher energy prices is the increased use of agricultural lands for energy production, in other words, the production of grains for alcohol (ethanol) distillation rather than for human and animal consumption.[67] Again, this is primarily an American concern; Canadian policy-

59. Esseks, *Nonurban Competition for Farmland* in FARMLAND FOOD AND THE FUTURE 49 (M. Schnepf, ed. 1979).

60. Barse, *Agriculture and Energy Use in the Year 2000: Discussion from a Natural Resource Perspective,* 59 AM. J. AGRIC. ECON. 1973 (1977).

61. *Id.*

62. Raup, *Competition for Land and the Future of American Agriculture* in THE FUTURE OF AMERICAN AGRICULTURE AS A STRATEGIC RESOURCE 41 (S. Batie & R.G. Healy, eds. 1980).

63. Brewer & Boxley, *The Potential Supply of Cropland,* THE CROPLAND CRISIS, MYTH OR REALITY? 93 (P. Crosson, ed. 1982).

64. McMartin, *Western Coal: Energy vs. Agriculture,* 36 FARM RESEARCH 12 (1979); J. LIPPE & R. PETTY, EFFECTS OF ENERGY DEVELOPMENT AND PRODUCTION ON AGRICULTURAL WATER REQUIREMENTS (1980); N. Whittlesey, Agricultural Impacts of Oil Shale Development, U.S.D.A. Natural Resource and Economic Development Working Paper 46 (1978); CONGRESSIONAL OFFICE OF TECHNOLOGY ASSESSMENT, IMPACTS OF TECHNOLOGY ON U.S. CROPLAND AND RANGELAND PRODUCTIVITY (1982).

65. CONGRESSIONAL OFFICE OF TECHNOLOGY ASSESSMENT, *supra* note 64.

66. *Id.*

67. Sampson, *Land for Energy or Land for Food?,* 12 ECOLOGIST 67 (1982).

makers view this as a moot issue, given Canadian petroleum supplies.[68] With the temporary surplus in global petroleum supplies, and the concurrent drop in domestic gasoline prices and change in energy policies in the United States, the political attractiveness and economic viability of creating a billion gallon ethanol industry has declined during recent years. In light of the large number of uncertainties, it has been counselled that projecting future agricultural land requirements for production of grain for ethanol production is hazardous.[69] This is wise advice, particularly given the political dimensions of the program. It is possible, however, to estimate the potential land use impacts given various levels of ethanol production. With current technology, a bushel of corn produces 2.67 gallons of ethanol.[70] Taking into account the grain by-products produced in making ethanol from corn, it was calculated that the production of two billion gallons of ethanol would require 2,222,000 hectares of cropland, or .001 hectares for each gallon of alcohol produced.[71]

Therefore, assuming these projected yield ratios, each one percent substitution of ethanol in the United States gasoline market, at a 10 percent blend ratio, would require 1,111,000 hectares of "fuel growing" cropland. Clearly, a large-scale ethanol industry would impact the United States agricultural system.

Water Availability and Cost

There is growing recognition that constraints on the availability of water resources threaten not only the potential for expansion of irrigated agriculture, but also the continued maintenance of existing irrigation activities. As water costs increase because of decreasing water tables, rising energy costs, use of non-renewable water supplies, and increased competition from urban and industrial uses, the opportunities for maintenance of the status quo, let alone expansion in irrigated acreage, are slim. At present approximately 11 percent of U.S. farmland is irrigated, compared to 1.7 percent for Canada.[72] While a reduction in the availability of water for irrigation would affect agricultural opportunities throughout North America, the impact would be most pronounced in the western United States, roughly west of the 100th meridian. About 83 percent of the U.S. irrigated area is in these seventeen western states.[73]

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68. *Id.*
69. SENATE COMM. ON AGRIC., *supra* note 52, at 172.
70. *Id.*
71. *Id.* at 170.
72. Davis, *Economic and Environmental Effects of Regional Water Limitations* in RESOURCE CONSTRAINED ECONOMIES: THE NORTH AMERICAN DILEMMA 96 (Proceedings of the 34th Annual Meeting of the Soil Conservation Society of America) (1979).
73. K. FREDERICK & J. HANSON, WATER FOR WESTERN AGRICULTURE (1982).

