GEOSCIENCES, AGROECOSYSTEMS AND THE RECLAMATION OF DEGRADED LANDS

L. P. GOUGH, S. B. HORNICK and J. F. PARR

Introduction

Purpose

We examine the general topic of agrogeology as it relates to the improvement of agroecosystems (agricultural practices perceived as having some ecological stability) and the reclamation of degraded lands. Emphasis is placed on research trends and results from arid and semi-arid regions in both developed and developing countries, here exemplified by the U.S. and India. We elaborate on research areas perceived to be mutually beneficial and focus on ways to improve planning, coordination, and ecosystem consciousness of reclamation projects. Throughout, we discuss the possible linkages between the geosciences, agriculture, the ecological sciences and efforts to maximize production on lands being reclaimed.

Reclamation efforts

In the U.S., reclamation laws and efforts are concentrated on land that has been degraded due to mining, logging, road building, and urban development (Schaller and Sutton 1978). Unlike India, few areas in the U.S. are reclaimed for row crop production or other agricultural purposes except for the establishment of animal grazing lands (Halvorson *et al.* 1987). Indian wastelands are being created by land overuse brought about by pressures from the increased populations of people and animals. Overgrazing, fuelwood harvesting, soil erosion, desertification, and salinization from excessive and improper irrigation, are some of the forces that have accelerated Indian land degradation (Fig. 1). Land stabilization is the initial priority of reclamation in India, as it is in the U.S., followed by conversion to forestry, agroforestry, or row crop production. These management practices reduce the rate and extent of various degradative processes.

Ecosystem approach to reclamation

Although a strong interest in the conservation of our natural resources has been a priority in the U.S. for half a century, the integration of knowledge about ecosystems (which began to greatly expand in the mid-1960s) with agricultural and reclamation practices has been slow. The soil resources of countries worldwide are being severely and rapidly exploited by overgrazing, compaction, pollution, erosion, salinization, and desertification (Brown 1978). There is an urgent need to recognize the importance of overall ecological management in the establishment and maintenance of reclaimed lands.

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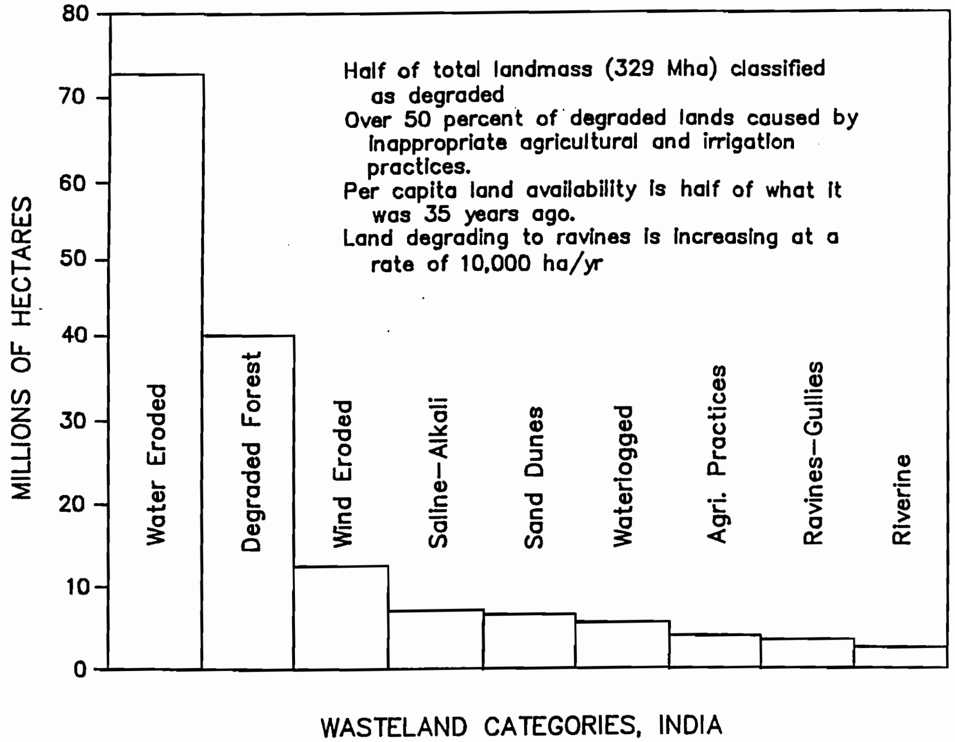

Fig. 1. Wasteland categories and estimated land area (from National Wasteland Development Board 1986, Sivaramakrishnan 1987, National Commission on Agriculture, Government of India, no date).

