LAND USE MANAGEMENT

Willy Verheye
National Science Foundation Flanders/Belgium and Geography Department, University Gent, Belgium

Keywords: Agro-forestry, erosion, heavy metals, land reclamation and rehabilitation, mining, nature reserves, nitrate and phosphate pollution, pesticide contamination, precision agriculture, pollution treatment, roads and infrastructure, soil compaction, soil quality, sustainable land management, urban and industrial development

Contents

Summary

Land use management is multifaceted. While in the past it referred mainly to arable farming and crop production, it includes nowadays many other uses liking housing, urban and industrial development, infrastructure and roads, recreation and leisure, mining, nature conservation, landscaping, etc. This overview paper deals with both agricultural and non-agricultural land use management including land reclamation, soil conservation and protection of the environment.

In order to meet the high production objectives modern agriculture requires many fertilizers, herbicides and pesticides, and is based on highly mechanized field operations. This leads to a number of environmental problems which are mainly reflected in soil and groundwater pollution, soil compaction and increased surface erosion.

Non-agricultural uses become, however, more and more important in industrialized countries and they occupy a steadily increasing acreage. These uses focus in particular on urban and industrial development, roads and infrastructure, mining, forests and nature reserves. In the light of a growing concern for environmental protection, after-care and land reclamation become an important issue. These focus in the first place on the prevention of erosion and contamination, the introduction of environmental-friendly farming practices and production systems, and ultimately in the banning of the most toxic products and in the treatment and rehabilitation of polluted sites. The ultimate goal should be a sustainable land use in a healthy soil environment.

1. Introduction

Management refers to the act, art or manner to handle and control things carefully. It stands for technical ability, tactfulness and long-term vision. Land use management focuses in particular on land and on the way land is used for production, conservation or aesthetic reasons. Land management requires decision making and is determined by the purpose it serves, i.e. food production, housing, recreation and leisure, mining, etc., and by the nature and the properties of the land itself.

While in the past land use management focused mainly on agricultural production, it now deals also with many other uses like urban development and residential housing, infrastructure and industrial zoning, protection and maintenance of green areas and forests, and land reserved for or used as a support for buildings, a filter for water or a site for sewage disposal, mine spills, etc.

Good land management is closely linked with the principles of wisdom. It involves the application of traditional inherited knowledge (which has proven its value in the past) while at the same time it requires the incorporation of modern technical know-how. Land management, and agricultural land management in particular, has three main objectives. It has an economic or production target focusing on the optimization, in the sense of a sustainable maximization of outputs. It holds a conservation objective for maintaining the available properties, potentials and outputs. It finally involves a reclamation aspect with a view to eliminate constraints, avoid degradation and improve or restore the land properties and use potential. Good management requires also that good practices are maintained in time, and that it is prepared to adapt to changing conditions.

In this paper an overview is given of the major land management issues related to agricultural and non-agricultural land uses, land reclamation, rehabilitation and restoration, soil conservation and protection of the environment.

2. Agricultural Land Management

Agricultural land management has undergone very important changes over the past centuries, and has moved from an almost exclusive supplier of food products for local consumption to a market-oriented activity. The decisions related to agricultural land management are mainly determined by lifestyle, needs and risks. The key issues dominating present-day management have been outlined in more detail in *Land Quality Indicators(LQI): Monitoring Land Evaluation* and *Land Use Planning for Sustainable Development.*

2.1 Traditional Agricultural Land Management

Traditional agriculture has evolved from the need to reduce the risks of hazardous hunting and fruit collection, and to satisfy basic food requirements for individuals and local communities. It made use of the natural properties of the land without major amendments, applied the inherited knowledge of the elderly, and did not aim for high production but for food security with a minimum risk. It was the cornerstone of food production and food supply before the development of the major cities in Europe, and it is still in use in many subsistence economies in developing countries and remote areas in general. This system is gradually disappearing in the world.

Traditional farming focuses in first instance on satisfying the family food supply, without direct incentives for excess production. With a progressive development of the cities many people were no more able to produce their own food, and farm products were offered on the market. Under those conditions, a need was created for a better and higher production to satisfy market demands and to look for new products and production methods. This new situation stimulates also the improvement of land management practices.

This type of ameliorated traditional land management and comparatively low yields has dominated agriculture in the Middle Ages and beyond, and did not change much up to the time (see below, section 2.2) that biotechnological progress and the development of agrochemicals completely modified the farming practices. Farm operations in this period are still largely carried out by human labor force and animal traction, and farm implements remain rather rudimentary. This development stage is still widely observed in many developing countries, where most farming is of the level of subsistence agriculture, with only a small fraction allocated to the production of cash crops.

2.2 Modern Agricultural Land Management

In the late 1940s traditional agricultural land management has undergone tremendous changes as a result of biotechnological progress in seed selection and an increased use of agrochemicals and operational machinery at all production levels. A key issue in the development of modern agriculture has been the introduction of mineral fertilizers which, besides their low cost, are more efficient than manure, and of pesticides against diseases and yield losses. Agriculture from this moment has mainly developed as an economic activity at the same level as manufacturing, servicing and banking. Modern farmers have become land managers, and their agricultural output is almost completely sold on the market.

