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Table of contents

1.[Introduction](#_Toc212017286) 1

2. Soil degradation . 2

2.1 Water erosion .4

2.1.1. Sheet erosion .5

2.1.2. Gully Erosion .5

2.1.2. Gully Typology .6

2.2. Wind Erosion .11

2.3. Other types of degradation .12

2.3.1. Salination and waterlogging .12

2.3.2. Soil Acidification .13

2.3.3. Soil Compaction .14

2.3.4. Draught .15

2.3.5. Contamination by hazardous waste .17

3 Factors influencing crop production .19

3.1. Temperature, Radiation, and Evaporative Potential .20

3.2. Soil fertility and fertilizers .21

3.3. Water Availability and distribution .24

3.4. Soil Aeration and drainage .25

3.5. Plant density .27

3.6. Crop variety .27

References .30

1. Introduction

Erosion is a natural and continuous process. Soils are created through erosion of parent material and either local deposition or transport and deposition elsewhere. Erosion, is defined as the detachment or uptake, and transport over a certain distance of material of the upper layer of the earth crust by an agent, like water, wind or ice. This mass movement of soil particles, is part of the process of soil degradation. Before erosion takes effect, the degradation process often has started with qualitative changes in the soil, like loss of nutrients, loss of organic materials, reduced soil life and loss of soil structure.

There are three forms of erosion characteristic of degraded arid and semi-arid rangeland areas(FAO website,2000): Sheet Erosion the most common form of erosion. Unprotected soil particles are loosened by trampling, through wind erosion and by the impact of rainfall. The soil particles are then transported by rainwater surface flow to the river and stream systems. Sheet erosion is characterised by a general lowering of the soil level, leaving raised pedestals where the root mass of the remaining vegetation protects it. Wind erosion less common, but again takes place after vegetation has been lost and when soil particles are loosened. Early signs of wind erosion include deposition of sand particles around plants and micro-ripples on the surface of exposed areas. The final extreme is the classic sand desert dune structures. Gully Erosion the most obvious and dramatic demonstration of erosion, although in most areas actually less significant in terms of total land degradation. Gully erosion rarely occurs without sheet erosion. The trigger for gullying can be the loss of vegetation in areas where the microtopography results in concentrated streamflow during the rains. They can also be triggered by erosion along livestock tracks, footpaths and road edges. The process can start with "rills" and end up with gullies that are tens of metres deep.

# Soil degradation

Among the land used for agriculture- soil is an important component. The intense and increased pressure on land leads to its degradation and pollution, which may result in a partial or complete loss of it’s productive capacity. Soil degradation can be described as a process by which one or more of the potential ecological functions of the soil are harmed. These functions relate to bio-mass production (nutrient, air and water supply, root support for plants) to filtering, buffering, storage and transformation (e.g., water, nutrients, pollutants), and to biological habitat and gene reserve. Soil degradation is defined as a process that lowers the current and/or future capacity of the soil to produce goods and services. Two categories of a soil degradation process are recognised, viz., displacement of soil material (e.g., soil erosion by water forces or by wind forces) and in situ soil deterioration covering chemical or physical soil degradation.

Classifications of soil degradation types, are:

Water erosion Wt:

Loss topsoil Wd

Terrain deformation/mass movement Wo

Off-site effects Wo

reservoir sedimentation Wof

flooding Woc:

Coral reef and seaweed destruction E:

Wind erosion Et:

Loss of topsoil Ed

Terrain deformation Eo

*Chemical deterioration* Cn:

Loss of nutrients and/or organic matters Cs:

Salination Ca:

Acidification Cp

Pollution Ct

Acid sulphate soils Ce

Eutrification P

*Physical deterioration* Pc: Compaction, sealing and crusting Pw :Water-logging Pa:Lowering of water table Ps: Subsidence of organic soils Po: Other physical activities such as mining and urbanistion.

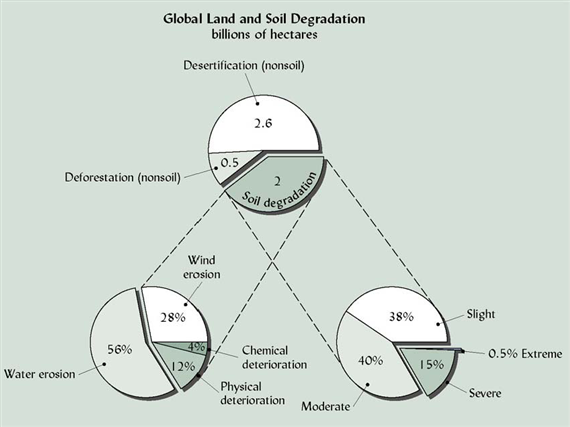


Figure 1 Globaol soil degradation

The primary cause of soil degradation is erosion, but compaction, salinization, and depletion by nutrient demanding crops may also cause degradation.

Soil degradation is which the movement of soil particles from one place to another by wind or water, is considered to be a major environmental problem. Erosion has been going on through most of earth's history and has produced river valleys and shaped hills and mountains. Such erosion is generally slow, but the action of man has caused a rapid increase in the rate at which soil is eroded (ie. a rate faster than natural weathering of bedrock can produce new soil).

