GOVERNO DO ESTADO DO CEARÁ
Secretaria dos Recursos Hídricos

Innovative Edaphic and Hydroenvironmental Control Practices for Ceará Semiarid Region

Volume 2

Série: Tecnologias e Práticas Hidroambientais para Convivência com o Semiárido

INNOVATIVE EDAPHIC AND HYDROENVIRONMENTAL CONTROL PRACTICES FOR CEARÁ SEMIARID REGION

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Volume 1 - Bacias Hidrográficas: Aspectos Conceituais, Uso, Manejo e Planejamento

Volume 2 - Práticas Inovadoras de Controle Edáfico e Hidroambiental para o Semiárido do Ceará

Volume 2 - *Innovative Edaphic and Hydroenvironmental Control Practices for Ceará Semiarid Region*

Volume 3 - Avaliação Geoambiental de Práticas Conservacionistas Implantadas na Microbacia do Rio Cangati, Canindé-CE

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Volume 6 - *Socioeconomic Evaluation of Results and Impacts of Ceará Hydroenvironmental Development Project and Suggested Policies*

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INNOVATIVE EDAPHIC AND HYDROENVIRONMENTAL CONTROL PRACTICES FOR CEARÁ SEMIARID REGION

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SUMMARY

FOREWORD

Water, soil and flora trinomial makes a perfect combination for nature preservation. Among the components of natural cycle, such as sun, air, animals and others, man stands out as the center of a life preservation or degradation process in the planet. Man action in Earth, which is determined by their need of association, survival, rationality, sensitivity, progress satisfaction and other spiritual expressions, will affect directly and especially the water balance. This explains why no sustainable water resource development project will put aside the basic concern with environmental control.

The Integrated Water Resource Management Project (PROGERIGH), the greatest and most important water supply program in the State, would not succeed in promoting a new positive experiment in Ceará without including in its actions a basic nature preservation activity, such as the Hydroenvironmental Development Program (PRODHAM). This Project, the focal point of which is soil preservation, looks into the future by recovering degraded areas, reducing desertification and assigning the man the high status of natural resource regeneration agent. Who knows if by the end of this century this man's behavior will not have been their noblest mission in the Earth?

In this sense, the governmental project scores a point in favor of environmental protection, not only in terms of care with nature, but especially in terms of its recovery, by redeeming the ecosystem lost in the past.

Hypérides Pereira de Macêdo

Ex- Secretary of Water Resources of the State of Ceará

Introduction 1

INTRODUCTION

Problems associated with natural resource use, management and preservation in the State of Ceará require a resolute action by the State Government and the whole society to address the issues related to environmental degradation, inadequate soil use and reduction of harmful water shortage effects from periodic droughts in Ceará semiarid region.

However, to undertake such a task, a technological focus able to support the needs of proposed actions is critical.

Soil erosion by water, as the major problem of natural resources in the State, needs to be understood as a complex phenomenon that starts with soil structure disaggregation by direct raindrop impacts, followed by soil transportation and sedimentation. It is important to understand the whole process to develop strategies that are able to tackle the causes, rather than concentrating efforts on effects or less important parts of the problems.

PRODHAM will be initially implanted in four Pilot Microbasins in the State of Ceará, each of which covers a surface area ranging between 3,000 and 5,000. Developing that action will always require a permanent effective flow of information between coordination and control structures and the executing team.

Such actions include, without limitation, planning of hydrographic microbasins and respective agricultural properties, recommendations and assistance on technologies, producers organization, etc.

That process, which comprises the formulation of a program and its field implementation, very often experiments technological deviations when a fast information flow fails to occur. In that process, the field professional that is very often isolated in small municipalities and sometimes experiments interrupted flows of information, both in terms of quality and quantity, unintentionally starts to deviate from basic technological guidelines of scheduled actions:

PRODHAM Technical Operation Manual, the contents of which include an array of information that the field professional may use to achieve the objective and targets of actions proposed by the Program.

In short, the Technical Manual has the following objectives:

- To inform all participants, especially field professionals, of PRODHAM technical strategy;
- to show a series of alternatives to the technical strategy, which may be recommended at both local and regional level, without however constituting 'technological packages';
- to serve as a basic material for different levels pf personnel training, and a daily reference material for field professionals; and
- to make the technological status scheduled for the project closer to the real status of its field implantation.

Given the dynamism of scheduled activities, the technological knowledge, the project lifetime and other contingencies, this Technical Manual is being prepared to contain graphic characteristics to allow its periodic evaluation, and is subject to eventual adjustments consistent with the dynamics of action development.

Hydroenvironmental Problem 2

2 – HYDROENVIRONMENTAL PROBLEM

In general, it may be said that water erosion and indiscriminate removal of vegetative cover are the major problems faced by hydroenvironmental resources in the State of Ceará. As this is a State where economy is highly dependent of agricultural sector, coexisting with such problems implies to accept the gradual soil impoverishment at the medium and long term.

Actually, erosion is not the only natural resource problem; however, other problems, nevertheless their high importance, do not achieve its magnitude level, as such problems in whole or in part, derive from erosion process.

The analysis of the diagram below makes us understand how environmental problems interact with one another and very often cause other problems.

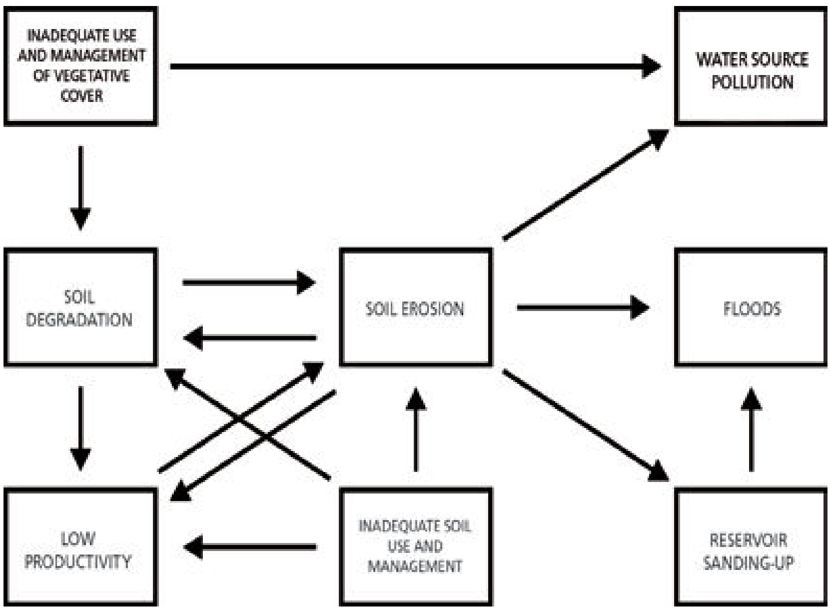


Figure 1 – Diagram of Environmental Problem Interaction

By considering soil erosion as the major problem, its consequences include problems related to water source sanding-up and pollution. However, erosion results from other existing factors all of which are related to inadequate use and management of natural resources Likewise, low productivity and soil degradation interfere with erosion, as they affect vegetal production, and are similarly caused by erosion, thus closing a cycle that is extremely harmful to environment preservation and social welfare.

The Agronomist Engineer Guimarães Duque, in his work "Solo e Água no Polígono das Secas" (Water and Soil in Drought Polygon), emphasizes that: "The system has led to unrestrained erosion and land denudation, thus breaking the natural equilibrium between soil, flora, water, fauna and human economic life. Man's devastation of native vegetation causes thousands of harmful consequences when rational methods are not used to keep the harmonious equilibrium of climate, plant, water and animal forces."

In addition to vegetation, type of soil and topography, erosion is strengthened by wind speed, rain intensity and ambient temperature that dry up the soil. These three climatic agents in semiarid region are quite unfavorable to soil fertility maintenance.

Effect of climatic factors, upon preventing shallow soil preservation and promoting the fall of vegetation leaves, makes the wind hit the soil surface.

In summer, naked land, evapotranspiration and constant wind cause soil erosion. In winter, the harmful flood effects start with the first rains, which hit the dry vegetation and nearly-naked soil. In fact, soils in semiarid region are subject to weathering throughout the 12 months of the year. In Figures 1 and 2 it is possible to note the causes and consequences of erosion and the required actions to mitigate erosion effects.

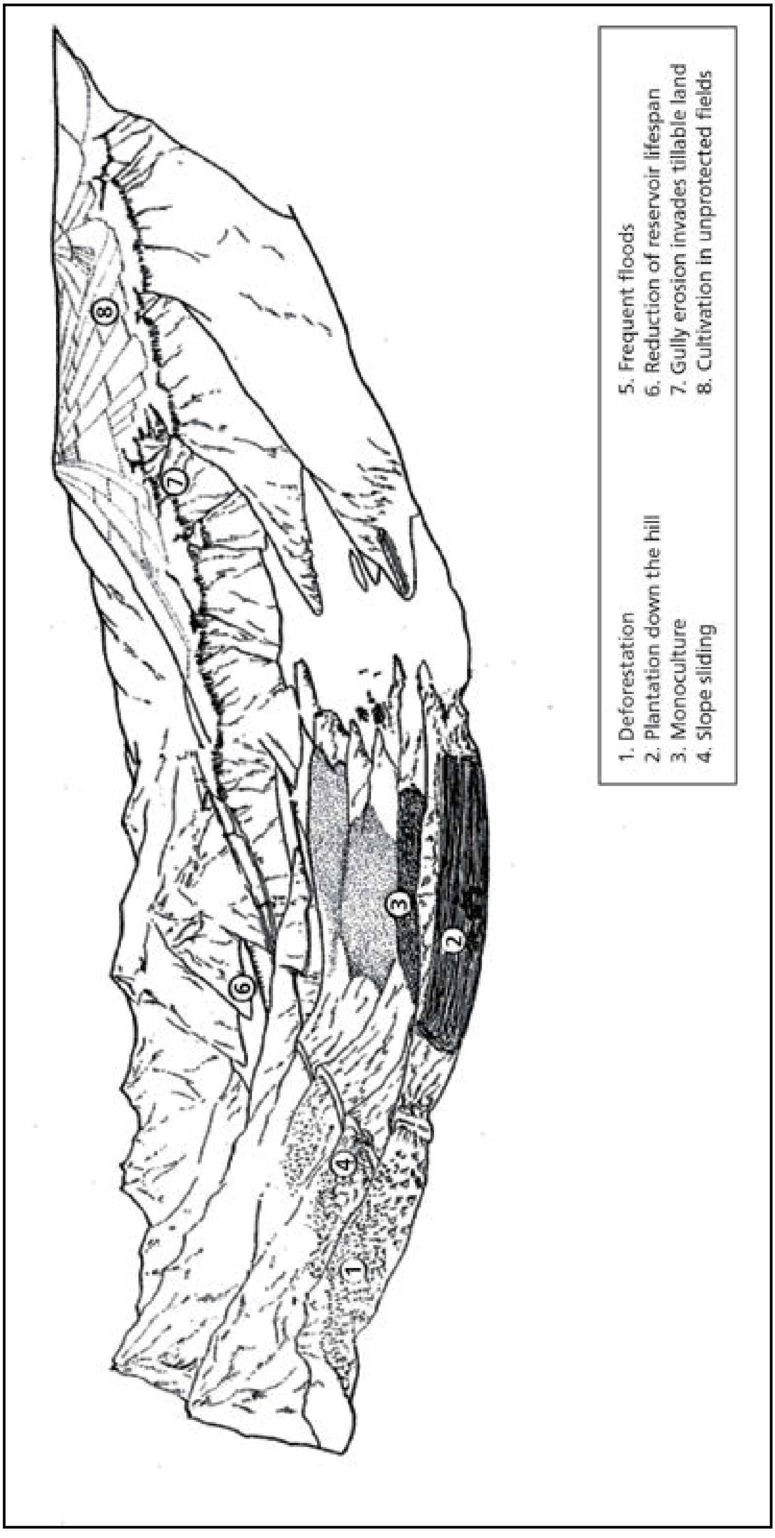


Figure 2 – Causes and Consequences of Erosion
Source: IAPAR (1998)

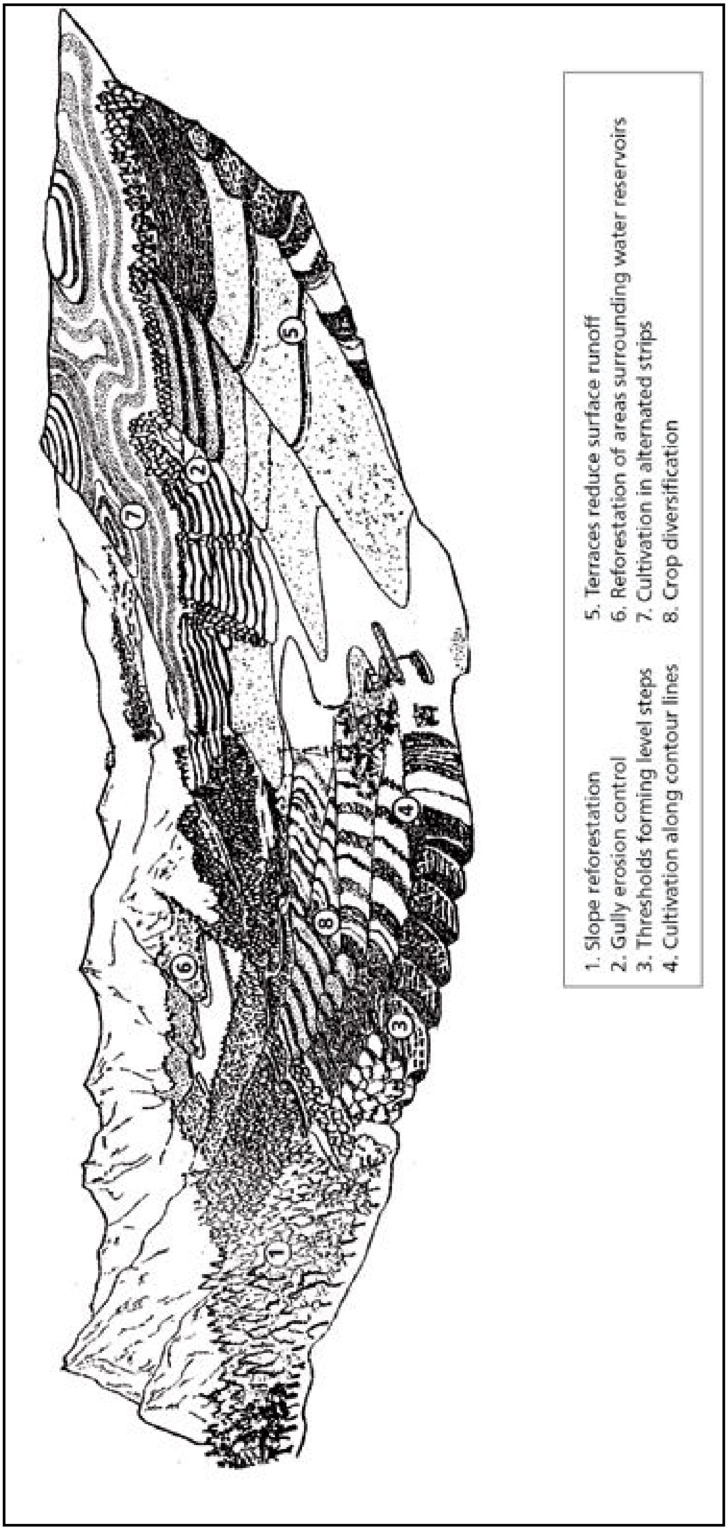


Figure 3 – Demonstration of Means to Prevent Soil Degradation
Source: IAPAR (1998).

Photo 1 – Impact of the Rain Drops on the Ground.
Source: Naval Research Laboratory / USDA Soil Conservation Service – Mitchel, J. K.

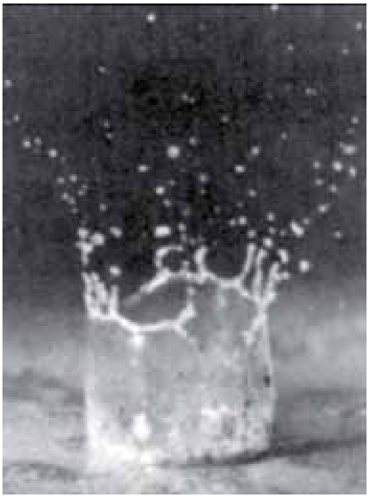


Photo 2 – Impact of the Rain Drops on the Ground.
Source: Naval Research Laboratory / USDA Soil Conservation Service – Mitchel, J. K.

Photo 3 – Impact of the Rain Drops on the Ground.
Source: Naval Research Laboratory / USDA Soil Conservation Service – Mitchel, J. K.

Photo 4 – Impact of the Rain Drops on the Ground.
Source: Naval Research Laboratory / USDA Soil Conservation Service – Mitchel, J. K.

Foto 5 – Groove Erosion as a Consequence of Soil Compaction
Source: Z. J. Mazuchowski and R. Lderpsch.

Alternative Environmental Control Practices 3

3 – ALTERNATIVE ENVIRONMENTAL CONTROL PRACTICES

3.1 – Stone Dams

3.1.1 - General

Stone dams, also known as "successive dams" are constructed in the format of lying Roman arch and loose stones disposed in "wedges" in tributaries (streams) of the 5th hierarchization order and above, in the Hydrographic Basin. This work is based on a real experience that has been adopted for many years by Zero Base Project of Caroá Farm in Afogados da Ingazeira - Pernambuco (TBZs – Zero Base Technologies). A visual detail of the dam may be seen in Photo 6.

Photo 6 - Stone Dam – Zero Base Technology (TBZs)
Source: João Bosco de Oliveira.

However, to make tasks required by those simple small works easier, the observance of some construction parameters is recommended, which even without requiring a millimetric accuracy, will help to identify the best way to perform the corresponding tasks.

3.1.2 - Purpose

With respect to hydroenvironmental matter, the great importance of that work (Stone Dam) lies in the reduced magnitude of damages resulting from inadequate management of agroecological capacity and forms of soil use in hydrographic microbasins. Thus, a differentiated demand for technological innovations should be considered, in particular in microbasins with a heterogeneous land structure and degraded areas.

The introduction of an ecodevelopmental and conservational culture that gives priority to the exploration and preservation of natural resources is highly important, especially those related to the rational use of soil and water in Ceará semiarid region.

Implantation of successive stone dams aims among other things to:

- Promote gradual sanding-up/sedimentation of eroded and rocky riverbeds in microbasins;
- promote gradual soil desalination and fertilization and water quality in microbasin tributaries;
- promote the quasi-spontaneous resurgence of several forms of vegetal and animal life;
- reduce the pressure of forms of animal life on forms of vegetal life occurring in bumps of hydrographic microbasins, benefited by a new more accessible, abundant and diversified availability of food at the bottom of the valley;
- provide water supplies for animal consumption according to a temporal and spatial distribution to explore vegetal production in brushwood areas; and
- provide a vegetative substratum in sedimented terraces created in valley bottom, to enable a diversified livestock production supported by available water.

3.1.3 - Location

In TBZ group, the most important aspect of dam implantation process is the correct management of location, anchorage and demarcation trinomial prior to starting the construction of work.

In any case, the selection of locations adequate to stone dam construction should meet some basic requirements. The most critical of all requirements is that the sites selected for location of works are provided with minimum conditions for anchorage of structures to watercourse margins, on a case-by-case basis. In addition, each work site should be provided with the adequate material in quantity sufficient to meet the construction needs.

After the selection of tributary (stream) to be worked in the microbasin, the construction should be made from downstream to upstream (Figure 4) to the water flow.

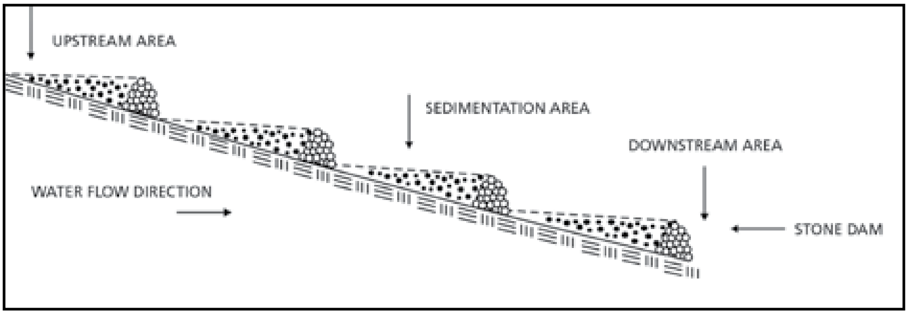


Figure 4 – Sequence of Stone Dams
Source: Padilha (1997).

3.1.4 – Structure anchorage

To meet the structural anchorage needs at different situations of work execution, the largest four stones should be selected on the stream margins to serve as anchorage points. Such points are shown in Figure 5, represented by points “a”, “b”, “c” and “d”, with emphasis for the function of points “a” and “b”.

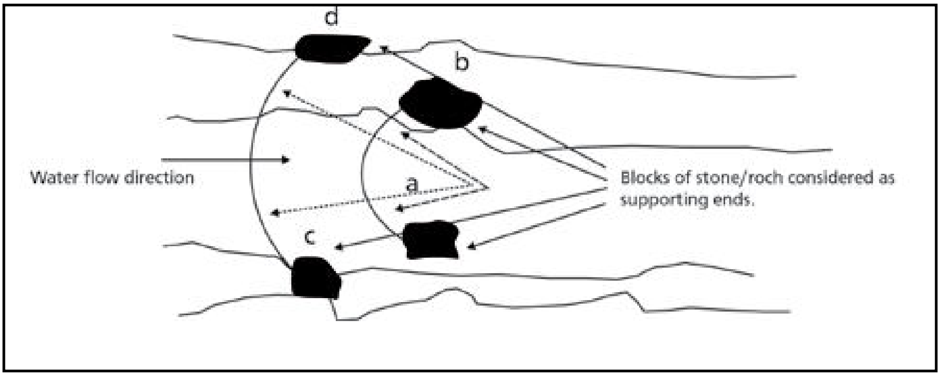


Figure 5 – Store Anchorage Structure
Source: Padilha (1997).

If no rock outcrops occur on the stream margins, anchorage should be made artificially through the implantation of supporting stone blocks.

3.1.5 – Structure format

a) Plan view

Stone dam or successive dam is constructed in the shape of a lying arch as viewed from above. At the plotting of work, an arch should be configured at a horizontal angle of approximately 120o, that is, more or less one third of a circumference, as shown in Figure 6, looking like a first quarter moon.

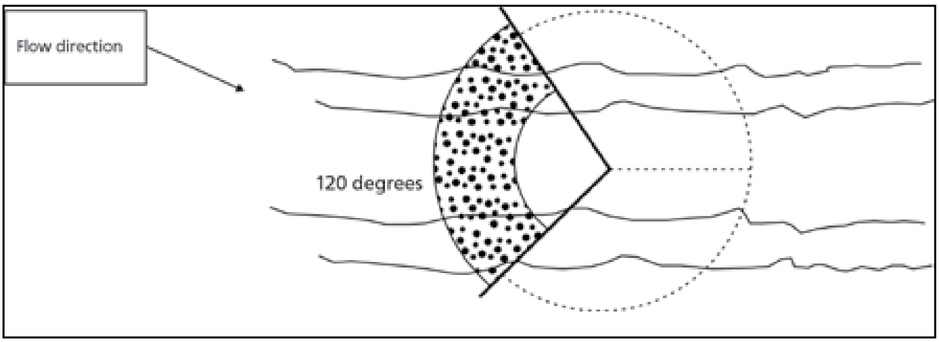


Figure 6 – Plan view of a Successive Stone Dam
Source: Padilha (1997).

b) Cross-sectional view of work

The cross-sectional view of the main dam body located in the stream channel to be dammed in Figure 7 shows that the body of work has a trapezoid cross section of standard proportional dimensions (h, b, b1 and b2).

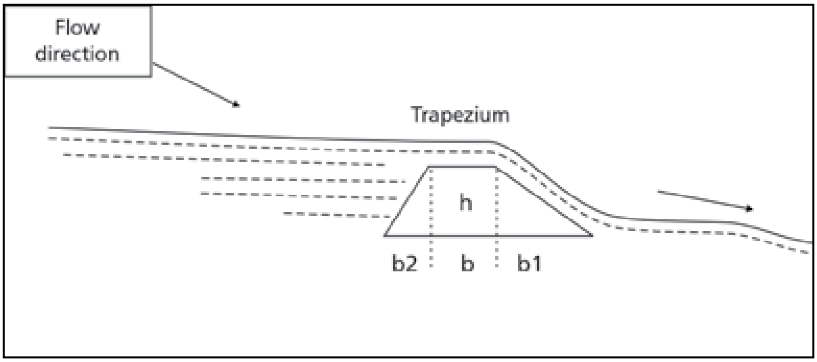


Figure 7 – Cross-sectional View of a Stone Dam
Source: Padilha (1997).

c) Longitudinal view of work

Figure 8 shows the longitudinal section of part of main dam body inside the stream channel, until its shoulders. The longitudinal section of this part of dam body has an approximate format of a saddle of horizontal center and standard proportional dimensions (h and hr).

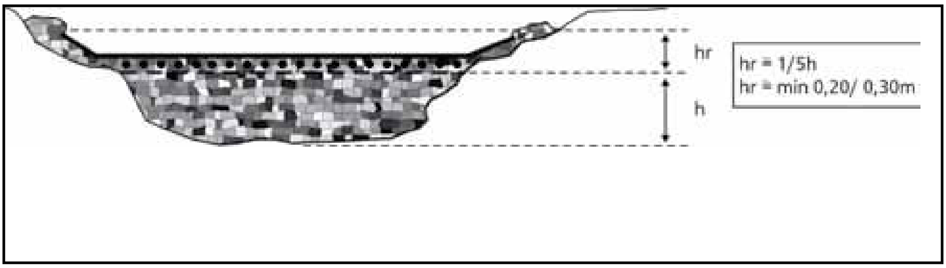


Figure 8 – Longitudinal View of a Stone Dam
Source: Padilha (1997).

3.1.6 – Basic stone dam dimensions

a) Basic dimensions of stone dam body cross section

Trapeziums resulting from cross sections of main dam body, the sides of which constitute the dam bumps, should have the following proportions:

- **Downstream bump (DS)** – (b1 = 1.5 for h = 1), a ratio of approximately 1.5/1 between the base and height of bump cross section touching vertically the dam crest arch on downstream side (Figure 9).

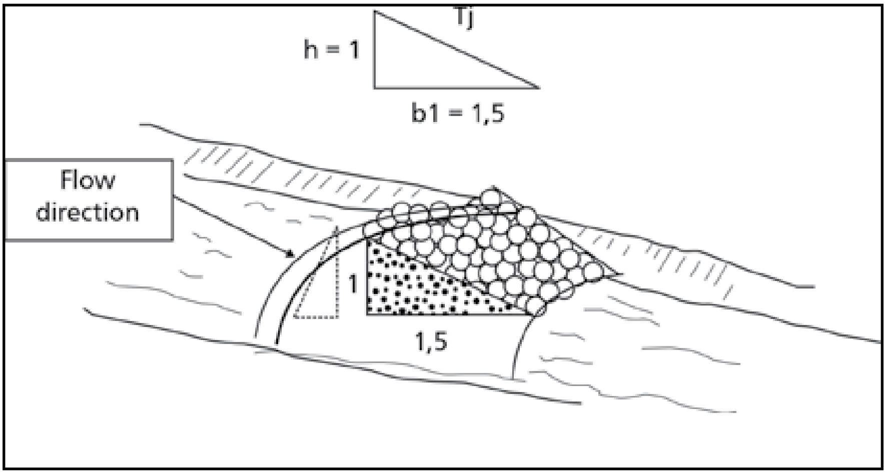


Figure 9 – Structure and Dimensions of Downstream Bump of a Stone Dam
Source: Padilha (1997).

- **Upstream bump (US)** – (b1 = 1.5 for h = 1), a ratio of approximately 0.5/1 between the base and height of triangle transversal to bump, touching vertically the dam crest arch on upstream side (Figure 10).

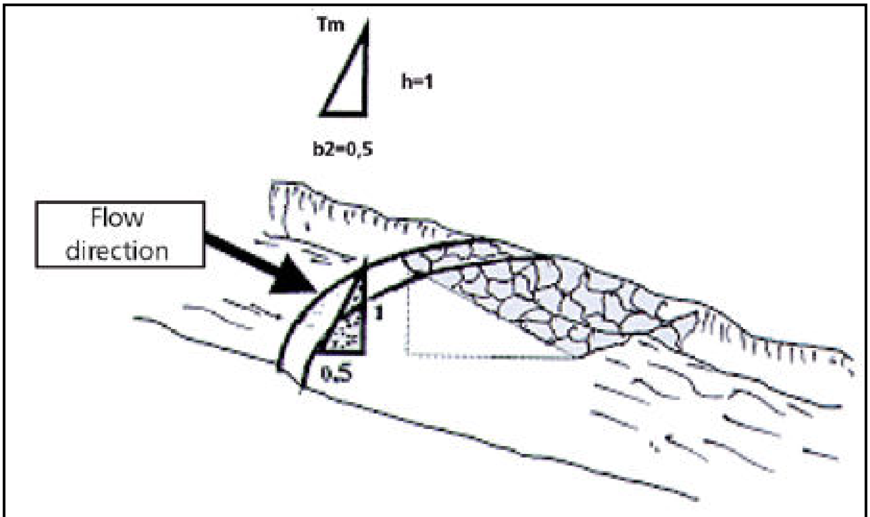


Figure 10 – Structure and Dimensions of Upstream Bump of a Stone Dam
Source: Padilha (1997).

b) Extension of work

Dam extension (letter e of Figure 11) should ensure that rainwater will flow mainly on the dam crest. Extension comprises the average length of projected arch (e) in a single body geometrically continuous in relation to crest and shoulders. As such, that extension is equivalent to the sum of lengths of leveled crest and bumps of corresponding shoulders.