In modern agriculture farming has shifted from a labor- to a capital-intensive operation, and mechanization has taken over most human manpower, though for certain crops there might still be a temporary demand for labor force at critical periods in the season. Moreover, modern land management is characterized by a growing demand for record-keeping, enhanced administrative and financial skills, adapted management between different fields, increased capital inputs, and a higher specialization in land use options resulting in a partial take-over of specialists and firms over individual farmers.

Modern farming methods in developed countries have resulted in peak yields which are on average three to four times higher than 20-25 years ago. These are obtained from fully mechanized farms, specialized in the production of only a few crops and operating on large fields, with the use of high amounts of fertilizers and pesticides.

In developing countries the introduction of modern agricultural land management has mainly resulted in the creation of large plantations of industrial crops like oil palm, rubber, coffee, pineapple, etc. For an optimal scale effect those plantations must cover more than 3,000-5,000 ha, and crop production is supported by new and improved cultivars, sophisticated detection methods to identify and cure plant diseases, optimal planting densities, etc.

Various types of agricultural land management linked to modern farming are discussed *in extenso* in *Management of Agricultural Land: Climatic and Water Aspects,* and *Management of Agricultural Land: Chemical and Fertility Aspects.*

2.3 High-Tech Land Management: Precision Agriculture

Precision agriculture is a computer-guided cost-effective production method, which finds its origin in soil variability and the need to limit unproductive inputs to optimal yields, while at the same time reducing pollution. It starts from the anomaly that historic agronomic practices are mainly developed on a farm or field basis while recommendations on tillage, seeding, fertilizing, weed control and other farming practices focus mainly on specific soil properties. Spatial variations of those properties, even within the same soil unit, cause, however, uneven patterns in crop growth and production, and decrease the efficiency of fertilizers and of any other practices applied uniformly over the field.

Precision agriculture focuses on a more soil-specific management that aims to prevent over- or under-application of inputs resulting from such a uniform field application. In other words, this technology implies the application of inputs on a micro-scale rather than on a field scale. The technique is known under a variety of names: farming by soil, spatially prescriptive farming, and computer aided farming, farming by satellite, high-tech sustainable agriculture, soil-specific crop management, site specific farming, precision farming, etc. It has been extensively described and documented in the proceedings of a series of seminars in 1993, 1995 and 1999 respectively edited by Robert *et al*.

Precision farming is a new technology. Its basic research dates back to the early 1980s, but it is only since the 1990s that it has been effectively implemented in the US, and to a lesser extent in Canada. In Europe, it was promoted by environmentalists focusing on the need to adopt management practices which combine profitability with minimum impact on the environment; attempts to put it in practice have generally been restricted to a few innovator farmers in the UK and Germany. The main reason why the technique is not easily accepted in most European countries is because it is not cost-effective when applied on land parcels which are too small.

In most other parts of the world precision farming is practically unknown, except in those countries (Japan, Malaysia, Taiwan) where the use of component technologies such as Geographic Information Systems (GIS) and remote sensing are common.

Two important factors have speeded up the development of precision agriculture: modern technology and environmental concern. The advent of computer-processed spatial data, together with progress in geo-statistical analysis, has enabled the display of that soil, hydrologic and microclimatic features that are relevant to agronomic practices. With the recent development of global positioning systems (GPS) suitable to on-site applications, the capability became available to deliver real-time and real-space changes in almost any agronomic procedure.

The implementation of precision agriculture implies a number of consecutive steps. First it is necessary to identify the parameters that affect crop growth and at the same time are of concern to the farmer. In principle, these parameters refer primarily to soil nutrient status, organic matter content, pH, moisture storage and water movement in the root zone.

The next step is to prepare the variability pattern on the field maps for application of differential management within a field. This should in first instance be obtained from existing soil maps and reports, in particular through digitizing and linking them to a global positioning system (GPS) as a tool to control and navigate the fertilizer or other applications as they move across fields.

However, as conventional soil maps are usually not designed to provide these fine-scale variations in soil attributes, a re-interpretation of existing data is often required. This can be done through pedo-transfer functions, process-oriented simulation models, statistic and geo-statistic approaches (that relate information on point data such as fertility samples to a larger area), or by additional field data collection. The result is a new computerized map which can be "read" by high-technology chemical spreaders and be properly interpreted to adapt fertilizer and pesticide doses and blends as the machines move across the fields.

A good exercise of such an interpretative approach is given by Mulla (1993) for a wheat farm in Eastern Washington State, USA. The author first found a good correlation between organic matter, soil P and wheat yields using standard statistic and geo-statistic approaches. He then showed a relationship between topography and organic matter content especially in the eroded areas, and made a positive correlation with the N and P status of the soil, and with the water storage capacity of the profile. Refining the mapping of organic material through remote sensing techniques allowed then to divide the fields into management zones with different soil fertility and water retention levels, two factors which have a significant impact on soil composition and average crop yields.

The final step is to manage properly each site in the field for an optimal production at the greatest return without damaging the environment. Decision making in this respect depends both on a good knowledge of the local environment and on a number of factors, of which advanced technology (such as the choice of optimal crop cultivars and pesticide choice), productivity, profitability and environmental concern are amongst the most relevant.