The perceived need for quick solutions to food shortages has resulted in long-term damage to many important agroecosystems (Papendick 1987). To paraphrase C.R. Wharton (1977), just as agricultural concerns can no longer be the exclusive property of agricultural scientists, awareness of ecological problems is no longer the sole responsibility of the ecologist. Reclamation of agricultural lands is truly becoming an integrated, multidisciplinary science with an ecological focus.

Background

Agriculture and agroecosystems

Agronomic investigations have been compartmentalized into research areas such as germplasm physiology, nutrient- and water-use efficiency, pesticide and herbicide requirements, and soil utilization. Such an approach has traditionally been concerned with maximizing yield often at the expense of the balance of the agroecosystem. In developed countries this has resulted in costly energy- and chemically-intensive agricultural practices.

Eight billion people will occupy this planet in 12 years, 1 billion of these in India alone; by 2050 India may surpass China as the most populated country with a population of 1.6 billion. A major challenge of agronomy and the geosciences is to assist in finding ways of improving the welfare of resource-poor farmers, while at the same time mitigating the consequences of unplanned land-use activities and increasing population pressures (Cooray 1988). Papendick (1987) states '. . . it is evident that present farming practices are resulting in extensive damage of soil and water resources, environmental degradation, and undesirable disruption of social structures.' Because of the growing concern for proper land-use strategies, organizations like the Institute for Alternative Agriculture[1] stress the adoption of low-cost, resource-conserving and environmentally-sound farming and reclamation methods. Conferences, such as the recently held symposium on the Role of Ecology in Sustainable, Lower Input Agriculture (Ecological Society of America, Columbus, Ohio, August, 1987), are becoming more popular.

Agriculture and famine

Innovative and productive agricultural practices have tempered world-wide famine predictions (Mellor and Gavian 1987). The 'green revolution' (the development of high-yielding cultivars) of the past two decades has been adapted and expanded within many developing countries (Swaminathan 1987). The consequences have been dramatic; countries such as India, China, and Bangladesh have recently become competitors in the world export grain market (Harrison 1987). International research facilities such as IITA (International Institute of Tropical Agriculture), ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), and ICARDA (International Center for Agricultural Research in the Dry Areas) have contributed significantly to the improvement of crop germplasm and dryland agricultural practices (Wade 1975). World food production has actually kept abreast of the burgeoning population growth (Harrison 1987). Nevertheless, it is estimated that India, for example, must double its current agricultural production of 0.86 tonnes per hectare (t/ha) by the year 2000 (Venkateswarlu 1985).

Unfavorable weather resulted in crop failures and food shortages in the Sahelian zone of Africa in 1983-85. It has been argued, however, that the actual famine was the result of civil unrest, ineffective government infrastructures, and the improper management of ground water, soils, and agrochemicals (Mellor and Gavian 1987). It is also noteworthy that post-harvest crop losses were significantly affected by improper harvesting, handling, sanitation, storage, crop drying, and distribution practices. Unfortunately, no matter how successful crop production and distribution become, some areas of the globe will probably always experience famine and malnutrition.

Modern agroecology

Agriculture and agrominerals

Agrogeology has traditionally emphasized the mapping and resource appraisal of agricultural minerals (*e.g.*, potash, phosphate rock, nitrogen sources, sulfur, and soil

