SUSTAINABILITY OF AGRICULTURAL PRODUCTION UNDER IRRIGATION

Cesáreo Landeros-Sánchez, José H. Rodolfo Mendoza-Hernández and David Palma-López
Graduate College in Agricultural Science, Mexico

Keywords: Aquifer, agroecosystem, agriculture under irrigation, chemigation, environmental changes, irrigation, nitrogen contamination, pesticide contamination, salinity of agricultural lands, sewage irrigation, soil erosion, soil salinity, sustainable agriculture, waste water, water management, water quality, water resources.

Contents

UNESCO – EOLSS SAMPLE CHAPTERS

Summary

Irrigation has historically been viewed as a mechanism for stabilizing agricultural productivity by overcoming problems associated with drought and allowing for crop diversification. Despite the increased production, diversification, and associated economic benefits they bring, the sustainability of irrigation is questioned. This is largely due to its sometimes detrimental effect on the environment (waterlogging, soil salinity, and groundwater contamination). The fundamental cause of water quality problems with irrigation of agricultural lands is the lack of water management or poor management at farm level.

The environmental changes caused by agriculture under irrigation are manifested as deforestation, climate changes, extinction of vegetal and animal species, soil loss by erosion, soil salinity, soil sodicity, water contamination, contamination of aquifers, plant and animal genetic modification, and the appearance of new illnesses in humans caused by agrochemicals.

Sustainable agriculture may be defined as the activity oriented to produce food in a suitable quality and quantity using practices that conserve natural resources and guarantee food security for the world. Land use, crop choice, irrigation, and fertilization are accomplished in such a way that the soil is not depleted over time. This generally

implies organic farming techniques, which have many advantages.

This article considers how agriculture under irrigation can become a sustainable activity. To achieve this, policy and institutional improvements are important but the failure to recognize water as a social, economic, and life-sustaining good constitutes a major obstacle to such changes. Future management policies must reflect this basic reality by integrating goals for social welfare, environmental integrity, and economic development with corrected valuation and pricing. It is also very important in many countries to create a water culture, with the aim of improving irrigation infrastructure programs and water management at plot level.

1. Introduction

Sustainable agriculture is the activity oriented to produce a suitable quality and quantity of food in a way that preserves agroecosystem resources and guarantees food security for the world (see *The Role of Food, Agriculture, Forestry, and Fisheries in Human Nutrition*).

It is said that in sustainable agriculture, land use, crop choice, irrigation, and, fertilization are accomplished in such a way that the soil is not depleted over time. This generally implies organic farming techniques. Although more expensive, this type of farming has many advantages, for example:

- Farm land can be used for a very long time, without eroding or deteriorating beyond what is called the “geologic rate” of erosion.
- Crops and the environment are not poisoned by pesticides and other toxic chemicals.
- Trace minerals are not depleted from the soil, so the crops are nutritionally superior; and
- All food produced in this way tastes better.

When primitive humans changed from a nomadic to a settled way of life, agriculture became their preponderant activity. This in itself caused an alteration to the ecological equilibrium of their habitat and its surroundings, involving the use and transformation of natural resources in a more intensive form, and produced a transcendental change in the primitive way of life.

In the course of agricultural development, new methods and techniques for agriculture were developed in order to increase crop yields and satisfy the food and fiber demands of a growing population (see *Research in Food, Feed, and Fiber Production*). On the other hand, natural resources such as soil, water, flora and fauna came under considerable pressure from an increasing population and the agriculture that gave rise to it. In more recent times this phenomenon has led not only to the development of new methods and techniques for improving agricultural production, but also to the elaboration and use of organic and inorganic agrochemicals. In the early stages of agriculture there were few such substances, but at present they exist in great numbers and have a complex composition. It is estimated that around 70 000 agrochemical products are nowadays used to improve the quantity and quality of agricultural

UNESCO – EOLSS SAMPLE CHAPTERS

production. However the use of these products has caused damage to agricultural lands, which is manifested by processes such as salinization (see *Drainage of Irrigated Lands*), heavy metal contamination, and concentrations of organic compounds that take many years or decades to dissipate. Such new methods and techniques, and the excessive use of agrochemicals in agriculture, have thus contributed significantly to the deterioration and contamination of soil, water, atmosphere, and biodiversity (see *Impacts of Agriculture on Human Health and Nutrition*).