The availability of low cost and relatively abundant water for irrigation has enabled the western states to diversify from an agricultural economy focused on rangeland agriculture and dryland farming to an agricultural base increasingly dependent on irrigation. Irrigation has permitted the creation of new agricultural land by opening up areas that are, under normal conditions, too dry. Irrigation has created an additional 4 to 5.3 million hectares of agricultural land in the western United States.[74] In 1977, irrigated agriculture encompassed approximately 20 million hectares of agricultural land in the western states, or about six percent of the total agricultural land in the region.[75] For land used as cropland, however, the reliance on irrigation is even more critical. In 1978, more than 80 percent of the harvested cropland in California, Arizona, and Nevada was irrigated with 45 to 80 percent of the harvested cropland in Idaho, Wyoming, New Mexico, and Utah also dependent on irrigation water.[76]

Irrigated lands have significantly higher yields per hectare than non-irrigated areas, and also tend to produce higher value crops. As a consequence, the irrigated portion of the agricultural base generates a disproportionate share of agricultural income. In 1980, cash receipts from farm marketing in the seventeen western states were $59.3 billion.[77] This is approximately 43 percent of the income derived from farming in the United States.[78] Forty-one percent of U.S. agricultural exports in 1980–81 were produced in this region.[79] At the present time, the availability of "surplus" water for expanded irrigation in the western United States is reaching limits throughout the region. Total water use exceeds stream flow in twenty-four of the region's water resource subregions, with most of the remaining twenty-nine subregions exhibiting little excess between stream flow and total water use.[80]

A second and increasingly important source of irrigation water is groundwater. For the past several decades, the growth in western irrigation has been based on the development of groundwater resources. Between 1950 and 1975, groundwater withdrawal had increased by 300 percent, and the mining of groundwater has accelerated.[81] Mining, the process of withdrawing water at a rate faster than recharge, exceeds 22.4 million

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74. *Id.*

75. U. S. DEP'T. AGRIC., SOIL CONSERVATION SERVICE, NATIONAL RESOURCES INVENTORY, BASIC STATISTICS (1980).

76. CONGRESSIONAL OFFICE OF TECHNOLOGY ASSESSMENT, WATER-RELATED TECHNOLOGIES FOR SUSTAINABLE AGRICULTURE IN U.S. ARID/SEMIARID LANDS (1983).

77. *Id.*

78. *Id.*

79. *Id.*

80. FREDERICK & HANSON, *supra* note 73, at 79.

81. *Id.* at 212.

acre-feet per year in the western states.[82] Mining produced 40 percent of the groundwater used for irrigation in 1975, and allowed the irrigation of 4.3 million hectares.[83]

In spite of enormous quantities of groundwater being mined, the physical supply of water stored underground is not threatened with depletion in any western resource subregion during the foreseeable future.[84] However, the economically feasible supply of groundwater for a low value use such as irrigation is threatened by overdrafts of aquifers and higher energy costs in several important agricultural areas. The most notable among these is the Ogallala aquifer region, extending from South Dakota to Texas and New Mexico.

The greatest threat to western irrigation comes from the growing demand for water from non-agricultural sources in this water scarce region. It has been projected that irrigation water consumption will decline by three percent from 1975 to 1985, and another three percent over the last fifteen years of this century.[85] In contrast, water consumption for all other purposes is expected to rise by 55 percent.[86] Irrigated agriculture is unlikely to acquire large amounts of new water, and probably will be losing control of some increment of the resource in the near future because it is a low value user of water that has benefitted from government subsidies and past preferential institutional arrangements.