[1] IAA, Inc., 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770

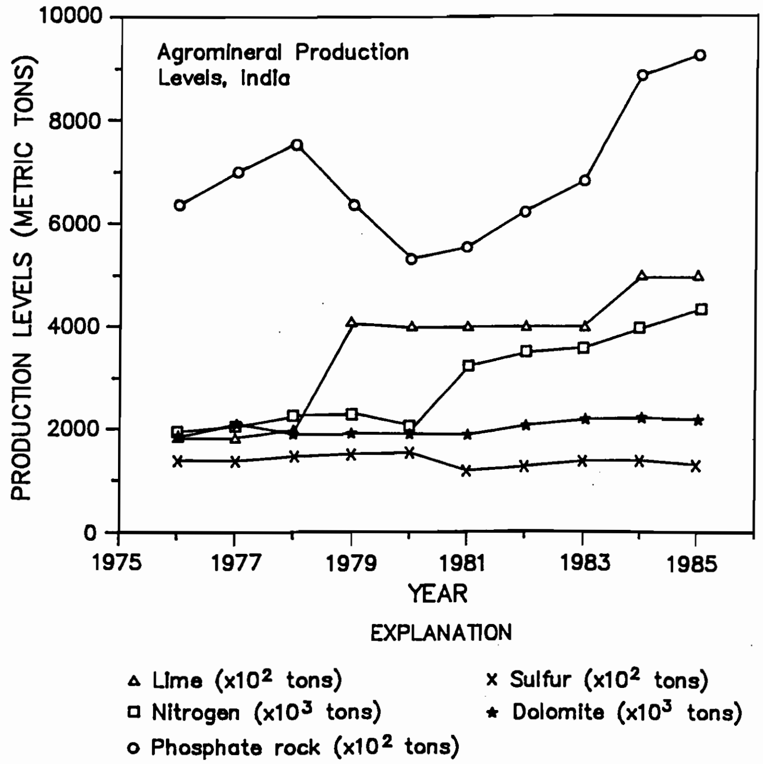

Fig. 2. Production trends of selected agrominerals in India between 1975 and 1985 (after Kinney and Shafer 1982, Kinney 1987).

amendment materials) (Fig. 2). This effort continues to be very important. Studies of surficial geology as they relate to the genesis and distribution of agricultural soils, such as loess, volcanic ash, and colluvium, have also been important research areas (Dhir and Singh 1985, Venkateswarlu 1987).

Wachira and Notholt (1987) predict that as much as a five-fold increase in chemical fertilizer use will be necessary in developing countries by the year 2000 if the world's population is to be adequately fed. In 1984, India ranked fourth in the world in the production and consumption of nitrogen and phosphatic fertilizers, and was a major importer of fertilizer raw materials and finished fertilizer (Kinney 1987). Despite this, the actual rates of nitrogen and phosphorus fertilizers applied by Indian farmers are relatively low compared with more highly developed agricultural countries.

Current research

In addition to agromineral resource appraisal efforts, opportunities exist for geoscientists to interface with the agricultural community at nearly all stages of land utilization, crop production, and reclamation. Some of the cooperative research areas are:

Remote sensing

Major advances have been made in methodologies for data acquisition and analysis and in remote sensing devices (Conant *et al.* 1983). Since Landsat 1 (formerly ERTS-1) was launched in 1972, scientists worldwide have used satellite data to inventory and monitor hydrology-related trends, agricultural lands, native vegetation, pollution plumes, and mineral resources. The U.S. has launched five Landsat satellites; Landsat 6 is scheduled for deployment in 1991. In addition to the multispectral scanners (MSS) of Landsat 1-5, Landsats 4 and 5 have thematic mappers (TM) which are more advanced scanners having greater spectral, radiometric, and geometric sensitivities. Although 2.6 times greater than MSS, the instantaneous field of view of the TM is only 30 m x 30 m. Commercially available TM resolution may soon be improved by a factor of 10 or more. Currently, the Earth Resources Observation Systems (EROS) Program, which is managed by the U.S. Geological Survey, gathers and disseminates a large proportion of the commercially available remotely-sensed data generated by both aircraft and satellites. India, through the National Remote Sensing Agency in Hyderabad, and the U.S. have worked cooperatively on projects involving EROS data, and data obtained from the European remote sensing satellite missions ERS-1 and ERS-2.

Land resource scientists are currently mapping and monitoring land degradation caused by wind and water erosion, salinization, flooding, deforestation, and sand dune encroachment (Siegal and Gillespie 1980). For example, in Kenya, Landsat imagery is being used to determine areas of overgrazing in relation to vegetation communities (Conant *et al.* 1983). Infrared imagery from MSS has been used to monitor the dispersion of oil spill patches and for changes in algal densities and communities resulting from nitrogen- and phosphorous-generated eutrophication (Spitzer 1986). Land use maps have also been prepared in some countries that provide estimates of available fuelwood biomass.