When humans became aware of the degree of deterioration and contamination that can now be observed in the environment, they started to develop and use new technologies and organic and inorganic products for agricultural use. The purpose of this was on the one hand, to mitigate the accumulated damage inflicted on the environment since the beginning of agriculture, and on the other, to preserve environment resources.

In spite of the severe damage that has been caused to the environment, agriculture has to be continued in order to guarantee food security for the world. Some years ago it was thought that the problem of feeding humanity had been solved through the appliance of science to agriculture. This led to the use of techniques of genetic improvement, plant production *in vitro*, and the use of a huge variety of chemical products. All this produced an immediate and explosive increase in harvest volumes obtained in the field (the Green Revolution), but also gave rise to irreversible damage to natural resources and to the ecological system as a whole. As a direct result of these actions, vast areas of agricultural land have become unusable for food production.

In the period since the Green Revolution, scientists, researchers, field technicians, farmers, and pro-ecology communities have come to understand that it is essential to preserve as much as possible of the environment so as to guarantee humanity's existence on the globe for future generations (see *Interdisciplinary and Sustainability Issues in Food and Agriculture*).

A sustainable agriculture is one that can provide for humankind's needs. These needs in the future, as in the past, will not be static. An agriculture that is sustainable today will likely not be relevant tomorrow. An agriculture that relied upon the draft horse in the early twentieth century in the United States might have been considered sustainable in its day, but soon became obsolete.

UNESCO – EOLSS SAMPLE CHAPTERS

2. The Current Situation of Agriculture under Irrigation

Irrigation has historically been viewed as a mechanism for stabilizing agricultural productivity by overcoming problems associated with drought and allowing crop diversification to occur (see *Irrigation Systems: Techniques and Technology*). It makes possible increased production, diversification, and associated economic benefits. Water resources and irrigation development have played a major role in human development throughout history. Most of the growth in food production needed to meet population increases over the past four decades has resulted from an expansion of the irrigated area (see *Distribution of Irrigated Lands and Water Consumption*). The world's 260 million irrigated hectares of land (2.6 million km^2, which is a sixth of the world's cropped land) now produces more than a third of the world's food supply. Irrigation, however, also introduces major changes in the environmental and socioeconomic conditions of these areas. In the process, the existing equilibrium is disturbed and over time, new conditions are established, with the underlying premise that they satisfy humankind's objectives better than those prevailing previously. Nevertheless, questions have arisen as to whether irrigation is capable of sustaining high levels of agricultural production in the longer term without damaging the environment.. This is largely due to its sometimes detrimental effects on the environment (waterlogging, soil salinity, and groundwater contamination). It is important that the long-term environmental effects of irrigation be understood if negative impacts on soil and water are to be avoided.

While contributing to the economic well-being of many countries, then, irrigation also has potential negative effects that have been known since ancient times, as attested to by the archaeological evidence of failed irrigation systems. The excess of soluble salts (i.e. salinity) remains the most pervasive water quality problem associated with irrigation, affecting about a third of all irrigated land.

In the United States, about 28% of irrigated land suffers from depressed yields due to salinity, which affects plant growth by reducing water uptake as a consequence of the high osmotic potential of high salt concentration in water. Ions such as sodium, chloride, and boron may also be toxic to plants and animals. Recently, high selenium levels in irrigation return flows in the central valley of California have resulted in higher toxicities in migratory birds using wetlands in areas receiving irrigation and drainage. Irrigation water provides a driving force for the downward leaching of chemicals; hence the amount of water applied may affect the movement of chemicals to groundwater.

The problems of water quality associated with irrigation differ for surface and subsurface return flows. Surface runoff from excess irrigation usually has increased concentrations of sediment and sediment-associated chemicals; slightly higher salt levels; increased but variable levels of pesticides, fertilizer nutrients, and bacteria; and increased amounts of crop residues and other debris. Drainage water that has moved through the soil profile will have much higher salt concentrations, little sediment or sediment-associated chemicals, and generally increased nitrate and soluble pesticides.