Climatic Change

Most researchers would agree that much of the impressive gain in the productivity of cereals in the post-war era can be linked to relatively stable, favorable weather conditions. However, evidence continues to accumulate which forewarns an end to this climatological normality. For example, a recent Environmental Protection Agency report expresses concern that the build-up of carbon dioxide (CO_2) and other "greenhouse" gases, including methane, chlorofluorocarbons, and nitrous oxide, are substantially raising average global temperatures.[87] Linked to this concern over warming trends is the international concern over changes in the global hydrological cycle.[88]

While most observers discount any attempts to make detailed forecasts on agricultural geography of a future, warmer earth, several highly re-

82. *Id.* at 82.
83. U.S. WATER RESOURCES COUNCIL, THE NATION'S WATER RESOURCES 1975-2000: SECOND NATIONAL WATER ASSESSMENT 20 (1978).
84. FREDERICK & HANSON, *supra* note 73, at 8.
85. U.S. WATER RESOURCES COUNCIL, *supra* note 83.
86. *Id.*
87. U.S. ENVIRONMENTAL PROTECTION AGENCY, CAN WE DELAY A GREENHOUSE WARMING? (1983).
88. ATMOSPHERIC ENVIRONMENT SERVICE, UNDERSTANDING CO_2 AND CLIMATE ANNUAL REPORT 1982-83 (1983).

garded computer forecasts are in agreement on a number of regional climatic variations which will likely accompany global warming. Two of these climatic shifts critically affect North American agriculture. First, the effect of increased CO_2 levels in the atmospheric circulation pattern will most probably result in a general poleward movement of agricultural zones.[89] Temperature increases in higher latitude areas could be as much as two to five times the global average.[90] Second, increases in precipitation may also occur.[91] As a result of the lengthened growing season, increased summer temperatures, and increased soil moisture in northern latitudes, agricultural development will be permitted in currently agriculturally marginal areas in Northern Canada.

Increased CO_2 levels may also create warmer and drier conditions in a broad band of land across western Canada and the United States, including the Prairies Provinces of Alberta, Saskatchewan, and Manitoba, the Great Plains and Midwest of the United States.[92] It has been postulated that the "southern Rocky Mountains or the Sierra Watershed regions could also be (similarly) seriously affected."[93] If the climatic models are correct, the climate in the United States "corn belt" could become a dry prairie, with insufficient summer rainfall to support forest growth.[94] The hot, dry summer of 1980 may be typical for the western two-thirds of the United States during the next century.[95]

The impact of this climatic shift on the North American and global agricultural outlook would be devastating. Warmer and drier climates would significantly affect the productivity of important cereal crops. A 1° Centigrade increase in temperature leads to a two percent reduction in the United States corn yield.[96] Similarly, other studies estimate that a 1.5° Centigrade temperature increase and a 10 percent decline in mean pre-

89. NATIONAL ACADEMY OF SCIENCES, FOOD AND NUTRITION STUDY (1977); Bach, *The Potential Consequences of Increasing CO_2 Levels in the Atmosphere*, in CARBON DIOXIDE, CLIMATE AND SOCIETY 141 (J. Williams, ed. 1978); Schneider, *Climatic Limits to Growth: How Soon? How Serious?*, *id.* at 219; H. FLOHN, LIFE ON A WARMER EARTH, POSSIBLE CLIMATIC CONSEQUENCES OF MAN-MADE GLOBAL WARMING (1981); Hansen, Johnson, Lacis, Lebedeff, Lee, Rind & Russell , *Climate Impact of Increasing Atmospheric Carbon Dioxide*, 213 SCI. 957 (1981) [hereinafter cited as Hansen].

90. Hansen, *supra* note 89, at 964.

91. Manage & Wetherald, *On the Distribution of Climatic Change Resulting from an Increase in CO_2 Content of the Atmosphere*, 37 J. ATMOSPHERIC SCI. 117 (1980).

92. Manage & Wetherald, *id.* at 11; Bach, *supra* note 89 at 152; Hansen, *supra* note 89, at 222; Schneider, *supra* note 89, at 965; FLOHN, *supra* note 89, at 38; W. BACH, J. PANKRATH & J. WILLIAMS, INTERACTION OF ENERGY AND CLIMATE (1980); W. KELLOGG, EFFECTS OF HUMAN ACTIVITIES ON GLOBAL CLIMATE (1977); Butzer, *Adaptation to Global Environment Change*, 32 PRO. GEOG. 269 (1980).