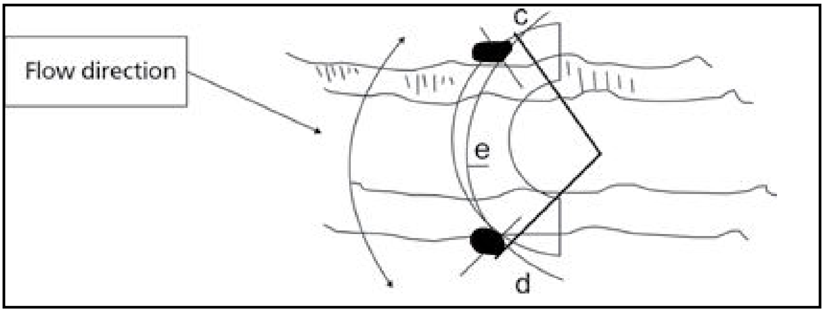


Figure 11 – Schematic Drawing of Extension of a Stone Dam Arch
Source: Padilha (1997).

In other words, to determine the length (e) of dam arch (Figure 11), shoulders should extend to the respective support ends, i.e., to the stone blocks (c) and (d) shown in Figures 4 and 10. Such supports shall be represented by two of four stones/rocks located in the form referred to above for the purpose defined by the term "support". They will serve as natural support for the dam and may be natural or implanted for that purpose.

c) Crest and shoulder height of stone dam

Maximum care is always required to allow the foundation stones of shoulders to be at levels above the work crest, thus preventing erosion on watercourse margins, on the junction of the stream channel with the main work body, and preventing future risks to dam integrity. This way, according to that recommendation, Figure 12 shows the maximum crest height in each dam, 20-30 cm per some 1/5 of height (h), smaller than the height of the lowest shoulder.

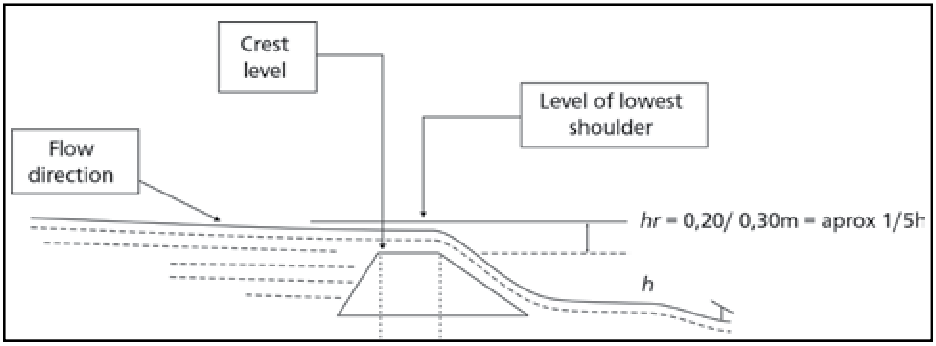


Figure 12 – Schematic Drawing of Height and Shoulders of a Stone Dam
Source: Padilha (1997).

d) Width of stone dam crest

To determine the crest width, the smaller base (b) of a trapezium should be taken as a reference according to Figure 13. At construction, it is recommended that the maximum extension (e) between shoulders be some 30 m, and the maximum crest height from the dam base (h) be up to 2.5 m. Crest width should range between 0.3 and 0.8 m. Crest (b) is approximately three times smaller that height (h), or b 1/3 h.

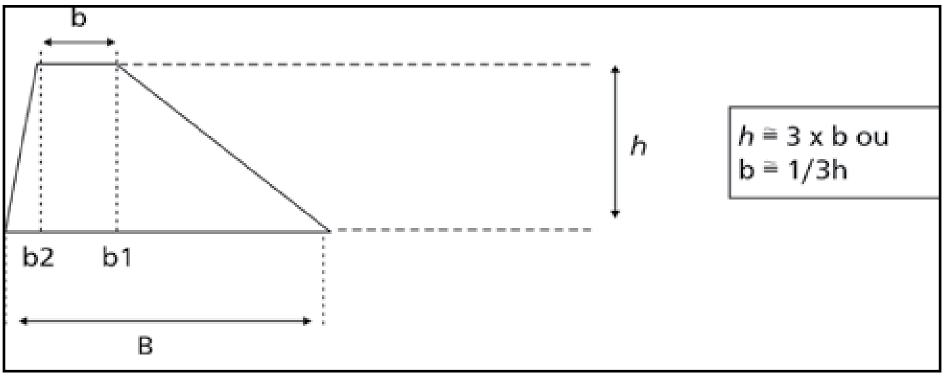


Figure 13 – Schematic Drawing of Crest Width of a Stone Dam
Source: Padilha (1997).

e) Width of stone dam base (skirt)

For an approximate determination of the largest trapezium base (B), or the dam skirt (Figure 13), which forms the cross section of the main dam body, the following formula is suggested:

B = 2 x h x b	onde	b_1 = 1,5 h
	B = 2 h	b_2 = 0,5 h ou
		(1,5 + 0,5) h

3.1.7 – Stone dam plotting

Horizontal plotting or determination of four (4) arches limiting the stone dam may be seen in the plan view (Figures 14 and 15).

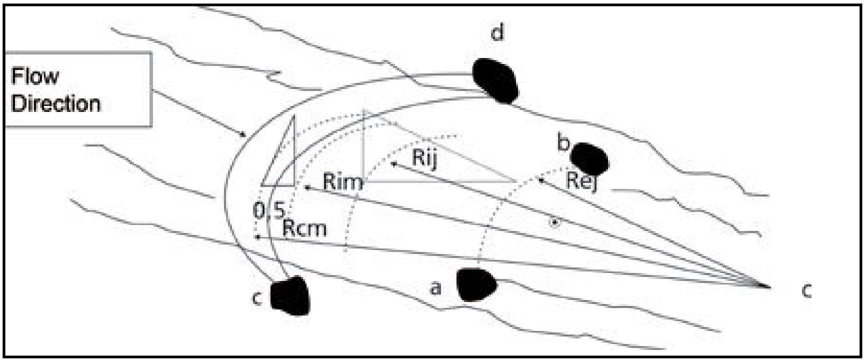


Figure 14 – Schematic Drawing of a Stone Dam Plotting
Source: Padilha (1997).

To plot 4 concentric arches that will limit horizontally the dam construction, a center (c) is selected in the axis of stream to be dammed. This way, based on Rej, Rij, Rim and Rem radiuses, arches are plotted at 120º, according to Figure 15.

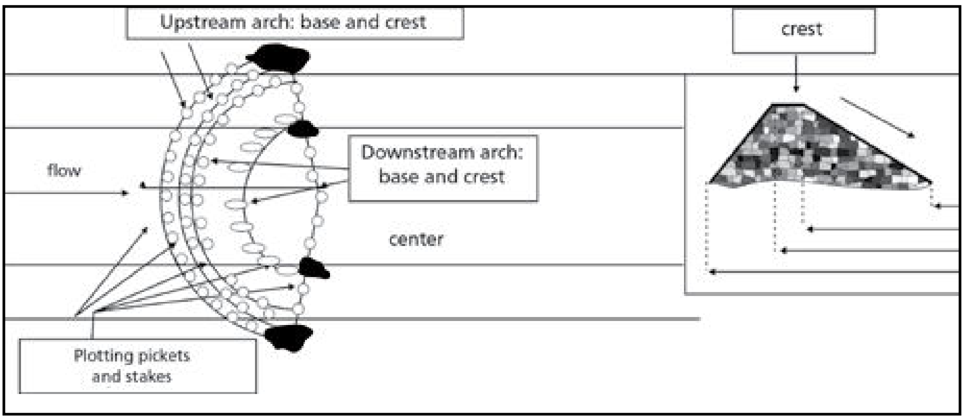


Figure 15 – Another Angle of the Schematic Drawing of a Stone Dam Demarcation
Source: Padilha (1997).

Then, the position of arches and how they should be plotted is explained below, based on corresponding radiuses.

a) Radius of downstream end arch - Rej

Center of radius of downstream end arch (Rej) should be plotted in a point on the riverbed to generate an arch from one side to the other, from the watercourse bottom to the largest stones that will support the future work (blocks a and b of Figure 16), naturally or artificially existing at both ends. At field conditions, plotting is made by two wooden stakes, one of which should act as a mobile center provided with a marking pointer, both joined together by a rope or nylon thread and, after stretched, will form that arch.

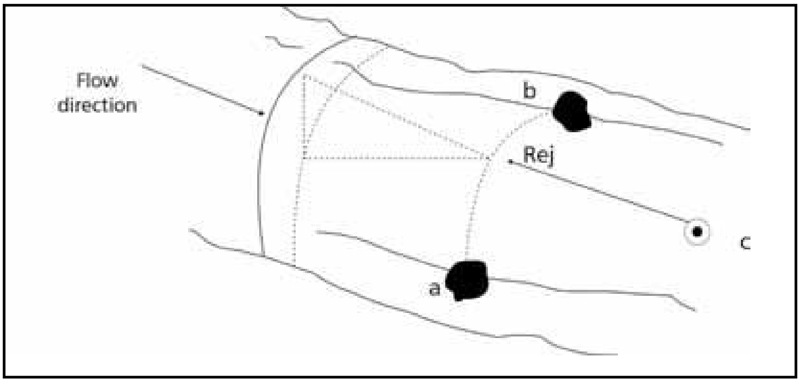


Figure 16 – Drawing of Radius of Downstream End Arch in a Stone Dam
Source: Padilha (1997).

b) Radius of intermediate downstream arch - Rij

The intermediate downstream arch will join together, on downstream side, the other two largest stones (c) and (d) to form the work. Its radius is similar to that of downstream end (Rej) plus 1.5 times the height (h) of dam crest, that is, (b1).

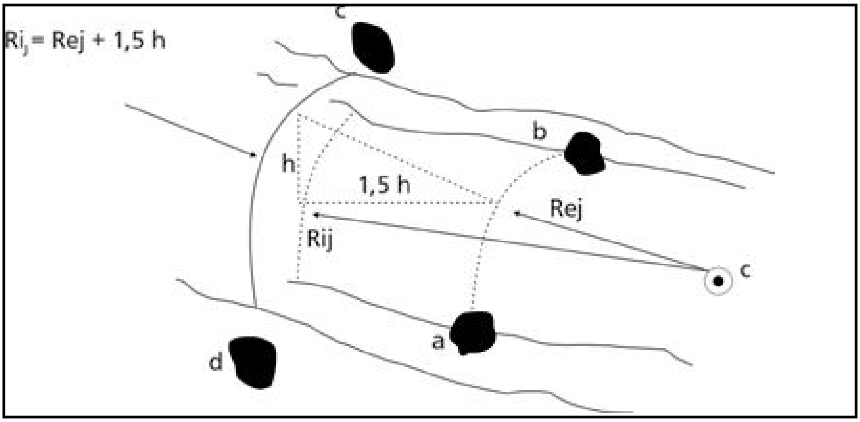


Figure 17 – Drawing of Radius of Intermediate Downstream Arch in a Stone Dam
Source: Padilha (1997).

c) Radius of intermediate upstream arch - Rim

The intermediate upstream arch will joint together, on the upstream side, the other two largest stones of the work (c) and (d), which will be then joined together by two intermediate arches, i.e., downstream and upstream arches. Its radius is similar to that of intermediate downstream arch (Rij) plus the width (b) of the smallest trapezium base forming the dam section. It should be remembered that the value if 1/3 h.

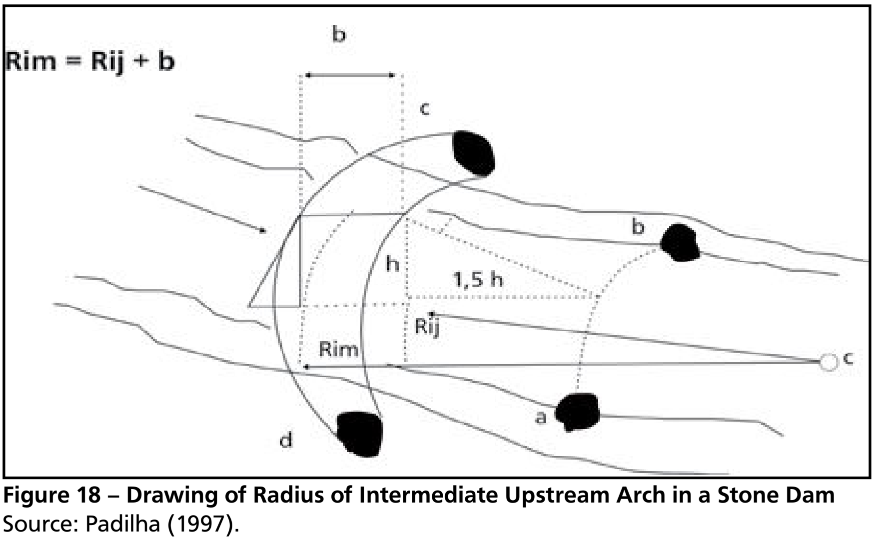


Figure 18 – Drawing of Radius of Intermediate Upstream Arch in a Stone Dam
Source: Padilha (1997).

d) Radius of upstream end arch - Rem

Radius of upstream end arch is similar to that of downstream end arch (Rej) plus the width (b) of the largest trapezium base forming the dam section. The corresponding generated arch will define the outline of dam on upstream side (Figure 19).

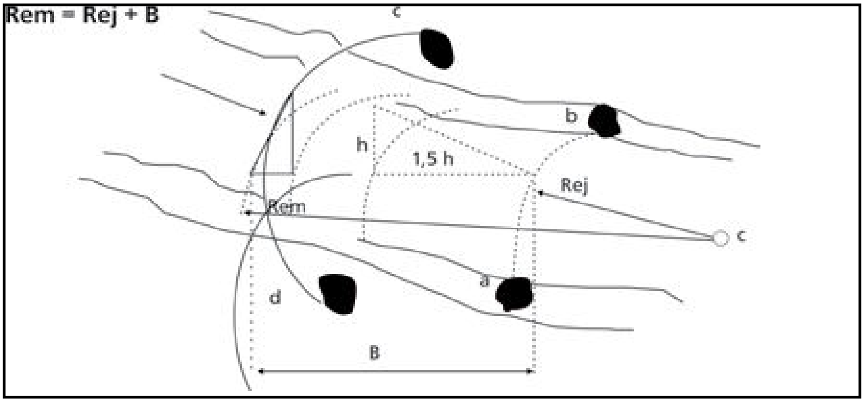


Figure 19 – Drawing of Radius of Upstream End Arch in a Stone Dam
Source: Padilha (1997).

e) Vertical plotting of a stone dam crest and shoulders

The stone dam height will be determined with the help of a hose level or other topographic instruments to establish the vertical dimensions. It should be remembered that the height of the lowest shoulder will determine the height of work.

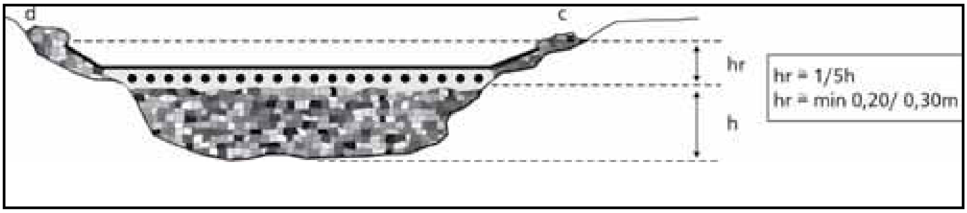


Figure 20 – Schematic Drawing of a Stone Dam Crest and Shoulder Plotting
Source: Padilha (1997).

3.1.8 – Sanding-up and sedimentation time

Time estimate for sedimentation process will depend on precipitation occurred in the work site, especially with respect to high volume and frequency of rains. Resurgence of herbaceous and arborous vegetation will depend on local edaphoclimatic conditions and anthropic action on the region.

Photo 7 – Effect of Sediment Retention and Resurgence of Herbaceous and Arborous Vegetation after Winter Period.
Source: João Bosco de Oliveira.

Photo 8 – Effect of Sediment Retention and Resurgence of Herbaceous and Arborous Vegetation after Winter Period.
Source: João Bosco de Oliveira.

3.1.9 – Organization of field staff and recommendations on work construction

During stone dam construction stage, after plotting activities, planning the use of labor is necessary, taking into account the following aspects:

- Prior to the start of work, the construction team should be duly organized;
- for all works, the team will be divided into stone block arrangers and transporters;
- it is necessary to know in advance all means that will support the construction;
- it is estimated that between 12 and 24 people are needed for each work;
- for each dam, work should only start when stone and rock deposits to supply the construction are identified;
- it should be checked whether vicinal roads parallel and adjacent to watercourse are already available before construction starts;
- all team members should be informed of the components of the several construction work stages; and
- care to be taken with workers' physical integrity, construction material handling and storage, use of tools and equipment, etc., should be informed.

3.1.10 – Tools required for construction

At start of works, each construction team should be informed that, usually, plotting instruments/material, tolls and equipment to be used during the work will include:

- Sickles to cut sticks and stakes used with raft nails for construction of "stretchers" or "banguês", or used alone for work plotting;

- 1.80-m long iron levers, ∅ = 3 cm, at the proportion of one (1) lever for every 5 workers;
- one or two 5-kg hammers to fractionate stones when necessary to make their transportation and handling easier;
- mattocks, shovels, pickaxes and hoes;
- auxiliary components, such as: 20-m long, 8-mm diameter transparent level hose, a bobbin of 50-m long nylon thread of the type used by masons, 2-m long measuring tape and one hammer for several uses;
- pair of leather gloves for each worker; and
- when possible, carts or wagons should be used as auxiliary equipment for material transportation.

3.2 – Underground dams

3.2.1 – Basic concept

a) Alluvial deposit

Nearly all watercourses – rivers or streams – flowing in Northeastern Brazil's semiarid region – except for São Francisco and Parnaíba rivers - are temporary or intermittent, because they dry up in most of the year.

Right after rains stop, rivers continue to flow for some time, fed by waters from saturated soils higher than the main channel, or "live channel" of the river. That is what hydrologists call river base flow, where surface runoff takes some days and even months to cease completely.

When the base river flow ceases completely, water continues to flow below the surface inside the "package" of detrital sediments – gravel, sand, silt and clay – which collectively constitute the alluvium of alluvial deposit. Such sediments originate from the sequence of processes occurring on the hydrographic basin surface, starting with erosion, or weathering of existing rocks, and followed by transportation by river water and finally the material sedimentation or deposition on the actual riverbed, well down the erosion source.

The alluvial deposit has much variable constitution, width and thickness due to several factors, such as: constitution and resistance of eroded rock; kinetic energy of the river that, in turn, will depend on riverbed sloping and valley width; drained volume of water, which will depend on precipitation rates; rains falling over the hydrographic basin; geostructural limitations, such as faults, fractures and folds in rock basement, among other less important f actors, such as vegetation, anthropic action, winds, relative humidity, etc.

This way, the alluvial deposit is quite irregular, varying between coarse composition with pebbles and coarse sand, and fine composition with silts and clays; such variations may occur in continuous or discontinuous layers in the form of lens, pockets or interdigitations, as shown in Figure 21.

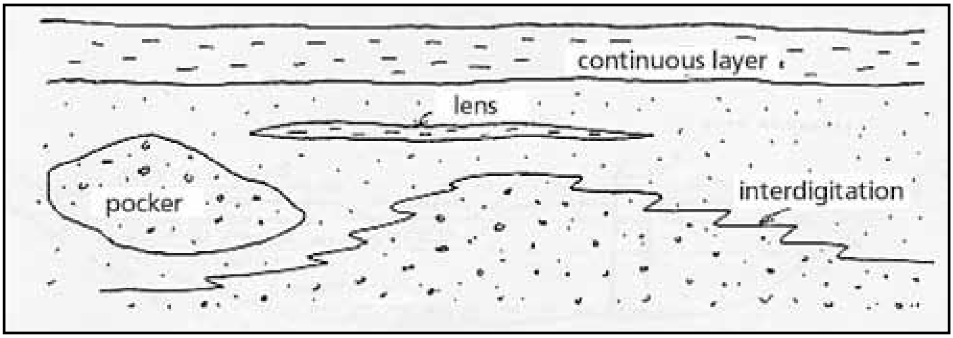


Figure 21 – Variations of Alluvial Deposit Composition
Source: Costa Duarte (1998).

The most frequent situation is, however, the occurrence of coarser sediments in the deepest portion of alluvial deposit, and finer sediments in its upper portion. This is due to the fact that the valley usually is V-shaped, where the deepest portion is narrower, what gives the river a greater speed resulting in the deposition of coarser material; as the valley becomes silted-up, that is, full of sediments, the channel opens out, the river becomes slower and carries finer sediments.

The oldest fluvial valley, know as paleovalley, in general is currently silted-up, where a new drainage occurs on the “package” of sediments to excavate the former deposit. This results in the formation of a narrower valley, where the river flows both at the initial and final annual flood stages, also known as live channel, and in laterally flattened surfaces, at somewhat higher topographic levels (in general 1-2 m higher), which are called fluvial terraces or alluvial terraces (Figure 22).

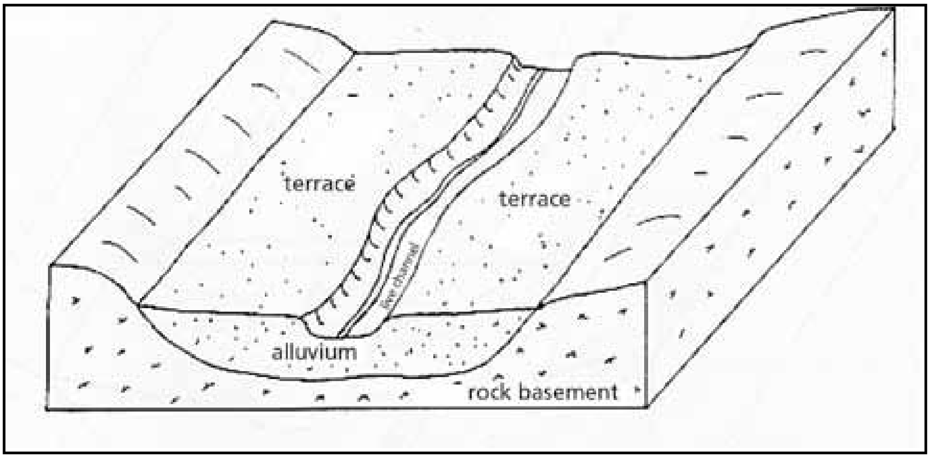


Figure 22 – Fluvial Valley Showing the Live Channel and Terraces
Source: Costa Duarte (1998).

Subsurface runoff occurring in the alluvial deposit when the river ceases to flow on the surface makes that deposit (also know as alluvial aquifer) lose gradually its accumulated water supplies, and even dry up completely at the end of dry period (Figure 23). Occurrence of piezometric wells (also called water holes) constructed in such alluvial deposits is common, which become completely full after the rainy period and completely dry at the end of dry period.

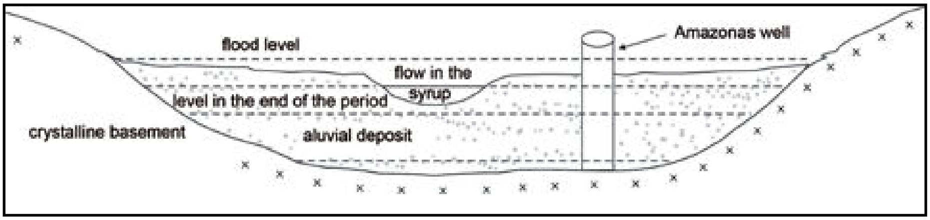


Figure 23 – Water Level Variation in Rain and Dry Periods
Source: Costa Duarte (1998).

b) Underground dam: what it is and what it serves for.

As mentioned above, water retained in alluvial deposit tends to drain completely in dry period, wasting a precious liquid that could be used for several purposes.

Underground dam consists of constructing a septum in the alluvial deposit to prevent accumulated water from draining during the dry period. By damming waters in upstream direction, that is, in the upper river course direction, water will accumulate, while in downstream direction, that is, in the lower river course direction, level will lower as time goes on (Figure 24).

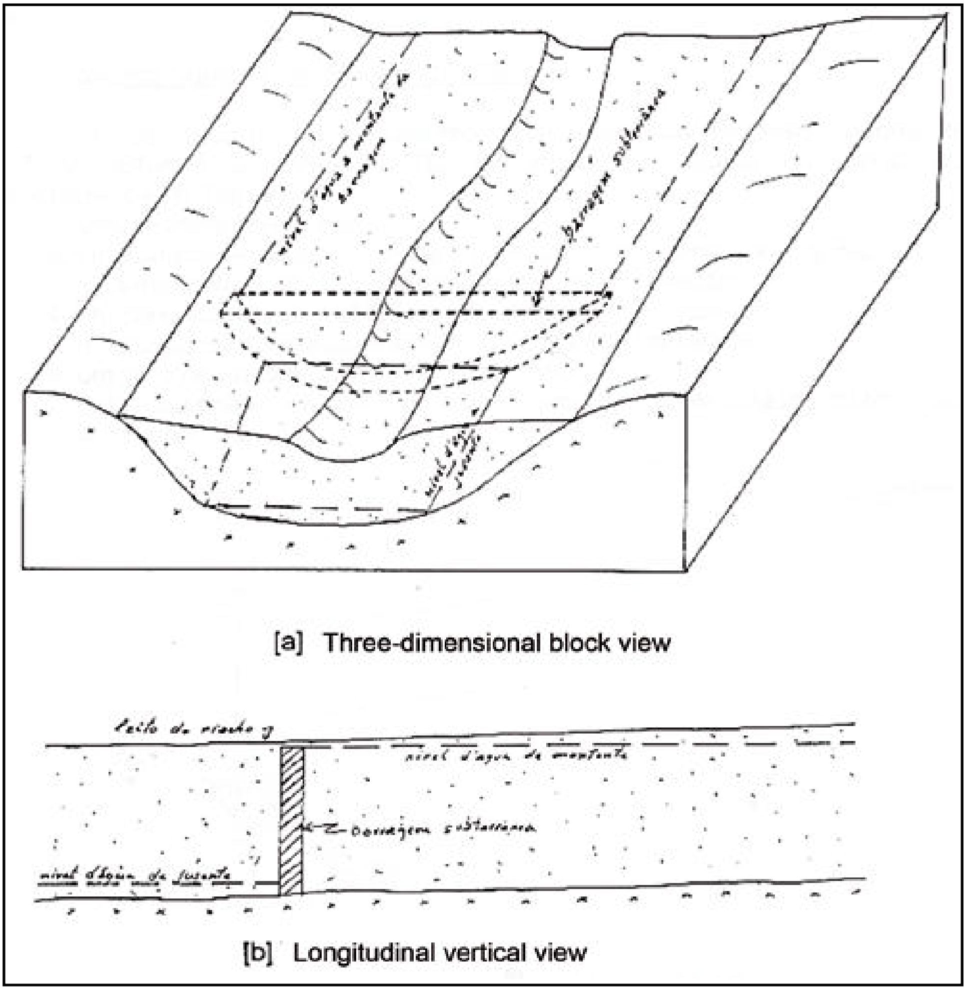


Figure 24 – Schematic Drawing of am Underground Dam Operation
Source: Costa Duarte (1998).

c) Types of underground dams

There are several underground dam constructive methods, three of which are indicated below in decreasing order of complexity and consequently in decreasing order of constructive and operational costs:

- CPATSA Model
- Costa & Melo Model
- CAATINGA Model

Those three types are briefly described below, while Costa & Melo model will be detailed in Chapter 4, because it is considered the most adapted to the reality of northeastern semiarid region for fully meeting its purposes and having quite affordable constructive and operational costs.

CPATSA underground dam

This type of underground dam was developed by CPATSA/EMBRAPA researchers in Petrolina/PE in early 1980's and consists typically of (Figure 25):

- Arch excavation;
- a high wall (about 1-m high) downstream to excavation;
- high wall and excavation waterproofing;
- spillway made of cement and masonry or concrete;
- a roofed cistern downstream to dam;
- a sand and coal filter in the excavation; and
- piping to convey dam water across the filter to the downstream cistern.

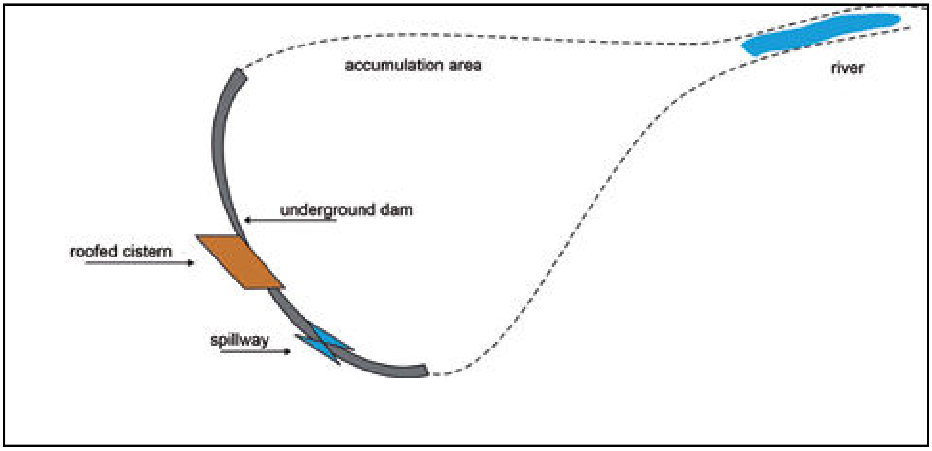


Figure 25 - CPATSA Underground Dam
Source: Costa Duarte (1998).