3. Managing Side Effects of Modern Agriculture

The search for excessive yields through the application of high fertilizer doses, use of herbicides and pesticides, highly mechanized field operations, and the modification, especially in Western Europe, of the former small-size parceling into larger fields has created since the 1980s and early 1990s a number of environmental problems, which are mainly reflected in soil and ground water pollution, soil compaction and in increased surface erosion. This has lead to a growing concern on the side effects of modern agriculture and to the promulgation of legislation for protecting the natural resources. This legislation has been enforced by the introduction of the principle that the polluter is directly responsible for the environmental damage and, hence, should pay for the reclamation costs.

3.1 Environmental Challenges: Soil Quality and Sustainable Management

Intensive agriculture leads to the modification of natural ecosystems, tends to reduce biological diversity, and may adversely affect the quality of the environment. The future will see a shift towards an environmentally and economically sustainable agriculture with much more attention paid to the side effects of modern farming and to environmental considerations in general.

Central in this debate is the concept of **soil quality**. Farming practices such as tillage, cropping patterns and fertilization influence the soil and water quality through changes in the soil capacity to produce and/or consume important atmospheric gases such as CO_2, N_2O and CH_4. Much like air and water, the quality of a soil has a profound effect on the health and productivity of a given ecosystem and the environment related to it.

Soil quality is defined as the capacity of a soil to function, both within its ecosystem boundaries and with the environment external to that system. Soil quality relates specifically to its ability to function as a medium for plant growth, in the partitioning and regulation of water flow in the environment, and as an environmental buffer.

Soil quality encompasses three broad issues: (i) plant and biological productivity; (ii) environmental quality, e.g. the ability of the soil to attenuate environmental contaminants, pathogens and offsite damage, with an impact on groundwater and surface water and air quality; and (iii) human and animal health, related to nutritional composition, quality and safety of food. Therefore, any protocol designed to determine soil quality must provide an assessment of the function of soil with regard to these three issues. To be of practical use, soil quality assessment must incorporate specific performance criteria of each of the three elements listed above, and it must be structured in such a way as to allow for quantitative evaluation and clear interpretation.

The definition and assessment of soil quality indicators is still a matter of debate. A broad discussion on this topic can be found in *Land Quality Indicators (LQI): Monitoring and Evaluation.* In a similar context Doran and Parkin (1994) have proposed the following set of basic soil quality indicators (other secondary measurements may be needed later):

- physical characteristics: soil texture, depth of soil and rooting, soil bulk density and infiltration, water holding capacity, water retention properties (as defined by pF data at field capacity and wilting point), water content at 105°C, and soil temperature;
- chemical characteristics: total organic carbon and nitrogen, pH, electrical conductivity, mineral N, P and K;
- biological characteristics: microbial biomass carbon and nitrogen, potentially mineralizing N, soil respiration, ratio between biomass C and total organic C, ratio between respiration and biomass.

The problem with soil quality assessment is that there is no uniform methodology for it. In a recent study on the changes of soil quality by modern farming practices in New Zealand Sparling (2004) investigated for nearly 600 sites all over the country the following key quality characteristics: organic matter status as expressed by total carbon, total and mineralizing nitrogen), acidity (pH), fertility level as reflected by phosphate status (Olsen, $NHCO_3$ extraction), and soil compaction (bulk density and macro-porosity).

Land use*	**Soil quality characteristic**						
	pH 2/1 wat/soil	**Tot. C** mg/cm³	**Tot. N** mg/cm³	**Miner N** µg/cm³	**P (Ols)** µg/cm³	**Bulk density** g/cm³	**Macro-por.** (%)
Indigenous forest (62)	5.4 ±0.6	57 ±20	3.5 ±1.2	102 ±42	12 ±14	0.77 ±0.2	19 ±10
Plantation forests (69)	5.4 ±0.4	46 ±18	3.0 ±1.5	63 ±34	10 ±12	0.78 ±0.8	27± 13
Sheep-beef pasture (154)	5.8 ±0.5	52±18	4.4± 1.7	131 ±62	21±19	0.91 ±0.2	15 ±12
Dairy pasture (139)	5.7± 0.4	67± 20	5.9 ±1.4	159 ±49	46 ±32	0.83 ±0.2	11 ±9
Horticulture (48)	6.3 ±0.4	53± 21	4.2 ±1.2	107 ±40	57 ±42	1.00 ±0.2	14 ±10
Mixed cropping (25)	6.1 ±0.5	41 ±11	3.4± 0.7	68 ±31	54 ±44	1.16 ±0.2	20± 22

Arable cropping (54)	6.2 ±0.6	44 ±24	3.5 ±1.5	54 ±31	53 ±47	1.04 ±0.2	19 ±16

* Figures in parenthesis show the number of sites in the land use category.