93. Schneider, *supra* note 89, at 222.

94. W. KELLOGG & R. SCHWARE, CLIMATE AND CHANGE AND SOCIETY (1981).

95. Hansen, *supra* note 89, at 965.

96. Biggs & Bartholic, *Agronomic Effects of Climate Change*, in PROCEEDINGS OF THE SECOND CONFERENCE OF CLIMATIC IMPACT ASSESSMENT PROGRAMS (A.J. Broderick, ed. 1973).

cipitation would reduce United States corn yield in the Midwest by approximately 10 percent, and Canadian spring wheat by approximately four percent.[97] Canadian government studies similarly indicate that a "combined 3°C temperature rise and 20 percent reduction in soil moisture indicate potential cereal grain yield losses of 19 percent for wheat, 14 percent for oats, and 11 percent for barley."[98]

These data provide some insights into the singular impact which might result from a warmer-drier agricultural future. Research carried out by the Institute for Ecology (TIE) is, perhaps, more instructive in that it explores larger scale effects.[99] The TIE research examined the impact of various climatic variations on North American grain output assuming a constant 1976 crop area and 1973 technology. One of the climatic scenarios used was 1933–36, a period marked by the warmest and driest summers in this century and not unlike forecasts for the next fifty year period. The effects of a replication of 1930s' weather, assuming current agricultural land and technology, would include a loss in production of 71 million metric tons or the equivalent of 27 percent of the combined 1976 U.S. corn, wheat, sorghum, and soybeans output and an 8 million metric ton loss in Canadian wheat production, the equivalent of 47 percent of the 1975 output.[100] Related research assuming current technology suggests that a return of the 1933–36 weather would reduce current Canadian wheat production to two-thirds of the 1970s' yields.[101]

Moreover, the negative consequences of CO_2 buildup on North American agricultural output may be further exacerbated by several combined actions or synergisms. First, these climatic shifts affecting North America may also occur in large portions of central Asia[102] and, perhaps, in western Europe.[103] Subsequently, cereal production in the Soviet Union, Peoples Republic of China, and, perhaps, the European Economic Community, could suffer losses paralleling or exceeding North American losses. Second, increased temperatures may increase the frequency and severity of pest and plant disease outbreaks, resulting in adverse impacts on agricultural output.[104] Third, warmer and drier growing conditions would necessitate increased amounts of water and energy resources in order to sustain existing levels of output. Greater agricultural use of water and

97. Shaw, *Climate Change and the Future of American Agriculture*, THE FUTURE OF AMERICAN AGRICULTURE AS A STRATEGIC RESOURCE 251 (S.S. Batie & R.G. Healy, eds. 1980)

98. ATMOSPHERIC ENVIRONMENT SERVICE, *supra* note 88.

99. INST. OF ECOLOGY, IMPACT OF CLIMATIC FLUCTUATION ON MAJOR NORTH AMERICAN FOOD CROPS (1976).

100. *Id.*

101. Gillespie, *Climatic Variability,* AGROLOGIST 28 (1977).

102. Hansen, *supra* note 89, at 965; Butzer, *supra* note 92; Bach, *supra* note 89, at 150.

103. BACH, PANKRATH & WILLIAMS, *supra* note 92; H. FLOHN, *supra* note 89.

104. Pimentel & Pimentel, *Dimensions at the World Food Problem and Losses to Pests*, WORLD FOOD, LOSSES AND THE ENVIRONMENT 1 (D. Pimentel, ed. 1978).

energy resources runs counter to trends discussed earlier, and would further preempt the application of these resources for expanding agricultural output. Finally, the potential for accelerating land degradation, especially through desertification and salinization, is greatly enhanced if this climatic scenario is realized.

The projections associated with climatic change do not convey a sense of security for North America's agricultural future. The climatic change constraint is considered in our analysis with the utmost caution because of the enormous ramifications for agricultural production and the scientific debate and caveats surrounding the reliability of these projections. Nevertheless, the considerable scientific evidence of increasing levels of CO_2 resulting in alterations in global climatic conditions cannot be dismissed or ignored. If the scientists and studies cited previously are correct, this most critical constraint to North American agricultural production over the long-term will be beyond society's ability to control or easily ameliorate.