Costa & Melo underground dam

This model was developed by UFPE researchers, Waldir D. Costa and Pedro G. de Melo, also in early 1980's, and was later modified, expanded and adjusted to local conditions by the first of researchers above, consisting typically of (Figure 26):

- Excavation of a rectilinear trench perpendicular to stream flow direction;
- impermeable septum along the trench;
- one or more piezometric wells, one of which close and upstream to the impermeable septum;
- rock filling by non-jointed well-arranged stones on the surface, close and downstream to the impermeable septum; and
- one of more piezometric wells along the dam "hydraulic basin".

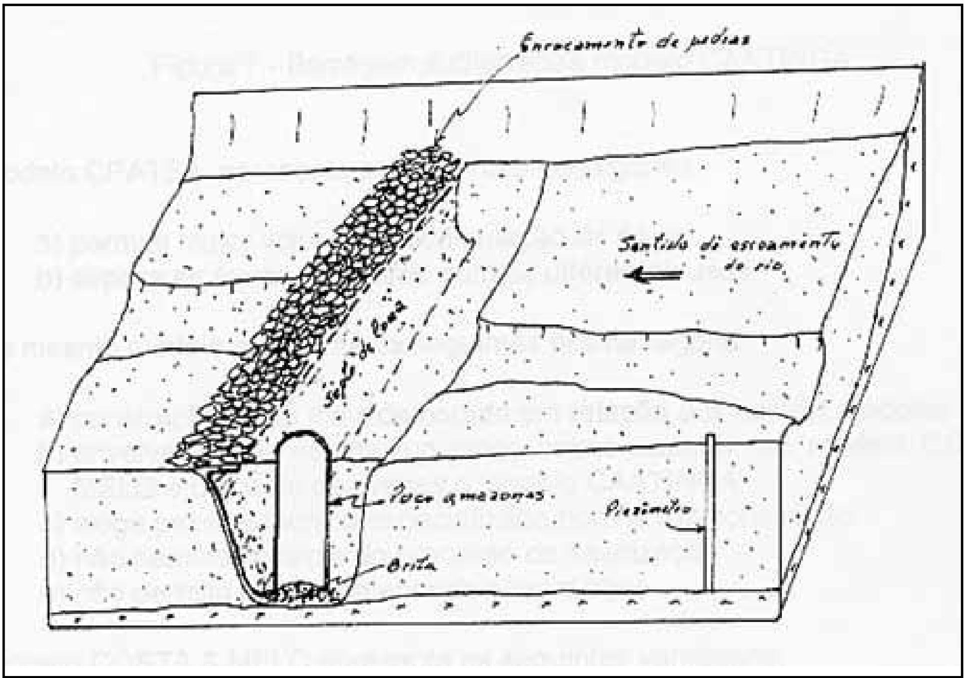


Figure 26 – Costa & Melo Underground Dam
Source: Costa Duarte (1998).

CAATINGA Underground Dam

This model was developed by an NGO named CAATINGA, which operates in the eastern region of the State of Pernambuco and has constructed some rudimentary hydraulic works for farmers living in that region. The model consists typically of (Figure 27):

- Excavation of a linear trench, mostly manually;
- trench filling with the same removed material submitted to compaction by animals; and
- rock filling non-jointed well arranged stones on the dam.

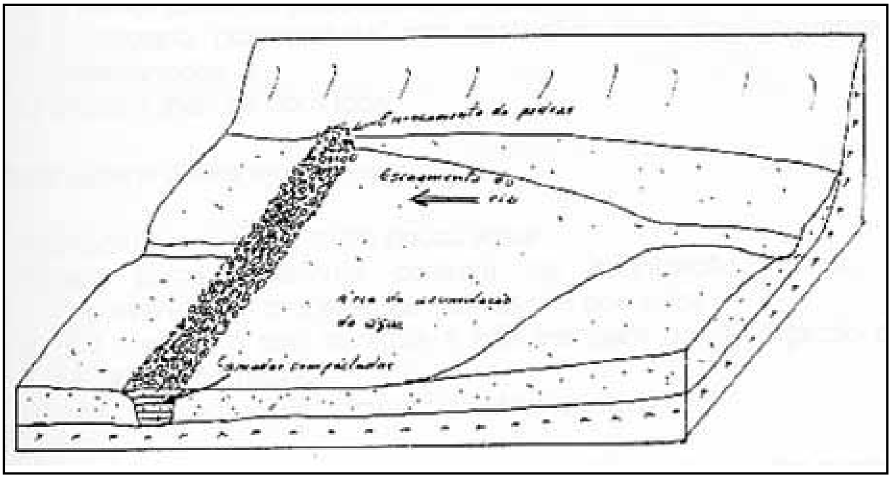


Figure 27 - CAATINGA Underground Dam
Source: Costa Duarte (1998).

CPATSA model has the following advantages:

- Allows a higher water accumulation volume; and
- separate waters according to their different uses.

In contrast, it has the following advantages:

- More time-consuming construction as compared to other models;
- involves costs at least five times higher than those of Costa & Melo model, and some ten times higher than those of CAATINGA model;
- requires specialized technical personnel for its construction;
- allows no salinization process control; and
- allows no water level monitoring.

Costa & Melo model has the following advantages:

- Fast construction (one or two days, if mechanized);
- low costs (some R$ 1,500.00, at 1998 prices);
- may be constructed by the workers of the particular rural property;

- provides conditions for salinization process control;
- allows water level monitoring all over the year; and
- may be used for multiple water uses.

Disadvantages of this model include:

- Higher cost as compared to CAATINGA dam model;
- cannot be used in any situation, as it depends on the existence of specific natural conditions.

CAATINGA model has the following advantages:

- Lower cost as compared to other models;
- used practically without any restrictions, given the low volumes stored; and
- uses local workforce.

Disadvantages of this model include:

- In general, it accumulates very little water;
- allows no salinization control and is highly susceptible to soil salinization process;
- allows no use of water, except for sub-irrigation in the actual live stream channel; and
- allows no water level monitoring.

Taking into considerations the pros and cons of each model described above, it can be concluded that the most adequate to Northeastern semiarid region is Costa & Melo model, which will be described in more details in item 3.2 of Chapter 3.

3.2.2 – Basic criteria for underground dam plotting

a) Social aspects and demand

The first requirement is the importance of work, as a public investment that does not arouse local community's interest will make no sense.

The water demand to be met by the work should be determined, as well as the use or uses expected for stored water, the number of benefited people, whether there is a real interest in its construction, and the landowner's commitment to preserve it and explore to the extent possible its water availability, especially for the cultivation of adequate crops.

Also taking into account that it is a public investment in a private land, the landowner should commit under a "public service agreement" to allow the use of water from the piezometric well (water hole) to be constructed near the underground dam by any community member, and therefore, allow free access to that well. Only the surface area where crops will be cultivated shall be of the landowner's exclusive use.

b) Water quality

Water should not have a high salinity, as this would tend to increase salt concentration and adversely affect the soil and existing crops. The ideal would be collecting a water sample from an existing water hole and measuring its electrical conductivity by a portable conductivity meter. If no conductivity meter is available, a little water could be tasted (without swallowing it) to check its taste (sweet, salty, brackish, sour, etc.).

If there is no water in the stream bed, excavation of water hole, local dwellers should be consulted about the conditions of water use when the stream is flowing; whether that water is well accepted by them or, if not, whether animals consume that water.

Another aspect to be checked is the existence of salt crusts in the alluvial deposit and the occurrence of certain grasses (by those who know them) that are typical of salt water.

c) Alluvial deposit thickness

Taking into account that evaporation can be up to 0.5-m deep, the alluvial deposit should be at least 1.5-m thick in the live channel of the watercourse (river or stream), to justify the implantation of an underground dam (Figure 28).

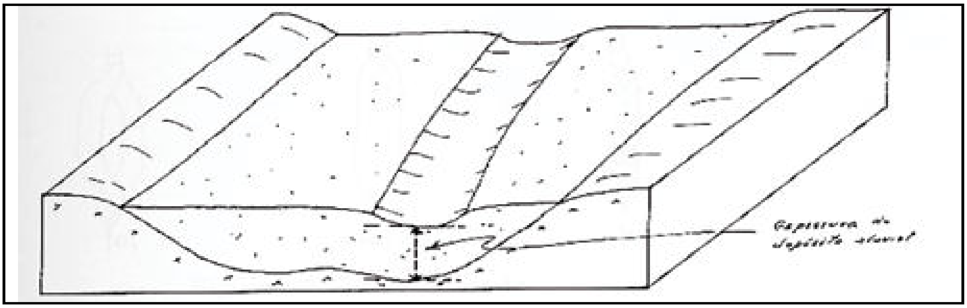


Figure 28 – Alluvium Thickness [Three-Dimensional Block View]
Source: Costa Duarte (1998).

To determine the deposit thickness, three drillings should be made, being one in the live channel, and one in each side, approximately equidistant from the live channel and the alluvial deposit margins (Figure 29). Eventually, one or two addition bores may be necessary.

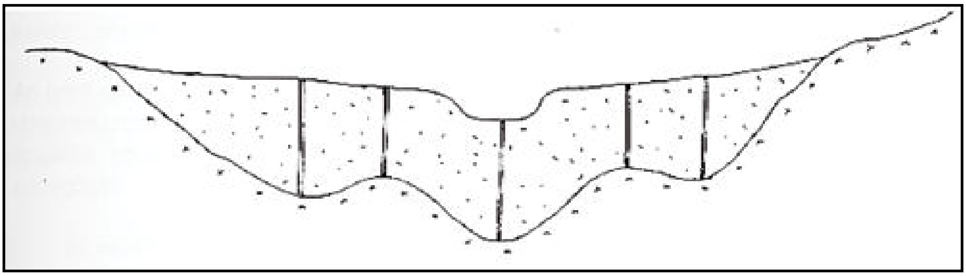


Figure 29 – Bore Arrangement [Vertical Section View]
Source: Costa Duarte (1998).

d) Granulometric alluvium constitution

Alluvium should have a predominantly sandy constitution of be mixed with fine material (silt or clay); however, in samples collected from drillings, sand should predominate over finer sections.

Auger used for drillings is provided with an open-strap part appropriate to bore and collect samples of silty-argillaceous material (Figure 30); another part in form of can provided with sharp blades at its end, appropriate to bore and collect samples of sands, and finally a helicoidal part that does not collect samples, but rather serves only to detect the deposit thickness and is used when the water level is reached and sample collection is no longer possible.

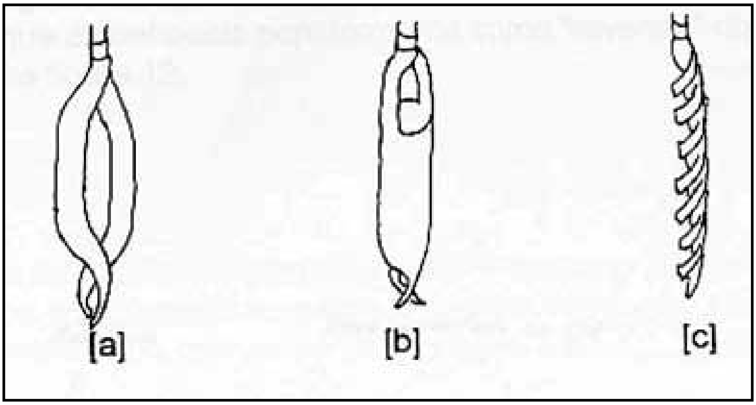


Figure 30 – Types of Auger
Source: Costa Duarte (1998).

e) Presence of water

If area survey is made during or after the rainy period, water level in the alluvial deposit is normally very close to surface or even reaches the surface. Therefore, that is not a good time to survey the location where an underground dam will be constructed, what should be done at the end of dry period, that is, close to the start of a new rainy period.

At the end of dry period, alluvial deposit is expected to be dry or have a reduced water-saturated thickness. Should this fail to occur, the location is not adequate for the dam, as any of the following situations is occurring:

- Existence of "door-stones", which are undulations of rocky bed or an occurrence of rock intrusions more resistant to erosion; in that case, the door-stone already constitutes a natural dam that causes the perennial existence of a high upstream water level, as shown in Figure 31.

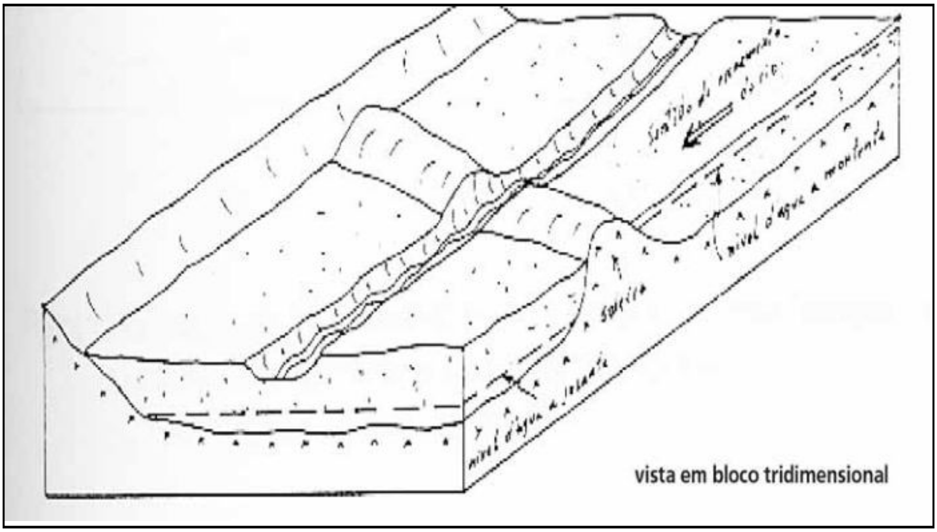


Figure 31 – Formation of a Natural Dam by "Door-Stone"
Source: Costa Duarte (1998).

- Existence of a surface damming (dam, reservoir, etc.) or a natural lagoon that provided, even beyond the limit of water accumulated on the surface, a vast area of upstream saturated alluviums, popularly known as reservoir 'revensa', as shown in Figure 32.

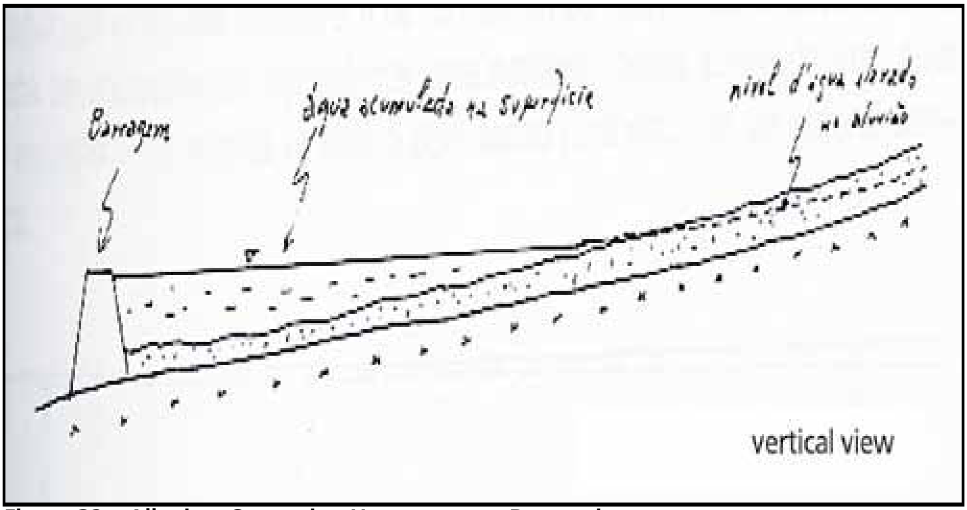


Figure 32 – Alluvium Saturation Upstream to a Reservoir
Source: Costa Duarte (1998).

f) Relation between "live channel" and "terraces"

Optimal situation for underground dam occurs when the "live channel" is not very deep in relation to "terraces" (Figure 33); otherwise, its thickness becomes very small at the lower portion of valley, and water accumulation is reduced.

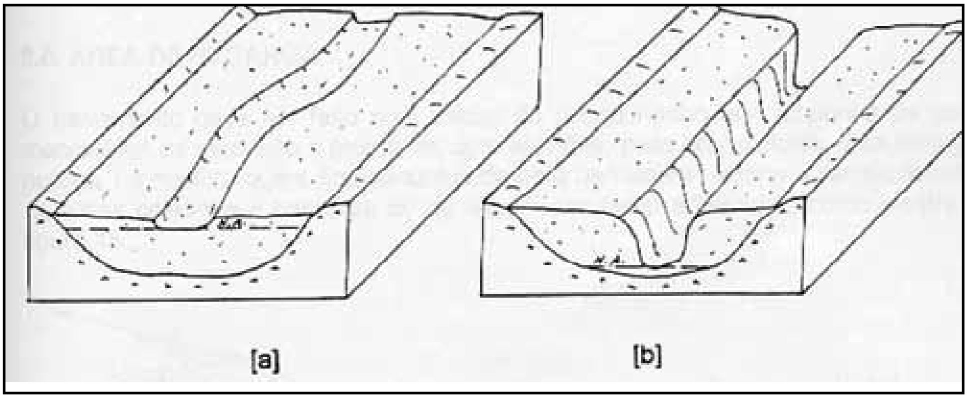


Figure 33 – Situation of Stream "Live Channel" in Relation to its "Terraces": in (a) it is Favorable to Damming, while in (b) it is Unfavorable [Three-Dimensional Block View]
Source: Costa Duarte (1998).

g) Soil inclination (declivity)

The watercourse where an underground dam will be implanted should have the softest longitudinal (along the course) declivity possible to allow stored water to extend to a greater distance. If the relief is strongly bumped, a situation that predominates in stream springs, water will accumulate in a very reduced area.

The desirable declivity angle should not exceed 20°, but, as topographic equipment is hardly available to measure that declivity – such as a level – a good judgment is recommended to select a semi-plain soil.

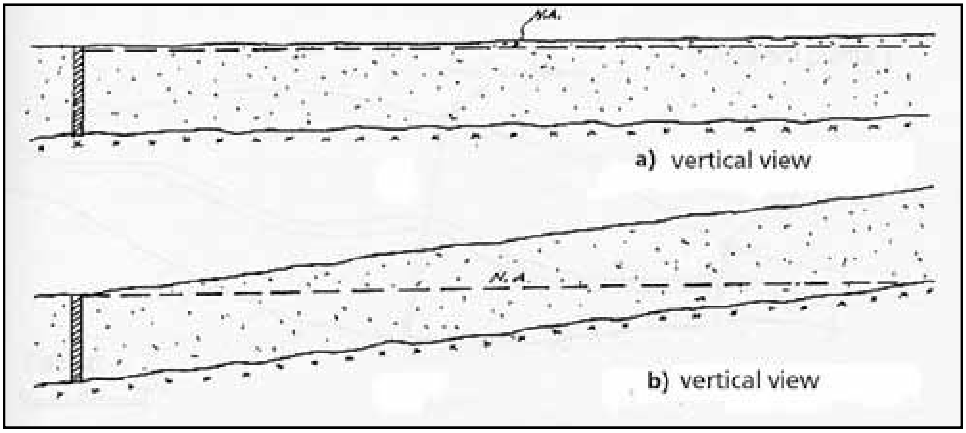


Figure 34 – Inclination of Alluvial Bed
Source: Costa Duarte (1998).

h) Recharge area

Dam should be located in a section of river or stream at least 1-km long on upstream side, provided with alluviums to allow natural recharge as dammed water is explored. Areas close to river springs should always be avoided, as shown in Figure 35.

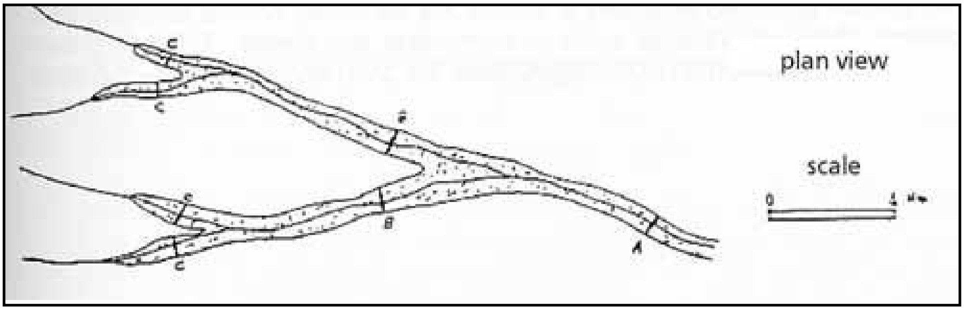


Figure 35 – Adequate and Inadequate Locations for an Underground Dam
Source: Costa Duarte (1998).

In the example above, the A would be the most favorable location, followed by B; in contrast, C location is fully unfavorable.

i) Alluvial deposit narrowing

Storage area should be as wide as possible, but the selected dam site should be narrow to reduce costs of excavation and canvas or other waterproofing material eventually used (compacted clay, for example). In addition, dam located in the widest area of alluvial deposit will waste the downstream area, which could be explored as a reservoir.

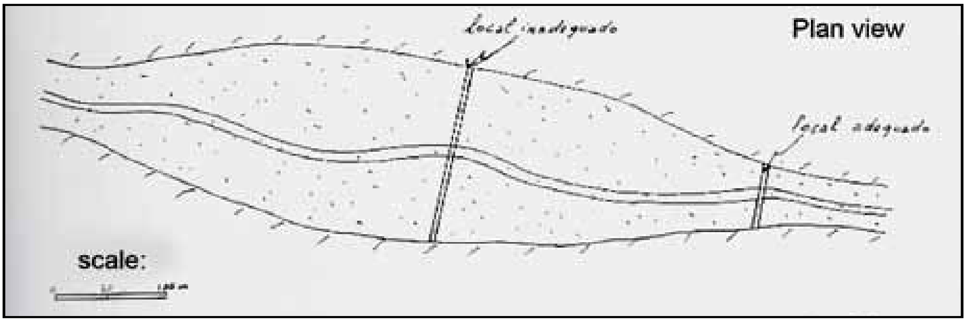


Figure 36 – Location of Dam Axis in the Alluvial Deposit
Source: Costa Duarte (1998).

3.2.3 – Method for alluvial area survey

Although simple, studies for location and specifications of an underground dam should not be waived, otherwise the expected results could be frustrating.

Activities included in study, in the chronologic performance order, are described below:

a) Data survey

This initial activity focuses on the selection of communities most in need of water supply from low cost interventions that will not imply the storage of great water volumes and high costs. If stored water is also used for irrigation, conditions for implantation of irrigated crops should be evaluated.

Items to be surveyed at this stage include the latest demographic data, especially on water demand, socioeconomic reports, hydrogeological reports, topographic and geological maps of the region, and especially aerial photographs.

b) Photointerpretation and analysis of topographic maps

Geological photointerpretation constitutes an important activity of survey of such alluvial water sources, as it will allow the existence of alluvial deposit to be detected, its geometry to be established, its area to be delimitated and evaluated, morphologic relations between live channel and alluvial terraces to be established, narrowest sections for lower-cost dam construction to be selected, and information on expected benefits to surrounding population to be complemented.

Combining photointerpretation with cartographic analysis will allow surface dimensions of alluvial deposits and hydrographic basin to be determined, which constitute very important items for calculation of storage capacity and explorable resources at the end of study.

c) Field reconnaissance

Field reconnaissance visit is indispensable, as many aspects of study cannot be evaluated by photointerpretation.

Morphology of alluvial deposit, especially the relation between the smallest channel or live channel and the largest channel and with alluvial terraces eventually integrated to alluvial deposit or constituting suspended terraces are highly important aspects that very often make the dam construction unfeasible.

Another critical item of study is water quality, for which water electrical conductivity should be immediately measured at that visit, using a portable conductivity meter.

On the other hand, the occurrence of a deposit with good potential and water quality is possible, where water level is very close or even emerging to the surface as a result of natural dams (crystalline basement threshold door-stones) along the valley. In such cases, underground dam becomes unnecessary, and only technically well-constructed shallow or piezometric wells are recommended.

In addition to field survey items referred to above, the visit will allow information of great interest for study may be obtained, such as:

- Current water supply conditions: if there is a public water supply system; if not, how water is supplied;

- how water sources are currently used: reservoir, clay pits, well, water hole, tank truck, animal back;
- the surface runoff system: number of months when surface runoff occurs, months of precipitation, etc.; and
- summary inventory of all existing wells, sources and reservoirs and their accurate location in maps.

d) Drillings with or without geophysics

Drillings are intended to explain the geometry and granulometric nature of alluviums. Samples collected from each bore are classified by the geologist, provided that such bores should reach the rock basement, and the depth at which water level was reached (as applicable), are recorded. Thereby, drillings aim to identify the granulometric composition of alluvial deposit, its thickness and water level depth or alluvial deposit saturation zone.

Basement depth and consequently the alluvial deposit thickness may be more accurately detected by geophysical methods (seismic or electroresistivity), provided that one or two measurement drillings are concomitantly made.

Based on drillings, the dam axis location is plotted, taking into account the narrower and shallower section and the location where a well should be sunk for essay.

e) Well sinking and pumping essays

Once the technical feasibility of dam construction is concluded from drilling analysis, a well provided with a piezometer should be sunk where pumping essay will be performed and hydrodynamic characteristics of alluvial aquifer will be evaluated.

Tubular well to be constructed should have the following characteristics:

- Depth: until the rock basement;
- drilling diameter: 10”;
- lining: 4” diameter PVC pipes;
- filters: PVC type, 1-mm opening, and 1.00-m to 2.0-m long; and
- prefilter: 2.0 – 4.0-mm selected natural gravel.

Piezometric well at a distance of 5 m from the producing well should have:

- Depth: similar to producing well;
- drilling diameter: 4”;
- lining diameter: 2”; and
- lining material: grooved plastic pipes at the same position of producing well filters.

Following well sinking, a pumping essay should be performed for a period of 24h per 12h recovery, where lowering x time values will be interpreted, and hydrodynamic parameters of alluvial aquifer are calculated.

Based on hydrodynamic parameters – transmittance and effective (or specific) porosity coefficient) – permanent supplies, regulatory supplies and resources available for exploration will be evaluated. Also, exploration discharge, pumping regime, interference between wells, and temporal lowering evolution should be established.

Very often it is not possible to make a pumping test, given the lack of water level in the alluvial deposit during the study. In such a case, instead of sinking a tubular well for pumping essay, a well may be sunk for alluvial aquifer hydraulic conductivity essay, without any piezometric well. Essay well may be lined by 2” diameter pipe.

Hydraulic conductivity essay that is most widely know in geotechnical environment as permeability essay may be performed by different methods, the most usual of which are:

- Infiltration essay at constant water level;
- Infiltration essay at variable water level; and
- Slug Test essay.

It should be pointed out that the evaluation of hydrodynamic parameters of alluvial aquifer may be waived, provided that the evaluation of volumes to be supplied is not imperative, for example, when it is intended to implant just a simple work to settle the man in the field by offering sub-irrigation conditions for a small subsistence crop area.

Evaluation of potential alluvial deposit availability resulting from a dam shall only be necessary when the implantation of a public water supply system for the community is planned.

f) Water collection and physical-chemical analysis

During pumping essay, preferably close to its completion, a 2-liter water sample should be collected for full physical-chemical analysis. Analysis result will allow the alluvial deposit water to be hydrochemically characterized and classified in terms of potability and use for irrigation.

When a pumping essay is not necessary, water may be collected from a water hole existing in the alluvial area or from an excavation made at the time with the specific purpose of collecting water.

A physical-chemical analysis of collected water may be performed, or, in the case of urgent determination of dam construction location, only its electrical conductivity may be evaluated by a portable conductivity meter.

g) Project of Dam and Complementary Works

Once the dimensional parameters for underground dam construction are known, its project will be designed according to procedures described in the following chapter, where the following will be established:

- Length of dam axis;
- estimated average depth of trench to be opened;
- trench width;
- recommended type of septum;
- type of piezometric well;
- number of required wells in light of alluvial area extension to be used for dam; and
- number and location of piezometers

h) Final conclusive report

In possession of all such data, the final conclusive report containing the project for dam and complementary works may be issued.
Periodic (monthly) measurements of water level and chemical quality are recommended to be made, as they are indispensable for alluvial aquifer exploration control.

3.2.4 Construction of "Costa & Melo" underground dam

a) Trench or ditch opening

Once the best section to dam the alluvial deposit is selected, taking into account the criteria mentioned in chapter 3.2, especially items (a) and (i), a trench is opened based on the following principles:

- Trench direction should be perpendicular to water or stream flow;
- trench should be straight to reduce costs of excavation and future canvas;

- excavation should be as deep as the rock basement, including its alteration cover, which should also be removed to prevent percolation through that material;

- material removed from excavation should be always accumulated on the upstream side of trench or on its sides, but never on downstream side to avoid affecting adversely the installation of canvas and construction of piezometric well at the following stage.