This has resulted in a loss of productive soil from crop and grazing land, as well as layers of infertile soils being deposited on formerly fertile crop lands; the formation of gullies; siltation of lakes and streams; and land slips. Man has the capacity for major destruction of our landscape and soil resources. Hopefully he also has the ability to prevent and overcome these problems.

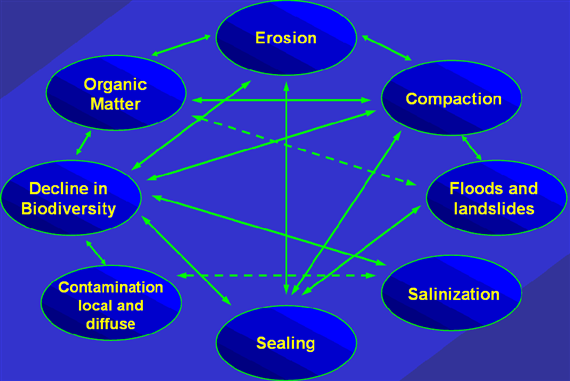


Figure 2 Relation between types of degradations

# Water erosion

Water erosion depends on four factors: rainfall, soil type, slope gradient, and soil use/vegetation cover. Loss of soil structure becomes often most visible in encrustation of the soil. That is, the hardened topsoil seals off the underlying soil layers, and water - especially after a dry period - cannot enter the soil. The result is a superficial and eroding run-off. Encrustation may have various reasons: insufficient plant cover makes raindrops directly impound the soil; soils containing fine soil particles (silt) are more vulnerable; recent research has shown that the topsoil may become hydrophobic due to compounds leached from plants. Three types are distinguished: sheet, rill and gully erosion. In sheet erosion, the top layer is more or less evenly removed. With rill erosion, a series of parallel superficial gullies is formed in the topsoil. Gully erosion is the formation of deep, disparate trenches, often in existing depressions. The last form of erosion is the most difficult to remedy, because of the amount of top (and deeper) soil removed.

# Sheet and Rill Erosion

Sheet erosion is the removal of surface soil in thin layers by raindrop impact and shallow flows of water on ground surface. Sheet erosion occurs in areas between rills, the eroded sediment moves to rills and then gets transported downslope if sufficient sediment transport capacity is available. Rill erosion is usually linked with sheet erosion as the shallow flows of water driving sheet erosion tend to merge. Rill erosion occurs in small channels (1– 200 mm in depth and width) that can be easily smoothed out or obliterated by normal tillage. Rill erosion is common in bare bare agricultural land, particularly in freshly seeded soil where the soil structure has been loosened.



Figure 3 The effect of sheet erosion a) on cultivated land (soil loss less than 0.5 t/ha and b) bare land prepared for sowing with soil loss between 15-35 t/ha

# Gully Erosion

Gullies are an important part of the soil erosion process and their occurrence and development may cause serious problems to a region’s economy. The case studies reveal that gully development occurs in accordance with allometric principles which are characteristic to a variety of natural phenomena; sidewall processes are 5–10 times more effective in dislodging soil and rock compared to downcutting and are highly dependent on the silt-clay content in the gully perimeter; and the hydraulic efficiency of gullies is substantially lower compared to streams, and thereby the transport of debris along the gully is essentially a pulsating process.

The rate of gully head cutting is over 1.5 m/year for gullies cut in sandy deposits and under 1 m/year for the gullies cut in marls and clays. A model of gully development is proposed which shows an accelerated rate of gully development immediately downstream after their initiation and a reduced progress and even cessation of advance when attaining an equilibrium length.

Gully erosion is one of the most destructive soil/land erosion processes; within a short period of time the topsoil and the underlying unconsolidated rock substrate are removed by runoff, resulting in the formation of a steep-sided channel deeper than 2 m, with an abrupt gully headcut and numerous thresholds in the channel thalweg.

This landform is commonly known as a ravine (gully), albeit it bears different names across the Globe (e.g., arroyo or coulee in USA, uvrag in Russia, burone or fosco in Italy, ravin in France, donga in South Africa, lavaka in Madagascar, nullah in India, etc.).

Due to the typically high gully development rates, these landforms have significant impact on vast farmland areas. Furthermore, they deliver large amounts of sediments to rivers and reservoirs. Gully erosion is regarded as an indicator of desertification (UNEP 1994); the main causes of which are allegedly global climate changes and anthropogenic. However, experimental studies on gully erosion commonly lacked the ampleness of those dedicated

to surface sheet erosion, even in Europe . Gully erosion rate estimates showed that gullying is responsible for a large extent of the topsoil loss in small catchments, ranging to as high as 90 % or above in numerous instances.

# Gully Tipology

Gullies are ranked and classified according to a variety of criteria reflecting both the diversity of control factors and the genetic processes and evolution of these landforms; thus, we believe it is necessary to discuss first the most relevant aspects regarding gully classification. The following classes of gullies were identified as typical for the Romanian territory (cf. Bălteanu and Taloiescu 1978; Rădoane et al. 1999; Ioniță 2000): continuous gullies1 and discontinuous gullies are types of landforms which indicate the stage and pace of gully evolution; the gully planform may provide clues regarding their origin and the relation to the type of rock deposit whereby they were incised Fig. 4 shows a summarized classification with short comments provided for each type); the location of gullies within drainage basins/catchments is relevant when determining the type of ephemeral runoff, the role of drainage upstream of the gully headcut or the occurrence of piping conditions.