Synopsis

The dynamic character of the resource and environmental constraints underscores the difficult mix of problems North American society must overcome in the future to meet the expected increases in the demand for food. Exactly how these constraints will change over space and time is, of course, more in the realm of conjecture than testable theory. But the preceding discussion has provided sufficient direction and focus to justify sketching a synopsis of the change in the absolute and relative importance of five constraints over the mid and long-term. Although the magnitude of the constraints is scaled arbitrarily, their initial ranking and change over time reflect the findings from the analysis (Figure 2).

Land degradation and competition for agricultural land represent significant constraints to agricultural production during the short-term. So long as land contributes a sizeable proportion to existing production, threats to that base, either qualitatively or quantitatively, are bound to have an influence. During the mid to long-term, competition for agricultural land will decline in absolute and relative importance, whereas all of the other constraints are expected to increase in importance. Both declining rates of population growth overall and the continued increasing importance of growth in agricultural yields, related to increases in agricultural technology, explain this lower ranking.

The dramatic rise in the importance of climatic change is in response to the warming and drying trend projected by a number of scientists. Throughout much of the cereal producing regions of North America a decrease in precipitation and an increase in temperature will constrain yields considerably. Similarly, increases in the real cost of energy, more

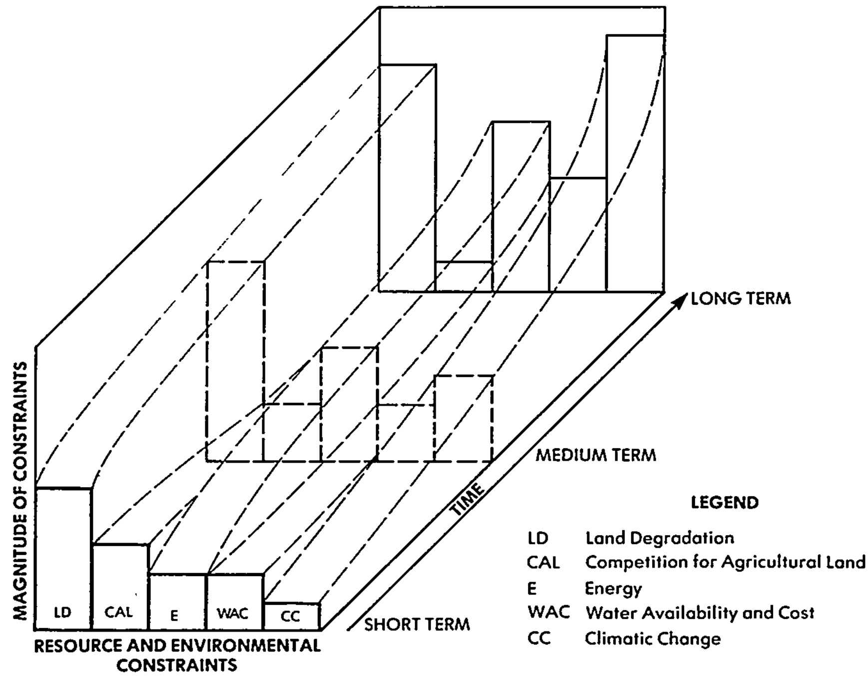

FIGURE 2. CHANGES IN IMPORTANCE OF RESOURCE AND ENVIRONMENTAL CONSTRAINTS IN AFFECTING FOOD PRODUCTION.

reliance upon energy intensive agriculture, and anticipated increases in the need for groundwater supplies for irrigation because of drier climatic conditions will make energy and water availability and pricing ever more important components and constraints in the future of North American agriculture. Land degradation is also expected to increase in absolute importance because of continued reliance by both countries on expanding exports of grains to earn foreign exchange and because the income position of farmers is not expected to improve appreciably.

Paralleling the change in the importance of the individual constraints are new, evolving, interactive or synergistic effects whose outcome may be greater than the sum of their constituent parts. Exemplifying this synergism are the interactive effects between climatic change, energy, and water availability. If climatic trends create drying trends, more irrigation will be required, as will more energy to sustain that irrigation system. Hence one factor, a decrease in moisture, may trigger a round of secondary consequences.