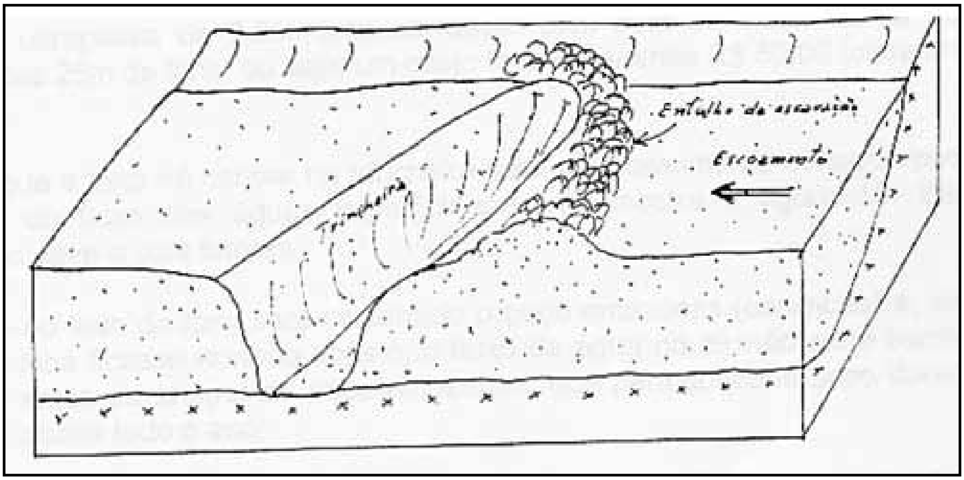


Figure 37 – Trench opening
Source: Costa Duarte (1998).

Excavation of trench or ditch can be made in two different ways: mechanical or manual. Mechanically, it can be opened by a crawler tractor or backhoe, the latter of which is most indicated when alluvium thickness is larger than 3 m or when the water level is high.

Upon the occurrence of a water saturated thickness not exceeding 2 m, excavation may be made using at the same time a pump to drain water level; for saturated thickness exceeding 2 m, excavation should not be made and should wait for the end of extended dry period; if in that period water is still occupying a great alluvium thickness, this fact reflect the situation characterized in item (e) of chapter 2.2.

Manual excavation should be made by a group of at least ten workers in pairs; in each pair, one worker makes the excavation using a pickaxe, hoe and shovel, and the other worker fills the handcart to remove the material from the trench. It is estimated that each pair will excavate and remove in average 2 m3 of earth per day.

b) Implantation of impermeable septum

Impermeable septum may bee of different types, such as:

- plastic canvas;
- compacted clay;
- stone or brick masonry; and
- juxtaposed stakes.

Plastic canvas is the faster and cheaper construction method, as the operation can be completed in a lithe more than one hour; the cost of a linear meter of 6-m wide 200-micron plastic canvas (the most resistant) is around R$ 2.00 (two reais); as generally the average alluvial package thickness does not exceed 2.5 m, a 50-m long dam will require only 25 m of canvas, amounting to only R$ 50.00 (fifty reais), at 1998 prices.

Canvas position on the trench will be invariably on the side opposite to surface water flow, as shown in Figure 38. This requirement is due to two factors:

- As a piezometric well (water hole) will be constructed adjacent to the canvas, if the canvas was placed on the opposite side water flow in alluvium would be dammed before reaching the piezometric well, which would remain dry almost the whole year; and
- the trench will work as a drain for surface water catchment due to greater permeability after soil removal; if the canvas was placed on the opposite side, this factor favorable to water infiltration in underground dam would be lost.

Canvas installation does not require a whole piece along the entire dam axis; Pieces of canvas may be cut out, being such pieces wider for their placement on the deepest part and on sides of trench; as the trench become shallower, juxtaposed pieces will be narrower.

Juxtaposition of canvas pieces can be made just by superposing one on the other by 0.30 m from their ends, as a strong tightness is unnecessary in this type of dam due to the slow movement driving the groundwater flow.

Before installing the canvas, tips of roots emerging along the trench walls should be cut by knife to prevent them from boring the canvas at its installation. In the future, some of such roots are likely to perforate the canvas, but, as mentioned above, such small bores will not endanger large-scale water storage.

The upper end of canvas should be held by stones or heaps of sand on the upper edge of trench and on the lower end of canvas at the base of its walls.

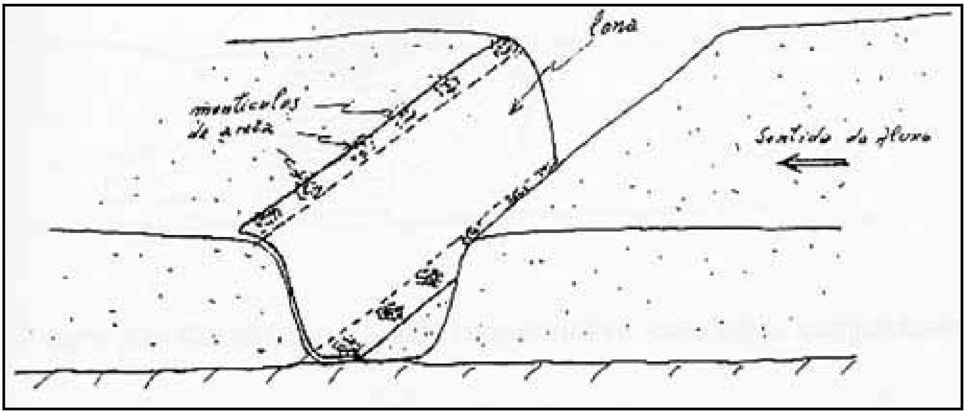


Figure 38 – Installation of Canvas to Cover the Trench Wall
Source: Costa Duarte (1998).

Compacted-clay septum is made by placing 0.20-m high juxtaposed clay layers, followed by a compaction after the placement of each layer (See Figure 39). Compaction may be made mechanically, using a steam roller or sheepfoot roller, by man-driven animals – donkeys, horses or oxen – walking continuously on the layer, or by manual rammers.

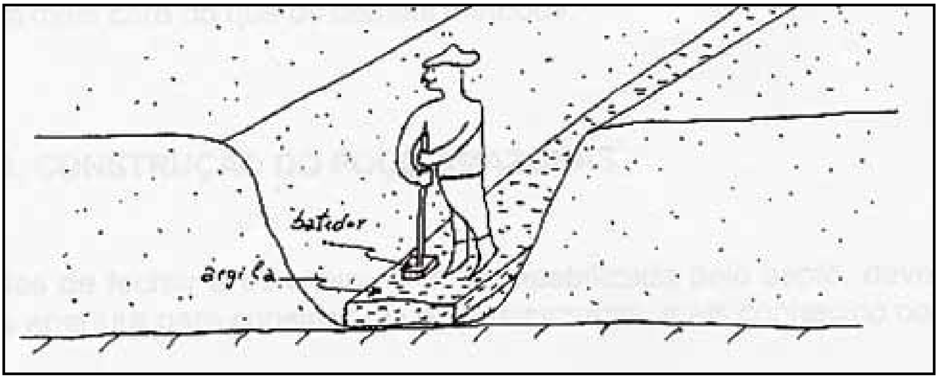


Figure 39 – Compaction of each Clay Layer
Source: Costa Duarte (1998).

Clay septum width must not exceed 1.0 m, and the gap between the septum and trench wall should be filled with material removed from trench excavation as septum is becoming higher (Figure 40).

Construction of stone or brick masonry septum is nothing different from the construction of a wall foundation after excavation, using the same process mentioned above.

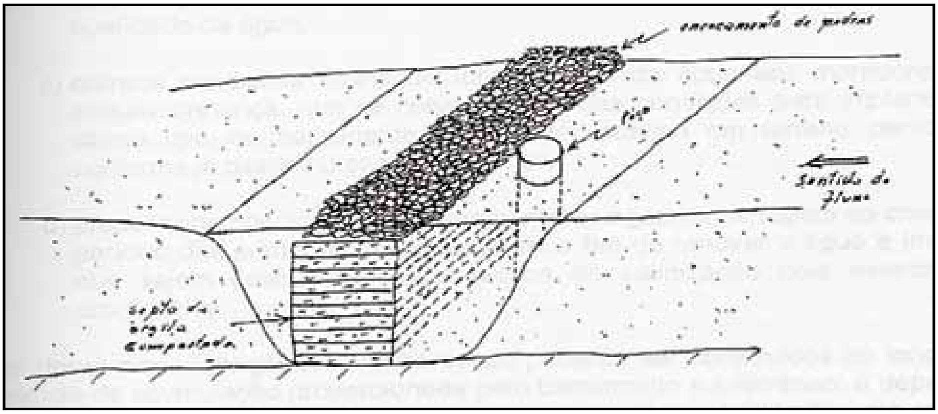


Figure 40 – Construction of Impermeable Septum Made of Compacted Clay
Source: Costa Duarte (1998).

With respect to the implantation of juxtaposed stakes for watertight septum construction, this a more hard-working technique, as it requires first of all the existence of special timber that resist to water without decaying; second, it requires a pile driver to drive such stakes side by side; finally, it also requires a saw to cut the excess plank when it reaches the rock basement. In addition, that technique is perhaps the most recommended for the construction of dams in places where water level is high. Given the inexistence of dams constructed according to that technology, the exact costs of its implantation is ignored, although it can be said that it is much more expensive than all other methods.

c) Construction of piezometric wells

Prior to closing the trench waterproofed by the septum, its opening should be used to sink a piezometric well, more knows as water hole.

The construction of a piezometric well adjacent and upstream to the watertight septum in the deepest section of trench is an indispensable requirement for the following reasons:

- Because it is placed in the deepest section of underground dam, it will enable a better use of saturated water layer for pumped or manual collection;

- it allow water level evolution in the underground dam during a dry period, as well as water quality to be continuously monitored;

- if provides easy water supply conditions for the surrounding population, which is one of the requirements for the implantation of this type of dam by the public sector in a private land, as mentioned in the previous chapter; and

- it provides conditions for dam water drainage upon the arrival of the first annual rains, by renewing the waters and preventing the development of salinization processes by progressive evaporation.

In addition to this "mandatory" well, others may be constructed along the storage surface provided by the underground dam, depending on area extension and stored volumes; new wells will make a better distribution of water points for several uses easier.

It may be constructed by several methods, two of which stand out for being more widely adopted: preformed ducts or semi-porous rings and brick masonry.

Piezometric wells, regardless of the type, should be sank in the deepest section of trench to enable the catchment of a greater water saturated thickness and full drainage as necessary (Figure 41).

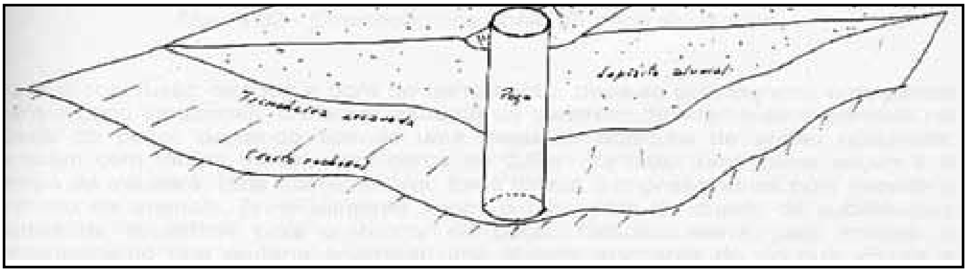


Figure 41 – Position of Piezometric Well in the Trench
Source: Costa Duarte (1998).

Construction of the first type of well is easier because it is faster. It consists of superposing rings, preferably with a diameter of 1.0-1.2 m and 0.5-m high, to make their transportation and placement one on the other easier.

It is recommended that, before installing the first ring, a 0.20-m high gravel or crushed-stone layer with a surface area of 1.5 m x 1.5 m is placed on the trench bottom on which the well will be constructed. That coarse material layer has two purposes: provide a greater permeability for water inflow through the bottom of well and prevent the access of fine material upwards, leading to well sanding-up.

Once the gravel or crushed-stone layer is placed, the first ring laid is implanted properly leveled by a spirit level to allow full verticality. Once the verticality of the first ring is certified, the others will be easily placed one on the other surrounded by a part of material removed from trench excavation to make access easier as the well becomes higher. The last ring should be some 0.4 m above the ground surface, and may even reach 0.80 m when the ring is not 0.5-m high (1.0-m high rings are more commonly found) (Figure 42).

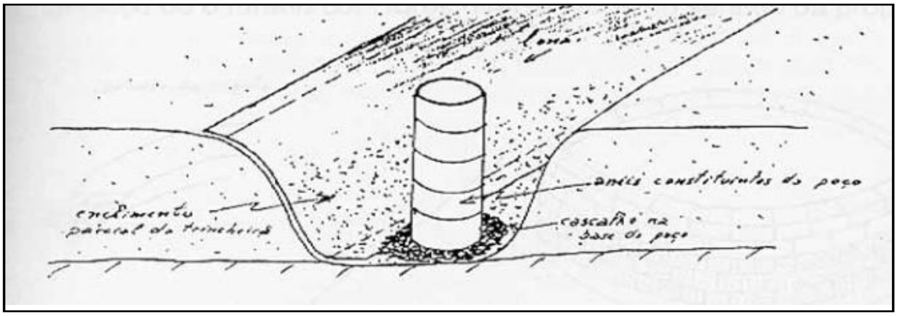


Figure 42 – Implantation of Rings in Piezometric Well
Source: Costa Duarte (1998).

After the completion of the whole dam work, a cover should be provided for piezometric well, preferably made of concrete and cemented to the well opening, with a small 2.5-m2 square opening provided with a mobile cover; another option is a fully removable wooden cover. This cover is indispensable, as it prevents the ingress of animals, especially toads and frogs, in addition to the fall of other substances from the surface into the well. It also serves to prevent sanding-up caused by a great river flood that eventually covers the well.

The construction of brick masonry piezometric well is a more time-consuming work that can take place when dam is constructed manually, as in such a case the delay of trench opening may correspond to well construction, provided that the excavation of presumably deepest site is made initially (after auger drillings are completed). Then, when a piezometric well is constructed in the center of dam, excavating team will continue to excavate the rest of trench to both directions of stream margin.

Two ways may be adopted for the construction of brick masonry piezometric well:

1. A triangular concrete base is prepared on the flat surface in the site where the well will be constructed, as shown in Figure 43, with a diameter of some 2.0 m; a brick wall is then constructed on that base, preferably holed bricks, where brick holes should face the inner part of well; after laying the first three brick rows to a height of approximately 0.5 m, bricks are externally coated by a thin nylon gauze to prevent the ingress of sediments in the well. Then, excavation should start in

the well, throwing the removed material out of the well; as excavation proceeds, well will sink because of its own weight; care should be taken to ensure a uniform excavation along the whole wall of well, to allow it to sink evenly, without tumbling to any side. In the next rows above the first three rows, it is not necessary that brick holes face the inner part of well and therefore both solid and holed bricks may be used with holes facing the wall.

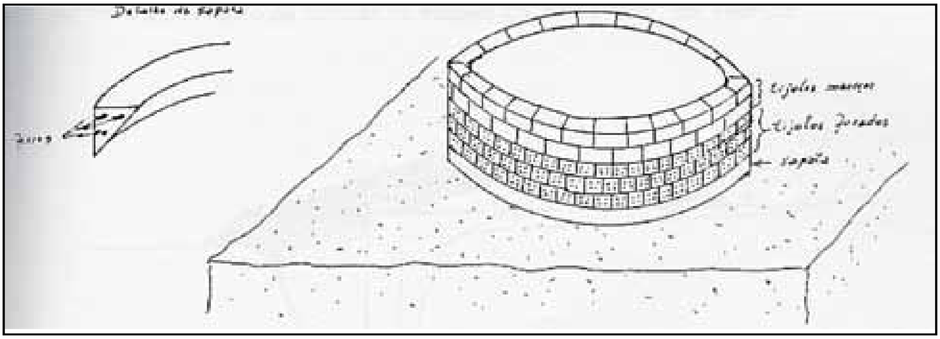


Figure 43 – Construction of Brick Piezometric Well
Source: Costa Duarte (1998).

2. First, an excavation is made at a diameter larger than that of well to be constructed and upon reaching the bottom, a flat base is prepared on which the well wall is constructed. The well wall may be constructed on a non-triangular base, as it does not have the cutting purpose of the above. Brick arrangement, as far as holes are concerned, may be the same of the previous method.

d) Trench filling

Once the watertight septum and the piezometric well haves been completed, trench may be completely filled with the removed material. It can be filled mechanically or manually, depending on the process adopted for its excavation.

e) Stone foundation

After the soil surface has been fully flattened after trench filling, a foundation of non-joined arranged stones is set.

Stone size range between 0.3 and 0.5 m, which may be rounded, semi-rounded or even angular, depending of their origin: river beds (generally semi-rounded), stone pits or local rock outcrops.

Rock foundation should be not more than 0.5-m high, as its purpose is not to fully dam the watercourse, but rather to provide a partial retention of water to make infiltration to subsoil easier upstream to dam. In addition it will accumulate a water volume for some days, which will allow the cultivation of floodland crops, such as rice, for example.

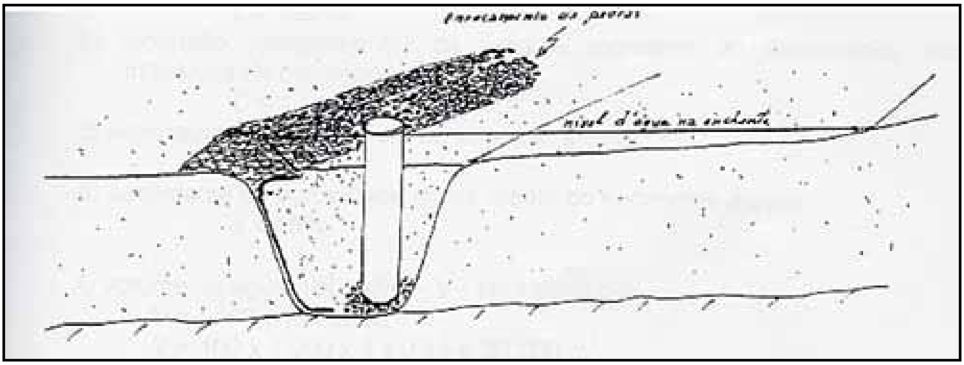


Figure 44 – Surface Stone Foundation
Source: Costa Duarte (1998).

Taking into account its purpose of allowing a greater water infiltration, this rock foundation cannot be located upstream to underground dam, but only downstream, as shown in Figure 44.

f) Piezometers

To evaluate accurately the distance reached by dammed water and monitor the progress of level lowering, the construction of one or two piezometers upstream to underground dam is advisable, which should be disposed at variable distances according to the dam storage capacity. In general, it is admissible that both piezometers are 100-m spaces from each other, and the first of them is also at a distance of 100 m from the dam site.

The construction of such piezometers is very simple, by making a 3” diameter bore by auger and inserting a 2” diameter plastic PVC pipe grooved over the first lower meter. The pipe should protrude by 0.3-m from the surface, on which a sealing plastic cover should be placed to prevent children from throwing stones into the well.

3.2.5 – Water accumulation and cost analysis of an underground ground

To allow an approximate estimate of water availability provided by an underground dam and the cost of water resulting from that intervention, a hypothetic calculation of a dam will be shown below, according to the characteristics of the alluvial deposit of a particular region.

Suppose that a river valley in a particular location has the following characteristics identified by a study as specified below:

- Average width of alluvial deposit in section covered by dam: W = 100 m;
- extension (length) of section upstream to dam in dam influence area: L = 1 km;
- average saturated thickness of alluvial deposit: T = 2 m; and
- average effective porosity coefficient of alluvial sediment: X = 15%.

Volume of available water - V – is given by:

- V = W x L x T x X, or:
- V = 100 x 1,000 x 2 x 0.15 = 30,000 m^3

Considering an average consumption of water of 60 l/inhabit/day in rural zones, this volume would be sufficient to supply 200 families for one year or irrigate 5 ha for 8 months (considering 4 rainy months).

The cost of such a dam will vary according the valley width in dam location and deposit thickness, in addition to the type of septum to be used.

Assuming a 50-m long dam axis with an average depth of 2.0 m, including a plastic canvas septum and the construction of a piezometric well using pre-formed porous rings, the variable will only depend on the process – manual or mechanical. Cost estimate of construction of that dam is shown below, including the cost of survey to select the best location (at 1988 prices, and R$ 1.00 = US$ 1.15).

- SURVEY FOR SITE SELECTION

Percentage of monthly wage of a technician (5%)	R$ 100.00
Transportation and meal expenses	R$ 100.00
	R$ 200.00

- CONSTRUCTION BY MANUAL EXCAVATION

(Trench with an average length of 50 m, average depth of 2.0 m and width of 1.0m)

Excavation of 100 m3 at R$ 7.00	R$ 700.00
Trench filling: 100 m3 at R$ 3.00	R$ 300.00
200-micron, 6-m wide plastic canvas: (25 m at R$ 2.00)	R$ 50.00
Piezometric well: 6 rings with the diameter of 1.20 m	R$ 210.00
Gravel for well foundation: 1 m3	R$ 40.00
Foundation stones	R$ 100.00
Transportation of material for the work (in average)	R$ 100.00
	RS 1,500.00

- CONSTRUCTION MY MECHANICAL EXCAVATION

(Trench of the same length and depth, and width around 2.0 m)

Excavation of 200 m3: 15 h of tractor at RS 35.00	R$ 525.00
Filling of 200 m3: 5 h of tractor at RS 35.00	R$ 175.00
c + d + e + f + g (similar to item 2)	R$ 500.00
	R$ 1,200.00

Therefore, the price of a medium-size dam will range between R$ 1,400.00 and R$ 1,700.00, including the piezometric well. Such prices may vary from R$ 1,000.00 for small dams, to RS 3,000.00 for larger dams, when pumping is necessary to lower water level.

Considering a medium-size dam like in the example above, storing 60,000 m3 at an average price of R$ 1,500.00 will cost only R$ 0.05 (five centavos) per m3.

3.2.6 – Advantages of Underground Dams over Surface Dams

The many advantages for other types of interventions, especially for surface dams, when the required demand is consistent with the volume of water likely to be stored in that deposit, include the following:

- No loss of surface areas due to floods, and the same humidified channel can be used for plantation, what implies irrigation;
- greater water protection against surface bacterial pollution, as water is stored in subsurface;
- less loss from evaporation, as given the inexistence of a pond, insolation hardly works (only in the capillary edge);
- losses for infiltration in basement fractures are quite reduced, as in addition to differences in hydraulic load upstream to dam being

much smaller than in great volumes of water stored in the surface, flow through a porous environment is very slow, according to Darcy Law;

- their construction is much easier because, as the septum is confined in the alluvial deposit and does not require a large wall thickness or lateral shoulders in the valley;
- for the same reason, they have a great wall (septum) stability against erosion and no sign of collapse;
- construction is very economic, as they are a small work generally of reduced dimensions, as compared to those of surface dams;
- their construction is fast and may be completed in one or two days when the operation is mechanized, in contrast with surface dams, the construction of which requires several days and even years;
- they can be fully constructed using local labor, thus generating jobs for benefited population, and
- they do not require expensive treatment systems, maintenance, operation, electric power consumption and other costs typical of surface dams.

Photo 9 –Canvas Disposition in an Underground Dam
Source: João Bosco de Oliveira.

Photo 10 – Aspect of the Trench of an Underground Dam, Showing in the Center, the Piezometric Well Foundation
Source: João Bosco de Oliveira.

Photo 11 –Underground Dam Completion Stages
Source: João Bosco de Oliveira.

Photo 12 –Underground Dam Completion Stages
Source: João Bosco de Oliveira.

Photo 13 – Underground Dam Exploration by Grass Plantation
Source: João Bosco de Oliveira.

Photo 14 – Underground Dam Exploration by Grass Plantation
Source: João Bosco de Oliveira.

3.3 – Recovery and Preservation of Ciliary Vegetation in Watercourses

3.3.1 - General

This practice, from PRODHAM view, is highly important, given the peculiar soil use on watercourse margins in Ceará semiarid region. Pressure on such areas derives from high on-site demographic density and the low technological level adopted by the farmer through a degrading cultivation method.

In this context, recovery and preservation of ciliary vegetation constitute a highly important hydroenvironmental practice in terms of water retention, water erosion reduction, and reduction of sanding-up levels in tributaries in each hydrographic basin.

It is important to highlight that fluvial runoff is an integral part of hydrological cycle, which is fed by both surface water and groundwater.

Therefore, vegetative cover becomes necessary to maintain the geomorphologic process of the hydrographic basin.

Finally, it should be remembered that the proportion between surface waters and groundwater that feed the watercourse will vary according to the climate, type of soil, type or rock, declivity and vegetative cover.

3.3.2 - Main forest species for ciliary vegetation recomposition

Among the main forest species that could recompose the ciliary vegetation strip the following stand out:

a) **Carnauba**

- Vulgar Name - Carnaubeira
- Scientific Name – Copernicia Prunífera (Arr.)
- Family - Palmae
- Propagation – Seeds
- Use

Wax palm stands out in semiarid region as a vegetal species for multiple uses, of which the following stand out:

- Stalk provides timber for civil construction and woodwork, either whole or divided into rafters, beams, laths, ducts and stakes. Until recently, timberwork of most roofs originated from carnauba. All others cases included in its endemism area, even public buildings, use carnauba stalk for the construction of roof and floor framework, when they have more than one floor.
- The main product obtained from carnauba is the wax that covers the epidermic cells of leaves, especially its lower portion in the form of white powdered particles with a characteristic smell. Because of its commercial importance gained in this century, wax raised carnauba

to the category of extractive plant par excellence in Ceará valleys. Initially used for candle manufacture, several industrial applications emerged in the present days for carnauba wax, with great economic and social effects.

- In the big drought period, "palm-leaf of carnauba coendu" was used for human and animal food, by producing a yellowish amylaceous starch containing 8.5% water, 89.84% starch, 0.75% inorganic salts, and 0.91% cellulose. In the present days, exploration of carnauba leaves has reached an expressive economic value in handicraft market, producing several personal and decorative articles

b) **Juazeiro**

- Vulgar Name – Juazeiro
- Scientific name – Zizyphus Joazeiro (Mart.)
- Family – Ronacea
- Propagation – Seeds
- Use

Juazeiro is a typical arborous plant in backwoods. It prefers argillaceous alluvial soils, but it grows anywhere, including in most arid and stony tablelands where it acquires a nearly shrubby aspect. It remains always green and never loses all its leaves, which are renewed in October, even during the most inclement droughts, thanks to its broad and deep root system able to capture the scarce subsoil moisture.

In addition to the shade that it provides to mitigate insolation, its leaves and branches constitute one of the most valuable food recourses for the cattle in dry period.

According to Pompeu Sobrinho (1918 apud BRAGA, 1953), its chemical leaf composition is as follows:

- Total organic matter – 59.10%
- Azotized substance – 10.20%
- Fatty substance – 1.06%
- Non-azotized extract – 29.60%
- Cellulose – 16.20 %

According to Kellner and Woff (1948 apud BRAGA, 1953) its leaves have the following composition:

- Nutritional units – 56.10
- Nutritional starch value – 57.70%
- Nutritional calorie value – 231.2
- Nutritional ratio – 1:4.71

c) **Oiticica**

- Vulgar Name – Oiticica
- Scientific Name – Licania rígida (Benth)
- Family - Rosacea
- Propagation – Seeds and seedlings
- Use

Oiticica is a large tree that develops in deep river and stream alluviums to form long and narrow groves on the margin of ravines or dispersed in lowlands. This floristic aspect was greatly devastated by anthropic action at the deforestation of riparian areas.

Oiticica timber is white colored and contains intertwined fibers very resistant to crushing, and is used for the manufacture of ox cart wheels and crushers.

In periods of extended droughts, when pastures disappear completely, cattle eat its tender leaves.

However, its economic value comes from seeds that are rich in oil (60%), appropriate for paints and varnishes of high drying content.

d) **Marizeira** (Umari)

- Vulgar Name – Marizeira or Umari
- Scientific Name – Geoffraea spinosa (Jacq.)
- Family – Leguminosae Papilionoidea
- Propagation – Seeds
- Use

Large leafy tree that develops in lowlands. It is also know as “tree that shed water”, because this plant sheds waters through its buds at the beginning of rainy season. To backwoodsmen, the fact is considered as an excellent sign of abundant rains.

Its fruits, although bitter, are eaten cooked or in the form of pap in dry periods or even in normal times. Some dough is removed from its fruits (mesocarp) and used as expectorant and vermifuge.

Leaves serve as substantial food for the cattle, and the leaf tea mixed with buds is emmenagogic and antidysenteric.

e) **Canafístula**

- Vulgar Name – Canafístula
- Scientific name – Cassia Fístula (Linn.)
- Family – Leguminosae Casalpinoidea
- Propagation – Seeds
- Use

Large tree with shelled fruits. Seed pulp has a laxative and purgative value.

Leaves remain green throughout the summer, even in periods of extended droughts, and branches are quite used for animal food.

f) **Ingazeira**

- Vulgar Name - Ingazeira
- Scientific Name – Inga bahiensis
- Family – Leguminosae Mimosoidea
- Propagation – Seeds and seedlings
- Use

In general, it is a high, branched tree with fruits inside king and straight shells containing an eatable sweet pulp.

It provides white or reddish timber used for firewood, box and packsaddle manufacture. It is found in coastal humid sites, fresh mountains and backwoods where it is restricted to lowlands or follows the river margins.

g) **Mutamba**

- Vulgar Name – Mutamba
- Scientific Name – Guazuma ulmifolia (Lam.)
- Family – Esterculiaceae
- Propagation – Seeds and stalks
- Use

Medium size tree with dense and wide branches. Timber is pinky white colored and is used for internal works, woodwork, lath and box manufacture. Fruits and new leaves are used as cattle food. Shell produces resistant fibers for ropes and fabric manufacture.