Table 1: Soil quality characteristics (mean and standard deviation) of key soil quality characteristics, averaged across all soil orders, and arranged by increasing intensity of land use in New Zealand (Sparling, 2004)

The results displayed in Table 1 illustrate that soil characteristics differ with increased intensity of use, moving along the series: indigenous forest (the most un-spoiled land use and therefore being considered as a relative reference soil), plantation forest, sheep-beef drystock pasture, dairy pasture, horticulture, mixed cropping, and arable cropping. Soils under pasture, horticulture and cropping have more phosphorus and a more neutral pH. While pastures have also a higher organic matter and nitrogen status compared with other land uses, they also have a lower macro-porosity than other land uses, suggesting that compaction has occurred.

Sparling's observations show that dairy pasture soils differ most from those under indigenous forest. Overall, the order of decreasing soil quality is: indigenous forest < plantation forest < drystock pasture < horticulture < arable cropping < mixed cropping < dairy pasture. The characteristics of dairy pastures, with their high fertility levels (N and P), and lower macro-porosity indicating compaction, raise moreover serious concern about potential effects from leaching and nutrient runoff causing the eutrophication of lakes and streams.

Sparling's work is one of the first attempts to quantify the environmental effects of an intensive application of fertilizers and manure on farmland. High yields obtained in modern agriculture implicate, indeed, that high amounts of nutrients have to be supplied which should be fully available for plant uptake. Since the 1960s the consumption of mineral fertilizers has increased by more than 500 % in Europe and by 100 to 250 % in developing countries. Macronutrients such as N, P and K are supplied as single or compound fertilizers to the soil; micronutrients which are needed in smaller amounts are often administered as a foliar spray. In addition, there exist a wide variety of agrochemicals under the form of pesticides, insecticides or other soil amendments to overcome problems of pests and diseases, or of adverse soil conditions which need to be corrected for optimizing root development and nutrient uptake. These issues have been discussed in length in *Management of Agricultural Land: Chemical and Fertility Aspects, Desert Reclamation and Management of Dry lands: Fertility Aspects,* and *The Salinity and Alkalinity Status of Arid and Semi-arid Lands.*

The behavior and toxic effects of the most important contaminating agrochemicals in soil and water are discussed below.

3.2 Nitrate Contamination

Soils contain organic and inorganic nitrogen (N), most of the inorganic N in the form of nitrate (NO_3^-). Present-day nitrogen levels are however much higher in areas with intensive farming due to the high rates of fertilizers used for crop production, and the concentration of animals on large farms and ranches. The extent to which nitrate accumulates in the soil or moves into the water table is a function of the amount of nitrates in the soil, rainfall intensity, irrigation, soil texture and permeability, and the nitrate mobilized by the crop and microorganisms. The danger in nitrate pollution lies, however, in its high solubility and leaching to the ground water where under anaerobic conditions nitrate may be converted to toxic nitrite.

On average about 50 % (less in sandy or poorly drained soils) of the mineral N-fertilizers applied to soils is absorbed by the crops in the first year; a small amount is incorporated in the humus fraction and becomes available in a later stage. An important part of the nitrate fertilizers is thus lost, either by volatilization or by leaching and accumulation in deep soil layers or in the groundwater. Nitrate leaching is small during the growth season, but increases rapidly when rainfall exceeds evapo-transpiration. Nitrate application should therefore by preference be made at the stage of maximum root absorption and be avoided when plant activity is lowest. Nitrate contamination can be seriously reduced by introducing split applications and by making a realistic assessment of crop requirements and N-uptake.

Plants absorb nitrogen through their roots and convert it into proteins. Usually, the nitrate content of food and feed crops is not toxic to humans and animals. Through microbial reduction and under anaerobic conditions nitrate (NO_3^-) can be converted into toxic nitrite (NO_2^-). When browsed this nitrite accumulates in the digestive tracts of the ruminants (cud-chewing animals) where it interferes with the transport of oxygen by the bloodstream and, subsequently, causes poisoning. Monogastric (single-stomached) animals do however not develop a nitrate problem from the ingestion of nitrates.
Nitrate contamination may present significant public health problems in that groundwater provides drinking water for a major part of the population, both rural and urban. In high concentrations nitrate can impede oxygen transport in infants bloodstreams and cause *methemoglobinemia*, commonly known as the "blue baby syndrome". In this respect NO_3^- pollution of groundwater and drainage water has received an increased attention in recent years. In the US the maximum allowable concentration of NO_3^- in public water supplies (EPA norm) is 45 mg/l; in Europe the critical limit is set at 50 mg/l.

3.3 Phosphate and Potassium Contamination

Phosphate (P) from fertilizers and organic wastes is taken up by plants in an amount which rarely exceeds 15% in the first year. The excess is adsorbed (fixed) onto the soil particles and either stays in the soil or is carried along and deposited in surface waters, where it establishes an equilibrium concentration with the surrounding water, just as it does in the soil with the soil solution.

Phosphorus is easily fixed by clay and humus, but this fixation capacity is limited. The danger in phosphorous pollution lies therefore in the over-saturation beyond this fixation capacity (which is often the case in Western Europe) and, to a lesser extent, in the movement of clay and humus particles - through erosion - into surface waters. The result is an increase of the amount of phosphorus available for aquatic plants, mainly algae, and the depletion of oxygen in the water. This phenomenon, known as *eutrophication*, kills the fish and makes the water less suitable for recreation (swimming) because of its reduced transparency and bad smell.