Minimally processed agromineral application

Unprocessed phosphatic and potassic carbonatites and igneous phosphatic rock can be applied directly to agricultural lands to improve soil fertility and productivity. There is renewed interest in this field, particularly in developing countries. In the tropics, where weathering rates are high, the addition of minimally-processed agrominerals can enhance the availability of micronutrient (trace) elements that are commonly depleted (Chesworth *et al.* 1983). Recently, a conference in Zomba, Malawi, focused on agroecosystems which utilize phosphate rock (PR) instead of phosphate fertilizers. Reports at the conference were divided into sections on geology and resource appraisals, beneficiation, and processing and application (Commonwealth Science Council 1987). Mechanisms to enhance the dissolution of phosphate from PR to make it more available for plant uptake include partial acidulation (Jaggi *et al.* 1987), micro-organism interactions (Goldstein 1986), and mixing PR with ion-exchangers (Lai and Eberl 1986), peat, or pyrite (Chesworth *et al.* 1983). For example, the International Fertilizer Development Center (IFDC, Muscle Shoals, Alabama) has conducted extensive research in sub-Saharan Africa, Latin America, and in some Asian countries on the use of partially acidulated phosphate rock as an inexpensive, locally available source of agricultural phosphorus (Hammond *et al.* 1986). Because the dissolution of partially acidulated PR depends, at least in part, on decreasing the pH of the PR/soil mixture, its use on degraded lands with oxidizing pyrite should prove promising, provided that plant growth is not impaired by an equilibrium pH that is too low.

Geochemistry

Geochemical surveys and process investigations are important in the preparation of atlases of biologically active elements in plants, soils, and water. The significance of geochemistry in plant nutrition studies has been recognized for several centuries. It is only within the last three decades, however, that geochemistry has emerged as an important consideration in reclamation. The mode of occurrence, mobility, and uptake of metals by plants in degraded and reclaimed soils continues to be investigated from both a deficiency and toxicity perspective (Wali 1979). The relation between geochemistry, agricultural practices, and human and animal health is also being investigated. This research area, however, involves many complex variables and the results are often inconclusive. Most studies in the past have been primarily concerned with micronutrient deficiencies or toxic element excesses in consumed food or water (Gough *et al.* 1979).

More recently, interest in geochemical investigations has focused on the nutritional quality of foods as affected by agronomic practices. Cultivar selection and post-harvest handling are major contributors to the nutritional quality of crops. Agronomic management practices affect geochemical and biochemical processes which, in turn, influence nutrient uptake and the physiological production of organic nutrients such as vitamins (Hornick and Parr 1987). Research is needed, however, to determine what combination of management practices, agroclimatic conditions, and crop cultivars will optimize the nutritional quality of crops.

Ground water contamination

The contamination of ground and surface water is also a high priority area for research by agrogeologists. Youngberg (1987) states: 'Contamination of America's ground water resources from agricultural chemicals – nonpoint source pollution – has rapidly emerged as one of this Nation's most urgent agricultural, environmental, and public health issues.' In the U.S. the problem of nitrate, organic pesticides, and trace-element contamination of ground water from agricultural sources has been documented for at least three decades.

Within the last few years, a strong public concern has emerged which is likely to result in future regulatory actions. Nearly all of the rural families in the grain belt of the U.S. obtain their domestic water locally from untreated shallow wells (Hallberg 1987). Under some conditions nitrate can be converted to nitrosamines, which have been implicated as possible carcinogens for humans (Keeney 1986). Nitrate in the gut of infants can form nitrite causing a reduction in the oxygen-carrying capacity of red blood cells. The maximum allowable concentration of nitrate nitrogen in U.S. drinking water is 10 mg/L which seems to be the threshold level that can cause methemoglobinemia in infants ('blue baby syndrome')(Goolsby 1987).

Ground water contamination is not just a public health problem, however, because it implies that agricultural chemicals are being used inefficiently, and often indiscriminately, causing waste and economic loss (Stokes and Brace 1988). The long-held belief that high-yield production can only be achieved through heavy application of agricultural chemicals is slowly changing within the developed and developing countries.