According to these criteria, several types of gullies were established: valley floor gullies, whereby the evolution is linked to the valley concentrating the runoff/discharge; valley origin gullies which develop headwards along the channel ; hillside gullies located on the hillslopes, independent of the valley channel. Furthermore, gullies can be ranked according to their cross-section ranging from U-shaped gullies to V-shaped gullies, with many intermediate types. The shape of the cross-section is related to the resilience of rock deposits to erosion and the nature of geomorphic processes.



Figure 4 (by M. Rădoane and N. Rădoane 2016) Gully planform configurations

**a)** Trellis-type gully with depths ranging between 2 and 3 m, which initially formed along an old trail and eventually evolved on the bottom of a dell.

**b)** Gully bulb type, incised in predominantly sandy deposits which boosted processes such as suffusion/piping and collapse in the gully headcut area.

**c)** Gully composed of discontinuous secondary gullies and linear continuous gully.

**d)** Parallel gullies which developed as a result of cart trail relocation

**e**) Dendritic gully.

**f)** Hillside confluence gully forming at cart trail intersections.

**g)** Gully developed in river floodplain,

**h)** Linear gully



Figure 5 Groups of gullies

Gully Erosion Prevention and Control

Due to the particular mixture of topography, soil and climate aggressiveness specific to the European territory, soil erosion on sloping lands results in significant loss in both agriculture and other sectors of the economy. The structure of land use is dominated by agricultural land, which accounts for over 60 % of the total area. Scientific studies have shown that nearly 50 % of the agricultural land is affected by sheet erosion, gully erosion, or landsliding in various stages of evolution.

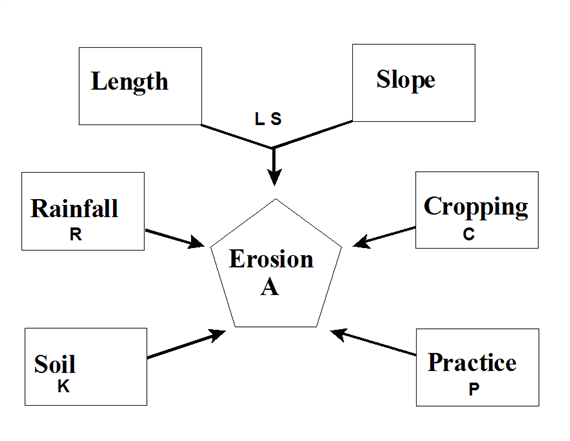


Figure 6 Erosion control factors

As erosion is caused by the effects of wind and water, then control methods are generally aimed at modifying these effects. Some of the most common control methods are listed below.

* Prevention of soil detachment by the use of cover materials such as plants (ie. trees, mulches, stubbles, crops).
* Crop production techniques (e.g. fertilizing), to promote plant growth and hence surface cover.
* Ploughing to destroy rills and contour planting to create small dams across a field, to retard or impound water flow.
* Filling small gullies with mechanical equipment or conversion into a protected or grassed waterway.
* Terracing of slopes to reduce rates of runoff.
* Prevention of erosion in the first place by careful selection of land use practices.
* Conservation tillage methods.
* Armoring of channels with rocks, tyres, concrete, timber, etc., to prevent bank erosion.
* The use of wind breaks to modify wind action.
* Ploughing into clod sizes too big to be eroded, or ploughing into ridges.



Figure 7 Degraded land versus improved lands (. (by M. Rădoane and N. Rădoane)

* 1. **Wind erosion**

Wind erosion is less well studied. Its main causes are disturbance of the vegetation cover (e.g. by overgrazing, inadequate cultivation practices and fires) and lowering of the water table (water use in excess of replenishment rate). Wind can then pick up soil particles and transport them away (deflation). Thus, at one place soil is lost, while at other places vegetation may be become buried. In addition, particle -laden wind can act as sand paper, and wear down vegetation, soil and rocks (abrasion). This exacerbates the effects of deflation. Wind erosion is not always detrimental. Loess soils (quite extensive in e.g. the PR of China) owe their existence to peri-glacial wind erosion, when under dry conditions fine particles were picked up from bare soils, and transported over large distances.

Wind erosion is closely linked to desertification, but certainly not limited to these areas. Areas particularly prone to wind erosion are loess soils and dryland soils. In dry regions, wind erosion is often strongly linked to water erosion, especially when seasonal rains follow long dry periods. On a dried out soil, this may result in strongly erosive surface flows (flash floods)

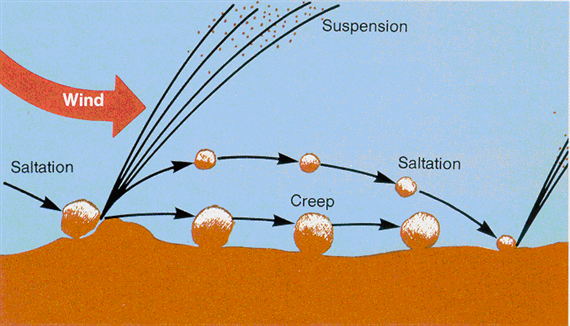


Figure 8 Wind Erosion (by L. Blaskó 2009)

* 1. **Other types of degradation** 
     1. **Salination and waterlogging**

Salt-affected soils generally occur in arid and semi-arid climates. In humid areas, the soluble salts originally present in soil material and those formed by weathering of minerals are carried down into the ground water and transported ultimately to the oceans. In humid regions salt-affected soils occur only when subjected to sea water intrusion in river deltas and other low lying land near the sea.