The effect of potassium (K) is quite similar, except that this element is better adsorbed (approximately 50 % in the first year) by the crops, and that it is more mobile in the soil than P. Part of the non-adsorbed K is leached (especially in sandy soils) and may accumulate in both the groundwater and surface water. The major part is fixed on the soil particles and is mostly made available to crops in a later stage, as is the case for P.

The degree of phosphorus (and to a lesser extent potassium) contamination of surface water depends on the excess P- and K in the soil and on the intensity of runoff and surface erosion. In fact, it has been observed that much of the pollution occurs at sites where unprotected soil is exposed to serious erosion. Where K and P fertilizers increase the vigor of a vegetative cover, erosion and pollution of surface waters are reduced.

3.4 Pesticide Contamination

Agrochemicals (pesticides) are used in modern agriculture to treat insect pests and diseases, and to control weeds. These products do not increase the intrinsic production capacity, but protect it against yield losses whereby the efficiency of production tools and methods is reduced. Pesticides include a large array of chemical products, including acaricides (against mites), herbicides (against weeds and herbs), fungicides (against fungi), nematicides (against nematodes), insecticides (against insects), etc. Pesticides can be of general application or focus on the treatment of one particular species or problem. They are only effective if they destroy the features or elements against which they were applied, and at the same time present a low toxicity for humans and animals, leave almost no residues in the harvest, and do not affect the quality and composition of the soil, and the surface or ground waters.

Soils possess remarkable power of breaking down some of the organic pesticides, in particular those that are termed as bio-degradable. Soil micro-organisms such as bacteria and fungi need carbon for energy in much the same way as animals need carbohydrates, and instead of getting this from plant and animal remains, many of them are able to adapt and use the carbon in herbicides. Some herbicides are broken down in a matter of days, while others are more persistent or are not broken down at all; they are then called non-biodegradable. In the latter case they accumulate in the soil, and affect adversely soil and water quality.

3.4.1 Types of Pesticides

At present, there are more than 1000 different types of pesticides, some 250 of which are used in agriculture and horticulture. This list is continuously changing since new formulas are applied and older products are taken off the market, either because they are banned by law (see section 5.3. below) or for commercial reasons. In recent years there has been a strong tendency to replace the most persistent and most eco-toxic products by less persistent or bio-degradable alternatives.

The organo-chlorines like DDT, chlordane, heptachlor, lindane, toxaphene, aldrin, dieldrin, endosulfan, etc. are very persistent insecticides, which are almost not volatile nor water-soluble. With the exception of lindane and endosulfan, all of them have now been banned by the World Health Organization (Table 7). Phosphoric esters (organo-phosphates) like parathion, malathion, diazinon, trichlorfon, dimethoate, fenthion, chlorfenvinfos are much less persistent insecticides, but some of them are more toxic for mammals (like parathion), and because some can be absorbed by plants, their residues can enter the food chain. The carbamates include as well insecticides as acaricides, fungicides and nematicides. Their toxicity for mammals is very variable, and their persistence in the soil is larger than for the phosphoric esters , but is generally limited to one year.

The herbicides include growth regulators and products with contact activity. The first group is rather selective for plants and has a low toxicity for mammals. Most of them are water-soluble and can therefore be found in the river system; if proper concentrations are applied they are almost not toxic for fish. Contact herbicides like dinitrophenols and cyanophenols are rapidly broken down and have a low toxicity for mammals. Triazines however remain for a long time in the soil and have therefore a much more adverse effect. Insecticidal pyrethroids like bioresmethrin, permethrin, deltamethrin, cypermethrin, etc. have a low toxicity for mammals, and have a short to very short persistence with little or no risk to enter in the food chain.

3.4.2 Soil and Water Contamination

Most pesticides used in agriculture leave a residue on the spot where they have been used. Whether this residue remains in the soil or moves with the soil water depends on the absorption capacity of the soil particles (clay and humus), soil pH and soil drainage. Soil permeability and surface slope are the two key factors which determine whether water leaches downward in the profile or is directed into surface runoff. These two pathways of water flow are responsible for the movement of pesticides into ground and surface water, respectively.

Once in the soil, pesticides affect the intrinsic soil properties and soil health, in particular through their impact on the microbial activities. They can also affect other plants and animals like earthworms and soil mites (which contribute to humus formation and soil structure) the activities of which can be reduced or influenced. Their predators can indirectly be affected as well, as earthworms for example resist well to insecticides but, once dead and eaten by necrophagous animals, the latter can become infected.

As for the water systems, the pollution of surface and ground waters depends on the solubility and the physicochemical composition of the pesticides. Water-soluble products in particular enter easily into the river system, and their eco-toxicity varies as a function of the tolerance level of species. Aquatic invertebrates react differently as a function of their habitat: micro-fauna and zooplankton are very sensitive to soluble pesticides; herbicides have in general very little effect on the aquatic fauna, but are toxic for many elements of the aquatic flora; most insecticides (such as pyrethroids) are very toxic for the aquatic arthropoda.

In general, one can argue that the time necessary for the re-establishment of the water fauna is inversely related to the water flow. This means that the recovery in marshlands and lagoons is much slower than in flooding rivers.