Our knowledge of the extent of pesticide pollution of ground water is minimal. The Agricultural Research Service (U.S. Department of Agriculture) recently initiated a multi-year plan to investigate the contamination of ground water by pesticides and nitrate.[2] The State of Iowa in cooperation with the U.S. Geological Survey, the U.S. Soil Conservation Service, and the U.S. Environmental Protection Agency, has formulated a state-wide pilot assessment of ground water contamination. In India there is a growing awareness of the adverse effects of pesticides in the environment; *e.g.*, concern brought on by the Bhopal disaster of December, 1984 (Buch 1985).

The importance of ground water contamination from using fertilizers and pesticides in land reclamation efforts is not well known. From a more pragmatic perspective, research to improve nutrient and pesticide use efficiency could help prevent or alleviate possible contamination problems. It has been shown that some reduction in the amount of fertilizer nitrogen applied to crops can actually increase their nutritional quality based on the vitamin C content (Hornick and Parr 1987). Thus, through improved management practices we can reduce our chemical inputs and maintain or increase nutritional quality while providing greater protection to our environment. By studying the many sustainable ('alternative') low-energy, low-fertilizer methods of Indian agriculture, the U.S. could gain valuable information on non-chemical weed and insect control practices that help to maintain acceptable crop yields without increasing agricultural pollution.

Agroecosystems and Reclamation

Land reclamation

In developing countries, industrial and mining activities and the absence of environmental protection practices, have led to the degradation of large, potentially important agricultural areas (Mann and Chatterji 1979). Research into ways of leaching, chelating, burying, immobilizing, or transporting specific industrial pollutants are being proposed (U.S. Dryland Farming Team Report 1987). In addition, poorly managed agricultural and irrigation practices, road building, and other activities have resulted in the degradation of an estimated 80 million hectares (Mha) in India alone. Dedicated land treatment systems offer considerable potential for relatively safe disposal of a wide range of hazardous organic and inorganic chemical wastes (Parr *et al.* 1983.) Use of these systems would, in effect, prevent industrial pollutants from being disposed of on cropland. India has recently instituted an ambitious reclamation advisory endeavor, the Wastelands Development Program, under the auspices of The National Wasteland Development Board (NWDB 1986). This effort is meant to augment several afforestation programs already in place.

[2] ARS Strategic Groundwater Plan 1. Pesticides; Plan 2. Nitrate. United States Government Printing Office, Washington, D.C., USA.

Soil fertilization and stabilization

The application of soil amendments can enhance soil fertility (chemical and biological properties), soil physical properties, or both (Severson and Shacklette 1988). Because of the close interrelationship between the physical, chemical, and biological characteristics of soil, changing a single parameter often affects other properties. Geological soil amendments such as clay (particularly phyllosilicate minerals like montmorillonite and bentonite), zeolites (hydrated aluminosilicates), volcanic materials (such as pumice, perlite, scoria), sand, rock fragments, peat, and humates, applied singly or in combination, serve to selectively improve a soil for a specific agronomic purpose (Severson and Shacklette 1988). Similarly, organic amendments such as crop residues, animal manures, and composted sewage sludges can be used as soil conditioners to improve soil physical properties while providing essential macro- and micronutrients for plant growth (Hornick *et al.* 1984, Parr *et al.* 1989). The judicious use of both inorganic and organic amendments creates a more favorable medium for plant growth. These amendments also help to conserve soil by improving or increasing soil tilth, water-holding capacity, water infiltration rates, aeration, and temperature.

Soil stabilization is one of the prime objectives of land reclamation. Consequences of poor stabilization range from loss of fertility to desertification. This latter situation has been defined as the irreversible change of drylands by aridization and the subsequent loss of biological productivity (Venkateswarlu 1985). Venkateswarlu states that in the Indian states of Punjab, Rajasthan, and Gujarat, an area of 1.4 Mha is threatened by desertification.