INSTITUTIONAL PERSPECTIVE

While the preceding discussion has painted an uncertain future for North American agriculture, it must be emphasized that there is nothing inevitable about these resource and environmental constraints. There exist within the current societal framework the mechanisms to address these problems. Because the adequacy of food supply over the long-term is dependent upon harmonizing demand and supply relationships, new institutional arrangements which address legal, research, financial, economic, and ecological concerns for improved management and allocation of agricultural resources are required. One perceptive commentator on water use in agriculture notes "It seems we are destined to confuse inadequate incentives and obsolete institutions with physical scarcity."[105] While not denying the existence of physical limits in the system, it is critical to recognize the potential advantages and need for change in our current institutional framework. Unless change is forthcoming we will have great difficulty sustaining current rates of growth in production and, hence, fall short in meeting expected future demands for food and fiber.

One step in this direction has been the recommendation by analysts that North America reduce food exports. Currently, one-third of all agricultural land in the United States is devoted to production for export.[106] Because of the importance of the export market to North American agriculture in terms of planted acreage and resource commitments, some have argued that a reduction in that market would mitigate a number of resource and environmental pressures.[107] While this argument has merit and deserves attention, it certainly cannot serve as a "best" solution for, not only would it deprive North America and the world of many benefits, it would create a whole new set of costs and problems. The alternative then is to change the institutional context within which these problems occur. In order to fully understand the difficulty of modifying the institutional structures affecting environmental and resource issues, a perspective on current institutional arrangements is valuable.

The problems of land degradation and water supply are classic cases of both market and non-market forces combining to produce the externalizing of costs to society in both an offsite and inter-generational context. The origins of land degradation in the form of soil erosion can be traced to a variety of direct and indirect government subsidies to encourage expanded production in marginal areas; the role of the market in encouraging the production of highly erosive crops, such as corn and soybeans; the pursuit of maximum, as opposed to optimal, returns; the

105. Castle, *Agriculture and Natural Resource Adequacy,* 64 AM. J. AGRIC. ECON. 811, 814 (1982).

106. SENATE COMM. ON AGRIC., *supra* note 5.

107. CROSSON & BRUBAKER, *supra* note 22.

undervaluing of agricultural land; inadequate funding for soil conservation improvement; and poor management strategies. Although the problem is reasonably well identified, there is little agreement as to what is a socially acceptable level of erosion and what are the best ways to bring into line the social benefits and costs of remedial measures.

In regard to the first issue, the use of T-values or tolerable levels of soil erosion has increasingly come under attack as a standard or guide. There is no consideration given to weighing the cost of lost production from soil erosion against the cost of remedial measures. It has been suggested that an alternative to the use of T-values as a standard to justify intervention is to employ a cost criterion in which the present (discounted) value of lost production be compared to the present (discounted) value of the cost of either conservation programs or improvements in yield through research and development.[108] This is clearly a difficult task since it requires an accounting of all costs of production through time.

In terms of the second issue, balancing costs and benefits, there are a variety of incentive and disincentive strategies, commonly referred to as the "carrot and stick" approach, aimed at achieving soil conservation.[109] Still the question remains, who should pay and in what proportion? It has been argued that if one wishes to protect the rights of future generations the costs of conservation should be broadly borne.[110] This is already the case to some degree, since current soil conservation programs are in the form of cost sharing through the Soil Conservation Service and Agricultural Stabilization and Conservation Service.[111] Because these programs are voluntary, the soil conservation districts with the worst erosion problems do not always attract the requisite funds, and these funds are not always spent on the most efficient projects. There are, of course, other approaches that could be adopted. The concept of cross compliance, for example, involves bestowal of additional benefits from federal programs on farmers who practice soil conservation, and the removal or reduction of benefits for those who do not.[112] Reduction in property taxation could also be used as an incentive to conserve soil resources.