3.4.3 Environmental Impact and Eco-toxicity

The environmental impact of pesticides used in agriculture is reflected in eco-toxic effects at the community level and in human health effects at the personal level. There exists a continuously updated list of Health and Safety Guidelines available through the WHO Sales Agents and Marketing and Dissemination networks in Geneva, Switzerland, or the Joint FAO/WHO Food Standards Program in Rome, Italy, indicating critical pesticide levels for human health.

In Europe and the US adverse health effects are assessed from tolerable health advisory levels and maximum contaminant levels. These are specific concentration levels for pesticides in drinking water which are deemed to be safe. Concentrations above these levels are not necessarily dangerous, but concentrations at or below this level have been determined to not present an unreasonable risk to human health, even when conservative allowances are made for the possibility of water consumption by the most sensitive members of the population.

Some chemicals within pesticides can have a eco-toxic effect on so-called non-target biota, such as birds, fish and microscopic aquatics. Toxicity criteria commonly used to describe the effects of pesticides on such organisms are:

- LD50’s : statistical estimate of the amount (mg) of toxicant per kg of bodyweight required to kill 50 % of the exposed members of the species; a distinction is made between oral and dermal LD50;
- acute NOEC’s : the 48h or 96h exposure level at which No Adverse Effects are observed;
- chronic NOEC’s : generally the 21-day exposure level at which no adverse effects are observed;
- half-life period in soils; and
- WHO toxicity class: This is a ranking of technical products (in terms of name or active ingredient; not the commercial brand) by the World Health Organization into four classes with decreasing health risks. These classes are (see also Table 7):

    - Class Ia: Extremely hazardous products characterized by an oral LD50 of less than 5 for solids and less than 20 for liquids, and a dermal LD50 of less than 10 for solids and less than 40 for liquids;
    - Class Ib: Highly hazardous products characterized by an oral LD50 of 5-50 for solids and 20-200 for liquids, and a dermal LD50 of 10-100 for solids and 40-400 for liquids;
    - Class II: Moderately hazardous products, characterized by an oral LD50 of 50-500 for solids and 200-2000 for liquids, and a dermal LD50 of 100-1000 for solids and 400-4000 for liquids.
    - Class III: Slightly hazardous products, characterized by an oral LD50 over 500 for solids and over 2000 for liquids, and a dermal LD50 over

1000 for solids and over 4000 for liquids.

Product		Environmental status and eco-toxicity level
Herbicides	2.4 D-amin salt	$C_8H_9Cl_2NO_3$ - Selective systemic herbicide. Not toxic for most animal species when used as recommended, moderately toxic for fish. Half-life in soils 7-35 days depending on pH. Almost not accumulating in soils. WHO Toxicity class II.
	Daconil*	$C_2H_3ClO_2$ - Selective contact herbicide. Very soluble in water. Used in combination with atrazine for total weed control in industrial sites. Toxic to bees. Toxic if swallowed. Corrosive. Causes severe burning. Toxicity class WHO: III.
	Diuron	$C_8Cl_4N_2$ - Selective systemic herbicide. Non-toxic for birds, moderately toxic for fish. Persistent in soils (Half-life 94 days); phyto-toxic soil residues disappear within 4-8 months. WHO: non classified.
	Terbuthylazin (Folar*)	$C_9H_{16}ClN_5$ - Herbicide. Phyto-toxic to many annual plants and to aquatic life. Half-life in biologically active soil: 30-60 days. Moderately harmful if swallowed. Toxicity class WHO: III.
	Paraquat (Gramoxone*)	$C_{12}H_{14}C1_2N_2$ - Non selective contact herbicide, absorbed by the foliage. Strong adsorption by soils resulting in complete decontamination. Toxic in contact with skin and if swallowed; irritant to eyes, respiratory system and skin. Toxicity class WHO: II.
	Glyphosate (Round Up*)	$C_3H_8NO_5P$ - Non-selective systemic herbicide, absorbed by foliage, inactivated in contact with soil. Low mobility in soil. Not toxic for birds, fish, insects. Half-life in soil 28-70 days. Irritant, risks serious damage to eyes. Toxicity class WHO: III
Insecticides	Monocroto-phos	$C_7H_{14}NO_5P$ - Systemic insecticide-acaricide with contact and stomach action. Controls a broad spectrum of insects. Non-phytotoxic when used properly. Very rapidly degraded (Half-life 1-5 days). Medium to low mobility in soil. Toxic in contact with skin, very toxic if swallowed. Toxicity class WHO: Ib. The use of this product should be banned.
	Terbufos	$C_9H_{21}O_2PS_3$ - Organo-phosphate, Systemic insecticide-acaricide and nematicide with contact and stomach action. Has effective initial and residual activity against soil-dwelling anthropoda. Rapid degradation in animals, plant and soil. No accumulation in soil (Half-life 9-27 days). Very toxic in contact with skin and if swallowed. Toxicity class WHO: Ia. The use of this product should be banned.
	Deltamethrin (Decis*)	$C_{22}H_{19}Br_2NO_3$ - Pyrethroid, Non-systemic insecticide with contact and stomach action. Effective against a wide range of pests, including locusts. Very toxic to fish. Strong adsorption to soil, where it undergoes microbiological degradation in 1-2 weeks. Half-life 30 days. No leaching, no incidence on micro-flora and nitrogen cycle. Harmful in contact with skin and if swallowed. Toxicity class WHO: II.
	Thiocyclam (Evisect*)	$C_7H_{13}NO_4S_3$ - Selective insecticide with contact and stomach action. Non-phyto-toxic to most crops at recommended doses. Toxic for birds and fish. Rapid degradation and moderately mobile in soil (Half-life 1-4 days) and plants. Harmful in contact with skin and if swallowed. Toxicity class WHO: II.
	Carbofuran (Furadan*)	$C_{12}H_{15}NO_3$ - Carbamate, Systemic insecticide-nematocide with predominant stomach and contact action. Used for control of soil-dwelling and foliar-feeding insects and nematods. Half-life