Sivaramakrishnan (1987) reports that an estimated 6 million tonnes (Mt) of soil were lost to erosion in India in 1972 and this figure increased to about 12 Mt in 1985. Successful research programs in soil conservation are currently investigating the potential of both native and introduced tree species for use in afforestation efforts including sand dune stabilization, shelter belt plantations, and silvi-pastoral agroecosystems. The Indian emphasis on the use of tree species in land stabilization efforts is a new concept in the U.S. Although India has conducted extensive research on the use of grasses for pasture development (Chakravarty *et al.* 1966), it is limited by a lack of germplasm diversity. In turn, India could benefit considerably from research in the U.S. on grass varieties used in reclamation (Barker *et al.* 1977). Cooperative research on seeding methods and rates, seed treatments and mixtures, fertilization and nutrient management modeling, as well as germplasm exchange, should be pursued.

Water use efficiency

In arid and semi-arid regions of India, rainfed agroecosystems are being improved through reclamation practices (Mann and Chatterji 1979). Centuries of practical agronomic experience with ephemeral monsoon rains have resulted in effective water use in agroecosystems (Gupta and Khybri 1986). Water catchment schemes including vegetative bunding and khadins (large bunds constructed across a valley toe), trap water for the production of short-season crops. Use of different cropping systems, such as strip-, mixed-, and inter-cropping decreases soil erosion and increases the retention and storage of soil moisture by reducing runoff (Singh and Bhardwaj 1986).

Increasing the efficiency of water harvesting techniques is becoming a high priority research area in India (U.S. Dryland Farming Team Report 1987). The U.S. has shown some interest in water harvesting research (Verma and Thames 1975); however, the Indian experience is extensive and their technology offers great potential for more effective reclamation programs in the U.S. desert southwest and central plains.

Importance of dryland agriculture

Dryland agriculture is often the principal kind of farming that is practiced in the arid and semi-arid regions of the world. Water for plant growth and development is supplied entirely by rainfall. Randhawa and Singh (1986) categorize dryland farming areas in India as those with a moisture-available period of less than 120 days, receiving 100-600 mm of precipitation in summer and winter months. In the area near Jodhpur (Rajasthan, India), about 370 mm of precipitation is received in 20 days spread over about 11 weeks (CAZRI 1985). The probability of severe drought in this area has been calculated to be about 40%. The region is currently experiencing a prolonged drought as monsoon rains received during the three summers, 1985-1987, have been erratic, infrequent, and considerably below normal.

On an average, irrigated lands are twice as productive as dryland agricultural lands (1.4 vs. 0.7 t/ha)(Venkateswarlu 1985). Nevertheless, India and other developing countries are beginning to recognize that dryland agriculture is more feasible and cost-effective for food production over the long-term than is irrigation. This is because new lands are not always available for irrigation development, the cost of development is often prohibitive, and soils are often marginal (*i.e.*, low fertility, sandy texture, and saline). Rainfed agriculture has been 'rediscovered' as not only potentially highly productive but also as more ecologically sound (Randhawa and Singh 1986). While irrigation systems are important in food and fiber production, they require increasingly sophisticated and costly management practices (Venkateswarlu 1985). Irrigated farming systems are also fraught with serious problems that can limit crop yield and productivity, including salinization, waterlogging, and the growth of aquatic weeds.

The importance of dryland or rainfed agriculture to the future food production potential of India, and the need to conduct research to improve the productivity and stability of these systems, was reinforced recently in a report to the Indian Council of Agricultural Research (U.S. Dryland Farming Team Report 1987). This report cites specific research needs and priorities for dryland agriculture that will help India to provide sufficient food and fiber for its projected population of one billion people by the year 2000.

Saline-alkali soils

The reclamation of saline-alkali soils is receiving increased attention in both the U.S. and India (Sandoval and Gould 1978, Bhargava and Sharma 1986, Yadav 1987). Many arid and semi-arid regions have extensive salt-affected soils that undergo further salinization from agricultural practices that trap and concentrate dissolved salts. In addition to the 7.5 Mha of land classified in India as saline-alkali, 25 Mha are threatened by salinity (Sivaramakrishnan 1987).