The fundamental cause of water quality problems associated with irrigation of agricultural lands is the lack of water management or poor management at farm level. Bacterial, nitrate, and pesticide contamination are other water quality concerns which are of relatively recent origin and have not been addressed adequately (see *Water Resources: Quality and Supply*).

In the northeast of Mexico, for instance, fertilizer and pesticide contamination in irrigated crop lands is relatively high due to an excess application of these agrochemicals. It is reported that 85 tons of agrochemical active substances and 82 000 tons of fertilizers are annually applied to an area of 200 000 hectares (2000 kn^2). Contamination of nearby estuaries by pesticide may account for the great volumes of dead fish that have been found there, and it is suggested that these pollutants are also responsible for muscle paralysis in humans. As regards excess fertilizers, it is believed that they are the cause of a phenomenon called "red tide," which is another cause of the death of fish and molluscs.

UNESCO – EOLSS SAMPLE CHAPTERS

The delivery of fertilizers and pesticides in irrigation water using a chemigation system is an efficient and growing practice. When used in conjunction with a drip irrigation system, it offers the promise of greatly reducing chemical contamination of drainage systems.

The long-term effect of irrigation on soil chemical and physical properties that affect soil productivity requires quantification. Irrigation encourages continuous cropping of land, which can have beneficial effects on soil properties. Improved yield and increased organic matter levels have been observed under long-term irrigated rotations. Irrigated production has also been shown to increase the total nitrogen and carbon content of soil in cases where these values were low in the native condition. Further work is required to document the long-term changes in soil properties brought about by irrigation.

-
-
-

TO ACCESS ALL THE **18 PAGES** OF THIS CHAPTER,
Visit: http://www.eolss.net/Eolss-sampleAllChapter.aspx

Bibliography

Bolt G.H. and Bruggenwert M.G.M. (1981). *Soil Chemistry A. Basic Elements.* Developments in Soil Science Series, 5a, Amsterdam, the Netherlands: Elsevier. [This includes basic topics on soil chemistry such as transport and accumulation of soluble soil components; chemical equilibrium and soil formation.]

Bouwer H. (1987). Effect of irrigated agriculture on groundwater. *Journal of Irrigation and Drainage Engineering.* **113**, 4–15. [This presents information on water quality problems caused by irrigation.]

Conservation Foundation. (1986). *Agriculture and the Environment in a Changing World Economy.* Washington, DC: Conservation Foundation. [Provides information about the influence of a changing world economy on agriculture and the environment.]

Crosson P. (1981). *Conservation and Conventional Tillage: A Comparative Assessment.* Ankeny, IA: Soil Conservation Society of America. [This provides a comparative appraisal study between soil conservation methods and conventional tillage.]

Deevey E.S., Rice D.S., Rice P.M., Vaughan H.H., Brenner M., Flannery M.S., *et al.* (1979). Mayan urbanism: impact on a tropical karst environment.. *Science*, 298–306. [This presents some issues of Mayan civilization and its impact on the tropical environment.]

Hall, G.F., Logan T.J., and Young K.K. (1985). Criteria for determining tolerable erosion rates. *Soil Erosion and Crop Productivity* (ed. R.F. Follett and B.A. Stewart), pp. 173–188. Madison, WI: American Society of Agronomy. [This describes how tolerable erosion rates can be determined.]

Lal R. (1987). Effects of soil erosion on crop productivity. Chemical residue company, critical reviews. *Plant Science.* **5**, 303–368. [This provides information on crop yield reduction due to erosion.]

Mannering J.V. (1979). *Conservation Tillage to Maintain Soil Productivity and Improve Water Quality.* Cooperative Extension Service Publication AY-222, W. Lafayette, Indiana: Purdue University, [This shows that conservation tillage can reduce erosion as much as 90% and improve water quality.]

Owens L.B. and Watson J.P. (1979). Rates of weathering and soil formation on granite in Rhodesia. *Soil Science Society of America Journal* **43**, 160–166. [This presents information on soil formation rates.]