Salination is a natural process, e.g. when surface water or superficial groundwater runs out from a hill region into a low-lying dry area. The latter is e.g. found in northern Chile where groundwater from the Andes surfaces in the Atacama desert. Evaporation concentrates salts in the upper layer of the soil. Of more concern is salination caused by irrigation in agricultural areas. When water is applied in a measure not commensurate with local conditions, the upper layers of the soil will function as a wick, transporting groundwater upwards. Evapotranspiration then will lead to rising salt levels in the top soil, lowering crop yields. An extreme case of salination is linked to water logging, heightening the water table to near the surface through an excess of infiltrated water. This may be the case in low-lying areas in irrigated land, or badly managed irrigation schemes.

Waterlogging undermines the equilibrium of infiltration and discharge through evapotranspiration and ground water streams. With reduced drainage capacity, greater evaporation results in accumulation of salts in the upper soil horizons. On the other hand, insufficient application will also lead to salinisation, as salts are not leached down. The two extremes just described indicate that salination can be prevented through measured irrigation, requiring careful planning, land development, and monitoring of irrigation areas.



Figure 9 Salinity and waterlogging (Photo by Aamir Saeed )

* + 1. **Soil acidification**

This is a problem becoming increasingly more common in cultivated soils. Soil acidification is the increase in the ratio of hydrogen ions in comparison to 'basic' ions within the soil. This ratio is expressed as pH, on a scale of 0-14 with 7 being neutral. The pH of a soil can have major effects on plant growth, as various nutrients become unavailable for plant use at different pH levels (see lesson on nutrition). Most plants prefer a slightly acid soil, however an increase in soil acidity to the levels being found in many areas of cultivated land in Australia renders that land unsuitable for many crops or requires extensive amelioration to be undertaken.

***Causes of soil acidification***. Acid soils can be naturally occurring, however, a number of agricultural practices have expanded the areas of such soils. The main causal factor is the growth of plants that use large amounts of basic ions (e.g. legumes); particularly when fertilizers that leave acidic residues (such as Superphosphate) are used. Soil acidity is generally controlled by the addition of lime to the soil, by carefully selection of fertilizer types and sometimes by changing crop types.

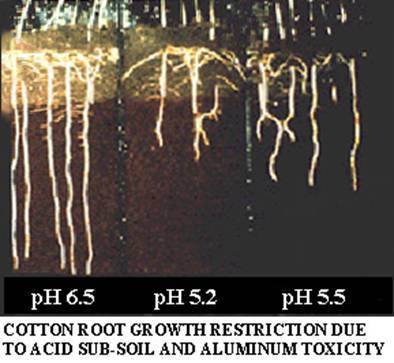
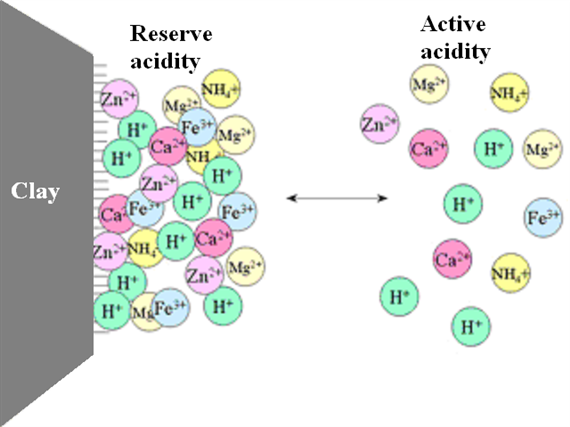


Figure 10 Soil acidifiation by L. Blaskó 2008

* + 1. **Soil Compaction**

Compaction of soils causes a reduction in soil pore space. This reduces the rate at which water can infiltrate and drain through the soil. It also reduces the available space for Oxygen in the plant root zones. For this reason, some of the major consequences of compaction are poor drainage, poor aeration, and hard pan surfaces which cause runoff. Compaction is generally caused by human use of the soil (ie. foot traffic on lawn areas or repeated passage of machinery in crop areas). Repeated cultivation of some soils leads to a breakdown of soil structure and this also increases the likelihood of compaction. Compaction can be prevented by farming practices that minimize cultivation and the passage of machinery. These include conservation tilling, selection of crops that require reduced cultivation, and use of machinery at times less likely to cause compaction (i.e. when soils aren't too wet or when some protective covering vegetation may be present). For heavily compacted soils deep ripping may be necessary.