In domestic medicine, bast is used as antiblennorrhagic astringent, expectorant and for manufacture of lotions to prevent hair fall and destroy parasitic affections in scalp.

h) **Mulungu**

- Vulgar Name - Mulungu
- Scientific Name – Erythrina velutina (Willd)
- Family – Leguminosae Papilionoidea
- Propagation – Seeds
- Use

High tree with trunk and branches containing few thorns. Timber is light, white and porous and has almost no application.

For home medicine, shell infusion is a good sedative and expectorant and is also used to speed up gum abscess maturation.

In ciliary reforestation, in addition to being used to protect river margins, it may be used with fruit tree species to provide edible fruits, associated with other species of environmental and economic interest.

The following fruit species stand out:

a) **Cashew**

- Vulgar Name – Cashew Tree
- Scientific name – Anacardium Occidentale (Linn.)
- Family – Anacardiaceae
- Propagation – Seeds
- Use

Hyperatrophic floral peduncle (pseudo fruit), the actual cashew, has multiple uses, from raw consumption to industrialization in the form of juice, sweet and several beverages, etc.

Cashew nut, the real fruit, has an expressive commercial and industrial value.

b) **Custard apple**

- Vulgar Name – Pinha, fruta do conde, ata
- Scientific name – Annona squamosa (Linn.)
- Family – Annonaceae
- Propagation – Seeds
- Use

Fruit is truly appreciated for its tenderness, taste and smell of its pulp that is divided into fruits and seeds. Leaf infusion is used for stomach disorders and bruises, and in sinapisms for headaches and neuralgia; its powder has insecticide action.

According to (1953), chemical composition of ripe fruit includes: water 62.90%, ashes 1.00%, cellulose 12.00%, resin 0.30% azotized matter 2.80%, starch 1.73%, pentaglucose 0.80%, tartaric acid 0,37%, and glucose 11.70%.

c) **Mango**

- Vulgar Name – Mango Tree
- Scientific name – Mangifera indica (Linn.)
- Family – Anacardiaceae
- Propagation – Seeds and seedlings
- Use

Mango tree is a tree of relatively easy implantation in riparian areas without irrigation.

From medicinal standpoint, use of mango is recommended in the treatment of chronic bronchitis and other chest affections, dysentery, intestinal hemorrhages, and bladder catarrh thanks to the presence of turpentine and other mains fruit components. It is also diuretic and milk stimulating.

d) **Umbu**

- Vulgar Name – Umbu or imbu
- Scientific Name – Spondias tuberosa (Arr. Cam.)
- Family – Anacardiaceae
- Propagation – Seeds and stalks
- Use

Low tree with twisted atrophic trunk. Fructification starting at the beginning or rains is abundant at a productivity exceeding 300 kg/tree/year. Fruits produce sweet juices and pulps rich in vitamin C, containing 33.3 mg/cc of ascorbic acid. Currently, Embrapa is developing a research project for improvement and reproduction of that species.

Umbu tree stores, in xylopod or ‘potato’ and roots a regular quantity of water, mucilage, starch and glucose for dry period. In acute starvation periods, backwoods inhabitants use the ‘potato’ to quench their thirsty and hunger.

e) **Cajá**

- Vulgar Name – Cajazeira or Caja
- Scientific Name – Spondias Lutea (Linn.)
- Family – Anacardiaceae
- Propagation – Seeds or stakes

- Use

High and upward tree that can be as much as 20-m high, covered by a rough, salient and grooved grey shell.

Fruit is edible and used for the preparation of jams and bottled fruit, but it is most valued as a soft drink of excellent flavor.

The shell, popularly known as "caracas", is used for modeling and xylograph. Shell infusion is used for gargles, while crushed seeds are used for urine retention and bladder catarrh. At the ends of its roots a tubercle develops, which in the past was used for flour preparation during extended droughts.

Photo 15 – Aspects of Ciliary Vegetation in Watercourses of Cangati River, Canindé, CE
Source: João Bosco de Oliveira.

Photo 16 – Aspects of Ciliary Vegetation in Watercourses
Source: João Bosco de Oliveira.

Photo 17 – Ciliary Vegetation Composed of Carnauba Trees
Source: www.digitalmemory.com.br/piaui/piaui.html

f) **Tamarindo**

- Vulgar Name – Tamarindo or Tamarino
- Scientific name – Tamarindus indica (Linn.)
- Family – Leguminosae Cesalpinioideae
- Propagation – Seeds
- Use

Tamarindo timber is used for manufacture of furniture and coal, in addition of its ornamental qualities.

Pulp contains 11.32% of acids (tartaric, citric and malic), and 21.32% of sugars. It is consumed "in natura", in the form of ice creams, refreshments and sweets. It is quite used given its refreshing and laxative properties, being therefore recommended for constipation and hemorrhoids. Its leaves may be used as fodders.

3.4 - Reclamation of Degraded Areas

3.4.1 - General

This practice is intended to areas that have undergone a severe erosion process where part of surface soil horizon has been eroded. Their recovery will require the combination of edaphic and conservational reforestation practices.

Conservational reforestation means the reforestation the basis objective of which is to obtain indirect benefits from the presence of vegetative cover.

Such indirect benefits include the improvement of local climate, fauna protection, prevention from erosion and regularization of hydrological cycle, as well as water quality maintenance.

Improvement of soil conditions by the present of vegetative cover is widely known and involves the improvement of physical and chemical properties. It increases fauna and soil activities, organic matter content, water storage capacity and aeration.

3.4.2 – Main forest species to reclaim degraded areas

Among the main forest species that could be used for degraded area reclamation the following stand out:

a) **Sabiá**

- Vulgar Name – Sabiá
- Scientific Name – Mimosa Caesalpiniaefolia (Benth)
- Family – Leguminosae minosoidea
- Propagation – Seeds and stalks
- Use

For animal food – leaves and ripe or dry fruits are fodders of high nutritional value for caprine, ovine and bovine animals.

For timber production – the plant is excellent for the production of stakes, posts, beams, forks and studs. It is very resistant to humidity, and because of its high density, it serves for production of coal of high specific heat.

b) **Mororó**

- Vulgar Name – Mororó
- Scientific Name – Bauhinia Forficate (Link.)
- Family – Leguminosae Cesalpincardeae
- Propagation – Seeds
- Use

For animal food – leaves and branches are fodders for caprine, ovine and bovine animals.

For timber production – stalk is used as quality beam and stake.

For medicinal use – Shell is used as astringent and expectorant.

c) **Aroeira**

- Vulgar Name - Aroeira
- Scientific Name – Astronium urundeuva (Engl.)
- Family – Anacardiaceae
- Propagation – Seeds
- Use

For timber production – tree of hard dark grey duramen used for civil construction, framework, posts, sleeper, hydraulic works, which is almost imputrescible in contact with the soil.

For medicinal use – Shell has balsamic and hemostatic action against airway and urinary system diseases, hemoptises e metrorrhagias.

For industrial use – given its high tannin content, shell is used in tanning industry.

d) **Catingueira**

- Vulgar Name – True Catingueira
- Scientific Name – Caesalpinia pyramidalis (Tul)
- Family – Leguminosae Cesalpinodeae
- Propagation – Seeds
- Use

For animal food – green or hayed leaves serve as fodder for animals; beans should be used carefully, as their tips are quite thin and may perforate the animal intestine and cause their death.

As medicinal plant – its leaves, flowers and shell are used to treat catarrhal diseases, diarrheas and dysenteries.

For timber production – used for firewood, stakes, posts and coal production.

e) **Algaroba**

- Vulgar Name – Algaroba
- Scientific Name – Prosopis juliflora (DC)
- Family – Leguminosae Mimosoidea
- Propagation – Seeds
- Use

Adult tree produces in average some 20 kg of fruits with the following composition: humidity 17.02%, raw protein 12.93%, ethereal extract 4.06%, nitrogen extract 41.16%, raw fiber 19.08%, and mineral residue 3.75%.

For animal food – in addition to leaves, the fruit is a nutritional food for bovine, caprine and ovine animals and also for man in scarce food periods.

For timber production – algaroba has a heavy and compact duramen that serves for furniture, sleeper, stake, firewood and coal production.

f) **Leucena**

- Vulgar Name – Leucena
- Scientific Name – Leucena leucocephala (S.P)
- Family – Leguminosae Mimosoidea

- Propagation – Seeds
- Use

For animal food – excellent forage species with high protein content for bovine, ovine and caprine animal food.

Leucena can be associated with subsistence crops to create a protein bank, thus reducing its implantation cost.

g) **Angico**

- Vulgar Name – Angico
- Scientific Name – Piptadenia macrocarpa (Benth)
- Family – Leguminosae Mimosoidea
- Propagation – Seeds
- Use

For timber production – angico tree provides timber for planking, framework, parket blocks and woodwork. Excellent for production of delicate furniture, firewood and coal. Shell, because of its tannin content (32%) is indispensable for tanning industry.

As a medicinal plant – shell infusion, syrups, maceration and dye are haemostatic, depurative, astringent and expectorant.

h) **Favela**

- Vulgar Name – Faveleira or Favela
- Scientific Name – Cnidoscolus phyllacantheis (Pax & K. Hoffm)
- Family - Euforbiaceae
- Propagation – Seeds and stakes
- Use

For animal food – ripe leaves and green shells serve as forage for bovine, caprine, ovine and porcine animals.

For timber production – its light and white timber is used for wooden shoe, door frames and box production,
Seeds, as shown by S.A.I./MA studies, which give favela tree an outstanding position as cooking oil and flour producer, are rich in mineral salts and especially proteins, according to the analysis:

Photo 18 – Aspects of Soil Degradation
Source: João Bosco de Oliveira.

Photo 19 – Aspects of Soil Degradation
Source: João Bosco de Oliveira.

Photo 20 – Detail of Linear Cultivation (2.5m X 2.5m) of Sabia trees, showing the Cover of Naturally Hayed Leaves: Reclamation of Degraded Areas
Source: José Armando Diógenes.

Photo 21 – Catinga Tree
Fonte: www.aprendendo.wordpress.com/2006/05/11/catingueira/

Photo 22 – Favela Tree
Fonte: www.cnip.org.br

Photo: 23 - Umbu Tree
Fonte: www.3.bp.blogspot.com/.../m2CxCpjWx1c/s320/icf5S.JPG
- EMBRAPA Semiárido

Photo 24 - Juá Tree
Fonte: www.focadoemvoce.com/caatinga/fotos/juazeiro.jpg

Photo 25 - Mororó Tree
Fonte: João Bosco de Oliveira

Photo 26 - Sabiá Tree
Fonte: João Bosco de Oliveira

b) **Oil**

Oil extracted from almonds	51.9%
saponification rate;	192.6
Acidity rate	0.76
Oleic acid rate	0.38
Density at 15°C	0.92
Refraction rate	1.47

c) **Tort**

Moisture	2.98%
Mineral matters	8.32%
CaO	0.68%
P_2O_5	4.28%
Proteins	66.31%
Glucose	3.58%

3.5 – Community water supply (Wells and Cisterns)

One of the most serious environmental problems in rural environment refers to surface water resource pollution caused by inadequate use of human and animal water supply.

Control of water pollution and contamination is critical to maintain a good life quality and should be integrated to a correct hydrographic microbasin management.

Deep well sinking, combined with the construction of cisterns and piezometric wells, are alternatives for water supply for human and animal consumption in hydrographic basin domain areas.

Lack or water supply increases in dry months (summer) and in years of low precipitation. For deep wells, in crystalline semiarid region, use of desalinators is indispensable, as water in Ceará semiarid region originates from a crystalline geological formation of reduce flows and high salinity.

3.6 – Adequacy of Vicinal Roads

3.6.1 - General

Upon undertaking the integrated soil and waster management, complementary measurements of roads located in the hydrographic basin should not be disregarded. Road inadequacy that is not integrated to the correct soil management system will give rise to several problems that will aggravate erosion in farming exploration areas by making their maintenance difficult and accelerating their degradation.

Cost of maintenance of in correctly plotted and badly constructed roads is high and difficult and will impose a heavy burden on municipal governments. At the same time, once the problem of throwing plantation waters on roads is solved, addressing the problem related to water accumulated on roads that invade farming areas, accelerate erosion and even make the installation of conservational practices impracticable is necessary.

This way, road adequacy integrated to soil management practices allows a better erosion control and reduces drastically the needs and costs of maintenance, what represents a substantial economy for the municipality and rural producer.

Road adequacy works comprise basically the relocation of critical sections, correction of road bed, primary cover of critical sections, construction of infiltration boxes and the construction of bumps for integration to terracing system and infiltration boxes.

3.6.2 – Available technology

Roadwork integrated with soil management practices should take into consideration some basic principles listed below:

- water in farming areas should not reach the roads; and
- water accumulated in road bed should be well distributed in farming areas to prevent erosion.

For that, soil maintenance system and road adequacy should not be implanted at the same time. It is recommended that, to the extent possible, road adequacy follows the original road bed without any relocation. This relocation is recommended when a serious problem cannot be solved by adequacy practices alone. Main situations where relocation of a road section may be necessary are:

- when the section is excessively long and causes exclusive water accumulation, the course may de relocated to reduce ramp length, taking into account the declivity limit admissible for the type of local traffic;
- when the original road bed adequacy cost is higher than relocating the road bed to a new course; and
- when it is not possible, in the original road bed, to solve some technical problem related to water runoff into the property of into the actual road.

Whenever it is necessary to relocate the road course, after this new course is demarcated, all other actions are similar to those of road adequacy in its original course, and therefore this work will describe only the methods and actions of road adequacy.

Road bed abandoned due to relocation should be recovered for productive system (crops, breeding and reforestation) or preservation system.

Definitions and technical parameters of scheduled works

Road bumps

There are mechanical barriers constructed along the road beds to intercept rainwater runoff and lead waters to terraces or retaining boxes.

- Parameters :
  - Spacing: similar to that of terracing
- Average dimensions:
  - Length: equal to road width + connection to infiltration box or terrace
  - Width: 3 - 6 meters
  - Final height (compacted): 0.3 – 0.5m
- Retaining boxes

These are excavations normally in sandy soils, along the road beds, designed to accumulate rainwater intercepted by bumps and make waters infiltrate in the soil. In sandstone roads, not always using the bump as an extension of terrace will be possible, because the road bed is be too deep way or because of permanent cover.

- Parameters
  - Retaining Box calculation should be based on the function of catchment area and precipitation (average maximum precipitation for a particular recurrence time).
  - Average dimensions (length x width x height): from 2 x 3 x 2 m to 3 X 3 x 2 m (from 12 to 18 m3).

  Note: one on each road side.

- Bed correction

These include earthworks by bulldozers, front-end loaders or crawler tractors to fill grooves and gully erosions on the road side with earth (Figure

45) and/or soften lateral bumps with widths ranging between 3.50 m and 6.00 m, in addition to arch and compact road beds.

- **Bump softening**: in basalt (annual crops), bump inclination should allow mechanization and provide a little accentuated terrace diversion at its junction with bump (Figure 46);

In sandstone, bump erosion should be considered, so that it is softened as much as possible (depending on exploration and ravine difference of level), in addition to caring with grass and tree plantation.

- **Cover**: this consists of placing stones (gravel) on the corrected bed along the most critical roads followed by immediate compaction.

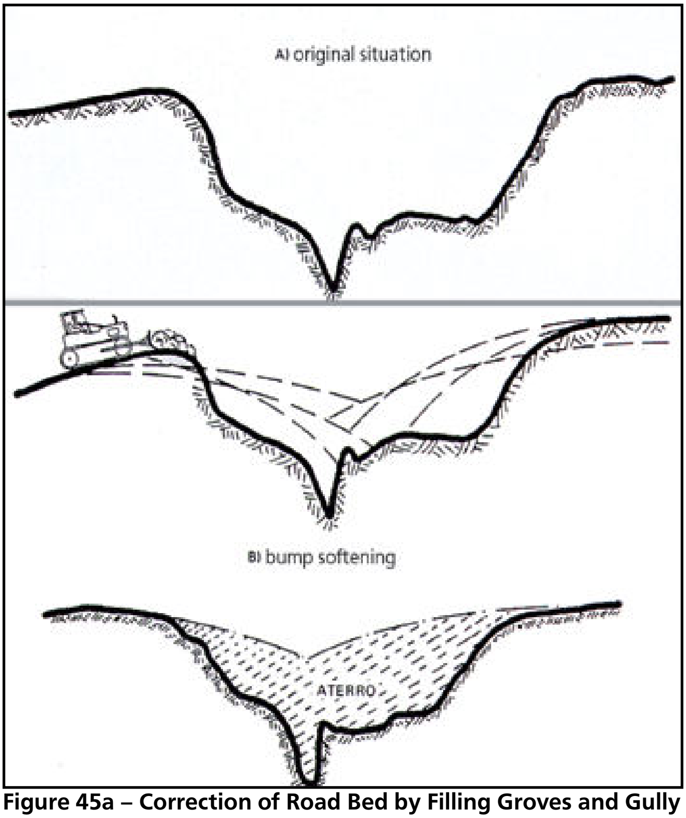


Figure 45a – Correction of Road Bed by Filling Groves and Gully Erosions on Road Sides with Earth
Source: IAPAR (1998).

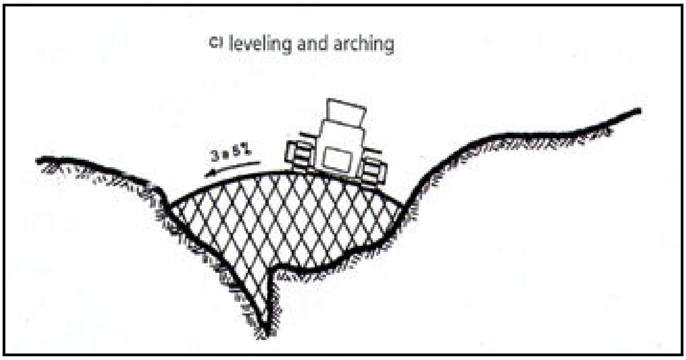
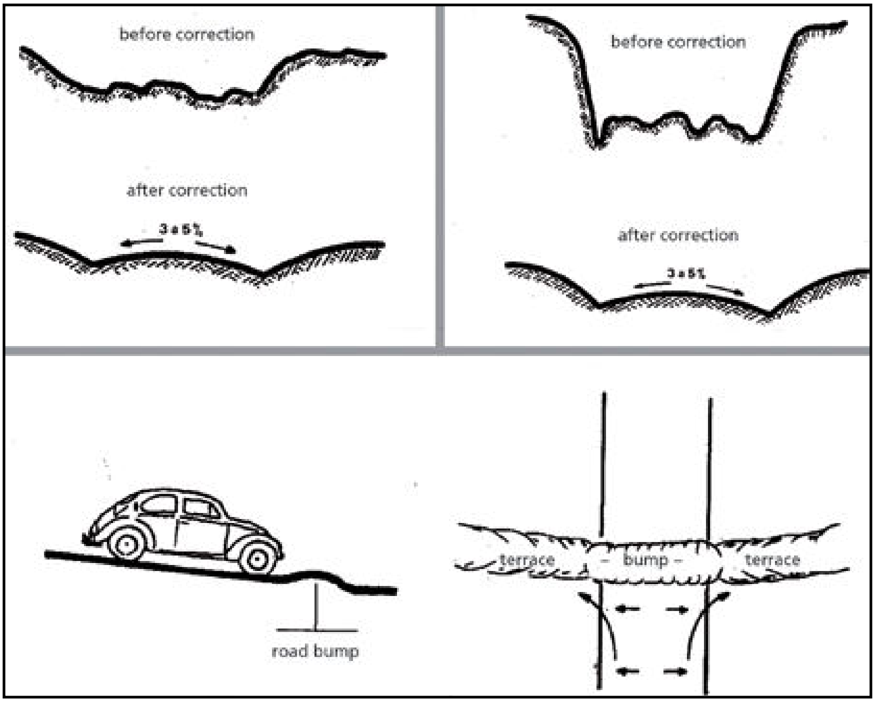


Figure 45b – Correction of Road Bed by Filling Groves and Gully Erosions on Road Sides with Earth
Source: IAPAR (1998).



3.6.3 – Implantation and Execution

A general description of road and way readequacy work follows.

Cut and fill actions to regularize the road bed and raise the roadway level to as close as possible to the soil level, using earth from lateral slope softening. Road bed is arched on the sides to transport rainwater to infiltration boxes or terraces, through bumps constructed along the road. The main stages to achieve this include:

a) **Survey/Planning**

- Identification of problems and critical points
- Proposal of adequate solutions
- Specification of Works per operation type
  - Measurements
  - Volumes
  - Schedule
- Selection of required equipment

b) **Execution**

- Plotting of required works
  - cuts
  - embankments
  - boxes
  - bed alignment

c) **Complementation**

- grass and tree plantation on slopes; and
- implantation of terrace of contour protection barrier upstream to the road or road section, integrated to permanent grass vegetation.

d) **Maintenance**

- Until slope consolidation and its full cover by grass, periodical cleaning of infiltration boxes should be maintained.
- After the first rains, road should be leveled again and bumps should be recovered due to the formation of grooves in the insufficiently compacted soil.

3.6.4 – Specific Situations and Remarks

a) **Occurrence of gully erosions on the road sides**

- It should be ensured that water runoff to the road are isolated and controlled before the start of adequacy works.
- Gully erosions should be filled with earth removed from slope softening followed by the best compaction possible. Then, leveling, arching, integration to terraces or boxes, and primary cover of critical sections should follow.

b) **Vegetation existing on slopes before softening**

- Vegetation existing in road gullies (napier, colony grass, capoeira, etc) should be eliminated without incorporating to road bed.

c) **Sandstone slopes**

- Grass should be planted on sandstone slopes to prevent infiltration box silting-up. Silk grass, African star grass and others may be used.

d) **Water from urban settlements**

- Given the complexity of the matter, it is necessary to activate the entities involved in periurban matters by designing a specific integrated project for the matter.

e) **Water from state of federal roads**

- It is necessary to evaluate the situation to discuss the matter with the Department of Edifications and Roads of the State of Ceará (DER) or the National Roadway Department (DNER) for a specific project.

f) **Leveled platforms**

- Typically, valley bottoms or mid-slopes should be protected by a terrace or vegetal barrier downstream to road bed to prevent eroded soil from depositing on the road bed.

- In such a case, the terrace or other form of surface runoff control implanted downstream to road bed should be at a distance smaller than that recommended by the table below, to compensate for road surface.

g) **Readequacy of culverts, bridges and shackles**

- As necessary, participation in execution and cost of works should be discussed previously with the municipal governments.

h) **Negotiations**

- Prior negotiations with producers, municipal governments and relevant entities are necessary to make participation clear and preserve the responsibility of each of them. At slope softening and road course rectification, there is often the need of eliminating cultivations lines and/or forest species, removing fences, displacing electric power and/or telephone posts, constructing or reconstructing/displacing small bridges, culverts, etc. All of this should have been previously established before the start of works, to which the involved parties should have previously agreed to.

Table 1 – Costs of Hours – Machines and Fuel for Road Readequacy Works

OPERATION	EQUIPMENT	REFERENCE VOLUME	OUTPUT	No. OF HOURS	COSTS OF FUEL	NOTES
Slope Softening	FIAT A8 7 8	-	120 A3/H	-	-	-
Cut and heaping	CAT 04	600 m3 /km	-	20 h	400 l	Gravel
Transportation	Ford Dump Truck	600 m3 /km	-	24 h	320 l	Gravel
Spreading	Bulldozer	600 m3 /km	-	30 h	300 l	Gravel
Compaction	Steam roller	600 m3 /km	10 h/km	10 h	2001	Gravel
Bed raising	CAT 06	600 m3 /km	-	34 h	680 l	-
Arching	Bulldozer	600 m3 /km	-	10 h	300 l	-
Construction of boxes	Front-loader	-	90 m3 /km	-	18 l/h	20 minutes per box in average
Construction of bumps	Komatsu D50	-	1.5 h/l bump 20 bumps/km	-	20 l/h	-

Source: IAPAR (1998).
NOTE: AVERAGE ROAD WIDTH: 6.5 m.

4 Alternative Edaphic Control Practices

4 – ALTERNATIVE edaphic control PRACTICES

4.1 - Terracing[1]

4.1.1 - Concept

Terraces are conservational structures constituted of a ridge (or dike), a canal or a combination of land and canal constructed across the soil slope and properly spaced.

Different types of terraces have been developed. For classification purpose, they me grouped as follows:

a) **Method of flood discharge**

- **Retaining terraces:** these are terraces constructed with a leveled canal blocked at the ends to allow storm water to be retained in the canal until infiltrating in the soil profile. It is indicated for deep and permeable soils and good electrical conductivity.

- **Drainage terraces:** these are terraces where the canal has a small declivity to allow water flowing to the canal to be directed out of protected area. Water should be directed, when possible, to protected talwegs.

- **Mixed terraces:** these are terraces where the canal has a small declivity and is provided with a zone for water accumulation, where a water intake pipe connected to an underground drain will slowly eliminate the excess water that cannot infiltrate in the soil.

b) **Cross section**

- Wide base terrace: these are terraces where both the canal and ridge allow mechanization (Figure 47). Earthworks strip width for this type of terrace is six to twelve meters.

- Medium base terraces: these have an earthworks strip width ranging between three and six meters and therefore cannot be worked by modern agricultural machinery.

1 - Technical recommendations of EMBRAPA National Soil Survey and Preservation Service.

- **Narrow base terraces (surrounding barriers):** terraces where dimensions and declivity of canal and ridge sides do not allow mechanization. Ridge slopes have generally a 2:1 or higher declivity and are usually covered with grass for greater stability. Earthworks strip width ranges between two and three meters. (Figure 48).

- **Terraces with steep back dike slope:** terraces appropriate for cultivation by agricultural machines in canal and front slope of ridge, but not for cultivation on back slope that usually has a 2:1 or higher declivity. Typically, back dike slope is maintained covered with grass for greater stability (Figure 49).

- **Zingg terrace:** these are terraces constructed with a wide and flat canal. Both the canal and dike slopes must be sufficiently wide to allow soil mechanization. (Figure 50).

- **Stair terraces:** these are terraces containing stairs and slopes (Figure 51). Stairs construction cuts the highest declivity lines and has a declivity opposite to that of soil. Slopes are too steep (generally 1:1) and usually maintained covered with vegetation. Step width should be determined according to the type of crop and management.

c) **Alignment**

- **Parallel terraces:** these are terraces where spacing is constant all over its length or, under uneven relief conditions, are constructed in parallel sections at different spacing.

- **Non-parallel terraces:** these are terraces constructed at variable spacing.

4.1.2 - Purpose

Terraces are nearly always used to reduce erosion. This is possible because the slope division into relatively short segments prevent surface runoff from reaching eroding speeds.

Practically, all types of terraces referred to above exert an effective action in erosion control, When properly planned and constructed, terraces may also serve for other purposes, such as:

a) Increase of the water retention capacity of soil for crop cultivation. Mixed and Zingg terraces are particularly efficient for that purpose. In such types of terraces, storm water remains in canal until infiltrating totally or partially in soil profile.

b) Reduction of flood sediment content. By reducing surface runoff speed, terraces also contribute to reduce substantially the quantity of transported soil particles, as sediment transportation capacity is proportional to the flood speed biquadrate. All types of terraces are able to reduce significantly the levels of concentration of solid material during floods.

c) Reduction of watercourse discharge peak. Terraces that allow greater water infiltration in soil (retaining terraces, stair terraces and Zingg terraces) are quite efficient in reducing the discharge peak in small hydrographic basins. This is highly important, as it supports the control of flood risk in lower areas.

d) Improvement of topography and mechanization of agricultural areas. Many treats of land under intensive use and subject to water erosion action display grooves that then to increase to form gullies that, in turn, will reduce the tillable area and sensibly affect the performance of agricultural machines. Terracing, when well planned, will prevent the formation of erosion grooves. When parallel, terraces also provide favorable conditions for crop mechanization, as dead lines are reduced to the minimum.

4.1.3 - Applicability

Because this is a practice that requires investments, terraces is only used when the desired erosion control is not achieved by the adoption of other simpler soil conservation practices. They are, therefore, particularly useful in places where rains usually occur at an intensity and volume that exceed the water storage capacity of soil and where other conservational practices, such as contour line cultivation, use of soil cover, etc., are insufficient to control floods.

A thoroughly analysis should be made of the several types of existing terraces to determine which of them are most applicable to local conditions before construction starts.

Precipitation, soil and topography conditions and crop to be cultivated in soil to be terraced are important factors in that analysis.

Retaining and Zingg terraces should be used in locations of low to moderate precipitation and permeable soil. Crops cultivated in canal of such terraces should be tolerant to expected flood period corresponding to the time necessary for water infiltration in the soil.

In areas where soil is not able to absorb very quickly the storm water, mixed terraces should be used, which will provide the desired flow.

When precipitation and drainage conditions are such that flood will exceed soil capacity for water infiltration and storage, drainage terraces should be used.

At selecting the form of terrace cross section, relief is the most important factor to be considered. Table 2 lists the classes of declivity most recommended for each type of terrace.

It should also be remembered that in narrow-base terraces, use of agricultural machinery is not possible. For that, such terraces have been mainly used in areas of perennial crops, where the traffic of agricultural machines is not intensive.

Table 2 – Types of Terraces Indicated according to Soil Declivity

Declivity	Type of terrace indicated according to soil declivity
2 - 8%	Wide-base terrace
8 – 12%	Terrace with steep dike backside and medium-base terrace
12 - 18%	Narrow-base terrace
18 - 50%	Stair terrace

Source: SNLCS/Embrapa.