Increasing the productivity of salt-affected lands can be accomplished by managing the rate, quality, and method of water application, and by altering the agricultural methods used for growing crops. In general, the management of salt-affected soils should include drainage to flush the salts, and the use of inorganic and organic amendments to displace exchangeable sodium. In Rajasthan, over 80% of the area has sodic ground water with an electrical conductance (EC) value of 0.2 mS cm^{-1}. Methods of cultivation for these soils include proper bunding and land leveling, and cropping patterns that utilize low water-requiring crops like raya (brown mustard). Germplasm research is being conducted to develop salt-tolerant varieties that can withstand irrigation water of 5-10 mS cm^{-1}. In addition, research is focusing on ways to develop rainfed agricultural systems that improve monsoon water harvesting for increased crop production and accentuate the flushing and leaching opportunities that rains provide. An integrated approach to fertilizer use and management, including micronutrient application, is also being followed (CAZRI 1985, Yadav 1987). In the alkali soil regions of Punjab, Haryana, and Uttar Pradesh, there is new emphasis on the establishment and utilization of grassland agroecosystems through more effective rainwater management (Kamra and Dhruva Narayana 1986).

Ecotechnology

In the U.S. the term ecotechnology is usually applied to the application of industrial techniques to certain aspects of ecosystem management, particularly in the area of microbially-dominated systems used in waste disposal, and plant and animal genetic engineering. There is an opportunity for ecologically manipulating certain aspects of reclamation. These ecotechnological approaches include water harvesting and the construction of water catchment agroecosystems, wasteland modeling and wasteland agroecosystem development and planning, and utilization of wetlands as ecosystem 'filters' for the reclamation of industrially-contaminated lands (Kleinman 1985).

Information exchange

Tremendous potential exists for information exchange between the U.S. and developing countries in the use of dryland farming practices for the reclamation of wastelands. The desert region of the southwestern U.S. is similar to the monsoonal climate in the arid and semi-arid western and northern sections of India, whereas the southern Great Plains have many soil and agroclimatic conditions similar to the arid and semi-arid regions of the Near East and sub-Saharan Africa (Parr *et al.* 1988). The U.S. has an established research capability in germplasm development, and geochemical classification and inventory for degraded lands, whereas India has made significant research progress in cropping systems development, water-use strategies, and integrated nutrient management practices.

Integrating knowledge

To best achieve a multidisciplinary effort in the reclamation and management of degraded lands a system of integrating knowledge is essential. We illustrate here the