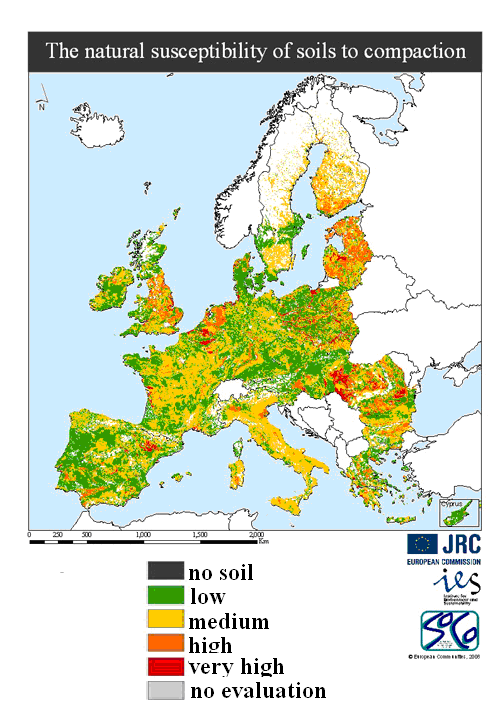


Figure 11 Natural susceptibility for soil compaction

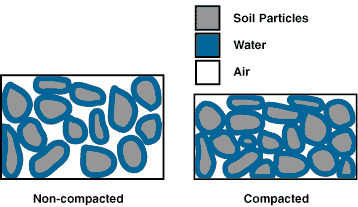


Figure 12 Non compacted and compacted soil

* + 1. **Drought**

Among the extreme meteorological events, droughts are possibly the most slowly developing ones, that often have the longest duration, and at the moment the least predictability among all atmospheric hazards. Due to these characteristics, particularly their temporal character, droughts cannot be compared with other weather and climate extremes such as floods, winter storms, frost etc. which contribute to the weather affected annual loss, also significantly. The major hydrologic hazards (e.g. flood and drought) are consequences of precipitation extremes. While floods may have mostly local economic impacts, drought's impacts usually influence large regions and almost the entire economy. There are many conceptual definitions of drought in the scientific literature.

Meteorological drought is often identified with atmospheric drought and defined simply with below mean precipitation amounts, sometimes combined with other parameters e.g. air temperature, humidity and wind velocity. As a matter of fact, the general term drought is not identical to precipitation deficit, but rather it is usually the consequence of below normal precipitation. Drought is by definition a regionally extensive deficiency in precipitation. Briefly, all other definitions of drought are related to the effect or impact of below normal precipitation on agricultural, water resources, social and economic activities. More precisely, atmospheric drought is a state of the atmosphere (not an instantaneous but an integrated state for a longer period of time) that results in less than average (for that period) precipitation amounts and/or below normal atmospheric humidity.

Agricultural drought occurs when the available soil moisture is inadequate to meet the evaporative demand. It can also occur, if meteorological anomalies take place during the plant specific time period (vulnerable stages of plant development) with regard to the water availability. In addition to lack of precipitation, other contributing factors may increase drought severity such as low humidity temperature and winds. Drought results in considerable crop yield losses (e.g. more than 10 % of the average yield). Hydrological drought occurs when river flows or stored water in lakes, groundwater, reservoirs and aquifers fall below some critical levels resulting from a long-term deficiency of moisture.



Figure 13 agricultural drought

* + 1. **Contamination by hazardous waste**

Hazardous waste is being produced in growing amounts as a necessary or wasteful by-product in the production of many products and chemicals. As treatment and safe dumping is often a very costly affair, it is attractive to get rid of it cheaply. This results in careless storage in basins, dumping mixed with normal garbage, and dumping in watercourses. For developed countries, export to developing countries may be an attractive possibility (in spite of the Basel Convention), leaving the receiving country with short-term money that could never possibly cover the costs of the long-term problem. Contaminated sites often start drawing attention when the consequences are already felt; remedial costs are often enormous, preventing a satisfactory solution.

 The presence of chemical residues can be quite a problem on a local scale. These residues derive almost entirely from long term accumulation after repeated use of pesticides, etc., or of use of pesticides or other chemicals with long residual effects. Some problems that result from chemical residues include toxic effects on crop species and contamination of workers, livestock and adjacent streams. Control is often difficult and may involve allowing contaminated areas to lie fallow; leaching affected areas; trying to deactivate or neutralize the chemicals; removing the contaminated soil; or selecting tolerant crops.



Figure 14 Soil contamination by hazardous waste

1. **FACTORS INFLUENCING CROP PRODUCTION**

There are several reasons why benefits and productivity may be less than desired. However, one of the important considerations is the complexity of the knowledge required for rapid progress in agricultural productivity. The engineer may design good facilities, the construction company may follow good practices, and the water supply may be adequate. But frequently not enough attention has been given to the factors of production other than water.

Agricultural technology has advanced rapidly during the last half century. In some areas average crop yields have more than doubled. For a few crops yields have quadrupled. Irrigation is a means for advancing to a higher technological level, and it should be used as a means of advancing to a higher level of productivity, creating a “middle class” in agriculture in developing countries, optimizing farm income from available resources, improving the environment, conserving the resources, and other objectives. For these reasons it is desirable that a knowledge of the factors of crop production be developed as an introduction to an improved understanding of the importance of irrigation.

Water is only one of several factors that influence the yield and productivity of agricultural crops.

Plant diseases and competition from weeds may have significant influence on whether or not it is profitable to irrigate a given crop. If diseases and weeds are adequately controlled, crop yields are largely determined by six factors of production. These are:

(1) energy (air temperature and solar radiation);

(2) soil fertility and fertilizers;

(3) water availability and distribution;

(4) soil aeration and drainage;

(5) plant density (spacing and leaf area index);

(6) crop variety or cultivar.