Terraces where the back slope of dike is steep allow cultivation in both the canal and the front ridge slope. Back slope, because it is steep, is usually maintained covered by vegetation.

Both the canal and ridge of wide-base terrace may be cultivated.

Stair terraces represent a high-cost construction practice and therefore should only be used in high-value land and high-return crops. Stair width should be determined according to the crop needs, required implements and soil depth.

Intensity of agricultural machinery use is a factor to be considered at the selection of the most convenient alignment between terraces. Many farmers avoid terracing their land because of mechanization constraints. In general, terraces should be parallel to the extent possible, especially in areas cultivated by annual crops. The construction of parallel terraces requires more intensive earthworks, not only between canal and ridge, but also between cut to embankment areas. Typically, the construction of such terraces also requires a detailed study of the area, for which planialtimetric maps, cut and embankment balance, layout, etc., are necessary.

4.1.4 – Terrace length and gradient

For contour terraces there is no theoretical limit for terrace length, especially when their ends are blocked. However, as it is rarely possible to maintain a canal at zero gradient, the construction of "pillows" at intervals of approximately 100 meters, or earth blocks to prevent water from flowing over large canal extensions is recommended.

Maximum declivity in gradient terraces will depend on length. Gradient terraces more than 450-500-m long should be avoided. This helps to prevent water from reaching eroding speeds in terrace canal. Table 3 indicates the maximum permissible declivity for terraces of variable gradient. It should be noted that in highest portions of terraces, larger declivities that decrease as terrace length increases are acceptable. This is very important, especially for the construction of parallel terraces where, because of gradient variation, alignment between them may often be improved. Minimum permissible declivities should not be smaller than 0.2%, as in practice water accumulation will inevitably occur when canal declivity is smaller than that.

Table 3 – Maximum Gradients for Different Sections of a Wide-Base Terrace

Distance from the highest terrace point (meters)	Maximum Gradient %
0-15	2.4
15-30	2.0
30-45	1.6
45-60	1.2
60-75	1.0
75-90	0.8
90-105	0.7
105-135	0.6
135-165	0.5
165-360	0.4
360-480	0.3

Source: SNLCS/Embrapa.

4.1.5 – Spacing between terraces

Judicious terrace spacing is of utmost importance for a slope protection system. Undersized spacing cause unnecessarily high construction costs, while oversized spacing may cause terrace failure due to its incapacity to retain upstream flood. Terraces with very wide spacing have also a limited effect on erosion control and canal is quickly obstructed by sediments, what will inevitably cause the ridge rupture.

Therefore, selecting the spacing between terraces should allow the canal to discharge upstream surface runoff or store it and prevent erosion. This way, it can be said that spacing will depend on factors that affect soil response to precipitation, such as susceptibility to erosion, declivity and type of crop, in addition to rain characteristics in the region and dimensions of terrace canal. Several empirical formulas have been presented, which relate one or more factors referred to above to spacing between terraces. In Brazil, Benthey formula has been more used, which provided the vertical terrace spacing:

$$EV = (2 + \frac{S}{X}).0,30$$

where:

EV = vertical spacing in meters

S = declivity

X = factor dependant on soil nature, its resistance to erosion, type of conservational practice and type of crop; it can range between 1.5 and 6.0 m.

Vertical spacing is nothing more than the difference of level between two consecutive terraces (Figure 52). To transform EV into horizontal spacing (distance between two terraces), the following formula should be used:

$$EH = \frac{EV}{S}.100$$

Table IV shows (x) values recommended by SNLCS/Embrapa/Rio de Janeiro. Such values have been widely used by Embrapa technicians to determine terrace dimensions (Table 4).

TABLE 4 - "X" Values to Be Used in Benthey Formula

EROSION CONTROL PRACTICES								
	TERRACES				SURROUNDING BARRIER		RETAINING RIDGE	Benthey Formula EV = (2 + D/x) x 0.305 "x" values
	Permanent Crops		Annual Crops		Permanent Crops	Annual Crops	Annual Crops	
	W/grad	Contour Line	W/grad	Contour Line	W/grad	Contour Line	Contour Line	
	high						high	1.5
	medium						medium	2.0
	low	high					low	2.5
Soil resist to erosion		medium						3.0
		low	high					3.5
			medium		high			4.0
			low	high	medium			4.5
				medium	low	high		5.0
				low		medium		5.5
						low		6.0

NOTE: HIGH – Argillaceous texture soils - MEDIUM – Medium texture soils - LOW Sandy texture soils
Source: SNLCS/Embrapa.

4.1.6 – Terrace construction

Before starting the actual terrace construction, the area should be properly demarcated to allow earthworks to be facilitated and carried out as scheduled.

For non-parallel terraces which approximately follow the contour lines, pickets used for terrace plotting are generally sufficient. Pickets indicate the lowest canal point (Figure 53).

For parallel terraces, where typically cuts and fills are necessary, earthworks should be in lateral and longitudinal directions. In such a case, cut depth at each picket should be indicated in the respective picket. In places where deepest cuts will be made, additional pickets are recommended away from the picket indicating the canal. In such pickets, the difference of level between the soil surface and the terrace canal bottom should be marked (Figure 54).

A great variety of equipment may be used for terrace construction, from simple manual tools, such as hoes and mattocks to heavy scrapers. In terrace construction where earth is required to be transported to reasonable distances (more than 80 m), use of appropriate earthworks equipment, such as scrapers, is necessary. Bulldozer should not be used when earth displacement will exceed 80 meters. When only lateral earthworks (from canal to ridge) are necessary, ploughs, planers, “V” dredges and scoop can be used, in addition to bulldozers and scrapers.

Earth required for ridge construction may come from a downstream, upstream or beside the terrace (Figure 55). When the borrow pit is located upstream to ridge, terrace is called Nichols terrace, and when it is located ion both sides, terrace is called Mangun terrace. In parallel terraces, where generally cut and fill sections occur, the same terrace may often have borrow pits located downstream, upstream or on both sides of ridge.

4.1.7 – Field location of terraces

Preliminarily, the location of terraces in relation to tracks, roads, draining canals and other characteristics of the area should thoroughly considered to prevent future problems, especially those related to mechanization, from occurring. It is particularly important that at this stage the surface drainage plan (draining canals, etc.) has been well established for the whole farm, to prevent water poured by terraces from causing damages to unprotected areas. Some steps that may help the field plotting of non-parallel and parallel terraces are described below.

a) Non-parallel terraces

1. Identification of the highest point of area to be terraced. A level should be used to identify that point, as very often it is not possible to find the highest point at naked eye.

2. Determination of soil declivity above the first terrace. This declivity should be measured from the highest point to 30 m below.

3. Use of maximum declivity (s) and graphs 1 and 2, by selecting the adequate Vertical Spacing (EV) or horizontal spacing.

4. Placement of the first picket in upper terrace. This picket generally is located below the highest point of the soil at the same spacing previously determined.

5. Terrace picketing. Pickets are placed at 30-m intervals in even soils with declivity up to 5%. Intervals exceeding 15 meters should be used for soils of declivity above 5% or uneven relief. For contour terraces, pickets should be all placed at the same height of the first picket. For gradient terraces, level readouts should increase as pickets approach the discharge point at a value equal to:

$\Delta H = i \,.\, \Delta x$

where:

ΔH = Level readout increase between two consecutive pickets.

i = Terrace gradient.

Δx = Spacing between pickets.

6. Verification of first terrace location. Due to topography variations, it is noted that, in some soils, locating the terrace in the form indicated above, will not comply with the recommended spacing along the terrace. This way, the determination and location of upper terrace is important before proceeding with all other terrace picketing. For that, soil declivity above the terrace should be measured at several points and spacing should be calculated using graphs 1 and 2. Then horizontal or vertical spacing between terraces should be measured at such points and compared to recommended spacing.

7. If necessary, terrace location should be changed to obtain the required spacing. In some cases, terrace may be moved downwards to obtain a better spacing, even though this may result in spacing larger than that recommended in other locations. In general, a greater spacing in a particular terrace sections is permissible when the respective area is not very large and topography would allow flood to spread out instead of concentrating, and when the wider spacing is close the highest point of terrace (terrace start).

8. Measurement of drainage area declivity in the second terrace. An adequate number of declivity determinations should be made to determine the average declivity of contribution area for the second terrace. If the terrace is short and relief is even, a single read out will be sufficient. If the soil is otherwise uneven and terrace is long, several declivity determinations are necessary to determine the average declivity.

9. Based on average declivity, spacing should be calculated by using graphs 1 and 2.

10. Location of the first picket in the second terrace using the spacing determined as above. If the second terrace has the same length and the same gradient as the first terrace, vertical spacing between both terraces will be the same allover them. In such a case, the first picket may be located at any point of terrace. Otherwise, if the length of second terrace is different from that of first terrace, the first point should be judiciously located in the second terrace to obtain the desired spacing between them.

11. Picketing the whole terrace.

12. Al other terraces will be plotted in the same manner as the second terrace

b) Parallel terraces

1. Soil should be systematized before terrace construction. If soil surface is uneven and rough, terrace location should be greatly improved if soil depressions are filled with earth from hills. This will also allow flood concentration to be reduced between terraces, in addition to making soil cultivation easier after construction.

Volume of earthworks prior to terrace construction will depend on soil depth and amount of funds allocated to this operation. In shallow soils, generally little systematization can be made, as a good portion of tillable layer may be used to fill soil depressions. In such soils, it could be more desirable to make deeper cuts in terrace canal and use that subsoil to fill depressions between terraces.

2. Number and location of discharge points (draining canals or underground drains) should be judiciously selected. Whenever a terrace system is to be implanted, a thoroughly study of number and location of drains to be used should be performed. In general, the greater the number of discharge points, the easier the construction of parallel terraces. It should be remembered, however, that when vegetated canals or additional underground drains are used, cost of terrace system will increase substantially. In addition, overuse of draining canals will exclude considerable land areas from production.

3. Planning the location of fences and surface or subsurface drains to make mechanization in terraced area easier. Terraces are more easily mechanized when they form a right angle with fences and drains. In some cases, terraces may be constructed parallel to fences, what will eliminate dead lines.

4. To reduce terrace curvature and improve parallelism between them, section location may be changed upwards or downwards. Changes to gradient terrace location can be made by changing canal cut depth, declivity along terrace, or combining such two options.

In general, changing cut depth is more effective when changing short terrace sections with the objective to reduce the curvature level. Changing declivity along the terrace is a method used to change When this resource is used, gradient limits shown in Table 3 should be followed.

When changing the cut depth is necessary, earth removed from deepest cut sections is deposited in sections of shallower cuts to maintain the cross section along the terrace. Permissible cut depth will depend on type of soil, type of equipment used for terrace construction and available funds.

Reduction of curvature and dead line area will depend on topography, type of soil and type of equipment used for terrace construction. Best alignments can be obtained in areas where topography is relatively even, declivities are moderate and soil are deep and permeable. However, it is always possible to improve alignment to a certain extent in any area. Usually, lined up annual crops are those which most require parallel terraces, to avoid problems to mechanization, which is typically intensive.

To the extent possible, even spacing between terraces should be obtained, by changing the canal declivity, what will represent no additional costs for their construction. When cut depth varies, construction cost increases due to additional earthworks.

Photo 27 – Terracing System, Aratuba-CE.
Source: João Bosco de Oliveira.

Photo 28 – Terracing System
Source: João Bosco de Oliveira.

Foto 29 – Terrace Planer
Source: Gastão Silveira.

A good terrace planning is of utmost importance. Time spent with this activity is generally compensated for the reduced construction cost.

Use of a topographic map containing 1.5-m spaced contour lines, or at a spacing similar to vertical terrace spacing, if smaller than 1.5 m, is recommended. The topographic map will give the advantage of having an accurate notion of the full terrace system, as location adjustments are easier and faster than field terracing picketing. Based on the topographic map, it will possible to make different attempts to locate the system as a whole, what almost always will result in planned terraces.

In possession of a topographic map, the following procedure is recommended:

1. Planning the best location in the map. Declivity in different parts of land should be measured, while spacing between terraces should be determined. Master terraces should be selected to locate the others as parallel as possible to the former, always taking into account the permissible depth limits for cuts and declivities.

2. Transferring the terraces from map to the field. After parallel terraces have been planned on the map, one of them should be picketed to the same position occupied on the map. For that, benchmarks should be established both in the field and on the map. Pickets in parallel terraces where there is a substantial cut depth variation should be approximately 15-m spaced from each other.

3. Picketing other terraces in a way that they are parallel to the first terrace.

4.2 – Draining canals

4.2.1 - Concept

Draining canals are surface drainage canal typically stabilized by vegetation and constructed with shapes forms and declivities.

4.2.2 - Purpose

Draining canals are used to convey concentrated flow of storm water to prevent groove erosion and formation of gullies.

4.2.3 - Applicability

Draining canals should be constructed and maintained whenever concentrated surface runoff forms are favorable to the formation of deep erosion grooves. They are particularly useful for the conveyance of water discharged by terraces. They should not be used, however, as continuous flow canals, where the continuous presence of water may affect the vegetation development and make canal unstable.

Sometimes, using permanently vegetated areas (pastures, woods, etc.) as draining canals is possible. When this is not possible, it is necessary to design and construct them. For that, the following should be considered:

- flow to be conveyed;
- form of canal;

- vegetation to be used;
- project speed; and
- canal capacity.

4.2.4 – Flow determination

Flow determination should be based on estimated flood in the canal contribution area. As typically direct flood measurements are not available, widely accepted formulas are used, which relate surface runoff to precipitation. One of the most used of them is the rational formula:

Where: $Q = \frac{CIA}{360}$

Q = Discharge peak in m3 /sec

C = Flood coefficient

I = Rain intensity for project return period and a time equal to that of continuation area concentration in mm/h.

A = Contribution surface area in ha.

4.2.5 – Form of canal

Form of cross section of draining canals may be triangular, trapezoid or parabolic. Natural, trapezoid and triangular canals after some period of time tend to become parabolic.

Trapezoid canals require less excavation than parabolic canals for the same capacity. In addition, this form of cross section provided a lower flow concentration in canal, and therefore should be used under conditions of steeper declivity. Triangular section causes the higher flow concentration and, therefore, should be used in softer declivities.

Geometric characteristics of three forms of cross sections are shown in Figure 56, together with formulas necessary to calculate hydraulic characteristics.

4.2.6 - Vegetation

Vegetation to be used in canal should be able to withstand local temperature variations, extended drought periods, without undergoing periodic submersions. It should also provide an excellent soil cover. Its root system should allow strong soil aggregation and be able to give the plants strength to resist flooding. It should not constitute crop plagues (invaders). Several species have been recommended for draining canal cover, such as: batatais grass (Paspalum notatum), kikuyu grass (Pennisetum clandestinum), Rhodes grass (Chloris gayana), ordinary kudzu grass (Pueraria thumbergiana), etc.

However, there have hardly been researches on best vegetal species for that purposes. Likewise, rugosity coefficient that is highly dependant of species and vegetation height has not been evaluated for Brazilian conditions. The suggest value (0.04) refers to a pessimist condition.

To establish the draining canal vegetation, soil should be corrected and fertilized to allow the vegetative cover to occur as soon as possible. Sowing may be made randomly or in lines perpendicular to declivity. When possible, seedling should be used for propagation. Dead cover should also be used, such as rice and wheat straw, etc., which can help in vegetation formation. That dead cover will serve as a barrier to delay flood speed, thus reducing the risk of seeds or seedling being pulled out, in addition to reducing the soil evaporation rate and therefore preserving moisture for better sprouting.

Table 5 shows the dimensions of parabolic draining canals for some discharge speeds. Values in first column (s) refer to soil declivities in %; values in second column refer to speeds (v) denominated in m/sec, and values in third column refer to maximum canal depths, in cm. The first line of table shows discharges in m3/sec. In the table body, values of maximum canal widths are shown. For other forms of cross section (triangular or trapezoid), canal size can be estimated by trial method. In such a case, values should be assigned to canal dimensions until reaching values that would simultaneously satisfy:

$$A = \frac{Q}{V}$$

and $$R = \frac{v^{3/2}}{S^{1/2}}$$

where Q and V values are pre-established (project discharge and speed, respectively).

4.2.7 – Project speed

Permissible speeds are influenced by the selected type of vegetation, declivity, and soil susceptibility to erosion. As such, for lawns, highest speeds are allowed, while lower speeds should be used for bunch grass. For soils resistant to erosion, grassed canals may convey floods at speeds of 2-2.5 m/sec, while stump grass should not exceed 1.2 m/s. For easily erodible soil, permissible speed should be 1.3 to 2 m/sec, depending on vegetative cover. Use of bunch grass to cover canals in soils highly susceptible to erosion should be avoided, especially when declivity exceeds 5%. However, when canal vegetation is not fully established yet, flood should not exceed 1.5 m/sec. Under such conditions, canal should be designed to convey floods at speed of 0.90 m/s, depending on soil resistance to erosion and vegetation characteristics.

4.2.8 – Canal capacity

Draining canal should be designed to convey floods at speeds equal to or lower than permissible speed. Speed in canal can be calculated by Manning formula below:

$$V = \frac{R^{2/3} . S^{1/2}}{\gamma}$$

Where:

V = Average speed in m/sec.
γ = Rugosity coefficient of canal (approximately 0.04)
R = Hydraulic canal radius.
S = Soil declivity in m/m.

Canal dimensions should be selected to allow project discharge (Q) occur at speeds lower than the project speed. For that, Manning formula should be solved by the trial method.

It should be pointed out that, although highly important for erosion control, vegetated canals have been little studied.

4.3 – Permanent Vegetative Barriers

4.3.1 - Concept

Permanent vegetative barriers are surrounding strips introduced in main crop and maintained by perennial plants that develop dense vegetation.

4.3.2 - Purpose

Permanent vegetative barriers are used to reduce surface runoff speed. This way, a reduced disaggregating power and flood conveyance capacity is obtained.

4.3.3 - Applicability

Vegetative barriers may be used for both annual and perennial crops. In some way, vegetative covers are an alternative for farmers that cannot afford to construct terraces. Although this practice excludes from production the land strips (2-3 m) where vegetative barriers are established, it dispenses with the use of machinery and workers necessary for terrace construction. Because no earthworks are necessary, this practice can be used in any type of soil sufficiently deep for the development of crops cultivated in strips. It has been noted that, for declivities up to 10%, Permanente vegetative strips are highly efficient. To determine space between strips, graphs 1 and 2 may be used.

In permanent vegetative barriers long-cycle plants with high root density and fast overhead development should be used. Leucena, lemmon balm and elephant grass are grasses that have such characteristics and have been successfully used in the construction of permanent vegetative barriers.

4.4 – Windbreaks

4.4.1 - Concept

Windbreaks are tree and shrub barriers to protect soils and crops from harmful wind effects.

4.4.2 - Purpose

Windbreaks aim to reduce wind speed. As a consequence, they also reduce wind erosion and maintain soil moisture by reducing evapotranspiration. In places where the occurrence of cold wind is common in winter, windbreaks may be useful to reduce temperature falls in farm houses, stables, hen-houses, pigsties, etc.

4.4.3 – Applicability

Use of windbreaks should be considered when wind erosion constitutes a serious problem, and when other practices have proved ineffective. Cultivation of windbreak trees and shrubs is generally expensive and the development period is very long. In addition, windbreaks occupy land areas that could be used for agricultural production.

The following factors should be considered at the construction of windbreaks:

- height;

- porosity;
- length; and
- location in relation to wind direction.

Importance of windbreak height and the angle that it forms with the predominant wind direction may be determined by the following formula (WODDRUFF & ZINGG, 1952).

$$d = 365,5\frac{h}{v}\cos\Theta$$

d = 365.5 cos

d = distance of protection provided by windbreak

h = height of windbreak

v = wind speed at a height of 15 m

θ = angle between wind direction and windbreak perpendicular line.

It is noted, therefore, that when wind is parallel to windbreak, a minimum protection is obtained, and when wind is perpendicular to windbreak a maximum protection is obtained. This, it is of utmost importance to identify the direction of predominant winds in the place where windbreaks are to be used. The formula above indicates that the distance between windbreaks should be proportional to windbreak height. However, in practice spacing between windbreaks is usually ten times its height.

Windbreak porosity is a major factor that influences wind capacity reduction capacity and particle transportation capacity. Studies made in other countries suggest that a 40% porosity is the most indicated for windbreaks. As smaller areas are required for plantation of porous windbreaks than for non-porous windbreaks, this information is highly important.

Porosity distribution in windbreak height has been still much discussed. It seems, however, that a uniform porosity from tree top to the soil is more recommended. For that, sometimes planting trees and shrubs of different sizes is necessary.

As the area protected by windbreak is approximately triangular, where the tree line constitutes the base of triangle, that area is as large as its length.

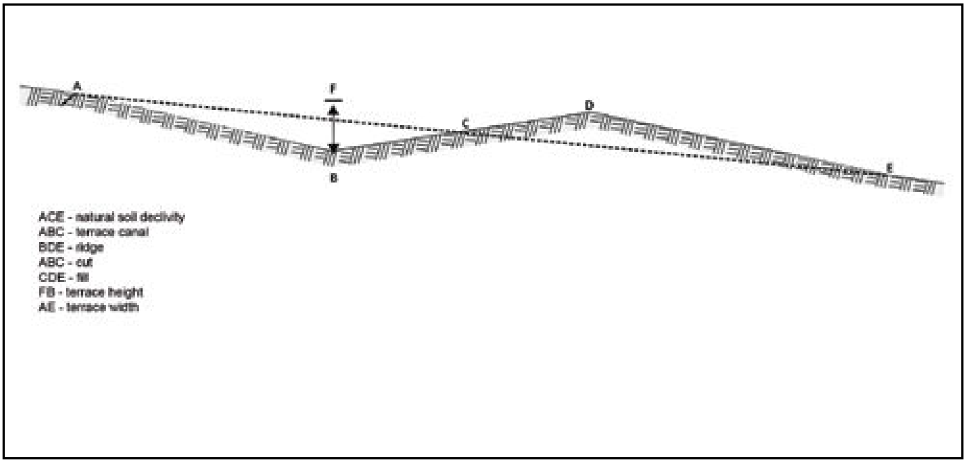


Figure 47 – Typical Profile of Wide-Base Terrace
Source: SNLCS/EMBRAPA

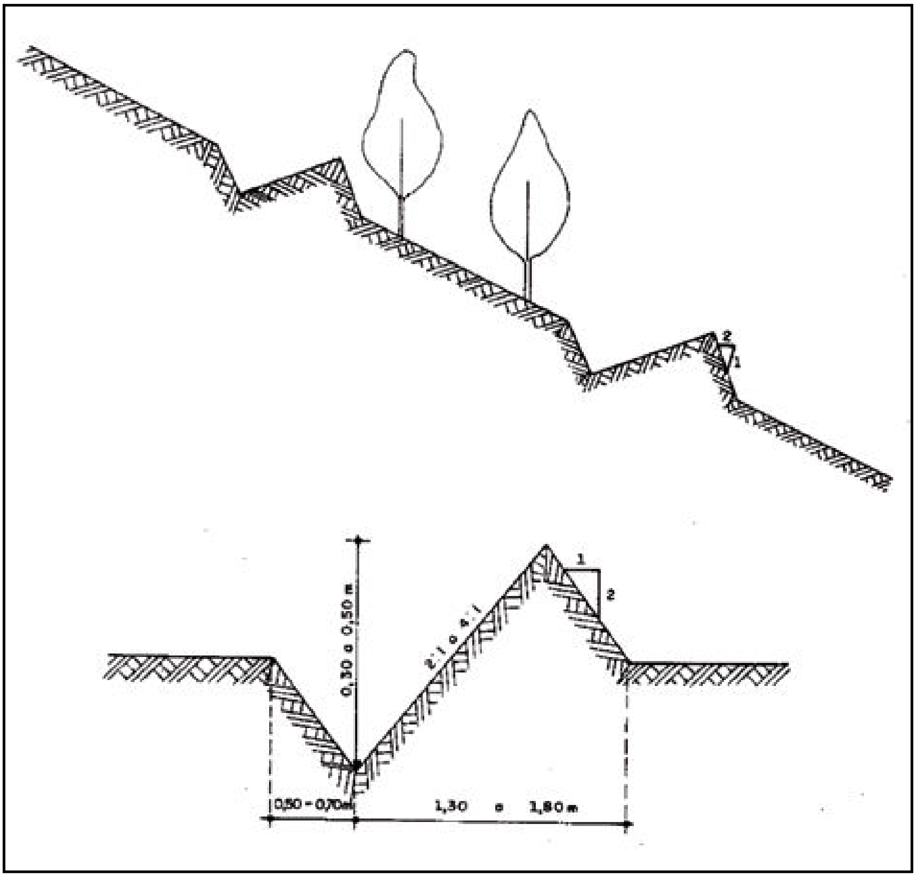


Figure 48 – Narrow-Base Terrace
Source: SNCLS / Embrapa.

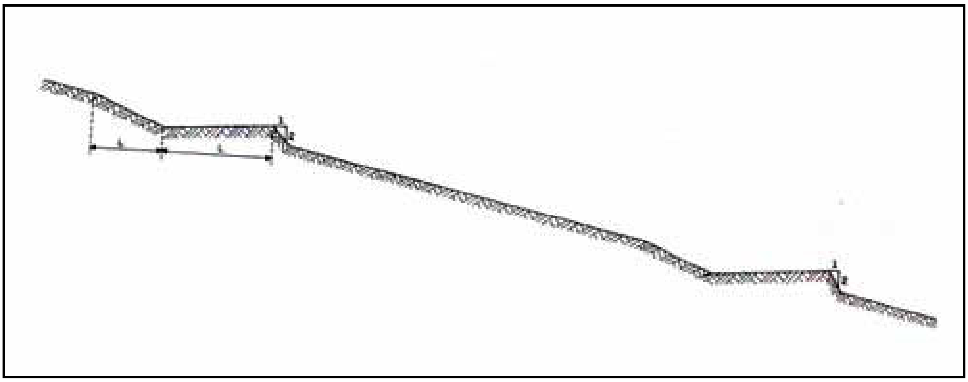


Figure 49 – Terraces Constructed with Steep Back Dike Slope
Source: SNCLS/EMBRAPA

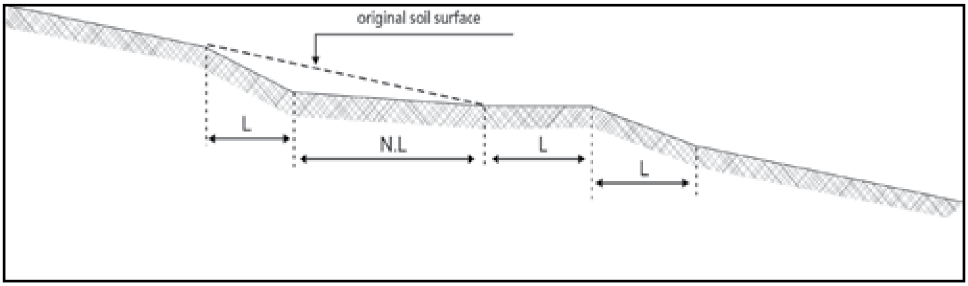


Figure 50 – Zingg Terraces
Source: SNCLS/Embrapa.

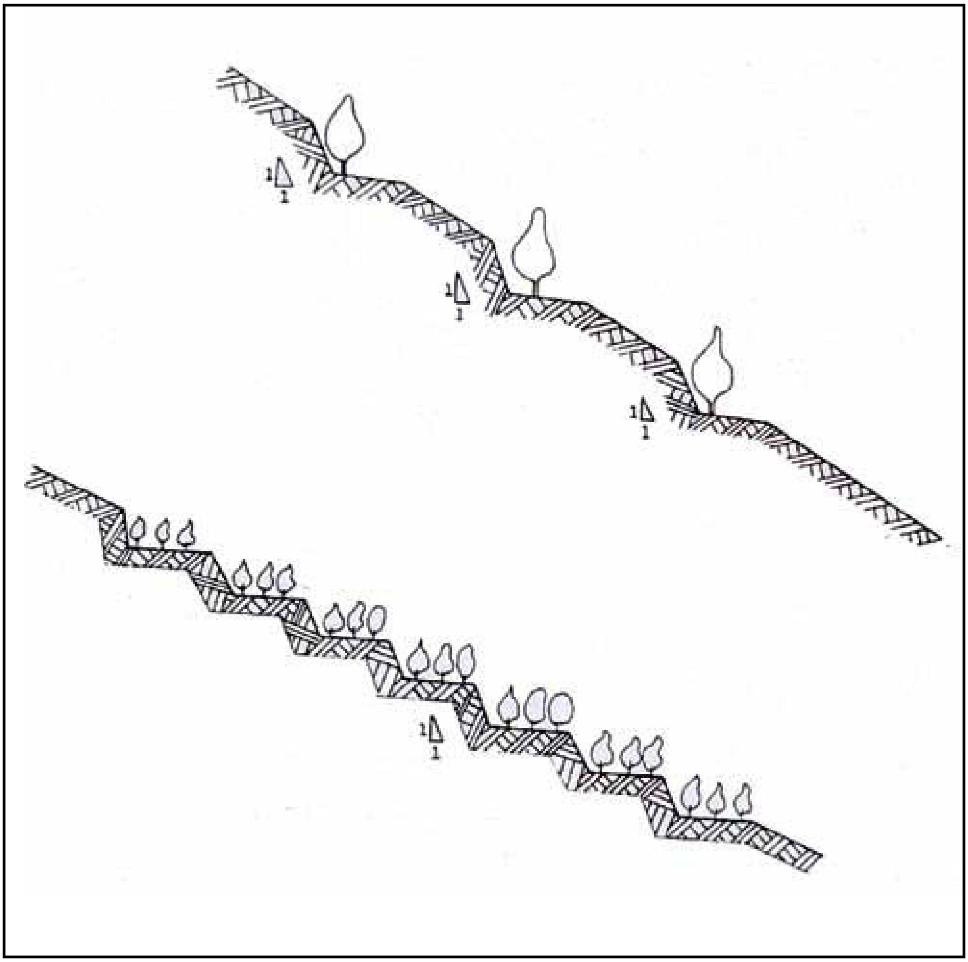


Figure 51 – Stair Terrace
Source: SNLCS/EMBRAPA

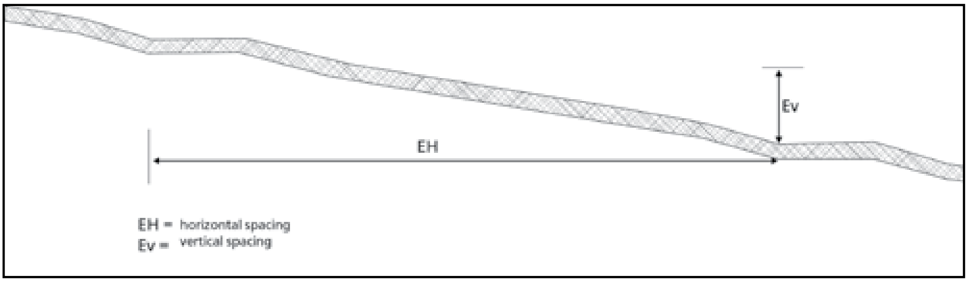


Figure 52 – Horizontal and Vertical Spacing between Two Consecutive Terraces
Source: SNCLS/Embrapa.