		in soil: 30-60 days. Very toxic by inhalation and if swallowed. Toxicity class WHO: Ib. The use of this product should be banned.
Fungicides	8-Hydroxy-quinoline sulfate (Cryptonol*)	$C_{18}H_{16}N_2O_6S$ - Fungicide-bactericide. Is a general disinfectant in horticulture. Non toxic. Harmful if swallowed. Toxicity class WHO: III.

* Commonly used trade names.

Table 2: Environmental status and toxic levels of some pesticides used in tropical plantation agriculture

It should be recalled that there is still considerable debate in the scientific community over the question which screening and analytical methods are the most appropriate to apply, as well as to the interpretation of the data.

Table 2 presents an example of the environmental status and eco-toxicity level of some currently used pesticides in tropical plantation agriculture.

-
-
-

Bibliography

Anz, C. (1993). *Afforestation Policy*. In: K.R. Volz and Weber N. eds: Afforestation of Agricultural Land. Publ. European Community, Luxemburg, pp. 9-10. [Short communication presented at the start of an EC seminar outlining the EC policy in favor of the afforestation of community agricultural land].

Barnishel, R.I., Darmody, R.G. and W. Lee Daniels (2000). *Reclamation of Drastically Disturbed Land.* Agron. Monogr. 41, Amer. Soc. Agron., Madison, Wi, 1082p. (A compilation of 38 papers dealing with the reclamation and restoration of land for agriculture, range, coal refuse, mines, metal works, etc.).

Brown, R., Huddleston, J.H. and Anderson, J.L. (2000*). Managing Soils in an Urban Environment.* Agron. Monogr. 39, Amer. Soc. Agron., Madison, Wi, (A state-of-the-art on the management of organic wastes, metal pollution, erosion and wastewaters in urban environments).

Burger, J.A. and Kelting, D.L. (1998). *Soil Quality Monitoring for Assessing Sustainable Forest Management, SSSA* Special Publ. 53, Soil Sci. Soc. Am., Madison, Wi., 17-52. [Paper providing definitions, rationale and historical background of the need for selecting criteria for sustainable forest development and management]

Burke, S. and Thornes, J.B. (1998). *Actions taken by Governmental and Non-Governmental Organizations to Mitigate Desertification in the Mediterranean*. EC. Dir. Gen. Science, Research and Development, European Community, Concerted Action Report 10, Office of the Official Publications of the European Communities, Luxemburg, 349p. [Discusses the problem of confusion in terminology and gives an overview of actions taken in the past 10 years in Greece, Italy, Morocco and Tunisia].

Coppin, N.J. and J.D.Box (1998*). After-use Options for Reclaimed Land - A Land Suitability Approach*. In H.R. Fox, H.M. Moore and A.D. McIntosh, eds.: Land Reclamation: Achieving Sustainable Benefits, Balkema Editors, Rotterdam/ Brookfield, pp. 351-360 (A paper describing an approach for after-use options based on a land suitability assessment).

Doran, J.W., Coleman, D.C., Berzdicek, D.F. and B.A. Stewart, eds. (1994). *Defining Soil Quality for a Sustainable Environment.* SSSA Spec. Publ. 35, Soil Sci. Soc. America, Madison, Wi, 244p. (A compilation of 18 papers on soil quality and soil quality indicators).

Doran, J.W. and T.B. Parkin (1994). *Defining and Assessing Soil Quality*. In: J.W. Doran *et al*., eds. Defining Soil Quality for a Sustainable Environment. SSSA Spec. Publ. 35, Soil Sci. Soc. America, Madison, Wi, pp. 3-21 (Paper discussing and defining soil quality and its evaluation through a soil qality index).

El-Ashry, M.T. and A.M. Duda (1999). *Future Perspectives on Agricultural Drainage*. In: R.W. Skaggs and J. van Schilfgaarde, eds.: Agricultural Drainage, Amer. Soc. Agron./CSSA/ SSSA, Madison, Wi, pp. 1285-1298 (Includes a number of interesting reflections to stop encouraging too high yields while damaging natural systems, and promotes the introduction of a more sustainable agriculture).

Fox, H.R., H.M. Moore and A.D. McIntosh, eds (1998*). Land Reclamation: Achieving Sustainable Benefits*. Balkema Eds. Rotterdam/Brookfield, The Netherlands/USA, 548p. (A compilation of 80 papers on land reclamation, restoration, habitat creation and after-use problems around mine sites and other polluted areas).