Crop production is a complex science. Failure to give proper consideration to any of the principal factors of production may reduce yields significantly below their potentials. Poor soil aeration or a poor selection of the variety to be planted may reduce potential yields to only half of the amount otherwise possible. The problems of the developing countries that result from low agricultural productivity and rapidly increasing populations have no simple solutions. Irrigation and water management alone, or adequate use of fertilizers with little attention to the other factors of production, may not produce satisfactory crop yields.

However, when all factors of production are improved, irrigation and fertilization may become very important as key elements for increasing crop production.

* 1. **Temperature, Radiation, and Evaporative Potential**

Crop growth and development are influenced by temperature, solar radiation, the evaporative potential, and the daily temperature range. The total number of growing degree days is usually used in the crop genetic coefficients for modeling crop growth and development. Growing degree days are calculated in several different ways depending upon the crop type and the yield model. Within a range of temperatures, potential crop yields have frequently been shown to be linearly related (proportional) to the evaporative potential. The optimum plant density or optimum leaf area index can be demonstrated to be a function of solar radiation. The optimum mean temperature range for a given plant species varies somewhat with the different cultivars of the species and with the daily temperature range.

Crop growth and development are influenced by photoperiod sensitivity, that is, latitude and day length. Crop yield models frequently contain a photoperiod sensitivity coefficient. The daily temperature

range (difference between maximum and minimum air temperatures over a 24‐hour period) can be used to estimate solar radiation and minimum relative humidity. Optimum mean temperatures for plant growth are influenced by solar radiation and relative humidity, or by the daily air temperature range. Research with one potato cultivar indicates that a low temperature range increases the optimum mean air temperature. Some crops produce best when the temperature range is low. The optimum temperature for plant growth is also influenced by other factors. Maize produced on a well aerated soil may produce maximum growth at a mean temperature of 28°C, but with poor soil aeration, growth rates may decline for temperatures above 21°C.

Table 1. Optimum and operative temperatures for selected crops by G. Hargreaves and G. Merkley

|  |  |
| --- | --- |
| Crop Group I | Optimum temperature: 15‐20°C; operative range: 5‐30°C ‐ arabica coffee, artichoke, asparagus, barley, beet, broccoli, Brussels sprouts, cabbage, carnations, carrot, cauliflower, celery, chard, chayote, chickpea, chrysanthemum, crucifers, cucumber, French bean, garlic,  gladiola, grape, green onion, lima bean, lentils, lettuce, linseed (flax), muskmelon, mustard, oats, olives, onions, parsley, parsnip, peas, pumpkin, potato, rape, roses, rye, snap bean, southern pea, spinach, squash, strawberry, sugar beet, sunflower, sweet corn, sweet pepper, tomato, and wheat. |
| Crop Group II | Optimum temperature: 25‐30°C; operative range: 10‐35°C ‐ avocados, banana, cassava, castor bean, cocoa, coconut, cotton, crow pea, eggplant, fig, French bean, grape, greater yam, groundnut, hot pepper, hyacinth bean, kenaf, mango, okra, oil palm, olive, para rubber, rice, robusta coffee, roselle, safflower, sesame, sunflower, sweet potato, tobacco, tomato and water melon. |
| Crop Group III | Optimum temperature: 30‐35°C; operative range: 15‐45°C ‐ corn (maize), rice, millet, sorghum, and sugar cane |
| Crop Group IV | Optimum temperature: 20‐30°C; operative range: 10‐35°C ‐ maize, millet, and sorghum |
| Crop Group V | optimum temperature: 25‐35°C; operative range: 10‐45°C ‐ pineapple, and sisal. |

* 1. **Soil Fertility and Fertilizers**

The application of an optimum amount of fertilizer often has the potential for doubling crop yields over those possible without fertilization. The productivity and economic viability of newly developed irrigation projects often depend to a large degree upon the proficiency of fertility management. Plants require several nutrients from the soil, and others from the air. These nutrients include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and others. Plant roots can typically absorb only a limited number of chemical compounds of the required nutrients, which means that organic decomposition and mineral weathering in the soil are needed to support plant growth. Organic decomposition usually

occurs on a large scale in an agricultural soil through the activities of many types of bacteria and other microorganisms, and the presence of sufficient nitrogen in the soil is critical for sustained levels of bacterial activity. Many manufactured fertilizers have a predominance of nitrogen, phosphorous, and potassium, often with some “trace” elements such as zinc, and manganese. Larger plants, such as maize (corn), tend to require more nitrogen than the smaller plants because nitrogen is critical in supporting vegetative growth.

Some of the required plant nutrients are actually toxic to the plants when small concentrations are exceeded in the soil. For example, boron is required by most plants, but when there is more than one part per million in the soil water it can severely restrict growth and production for many crop types.

Fertilizers can take the form of animal waste, plant material and industrial products. Some crop types are referred to as “green manure” and are used to improve soil fertility and physical soil characteristics. Green manure is a crop grown not to be harvested in the traditional sense, but to be disked or plowed into the soil where it will decay. Industrial, or manufactured, fertilizers are not “natural” like animal manure or vegetative matter, but contain the same basic soil nutrients and are no more of a “contaminant” than manure. Problems with using animal waste as fertilizer are the potential health hazard in handling, and the possibility of large amounts of weed seed. Nevertheless, animal manure has the advantage that it directly

adds organic matter to the soil, which can be a significant benefit for some soils. Compost is also used for fertilizers, but usually on a relatively small scale, that is, on small plots of land.