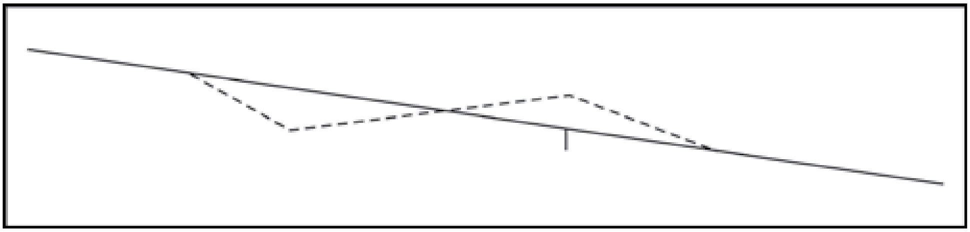


Figure 53 – Picket indicates the canal bottom
Source: SNCLS/Embrapa.

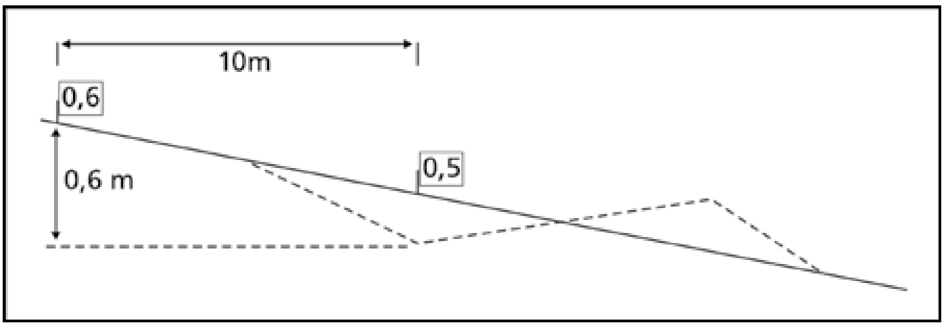


Figure 54 – Picketing in Deeper Cut Locations
Source: SNCLS/Embrapa.

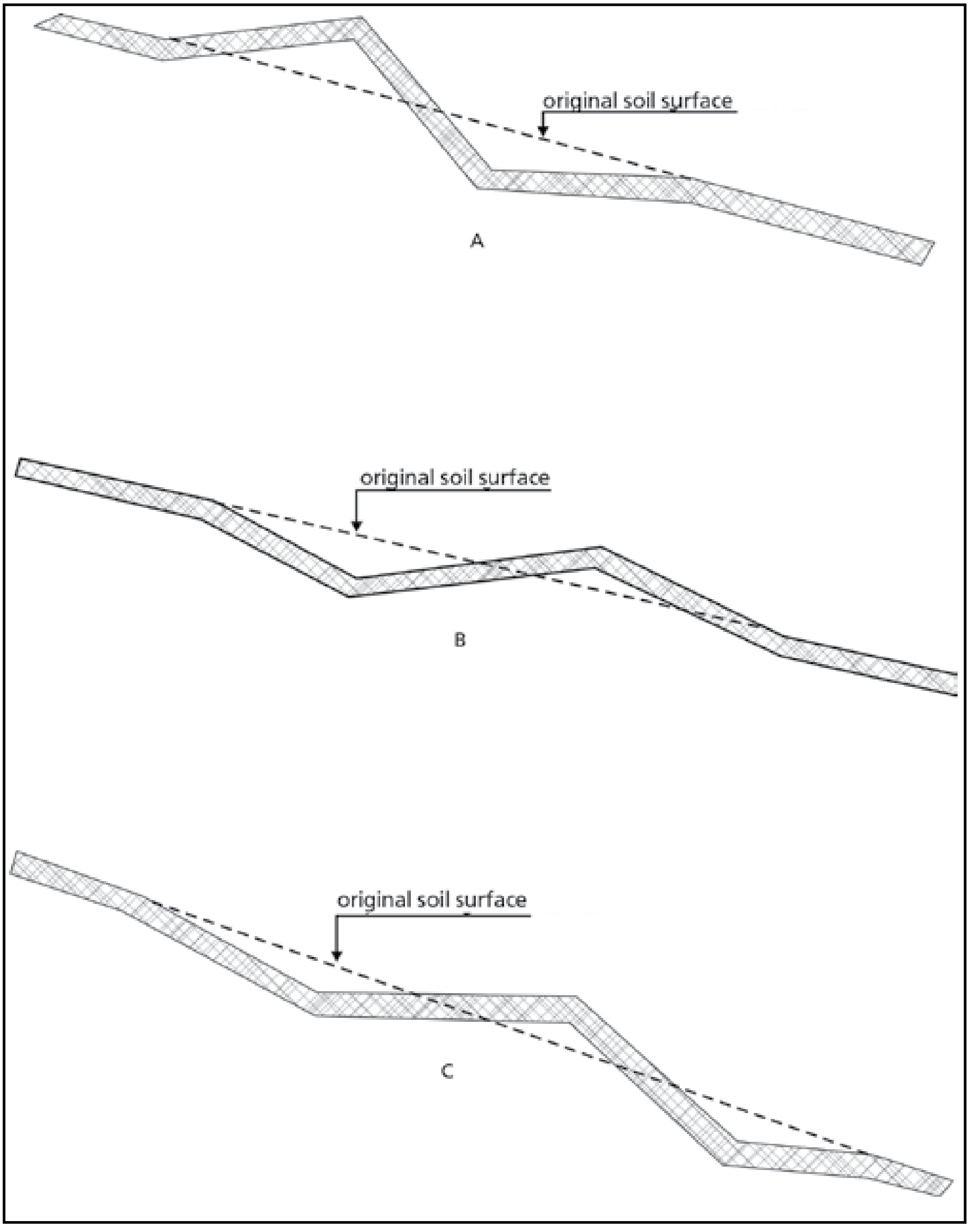


Figure 55 – Borrow Pit Areas Located Below (A), Above (B) and on Both Sides of Ridge (C).
Source: SNCLS/Embrapa.

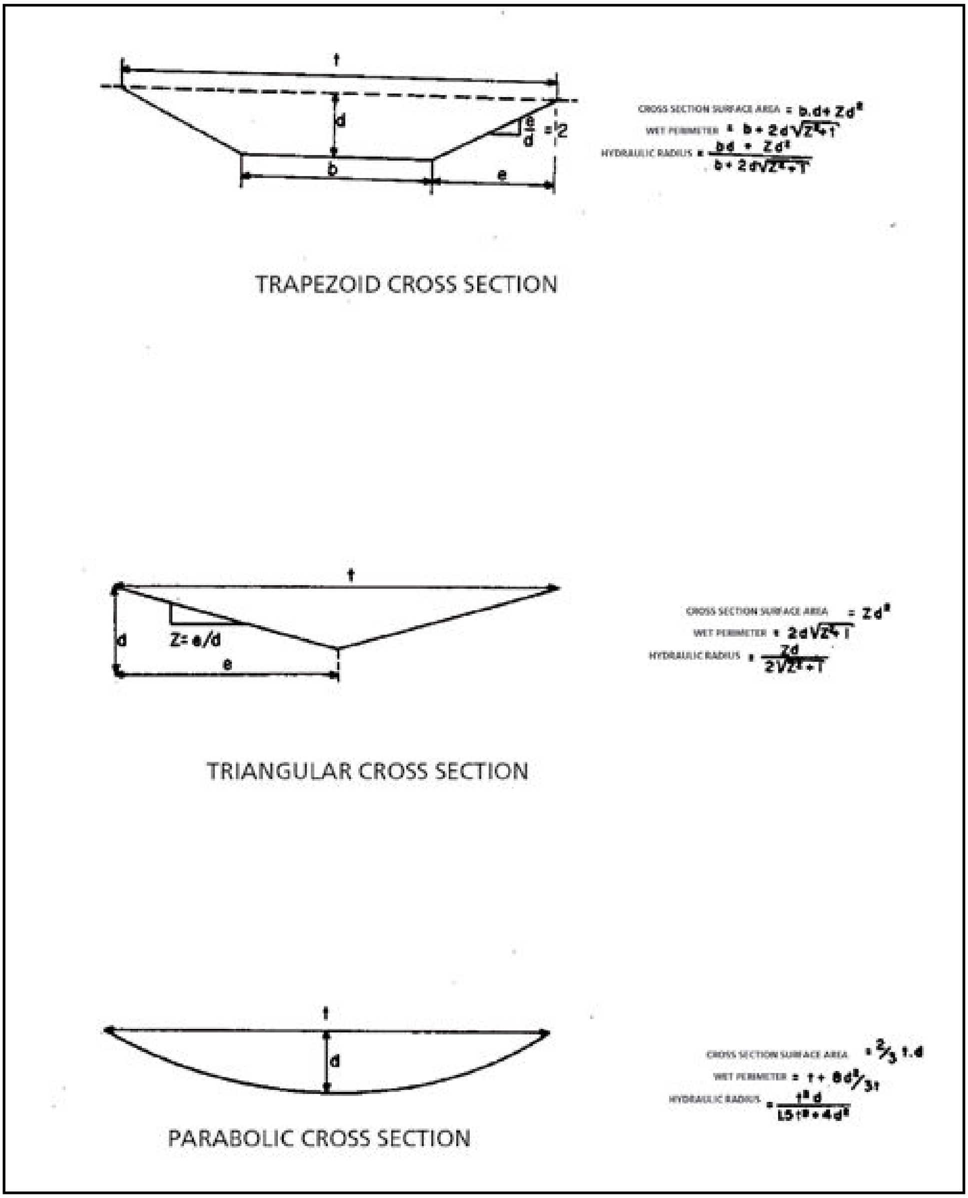


Figure 56 – Trapezoid, Triangular and Parabolic Sections of Draining Canals.
Source: SNCLS/Embrapa.

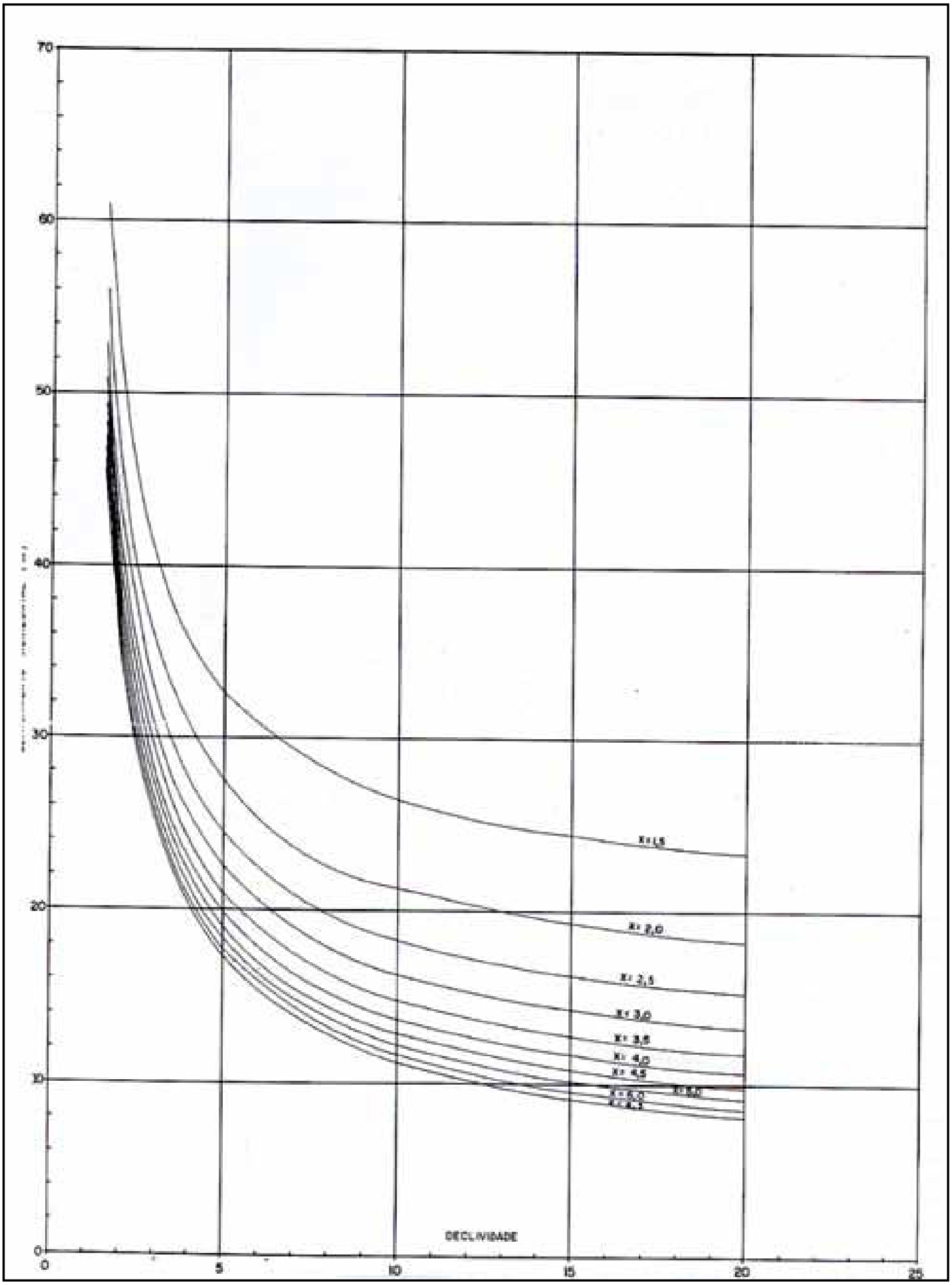
Table 5 – Dimensions of Parabolic Draining Canals

S %	V	d	DISCHARGE Q (m^3/s)																																					
	m/s	cm	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,2	1,4	1,6	1,8	2,0	2,2	2,4	2,6	2,8	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	**9,0**	**9,5**	**10,0**	**10,5**	**11,0**	**11,5**	**12,0**	**12,5**	**13,0**
	0,6	30	2,0	3,3	4,1	5,1	5,9	6,7	7,5	8,4	10,0	11,7	13,3	15,0	16,7	18,3	20,0	21,7	23,3	25,0	29,2																			
0,5	0,9	55								3,0	3,6	4,2	4,8	5,5	6,1	6,7	7,3	7,9	8,5	9,1	10,6	12,1	13,6	15,2	16,7	18,2	19,7	21,2	22,7	24,2	25,8	27,3								
	1,2	88																				5,9	6,6	7,4	8,1	8,8	9,6	10,3	11,0	11,8	12,5	13,2	14,0	14,7	15,4	16,2	16,9	17,6	18,4	19,1
	0,9	33							4,5	5,1	6,1	7,1	8,1	9,1	10,1	11,1	12,1	13,1	14,1	15,2	17,7	20,2	22,7	25,3	27,8															
1	1,2	50													5,0	5,5	6,0	6,5	7,0	7,5	8,7	10,0	11,2	12,5	13,7	15,0	16,2	17,5	18,7	20,0	21,2	22,5	23,7	25,0	26,2					
	1,5	70																				5,7	6,4	7,1	7,9	8,6	9,3	10,0	10,7	11,4	12,1	12,9	13,6	14,3	15,0	15,7	12,4	14,1	17,9	18,6
	0,9	19			4,4	5,3	6,1	7,0	7,9	8,8	10,5	12,3	14,0	15,8	18,5	19,3	21,1	22,8	24,6	26,3																				
2	1,2	30						3,3	3,7	4,2	5,0	5,3	6,7	7,5	8,3	9,2	10,0	10,8	11,7	12,5	14,6	16,7	18,7	20,8	22,9	25,0	27,1													
	1,5	42													4,8	5,2	5,7	6,2	6,7	7,1	8,3	9,5	10,7	11,9	13,1	14,3	15,5	16,7	17,9	19,0	20,2	21,4	22,6	23,8	25,0	26,2				
	0,9	14	3,6	4,8	5,6	7,1	8,3	9,5	10,7	11,9	14,3	16,7	19,0	21,4	23,8	26,2																								
3	1,2	22				3,4	4,0	4,5	5,1	5,7	6,8	8,0	9,1	10,2	11,4	12,5	13,6	14,8	15,9	17,0	19,9	22,7	25,6																	
	1,5	30									4,0	4,7	5,3	6,0	6,7	7,3	8,0	8,7	9,3	10,0	11,7	13,3	15,0	16,7	18,3	20,0	21,7	23,3	25,0	26,7										
	0,9	11	4,5	6,1	7,6	9,1	10,6	12,1	13,6	15,2	18,2	21,2	24,2	27,3																										
4	1,2	18	2,1	2,8	3,5	4,2	4,9	5,6	6,2	6,9	8,3	9,7	11,1	12,5	13,9	15,3	16,7	18,1	19,4	20,8	24,3	27,8																		
	1,5	25						3,2	3,6	4,0	4,8	5,6	6,4	7,2	8,0	8,8	9,6	10,4	11,2	12,0	14,0	16,0	18,0	20,0	22,0	24,0	26,0													
	0,9	10	5,0	6,7	8,3	10,0	11,7	13,3	15,0	16,7	20,0	23,3	26,7	30,0																										
5	1,2	15	2,5	3,3	4,2	5,0	5,8	6,7	7,5	8,3	10,0	11,7	13,3	15,0	16,7	18,3	20,0	21,7	23,3	25,0	29,2																			
	1,5	21						3,8	4,3	4,8	5,7	6,7	7,6	8,6	9,5	10,5	11,4	12,4	13,3	14,3	16,7	19,0	21,4	23,8	26,2															
	0,9	9	5,6	7,4	9,3	11,1	13,0	14,8	16,7	18,5	22,2	25,9	29,6																											
6	1,2	13	2,9	3,8	4,8	5,7	6,7	7,7	8,6	9,6	11,5	13,4	15,4	17,3	19,2	21,1	23,1	25,0	26,9																					
	1,5	18				3,3	3,9	4,4	5,0	5,6	6,7	7,8	8,9	10,0	11,1	12,2	13,3	14,4	15,6	16,7	19,4	22,2	25,0	27,8																
	0,9	7	7,1	9,5	11,9	14,3	16,7	19,0	21,4	23,8	28,6																													
8	1,2	10	3,8	5,0	6,3	7,5	8,8	10,0	11,3	12,5	15,0	17,5	20,0	22,5	25,0	27,5																								
	1,5	15		2,6	3,3	4,0	4,6	5,3	6,0	6,6	8,0	9,3	10,6	12,0	13,3	14,6	16,0	17,3	18,7	20,0	23,3	26,6																		
	0,9	6	5,6	7,4	9,3	11,1	13,0	14,8	16,7	18,5	22,2	25,9	29,6																											
10	1,2	9	4,2	5,6	6,9	8,3	9,7	11,1	12,5	13,9	16,7	19,4	22,2	25,0	27,8																									
	1,5	12	2,5	3,4	4,2	5,0	5,0	6,7	7,5	8,4	10,0	11,7	13,3	15,0	16,7	18,3	20,0	21,7	23,3	25,0	29,2																			
	0,9	5	10,0	13,3	16,7	20,0	23,3	26,7																																
12	1,2	8	4,7	6,2	7,8	9,4	10,9	12,5	14,0	15,6	18,7	21,9	25,0	28,1																										
	1,5	11	6,1	8,1	10,2	12,2	14,3	16,3	18,4	20,4	24,5	28,6																												

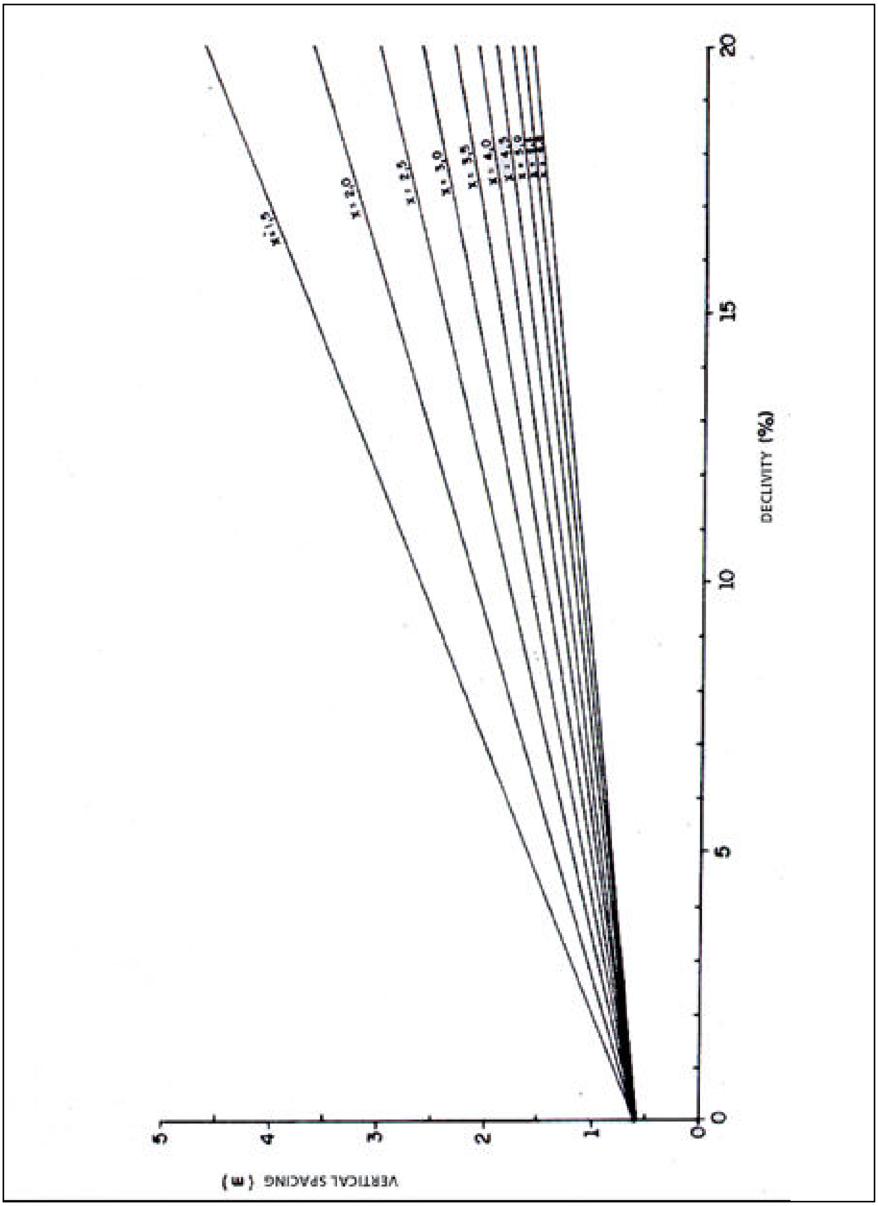
S = Canal Declivity V = Discharge speed d = Maximum canal depth

Note: Numbers in Table Body represent the Maximum Canal Width

Source: SNLCS/Embrapa.



Graph 1 – Graphic Benthey Formula Solution for Horizontal Terrace Spacing
Source: SNCLS/Embrapa.



Graph 2 – Graphic Benthey Formula Solution for Vertical Terrace Spacing
Source: SNCLS/Embrapa.

4.5 – Surrounding Stone Barriers

4.5.1 - General

In State of Ceará, problem of soil use and management is serious, especially in its semiarid region. Soils are mostly shallow and have very low water retention capacity. This characteristic is aggravated by precipitation regime: very heavy rains after extended dry periods find soil surface naked, without any vegetative cover, and compacted, what reduces its water retention capacity.

Insight of their characteristics of moderate to high erodibility, small effective depth, occurrence of stones, high deforestation rates and predatory use in subsistence agriculture, soils with litholic surface layer (non-calcic brown soils, red-yellow podsols, gravelly and litholic soils) require a judicious management and a greater attention to conservational aspect (MARGOLIS et al., 1985) than that usually given in the State of Ceará. Preliminary studies developed by Silva and Paiva (1985) in Quixadá-Ce, indicated that Surrounding Stone Barriers constituted a promising antierosive technique, based on observations of reduced silting-up in water reservoirs, and called the attention to benefits that could be provided in the short term by sediments retained by that practice, improving shallow and litholic soil properties.

4.5.2 - Purpose

Surrounding Stone Barriers segment the slope lengths, reduce flood volume and speed, force the sediment deposition in areas when stairs are constructed and natural stairs are formed. As a consequence, they increase the effective soil depth and reduce deteriorations caused by sediment, nutrient and organic matter export, thus improving infiltration conditions and water storage for plants. It should be considered that understanding such conservational techniques and their field application influence the increased soil productivity.

This conservational practice has the following objectives, among others:

- reduce the sediment mass through erosion control by surrounding stone barriers;
- change micro relief in the soil strip between two stone barriers, and increase soil depth;
- improve physical-chemical soil conditions, where that conservational practice is applied.

4.5.3 – Applicability and construction method

In soil units presenting stony surface (brown, non-calcic, red-yellow podzolic gravel) surrounding stone barriers should be adopted by giving priority to critical land area. This practice is adequate for small properties and depends basically on available workforce (Figure 57).

Efficiency of surrounding stone barriers as a conservational practice is clearly evidenced by sediment retention, which may be as high as 60 ton/ha–1/ year–1 of retained material.

With respect to effective depth, an increase is noted over the time of sediment deposition, when natural formation of stairs occurs.

Because of sediment mass retained by the surrounding stone barrier in deposition area, a substantial improvement is noted in all physical-chemical properties of removal areas, especially regarding organic matter and clay content, available water, N, Ca, Mg, K and P content, followed by a reduced Al content.

Spacing between surrounding stone barriers should comply with data contained in Table 6, similar to spacing used for terraces.

Table 6 – Spacing Adopted for Terraces and Contour Stone Barriers

DECLIVITY %	SANDY SOIL SPACING (m)		ARGILLACEOUS SOIL SPACING (m)		SILTY SOIL SPACING (m)	
	VERTICAL	HORIZONTAL	VERTICAL	HORIZONTAL	VERTICAL	HORIZONTAL
1	0.38	37.75	0.43	43.10	0.55	54.75
2	0.56	28.20	0.64	32.20	0.82	40.95
3	0.71	23.20	0.82	27.20	1.04	34.55
4	0.84	21.10	0.96	24.10	1.22	30.60
5	0.96	19.20	1.10	21.95	1.39	27.85
6	1.07	17.80	1.22	20.30	1.55	25.80
7	1.17	16.65	1.33	19.05	1.69	24.20
8	1.26	15.75	1.44	18.00	1.83	22.85
9	1.35	15.00	1.54	17.15	1.96	21.75
10	1.43	14.35	1.64	16.40	2.08	20.80
12	1.6	13.30	1.82	15.20	2.32	19.30
14	1.74	12.45	1.99	14.20	2.53	18.05
16	1.89	11.80	2.15	13.45	2.74	17.10
18	2.02	11.20	2.30	12.80	2.92	16.25
20	2.14	10.70	2.45	12.25	3.11	15.55

Source: SNLCS/Embrapa.

In surrounding stone barrier construction process, the following stages should be followed:

- determination of declivity of the respective area to select the horizontal or vertical spacing according to soil texture (Table 6);
- field contour line plotting according to selected spacing;
- construction of stone barriers along field plotted contour lines;
- Stones should be transported for barrier construction by “stretchers” or “power shovels”.

Construction is typically made using stones existing in the own land. Stone barrier is a kind of lath-and-plaster wall always constructed leveled. Both soil preparation and nature undertake to level the area between stone barriers.

Photo 30 – Surrounding Stone Barriers
Source: João Bosco de Oliveira.

Photo 31 – Surrounding Stone Barriers
Source: João Bosco de Oliveira.