It is clear that a variety of programs and measures will have to be pursued to achieve long-term sustainable agricultural production. The growth in the use of zero and minimum tillage[113] and the increased rec-

108. CROSSON & STOUT, *supra* note 33.

109. Timmons, *Protecting Agriculture's Natural Resource Base,* 35 J. SOIL & WATER CONS. 5 (1980).

110. CROSSON & BRUBAKER, *supra* note 22.

111. Timmons, *supra* note 109.

112. Benbrook, *Integrating Soil Conservation and Community Programs,* 34 J. SOIL & WATER CONS. 160 (1979).

113. Zero tillage represents planting of crops without disturbing surface soil and plant material. Minimum tillage is a planting strategy which avoids, as much as possible, disturbance of surface soil.

ognition and acceptance of the notion of the real social costs in many production decisions are positive signs. But public funds will be required commensurate with the problem, a notion which has become less politically acceptable during the past fifteen years. This is evidenced by the pattern of recent public expenditures. Between 1970 and 1977, total and federal net capital investment in permanent soil conservation improvements declined in real terms.[114]

The situation in Canada is much more rudimentary. There are no systematic studies of land degradation on a provincial or national level and an organizational framework for the management of soil erosion, equivalent to the United States Soil Conservation Service, does not exist. This is the partial result of the belief that the problem is not as serious in Canada as in the United States. Support for this position comes from data such as the lower rate of water erosion risk for much of the Canadian cropland compared to American cropland. In contrast, however, the average soil depth in much of the Canadian cropland is shallower than in cropland to the south.

Increasingly, the problems of dryland salinity have been attacked by a variety of research and educational programs and federal-provincial agreements for the subsidization of tests to discover the dynamics of dryland seep. This, coupled with the reduction in the use of summer fallow, are promising trends. Unfortunately, participation in soil conservation programs created by the Prairie Farm Rehabilitation Administration is entirely voluntary. The most recent and comprehensive national assessment of the land degradation problem warned that "[o]n the whole, little is currently being undertaken by way of preventative or ameliorative measures."[115]

An equally difficult resource issue is how to improve the efficiency and equity of water use in agricultural production. Irrigated agriculture is the largest single user of water in North America, accounting for 83 percent of U.S. and 46 percent of Canadian water consumption. But as a low value user generating a small return per unit of water input, irrigated agriculture is a popular target for reduced allocations.[116] In the United States, the Reclamation Act of 1902 set the stage for extensive use of water resources for agriculture as its primary objective was development oriented.[117] Today, with increasing competition for water resources from non-agricultural sources and increasing environmental degradation, the pressure for change is great.

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114. Timmons, *supra* note 109.

115. Coote, Dumanski & Ramsey, *supra* note 35, at vii.

116. Davis, *supra* note 72.

117. Schilfgaarde, *Water Conservation Potential in Irrigated Agriculture*, Resource Constrained Economies: North American Dilemma 219 (Proceedings of the 34th Annual Meeting of the Soil Conservation Society of America) (1978).

At the heart of the matter is pricing of water resources. Water resources are a very heavily subsidized input in the agricultural production process. Instead of water being priced at its marginal cost, it is often priced many times below cost, contributing to over-consumption. Groundwater tends to be pumped at levels well in excess of social efficiency.[118] As it has been noted:

> as long as farmers pay only a small fraction of the social value of water, do not bear the costs of their own additions to salt loads, and expect the federal government to pay most of the costs of structural solutions, their response to rising salinity levels will be largely to press for government investments to provide quality water.[119]

If more realistic pricing is in order, how will it be achieved? It will be more difficult to achieve greater efficiency through higher prices, as we have in the case of energy, because of the distributional and political characteristics of water rights.[120] Therefore, research into changes in riparian rights, managing common property groundwater resources, improvements in the use of energy, and the drainage of irrigated waters are priority areas for improving efficiency. There are, however, other complex issues and tradeoffs that reliance upon the market for pricing solutions may not address. For example, since irrigated agriculture is a land conserving technology, any reduction in the growth of irrigated area through increased price for water would, all other things equal, require greatly expanded rainfed farmland in order to offset the loss in production potential. If efficiency in the use of water grows commensurate with the cost for water, then the shift to rainfed areas will not become a significant issue.