The most common forms of nitrogen fertilizer are ammonium sulfate and ammonium nitrate, but anhydrous ammonia is also used extensively. Standard fertilizer classifications include the

percentages by weight of nitrogen, phosphorous, and potassium (N‐P‐K). These are the three main fertilizer components typically added to agricultural soils, but other chemical compounds are commonly added in much smaller quantities. As an example of an N‐P‐K specification, an 18‐18‐18 fertilizer will have 18% N by weight, 18% P and 18% K, with the remaining 46% being inert or “filler” material. The second figure is, in fact, traditionally representative of the amount of phosphate (P2O5), and the third value is the percent weight of potash (K2O) – if these values were in pure P and K the percentages would be lower.

Doorenbos and Kassam (1979) provide a list of ranges of fertilizer requirements for twenty‐six crops. The ranges in requirements for nitrogen (N) for leguminous crops vary from zero to 40 kg per ha, and for non‐leguminous crops, from 40 to 300 kg per hectare. For phosphate (P2O5) and potash (K2O) the ranges are 15 to 110 and 24 to 480 kg per hectare, respectively. The results from field trials, soil testing, laboratory pot tests, known interactions, and crop yield models can be very useful for determining the desirable amounts and frequencies of fertilizer applications.

Doorenbos and Kassam (1979) also give a table that includes fertilizer requirements for the growing period of different crop types. Table 2.2 is a summary of the fertilizer requirements from their table. It is seen that fertilizer requirements can vary significantly. For legumes a booster of about 20 kg of nitrogen usually produces good results. For other crops most require at least 100 kg of nitrogen per hectare. The average P2O5 and K2O requirements are about 100 kg per hectare for most agricultural crops.

Table 2. Fertilizer requirements in kg per ha for the growing periods of various crops by Doorenbos and Kassam 1979

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Crop | Nitrogen | | Phosphate | | Potash | |
| Range | Average | Range | Average | Range | Average |
| Bananas & pineapple | 200‐400 | 282 | 108‐156 | 129 | 132‐576 | 309 |
| Orchards and grapes | 100‐250 | 681 | 84‐168 | 122 | 60‐276 | 194 |
| Legumes | 0‐40 | 22 | 36‐156 | 101 | 30‐192 | 89 |
| Food grains | 100‐200 | 135 | 48‐192 | 101 | 30‐144 | 85 |
| Vegetables | 80‐170 | 109 | 60‐264 | 132 | 42‐192 | 131 |
| Field crops | 40‐200 | 106 | 36‐216 | 106 | 30‐192 | 108 |

The yield response to fertilizer can be shown as a function of the amount applied. If Y is crop yield and F is fertilizer amount, a typical yield function may be approximated by the equation

in which a is equal to the yield with no application of fertilizer, F; b is the initial slope of the yield curve (the increase in Y divided by the increase in F for the first 25 to 50 kg per ha of F applied); and c is determined from the amount of F required when Y is at a maximum.

* 1. **Water Availability and Distribution**

Water is absorbed by the plant roots from the soil solution, passes up through the plant and is transpired or evaporated from the leaves. Water also evaporates from soil and plant surfaces. It is difficult to measure the amounts of evaporation and transpiration separately. For that reason they are usually measured or estimated together as evapotranspiration. The major portion of consumptive use of water by crops is transpiration. Within the range of suitable temperatures, crop growth and production are approximately proportional to transpiration and for practical purposes are frequently assumed to be

proportional to crop water use, or evapotranspiration (ET).

Water from irrigation or rain is not uniformly available to the crop as some portions of the field receive more water than others. Within the same field, soils may not be uniform and water holding capacities and infiltration rates may vary considerably. Consequently, when water becomes fully adequate for all portions of the field there will be considerable excess or waste from some portions. As maximum yields are approached, efficiencies decline, producing an approximately exponential relationship between yields and water availability. Hargreaves (1975) obtained crop yield data from various crops and research trials and compared yields to the water available (initial soil water stored in the soil plus growing season rainfall plus irrigation water applied). Relative crop yields (Y) were used in order to compare different crops and yield units. A value of unity for Y was used for the maximum yield of each crop, and X is unity for the water required to produce maximum yield. The data used covered the range of values of X from 0.30 to 1.20. It was found that most of the yield data evaluated could be represented by the equation:

where Y is relative crop yield (fraction); and X is the depth of applied water. The equation is normalized such that for X = 1.0, Y = 1.0.

* 1. **Soil Aeration and Drainage**

Where natural drainage is inadequate and artificial drainage cannot be economically provided, thelands usually cannot be permanently irrigated. Rice is an exception − although rice grows well in standing water, drainage is required for most tillage and harvesting operations. Irrigation of lands where the original water table is less than thirty meters below the surface has usually resulted in eventual waterlogging or salinization or both. Control of salinity and methods of drainage are described in other sections, but in this chapter the emphasis is on soil aeration as a factor of production. The degree of aeration, or the amount of oxygen available to the plant roots, has a large direct effect on the rate of plant growth. There are also numerous secondary effects related to soil temperature, toxicity, plant diseases. and availability of nutrients.