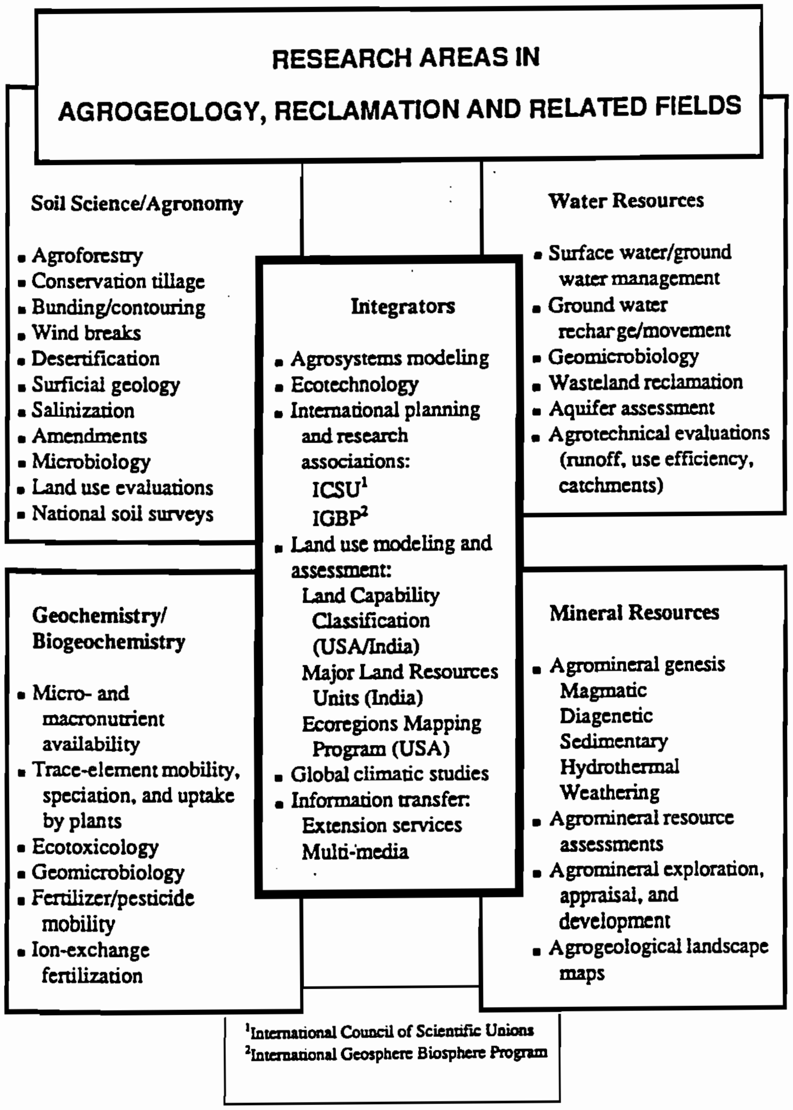

Fig. 3. The relation between agriculture, the geosciences, and ecological studies.

relation between agriculture, the geosciences, and ecological fields (Fig. 3). Four basic categories, soil science/agronomy, water resources, geochemistry/biogeochemistry, and mineral resources, have been used to delineate the various research activities. The fifth category lists some information integrators that are now in place for the U.S. and India. An area that has benefited from the integration of ecosystem knowledge with human activities is the Indian Thar Desert, the most densely inhabited arid region in the world (Joshi and Singh 1985). Of increasing interest in the U.S. is the use of the Geographical Information Systems (GIS) for 'stacking' base maps for interpretive purposes. A recent symposium emphasized GIS applications in the geosciences.[3] The effort to use GIS as a research tool, particularly for reclamation and agroecosystem processes, has begun.

Certainly one of the promising integrators of knowledge is the work of the International Council of Scientific Unions (ICSU) in creating the International Geosphere Biosphere Programme (IGBP) in 1986. To paraphrase Shearer (1988), the IGBP is supporting research that attempts to address the growing concerns over human-generated influences on the habitability of the earth from a truly holistic (or 'whole earth') approach. Many of these research efforts involve modeling aspects of complex systems. All of this, of course, implies that topical and basic research has established the foundation for the information used in the models.

Summary

This review suggests ways that agrogeology and the geosciences can contribute to agriculture and to the reclamation and management of degraded lands. We have emphasized the need to approach reclamation from an ecological perspective and to apply agroecosystem consciousness to improve land productivity. Increasing productivity can be achieved in part by developing agroecosystems that protect the dynamic soil resource, as well as the quality of ground and surface water. Low energy, low chemically-intensive sustainable agricultural practices of the developing countries have potential for the U.S. Their adaptation in reclamation efforts is promising but has not been widely demonstrated.

The traditional aspects of agrogeology, which include the mapping and classification of soils, and the appraisal of soil amendments and fertilizer minerals, are augmented by other areas of the geosciences in providing information for the management of both established agroecosystems and agroecosystems being developed on degraded lands. These disciplines must be integrated with agronomy and ecology to achieve a truly multidisciplinary approach to the entire process of land reclamation including assessment, planning, coordination, implementation, and management. By so doing, the ultimate success of reclamation projects will be considerably enhanced. This will also provide a sound and meaningful basis for cooperative research and information networking between the U.S. and developing countries.

We especially emphasize the following research and management strategies for integrating the geosciences with an agroecosystem approach to degraded land reclamation:

1. Agromineral resource appraisals as well as investigations of the use of soil amendments and minimally processed agrominerals in dryland farming systems.
2. International cooperation in the assembly and application of GIS information; investigations of the applicability of GIS to research on problems of trace element deficiencies and excesses, erosion, salinization, flooding, and deforestation.
3. Germplasm research that couples cultivar adaptability to dryland reclamation with enhanced nutritional quality of cultivars.
4. Investigations to assess and improve nutrient- and pesticide-use efficiency on degraded lands from both an environmental and economic perspective.

[3] GIS Syposium – Integrating Technology and Geoscience Applications, convened by the National Academy of Sciences, United States Geological Survey, and the Association of American State Geologists, September 26-30, 1988, Denver, Colorado, USA.

5. Research on the development of ecotechnological practices that enhance water catchment, wasteland modeling, and wasteland agroecosystem management and planning.
6. Research to determine the feasibility of adapting low energy, low chemically-intensive sustainable agricultural practices of developing countries to land reclamation programs in developed countries.

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