Haigh, M. (1994). *Reclaimed Land: Erosion Control, Soils and Ecology*. Balkema Eds., Rotterdam/Brookfield, The Netherlands/USA, 385p. (A compilation of 14 papers giving a good overview of the various aspects of land reclamation).

Hüttl, R.F. (1998). *Ecology of Post-Mining Landscapes in the Lusatian Lignite Mining District, Germany.* In: H.R. Fox, Moore H.M. and McIntosh A.D. eds.: Land Reclamation.: Achieving Sustainable Benefits, Balkema Eds. Rotterdam/Brookfield, The Netherlands/USA, pp. 187-192. (Paper describing the history of mine reclamation after the extraction of lignite in the region of Saxony south of Berlin, Germany).

IFC (1991). *Operational Policy on Environmental Assessment.* Doc OP 4.01 (1991) and follow-up document OP 4.09 (1998). World Bank Techn. Paper 140, Environmental Assessment Sourcebook, The World Bank, Washington, DC. (Provides environmental regulations in terms of threshold values of contaminants in soils and waters, and lists pesticides which can be used or have to be banned in agricultural projects sponsored by WB/IFC funding).

Lecomte, P. (1999). *Polluted Sites: Remediation of Soils and Groundwater*. Balkema Eds., Rotterdam, The Netherlands, 210p. (An overview of the types of contamination, the assessment of hazards, and the various remediation techniques to treat polluted soils and water).

Marks, R.S. and J.R. Ward (1993). *Nutrient and Pesticide Threats to Water Quality*. In: P.C. Robert, R.H. Rust and W.E. Laron, eds.: Proceedings of Soil Specific Crop Management, Amer. Soc. Agron., Madison, Wisc., pp. 293-299 (Discusses groundwater pollution and related health problems with examples from several parts in the USA).

D.J. Mulla (1993*). Mapping and Managing Spatial Patterns in Soil Fertility and Crop Yield*. In: P.C. Robert, R.H. Rust and W.E. Laron, eds.: Proceedings of Soil Specific Crop Management, Amer. Soc. Agron., Madison, Wisc., pp. 15-26 (Describes a case study where precision agriculture was applied: criteria used and procedures followed).

Robert, P.C., R.H. Rust and W.E. Larson, eds. (1993). *Proceedings of Soil Specific Crop Management.* Amer. Soc. Agron, Madison, Wi., 395p. (A compilation of 43 papers presented at an ASA workshop on soil variability and its management through precision agriculture).

Robert, P.C., Rust, R.H. and Larson, W.E. eds. (1995); *Site-Specific Management for Agriculture Systems,* Proceedings of an International Conference, Minneapolis, March 1994. Amer.Soc. Agronomy, Madison, Wi, 993 pp. [A compilation of 72 papers giving the state-of-the-art in various topics related to yield monitoring and mapping, soil resource variability, managing variability, engineering technology, profitability and technology transfer].

Robert, P.C., Rust, R.H. and Larson, W.E. eds. (1999). *Proceedings of the Fourth International*

Conference on Precision Farming. Amer. Soc. Agron, Madison, Wi., 2 vol, 1938p. (A follow-up and actualization of knowledge on soil variability and its management, engineering technology, profitability and environmental impact).

Skipper, H.D. and Turco (1995). *Bioremediation: Science and Application*. Special Publ. 43, Amer. Soc. Agronomy, Madison, Wisconsin, USA, 322p. (A compilation of 18 papers on the nature and processes involved in bio-remediation, and its application).

Sparling, G. (2004). *How much have our Farming Practices changed Soils ?* Soil Horizon, Newsletter of Landcare Research New Zealand Ltd., Palmerston North, pp. 8-9 (Provides the results of a study on changes of soil properties as a function of land use in New Zealand).

Spellerberg, I.F. (2002). *Ecological Effects of Roads*. Science Publishers, Enfield, USA, 251p.(An excellent monograph on the physical and chemical effects of roads and traffic, habitat fragmentation, road kills and other adverse ecological effects).

Viehmeier, N.D., ed. (1993). *Vetiver Grass: A Thin Green Line against Erosion*. National Acad. Press, Washington, DC., 169p. (A monograph on Vetiver grass and its impact on reducing erosion, documented with many case studies worldwide).

Biographical Sketch

Willy Verheye is an Emeritus Research Director at the National Science Foundation, Flanders, and a former Professor in the Geography Department, University of Ghent, Belgium. He holds an M.Sc. in Physical Geography (1961), a Ph.D. in soil science (1970) and a Post-Doctoral Degree in soil science and land use planning (1980).

He has been active for more than thirty-five years, both in the academic world, as a professor/ research director in soil science, land evaluation, and land use planning, and as a technical and scientific advisor for rural development projects, especially in developing countries. His research has mainly focused on the field characterization of soils and soil potentials and on the integration of socio-economic and environmental aspects in rural land use planning. He was a technical and scientific advisor in more than 100 development projects for international (UNDP, FAO, World Bank, African and Asian Development Banks, etc.) and national agencies, as well as for development companies and NGOs active in inter-tropical regions.