Pereira L., Gillies J., Jensen M., Feddes R., and LeSaffre B. (1996). Research agenda on sustainability of water resource utilization in agriculture. *Sustainability of Irrigated Agriculture*, pp. 1–16. NATO ASI series. Kluwer Academic. [This presents research needs on sustainability of the use of water resources in agriculture.]

Skogerboe G.V. (1990). A global view of the future development of irrigated agriculture. *Visions of the Future*. (Proceedings of the Third National Irrigation Symposium held in conjunction with the 11th Annual International Irrigation Exposition, Phoenix, Arizona, 1990), pp. 187–192. Michigan: American Society of Agricultural Engineers. [This presents a view of the future development of agriculture under irrigation.]

Wolter H. and Kandiah A. (1997). Harnessing water to feed a hungry world. *International Commission on Irrigation and Drainage Journal* **46**(1), 1–21. [Emphasizes the role of water in guaranteeing food production for the world.]

Yaron D. (1981). The salinity problems in irrigation: an introductory review. *Salinity in Irrigation and Water Resources* (ed. D. Yaron), pp. 1–20. New York: Marcel Dekker. [Provides an elementary review of salinity problems in irrigated lands.]

Biographical Sketches

Cesáreo Landeros-Sánchez took his M.Sc. in Water Management (Agricultural Drainage) in 1987 at the Agricultural University of Wageningen, the Netherlands, and his Ph.D. in Water Management oriented to Water Table Fluctuation and Solute Redistribution in 1995 at Silsoe College, Cranfield University, UK. He is currently Research Professor at the Graduate College in Agricultural Science, Mexico, Veracruz Campus, where was he previously Assistant Director and Associate Researcher. He has also served as Teaching Researcher and Assistant Director at the College's Tabasco Campus, and as Coordinator of the College's CRECIDATH Regional Center. Among other academic awards, he achieved membership of the "CADOS" Level II, "Colegio de Postgraduados"(2000–2001) for teaching and research distinction, and of the "Cuadro de Honor" for obtaining an average grade of 9.2 at Chapingo Autonomous University, Texcoco, Mex. Mexico (1976–1977), and was National Researcher Candidate, SNI (1990–1992). He has authored 54 national and international publications, and is a member of the Mexican Association of Soil Science, SMCS and National Association of Irrigation Specialists, ANEI, A.C.

David Jesus Palma-López achieved his Master's degree and Doctorate, both with distinction, in Soils and Agronomic Sciences respectively, the former at "Colegio Superior de Agricultura Tropical," H. Cárdenas, Tabasco and the Graduate College in Agricultural Science, Mexico, and the latter at Polytechnical National Institute of Lorraine, Nancy, France. He was National Researcher Candidate, SNI (1988–1991), won the Tabasco State Engineering Award in 1997, and his contribution to Professional Performance in the Field of Science and Technology was recognized by the award by the "XIII Reunión Científica, Tecnológica, Forestal y Agropecuaria Tabasco 2000." He has undertaken academic work in the soils department of the "Colegio Superior de Agricultura Tropical," H. Cárdenas, Tabasco and the Graduate College in Agricultural Science. He has also served in the Head Office of High Education and Scientific Research, Government of Tabasco State, and at the United Nations Program for Development. He is currently Professor and Secretary (Deputy-head) at the Graduate College in Agricultural Science (Tabasco Campus). He has written 65 international and national publications. He is a member of the Mexican Association of Soil Science, SMCS; Mexican Association of Botany; French Association for Soil Study; International Humic Substances Society, IHSS; Research and Academic Council of Tabasco State, Mexico.

José H. Rodolfo Mendoza-Hernández gained his M.Sc. in Hydroscience at the Graduate College in Agricultural Science, Mexico, before taking posts in the National Services of Seeds Inspection and Certification (SNICS), Mexico, and the Shared Risk Fideicommissum (FIRCO), Mexico. He is currently Associate Researcher at the Graduate College in Agricultural Science, where he has twice won the annual award for outstanding research. He is the author of nine national and international publications, and is a member of the Mexican Association of Soil Science, SMCS.

UNESCO – EOLSS SAMPLE CHAPTERS