Clearly, research and technology, the cost of energy, and public and private funding will play an increasingly important role in affecting the productivity of North America's irrigated and rainfed farmlands. The fact that productivity growth can be partitioned into genetic factors, a function of research and development, and technological factors, a function of energy intensive inputs, is worth stressing.[121] Because North American agriculture is already highly energy intensive and there is increasing evidence of declines in the marginal productivities of energy inputs, greater emphasis will need to be placed upon the genetic factor for increasing productivity. In other words, a science-based system of agriculture will have to replace a resource-based system. The importance of

118. Socially efficient levels of consumption of water occur when the benefits exceed the costs by the greatest margin. Where water is priced too low, excessive quantities are consumed resulting in a misallocation of a scarce factor of production.

119. Frederick, *Irrigation and the Adequacy of Agricultural Land*, THE CROPLAND CRISIS: MYTH OR REALITY? 117, 149 (P. Crosson, ed. 1982).

120. Castle, *supra* note 105.

121. Jenson, *Limits to Growth in World Food Production*, 201 SCI. 317 (1978).

sustained public funding for research into the genetic side is critical. It is unlikely that public expenditures for research will grow by more than three percent per year, which has been translated into a total productivity growth of one percent per year.[122] Unless energy prices decrease and the real price of commodities increases relative to the cost of factors of production, there is little chance that we can sustain our former high level of growth in productivity of the 1960s and early 1970s.

Although the specter of scarcity is hardly approaching the shores of North America, the relative lack of public investment in both Canada and the United States, and the lags involved in any genetic engineering program, will mean a heavy dependence on a resource-based agricultural system. Given this dependence, land could very well play an increasingly important role in the production process. Consequently, securing adequate protection of that land resource base for future generations, while balancing valid alternative uses of the land as well as individual property rights, has been one of the genuine challenges in the equitable allocation of land by state and provincial governments. The various policy responses have been well documented.[123] The anticipated decline in the non-agricultural demand for cropland over the mid and long-term should not serve as a source of complacency for resource and land use planners. At present the relatively large crop and land surpluses and payment-in-kind programs in the United States contradict the notion that farmland is scarce and in need of protection. Until we can convincingly demonstrate the existence of an economically and ecologically sound technology and mode of production which further reduces the importance of land, as energy-intensive machinery and fertilizers did in the post-war era, then protection of farmland is an important risk-aversion approach.

Complicating our ability to assess the magnitude of the resource and environmental constraints generally is the risk of major climatic change, as discussed earlier. Different temperature and hydrological changes require different resource responses, producing varied environmental impacts. The importance of understanding the resource implications of climatic change is a first priority. Other important strategies with respect to climatic change include methods for slowing the increase of carbon dioxide and programs aimed at increasing the resilience of plants to changes in moisture, pest populations, and thermal conditions. Unlike most of the other previously discussed constraints, the problem of climatic change is truly international in its scope, which clearly does not bode well for prompt

122. Ruttan, *Agricultural Research and the Future of American Agriculture*, THE FUTURE OF AMERICAN AGRICULTURE AS A STRATEGIC RESOURCE 117 (S. S. Batie & R. G. Healy, eds. 1980).

123. R. COUGHLIN & J. KEENE, THE PROTECTION OF FARMLAND: A REFERENCE GUIDEBOOK FOR STATE AND LOCAL GOVERNMENT (1980); Furuseth & Pierce, *A Comparative Analysis of Farmland Preservation Programmes in North America*, 26 CAN. GEOG. 191 (1982).

action. Nationally, funding for CO_2 climate related research for 1982–83 was approximately $25 million (Canadian dollars) in the United States, and $800,000 in Canada.[124]

FINAL ASSESSMENT

Attempts to minimize economic and environmental costs of expanded food production are worthwhile and attainable goals for North American society. The institutional response to resource and environmental constraints in agriculture will determine ultimately how successful society is at achieving these goals. While the market will remain the principal institutional means for the allocation of agricultural resources, a variety of public policies and programs can also play a critical role in achieving food security. The design and administration of those policies and programs will be challenging, given the dynamic and interactive character of the constraints and the numerous jurisdictions involved. And their effectiveness will depend as much upon expanded research into resource and environmental issues as it will upon reconciling the numerous trade-offs involved, particularly between present and future generations.

124. ATMOSPHERIC ENVIRONMENT SERVICE, *supra* note 88.