Respiration is essential for water and ion uptake by plant roots. Low oxygen (O2) content in the soil will decrease water and nutrient uptake by plants because of reduced root permeability for water. One of the harmful results is decreased transpiration of water which may result in wilting (wet wilt). Well‐aerated plants may take up two to four times as much water as poorly‐aerated plants. In poorly aerated soils, anaerobic respiration results in incomplete oxidation of organic matter and may result in products toxic to plants. Susceptibility of roots to attack by fungi and other organisms is often increased. With poor aeration, nitrate (NO3) may be lost through denitrification.

The first requirement for a high crop yield is a good stand. Aeration has an important role in plant survival in the early stages of growth. If the crop is grown for fruit or grain, a significant decrease in yield can result from low O2 levels (low levels of respiration) at the flowering or blooming stage.

Poor aeration may also result in reduced shoot growth and this can reduce yield whether the crop is grown for its fruit or its vegetation.

Photosynthesis results in the production of carbohydrates from H2O and CO2. The reaction requires energy. Respiration results in the conversion of carbohydrates to H2O and CO2 (water and carbon dioxide) and releases energy to be used in various plant growth processes. The requirements for respiration and the

energy from respiration increase exponentially with increasing temperature. At high temperatures waterlogging of the soil for only one day may be very damaging to crop production or even fatal to sensitive crops.

The tolerance to poor aeration depends upon temperature, the daily temperature range, plant species, and the variety or genotype within the species. There are wide variations in climatic and plant requirements for aeration and drainage, but, with the exception of rice, without good natural or artificial drainage there can be irrigated agriculture of only limited productivity and for a relatively short time.

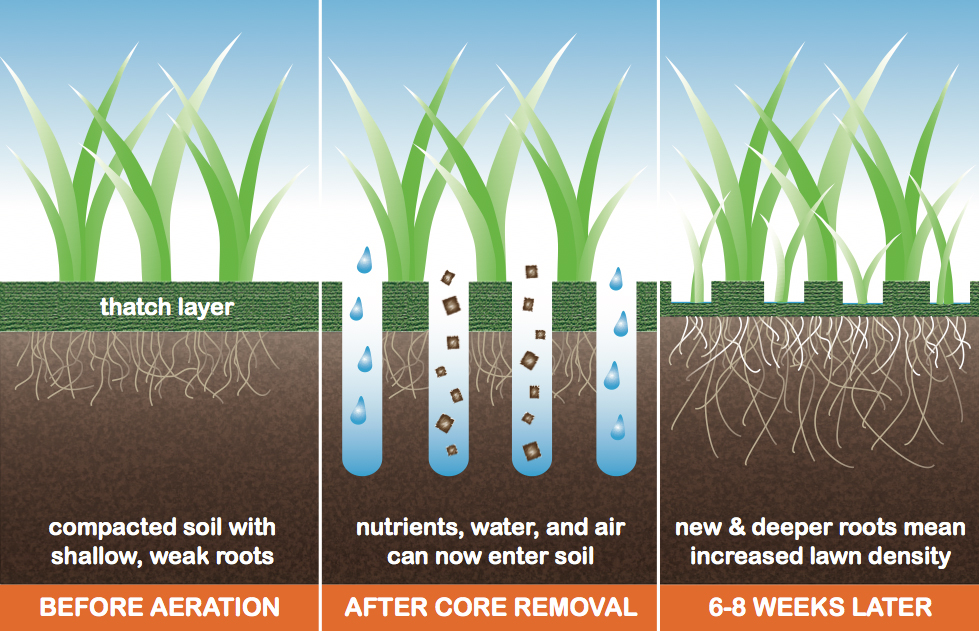


Figure 15 Soil Aeration

* 1. **Plant Density, Spacing and Leaf Area Index**

Within limits, yield per plant increases with a corresponding availability of growth resources or factors of production. Yields per unit area increase with increasing numbers of plants until plant population is sufficient for maximum resource utilization. The total yield per unit area then generally remains reasonably constant with increasing plant population over an optimum range. This range may include plant populations of two to four times that required for optimum resource utilization. Beyond this range of plant populations, yields per unit area decline.

The desirable plant population varies with the availability of resources. The best number of plants per hectare for irrigated agriculture may be two or more times that for dry‐land farming.

The amount of available solar energy has an important influence on the optimum plant population or upon the desirable leaf area index (LAI). The LAI is the ratio of the total leaf area of the plants on a fixed or unit area to the area of soil producing the plants.

* 1. **Crop Variety**

For given conditions of resources including soil, nutrients, climate, etc., one cultivar or variety of a given plant species may produce much better than another. For example, the crop genetic coefficients for fourteen maize cultivars were used with one set of resource conditions with the CERES‐Maize nitrogen model (Jones and Kiniry 1986). If, under the same resource conditions one variety will yield nearly three times as much as another, it is of considerable importance that the best cultivar for the resource conditions be selected.

Crop growth and development models are available for most of the food grains, cassava, groundnuts, soybeans, and other crops. Crop genetic coefficients are available for varietal comparisons using the yield models for several crops. This science or methodology is rapidly being perfected for various crops. At research stations field varietal trials have been carried out for many years. The availability of irrigation improves the desirability of selecting improved varieties. Both results of field trials and the use of crop yield models should be used in order to select the best varieties for irrigated agriculture.

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