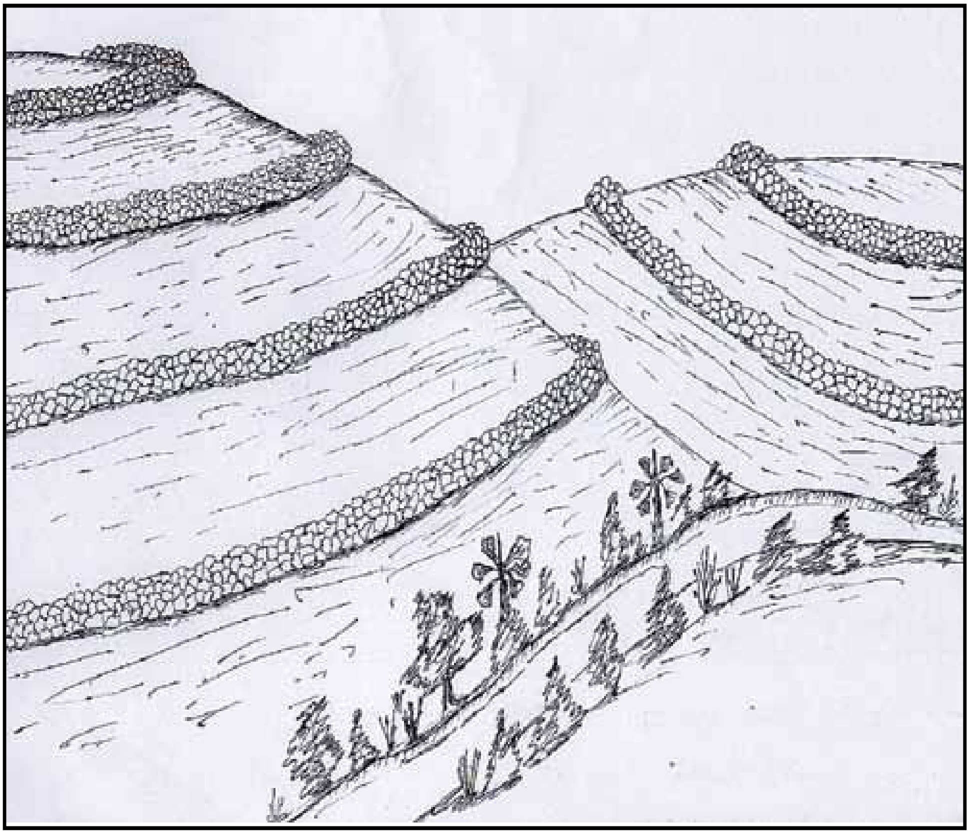


Figure 57 – Surrounding Stone Barriers
Source: João Bosco de Oliveira.

4.6 – Soil decompaction

4.6.1 - General

Soil decompaction process involves aspects that relate to physics, chemistry and biological properties, as well as environmental factors, such as climate, agronomic soil treatment, especially management and types of crops.

Compaction process is basically the change of a soil mass volume. It is a change to apparent soil density.

- Mineral soil – ranges from 1.1 to 1,6 g/cm3;
- Organic soils – ranges from 0.6 to 0.8 g/cm3.

To understand compaction process, it is necessary to have in mind that soil is formed by three phases:

- Solid phase – composed of mineral and organic matter;
- Liquid phase – represented by water; and
- Gaseous phase – constituted of air.

During the process, although those three phases maintain a certain equilibrium, some temporary variations occur in particular soils, due to some factors as rain, drought, traffic of machines and overgrazing on the soil.

A soil is considered optimal when it maintains the equilibrium among solid, liquid and gaseous phases, that is:

- contains some 50% of solids (mineral and organic material);
- contains some 20% of large pores storing soil air; and
- contains some 30% or small pores retaining soil solution of water.

When soil is subject to compaction, there is some deformation and displacement of solid particles and liquid phase, causing a reduction in its volume. This rearrangement of particle movement will depend on characteristics of each soil and occur in such a way that solid and liquid phases occupy the space reserved for gaseous phase. In case of argillaceous soils constituted of small particles and a greater total porosity, pressure effect is stronger and gives rise to compactions problems that are greater than those in sandy soils. When a load or pressure is applied on argillaceous soils, fine clay particles are moved to spaces left by coarse particles, such as sands, causing a volume reduction and consequent increase of apparent density, which is a characteristic of compaction. This harmful effect is more serious when a pressure is exerted on humid soils.

Soil compaction, therefore, will affect directly its porosity, that is, the empty spaces between solid particles. Such spaces are usually filled with air and water. When soil is compacted, pore size decreases and, under extreme conditions, pores may even disappear.

4.6.2 - Problems from soil compaction

Traffic of agricultural machines and overgrazing on cultivated areas is the most important factor in soil compaction. Pressure exerted on soil surface by machine weight and the high density of grazing animals give rise to an external force that leads to soil particle reorganization and make particles occupy small volumes. This is the characteristic of compaction phenomenon.

Compaction level or intensity will depend on a series of factors, such as:

- type of soil;
- current soil moisture;
- weight of machines and equipment;
- number of times that machinery crosses the same area; and
- number of grazing animals per area unit.

It should be considered that machine weight reaches the soil through its wheels and therefore, according to wheel width, that pressure may concentrate on a small strip of land or dilute to a wider strip.

Traffic of agricultural machines and overgrazing has been responsible for serious soil changes, what has influenced the soil-air-water behavior with harmful effects on plant development.

In soils that underwent a compaction, a series of physical changes occur, which affects directly the plants through their root system. Soil compression occurs thanks to a reduced size of pores, that is, space between solid particles occupied by air and chemical solution.

Reduction or narrowing of porous spaces impedes the development of roots that have difficulty to dilate the pore. Under such conditions, twisted roots are commonly sees, which grows horizontally instead of vertically. This is one of causes of fall of herbaceous plants and even larger trees such as Algaroba and Leucena, when there is some problem in the main root. If compaction problem also affects lateral roots, plants with small, thicker roots will be found.

In addition to affecting normal water infiltration in soil profile, and consequently increasing erosion by intensifying water runoff on the soil, compaction of certain soil layers affects adversely root development.

4.6.3 – Symptoms characteristic of compacted and dense soils

Soils with compaction or dense horizon problems display visual symptoms that can be directly detected by naked eye, or indirectly detected in cultivated plants.

Symptoms directly detected in soils:

- formation of crusts;
- fissures in tractor wheel treads;
- hardened zones below surface;
- puddles;
- excessive rain erosion;
- need of more power for cultivation machines; and
- occurrence of partially decomposed vegetative waster a long time after its incorporation.

In plants, the occurrence of soil compaction or dense layer problems can be determined by:

- low rate of plant emergence (germination);

- great variation of plant size;
- yellowish leaves;
- shallow root system; and
- twisted roots.

It is not difficult to recognize on site the soil compaction symptoms. Such signs appear both on the soil itself and in plants developing in that soil.

Plants suffer at developing in compacted soils, especially because of poor air and water circulation and physical difficulty of vertical root penetration.

4.6.4 – Recommendation to mitigate compaction effects

Good soil management aims not only to maintain a high soil fertility level by reducing erosion effects, but also to reduce compaction to the maximum extent, through the appropriate use of equipment and grazing rotation.

For an adequate use of soil aimed to reduce harmful compaction effects, the following actions should be adopted proactively:

- use tractors equipped with the largest wheel width;
- drive the tractor at the highest speed possible to reduce the time of soil compression;
- use well sized implements that do not require a great traction effort, thus allowing the use of smaller and lighter tractors;
- avoid transit across wet agricultural soils. Dry soils are more resistant to compaction;
- use deep subsoil tillage when dense soil layer exceeds 30 cm;
- use scarification practice when dense layer is less than 30-cm thick;
- in grazing areas, allow a good grazing rotation and controlled number

of animals per area unit;

- add organic matter to the soil or use the practice of dead cover with vegetal remains.

Photo 32- Scarifier for surface decompaction
Source: João Bosco de Oliveira

Photo 33 - Deep Soil Plough for Deep Decompaction
Source: Gastão Silveira

4.7 – Dead Cover

4.7.1 - General

Cultivation by revolving the soil to the minimum is a technique that has been used since the origin of civilization for food production. Soil was not revolved, having plants germinated among the dead cover resulting from decomposition of branches, leaves and other vegetation waste. In modern agriculture, this cultivation method started to be used to fight erosion and recover depleted and physically degraded soils.

The main principle of this method is maintaining crop remains on the soil, what create a protection layer on the surface – a dead cover.

Dead cover is undoubtedly essential for several reasons, among which the following stand out:

- contributes to soil moisture maintenance and prevents soil dryness by the sun;
- reduces surface temperature oscillations by providing an adequate thermal average for microbial life development;
- promotes the multiplication of micro, meso and macro through the decomposition of organic matter;
- protects the soil from rain action that causes disorganization;
- reduces weed competition.

4.7.2 – Purpose and applicability

Dead cover exerts a marking influence on physical, chemical and biological soil characteristics. Soil surface protected by mulch will not be hit by the direct impact of raindrops and consequent disaggregation. This will result in:

- reduction of surface sealing, where rain action in unprotected areas will disaggregate the particles that obstruct the pores;

- increased infiltration rates and consequent reduction of surface runoff.

Both quality and quantity of vegetation waste have influence on infiltration. Dense and thick dead cover promoted by vegetation waste provides the highest rates of water infiltration in the soil.

Effects on soil properties will depend on material used (residues, leaves, etc), quantity, material management and material composition (nutrients and Carbon/Nitrogen ration (C/N), and specific soil and climate conditions .

Table 7 – Chemical Composition of Some Residues Used as Dead Cover (Mulch), according to Kiehl, 1984.

MATERIAL (Vegetation Waste)	C/N RATIO (*)	N (%)	P_2O_5	K_2O
Guinea Grass	27.00	1.87	0.53	-
Elephant Grass	69.35	0.67	0.11	-
Corn Straw	112.00	0.48	0.35	1.64
Corn Cob	72.72	4.66	0.25	-
Rice Straw	53.24	0.77	0.34	-
Rice Shell	39.00	0.78	0.58	0.49
Sawdust	865.00	0.06	0.01	0.01
Bagasse	22.00	1.49	0.28	0.99
Carnaúba Straw	31.00	1.65	0.18	1.89

(*) C/N – Carbon/Nitrogen Ratio
Source: Keihl (1985).

Occurrence of layers compacted by disc harrow and moldboard plough may practically annul the effect of dead cover in relation to water infiltration in the soil, that is, mulch alone will not be sufficient to increase the water infiltration rates.

Mulch has a high soil moisture maintenance capacity, by reducing losses from evaporation, including that caused by winds in uncovered areas.

Very high or very low soil temperature (thermal oscillation) causes serious damages to crop development. A way to avoid that problem is using dead vegetation cover. Using that material, there will be no temperature increase in tillable layer due to low exposure and consequent reduction of rate of decomposition of soil organic matter.

This aspect is important due to marking effects of soil temperature on biological activity, seed germination, root development and ion absorption.

Photo 34 – Dead Cover (Mulch) in Beans Plantation
Source: R. Derpseh.

Photo 35 – Dead Cover (Mulch) in Vegetable Plantation
Source: João Bosco de Oliveira.

Dead cover affects nutrient availability either for physical soil changes, as water balance in soil, or soil residue decomposition, where stationary nutrients will be gradually mineralized and put at plant disposal. This decomposition time will depend on climate conditions, soil and material C/N ratio. Surface waste decomposes more slowly than when it is incorporated by soil preparation. This way, recycled nutrients, in case of plants used as dead cover, will be placed on soil surface for further use by crops.

Therefore, a soil protected by mulch will obtain greater water storage, greater control of invasive plants, in addition to preserving the soil and increasing crop production. It is therefore a critical practice to be considered in most soil management systems in semiarid regions.

4.8 – Cultivation in Contour Rows – Dry Farming System

4.8.1 - General

Cultivation in contour lines, also known as dry-farming, is a set of practices aimed at water saving in areas where water balance is decisive for successful agricultural activities.

A major principle of dry farming – according to Pimentel Gomes (1945) – is to make water penetration in soil easier, by reducing waster percentage lost in surface runoff and taking the best advantage of precipitation.

Under the conditions of our semiarid regions, where almost always the runoff percentage is high, only the application of that principle will bring very favorable results for agriculture. Pimentel Gomes (1945) also says that “reducing the percentage of evaporated water and using infiltrated water constitute the basin principles of dry farming.”

The researcher Sternberg (1951) advocates this process for Northeastern agriculture, by saying that: “Without intending in any way to exclude or disregard hydraulic and reforestation solutions, we should like to highlight a third solution for the best use of rainwater, which, although its efficiency has been acknowledged, has been neglected among us. However, it is in our opinion the focus of any program aimed to prevent drought effects and value the semiarid region. We refer to the set of farming practices that can be assigned the tile of conversational agriculture, the objective of which is soil and water conservation."

4.8.2 – Experience in other Semiarid Regions

In USA, American researchers Burnett & Fisher (1954) after having worked with cotton crops for a period of 25 years, at Spur Research Station in Texas, concluded that there is a positive correlation between soil moisture and cotton production.

Those same authors, upon analyzing experiments made over a period of 25 years, concluded that cotton cultivation in contour rows increases production by some 60%, as compared to conventional cultivation.

Retaining contour rows are also used in dry regions in Portugal and Spain according to Mela Mela (1966), with is differentiated from the American process by the use of a small dike between rows (Figure 57) to allow a greater uniformity in infiltration of accumulated water.

In India, precisely in Dry Farming Research Station in Sharlapur, a dry farming process known as Maharashtra was established, which is able to increase "rabi" productivity by some two and a half times as compared to traditional farming process (DONAHUE, 1962).

In Northeast Brazil, in the 1940-1950 period, researchers Pimentel Gomes and Guimarães Duque, among others, advocated and gave the first steps toward the application of dry farming processes and methods.

4.8.3 – Methods already adopted in Northeastern Brazil

In 1973, Instituto Nordestino de Fomento ao Algodão e Oleaginosa (INFAOL), based on previous experiments, started to adopt dry farming method, which provided that greater oil moisture infiltration by retaining rows and evaporation minimization by native vegetation windbreaks. INFAOL used preferably Guimarães Duque method.

- GUIMARÃES DUQUE METHOD

This method consists of making "contour rows" in area that is to be conserved, according to the spacing intended crops, associated with a windbreak system using the native vegetation existing before deforestation. Rows may be opened by disc harrows or three-line ploughs.

Purpose of rows is to make water infiltrate in the soil, what means water saving. This quicker water infiltration in a greater soil surface will result in extended moisture for crops.

For argillaceous soils, contour row implantation may be preceded of scarification or subsoil tillage, depending of depth of dense layer.

This method may be associated with terrace or contour stone barrier systems to provide a greater control of water erosion.

Crop cultivation may be made on the edge of constructed rows at a regular spacing between plants downstream to said row (Figure 58).

- ON SITE CATCHMENT METHOD [2](*)

On site rainwater catchment system consists of changing the soil surface in such a way that the soil between cultivation rows will serve as catchment area. This area has an inclination that will increase runoff while directing runoff to the soil portion explored by the root crop system. Figure 59 shows an illustration of that system.

CPATSA has technically and economically evaluated the following on-site rainwater catchment techniques:

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2 - (*) Technical recommendations from the Center for Farming Survey Tropical Semiarid Regions – CPATSA/Embrapa

- Tc_1 – grooves and ridges (ICRISAT-INDIA)
- Tc_2 – modified grooves (CP-MÉXICO)
- Tc_3 – modified grooves (Guimarães Duque-Brazil)

Soil moisture retention capacity is a factor extremely important for the success of that technology, as it is no use to produce excess water when it is not absorbed by the soil. Therefore, soil texture, structure and porosity, as well as root system depth are characteristics indispensable to planning that system.

On the other hand, some products may be added to the area explored by the root system, such as green fertilizer, manure, crop waste, compost and vermiculite, with the objective of improving the soil moisture retention capacity.

CPATSA has developed a simple animal-traction equipment to prepare the soil for on-site rainwater catchment. It should be pointed out that such modified grooves and ridges are made in contour with the minimum declivity possible.

Embrapa (1982 apud SHAANAN et al., 1979) and Embrapa (1982 apud Evenari et al., 1974) consider on-site catchment the most feasible of surface runoff exploration systems for the following reasons:

1. surface runoff production per are unit is inversely proportional to the size of the area. Under Negev desert conditions, on-site catchment can produce 10 to 30 times more runoff per area unit than hydrographic basins of several hectares; and
2. it does not require an intensive engineering planning and its construction does not require heavy equipment.

Anaya et al. (1976) developed a formula to calculate the spacing between rows for in-site rainwater catchment, as follows:

$$Ac = Es + \frac{1}{C}(\frac{Uc - P}{P} xEs)$$

Ac = Spacing between catchment rows

Es = Spacing traditionally used by producers

C = Runoff coefficient

Uc = Consumptive use of crops during the cycle (mm)

P = Precipitation during the crop cycle, at 50% probability (mm)

SAES-CV system with on-site rainwater catchment

On-site rainwater catchment may contribute greatly to reduce the number of life-saving irrigations by SAES system, as there is a greater availability of water for plants. Cultivation area (Ap) in SAES system is prepared in grooves and ridges using the CPATSA multicrop. Ridges have a 1.20-m wide plain surface and are laterally limited by 0.20-m deep and 0.30-m wide grooves, where spacing between grooves is 1.50 m, the objective of which is the application of water to food crops during life-saving irrigation. (EMBRAPA, 1982 apud ARAGÃO, 1980). Integrated crops, according to Embrapa (1982 apud SANTOS et al., 1981), should be arranged in such a way that the same crops are placed on the edges of the same groove, as shown in Figure 61. Groove system modified for on-site rainwater catchment consists of equally spaced grooves, where between two consecutive grooves there are two sloped plans, the first of which if formed by the edge of the actual groove, at a height of 0.20 to 0.30 m, and the second, which is longer, links the higher portion of the first plane to the bottom of the second groove. In this system, there some basic elements, as follows: the most external plane that serves as catchment area, the smaller plane that serves as cultivation area, and the actual grooves that serve as storage area. Therefore, as in this system there is only possible to implant just one row of plants per groove, the cultivation density should be modified and/or the cultivation area should be increased, as there is a greater availability of irrigation water.

Association of SAES-CV system with on-site catchment is extremely important for low precipitation regions.

Photo 36 – Soil Preparation for Dry Farming System
Source: Francisco Holanda

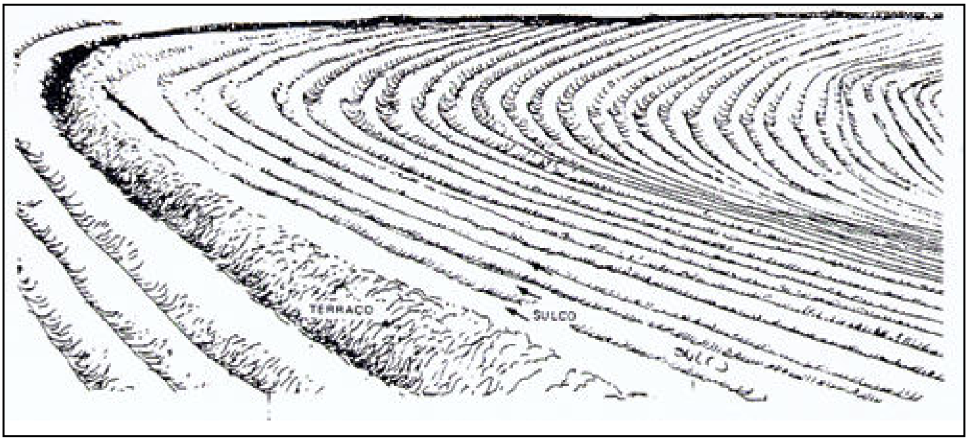

Figure 58 – Soil Preparation Arrangement for Dry Farming System
Source: Embrater.

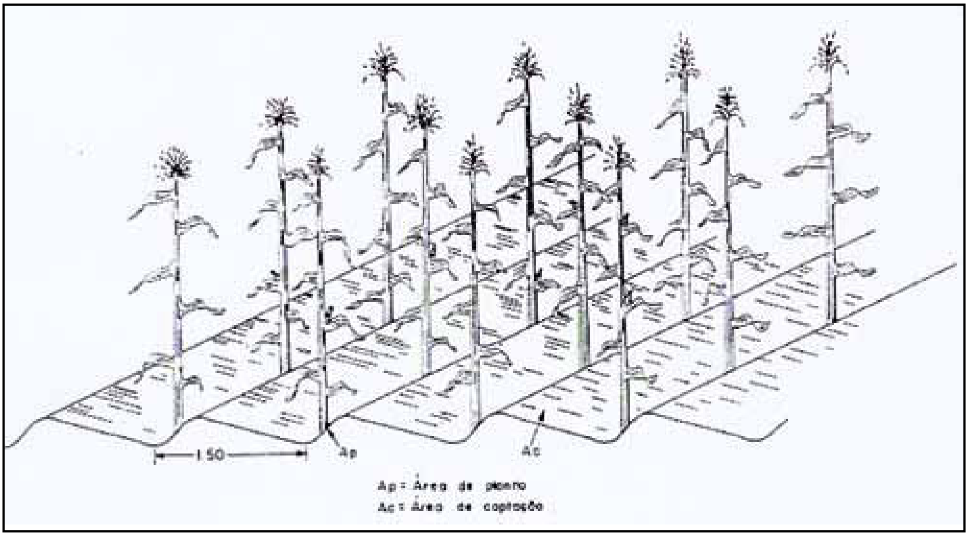

Figure 59 – Design of on-site Rainwater Catchment System
Source: CPTSA / Embrapa.

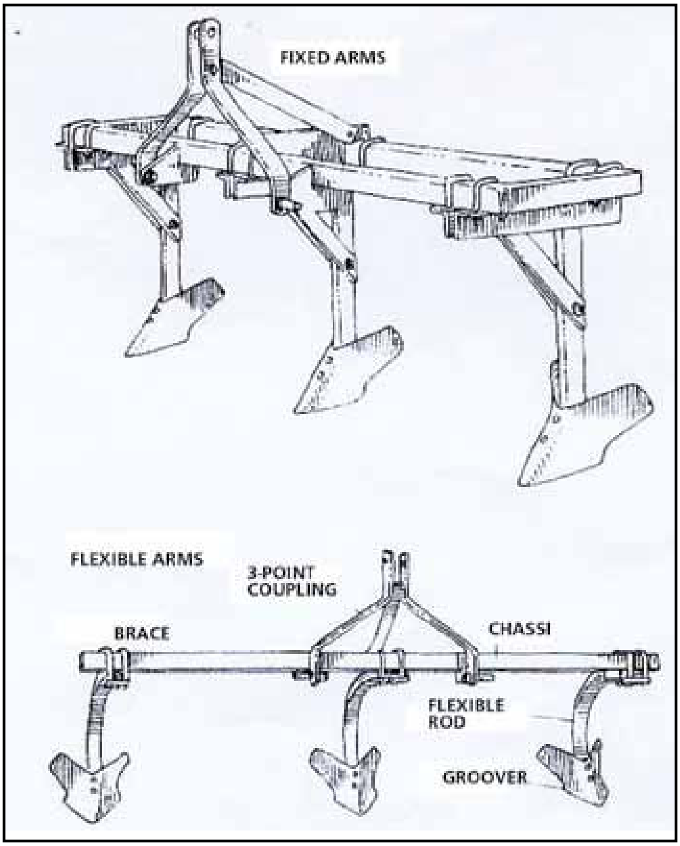

Figure 60 – Equipment Used in Dry Farming System
Source: Gastão Silveira.

4.9 – Organic Matter: Manure and Compost

4.9.1 - Manure

Manure is derived from animal excrements and urine mixed with straw, crop remains or other material used as bed.

Many centuries before the agricultural science was established, farmers already used manure to fertilize their soils. The importance of that fertilizer was so widely known that farmers raised cattle exclusively for manure production. Without any other use, animals in agricultural properties were considered a “necessary evil”.

4.9.1.1 – Chemical manure composition

Chemical manure composition is quite varied. Main determining factors include:

- animal species;
- animal age;
- food;
- regime; and
- nature of material used in beds.

a) **Variation according to animal species**. Excrements of horses and sheep contain less water that those of bovines and swine. They are, therefore, too consistent and permeable to the air, ferment at a pronounced increase of temperature and are of difficult conservation, being therefore know as hot excrements.

Table 8 shows the average composition of solid and liquid excrements of several animals.

Manure of bovines and swine is aqueous and has difficult fermentation.

As such, it preserves better its nutrients. It is called cold excrements.

Table 8 – Percentage of Composition of Animal Solid and Liquid Excrements

COMPONENTS	EQUINES		BOVINES		SHEEP		SWINE	
	SOLID	LIQUID	SOLID	LIQUID	SOLID	LIQUID	SOLID	LIQUID
Water	75.0	90.0	83.2	93.0	65.5	87.0	81	97
Organic matter	21.0	7.0	14.0	3.2	31.4	8.0	12	21
Ashes	3.2	3.0	2.0	3.0	3.1	4.5	4	1.2
Nitrogen	0.44	1.5	0.3	0.6	0.6	1.9	0.6	0.4
Phosphor	0.35	0.9	0.17	-	0.3	-	0.3	0.1
Potassium	0.15	1.6	0.1	1.3	0.15	2.3	0.3	0.8
Calcium	0.14	0.45	0.1	0.1	-	-	-	-

Source: Kiehl (1985).

Quantity of excrements produced by animals on a daily basis varies according to the age, food, etc. Table 9 shows the daily quantities of solid and liquid excrements produced by different animals for every 1,000 kg of live weight.

Table 9 – Excrements Produced by 1,000 of Live Weight in Kg/Day

ANIMAL	SOLID	LIQUID	TOTAL
Cow	25	10	35
Horse	20	5	25
Swine	24	17	41
Sheep	11	6	17
Fowls	-	-	12

Source: Kiehl (1985)

b) **Variation according to regime**. Animals under fattening regime in stables or semi-stables produce manure that is richer in nutrients that those under working regime; in the latter case, manure is poor because animals waste their energy to complement force production.

c) **Variation according to bed nature.** Material used in animal beds is generally made constituted of leaves, grasses, crop remains, sawdust, vegetal soil, etc. Absorbing property of those materials and their easy decomposition greatly influences the properties of manure produced.

The greater the absorbing power or bed material, the greater is its fertilizing value. The easier its decomposition, the richer the manure obtained, because it waste less energy in this process.

d) **Variation based on animal age.** Animals, at different ages, do not produce excrements of constant composition. When very young, their digestive capacity is greater than when they are adult or old. Young animals extract from excrements a greater quantity of nutrients, especially phosphor, used in the construction of their skeleton, and nitrogen for muscle building. Under such conditions, animals produce excrements of lower fertilizing value. Average composition in growing and adult bovines is as follows:

Table 10 – Percentage of Nutrients in Manures, according to the Animal Age

PERCENTAGE OF NUTRIENTS			
	NITROGEN	PHOSPHOR	POTASSIUM
Young animal	0.41	0.13	0.54
Adult animal	0.98	0.44	0.65

Source: Kiehl (1985).

e) **Variation based on food.** The more abundant and rich is the food consumed by animals, the greater is the fertilizing value of their manure. Thus, leguminous and oleaginous plants provide manure richer in nitrogen and phosphor than grasses (maize, cereal straw, and grass in general). Tuberous plants, such as potato and manioc, provide manure richer in potassium. Table 11 shows data from an experiment involving 550-kg milking cows that produce 6 liters of milk per day and are submitted to two treatments, one comprising 12 kg of hay and 12 liters pf water, and the other 70 kg of beetroot.

Table 11 – Influence of Food on Cow Excrement Composition

<table>
<tr><th colspan="7">NUTRIENTS IN KILOGRAMS</th></tr>
<tr><th>RATION</th><th>EXCREMENT</th><th>NITROGEN</th><th>PHOSPHOR</th><th>POTASSIUM</th><th>WATER KG</th><th>QTY. Kg</th></tr>
<tr><td rowspan="2">70 Kg of beetroot</td><td>Solid</td><td>0.33</td><td>0.24</td><td>0.14</td><td>83.0</td><td>19.0</td></tr>
<tr><td>Liquid</td><td>0.12</td><td>0.01</td><td>0.59</td><td>97.4</td><td>40.0</td></tr>
<tr><td rowspan="2">12 Kg of iron and 12 liters of water</td><td>Solid</td><td>0.34</td><td>0.16</td><td>0.23</td><td>79.7</td><td>22.0</td></tr>
<tr><td>Liquid</td><td>1.54</td><td>-</td><td>1.69</td><td>92.6</td><td>6.2</td></tr>
</table>

Source: Kiehl (1985).

4.9.1.2 – Quantity of animal excrements

Quantity of excrements produced every year will vary according to the animal type, age and food regime.

Average quantities for several animals are:

Table 12 – Quantity of Excrements Produced on an Annual Basis, according to Animal Characteristics

ANIMAL	QUANTITY KG	VOLUME m3 (500 kg of manure)
Fattening ox (600 kg)	25,300	42.8
Confined cow (400 kg)	11,400	19.3
Horse (500 kg)	12,200	17.3
Work ox (600 kg)	9,400	15.9
Hog (100 kg)	1,100	1.8
Sheep (40 kg)	550	0.9

Source: Kiehl (1985).

Some of criteria most adopted to calculate the quantity of excrements produced every year by animals include:

- Certain technicians establish a daily production of 7 kg of manure for every 100 kg of animal live weight. So, a 400-kg cow will produce everyday 28 kg of excrements, or 10,200 kg per year.

- Another criterion is to consider the quantities of excrement produced annually by animals as some 25 times their respective weight. This way, the same cow in the example above will produce 10,000 kg per year;

- Quantity of excrements produced every day may be obtained by multiplying the sum of weight of food without water plus bed by two. This way, a horse consuming every day 13 of hay, whose bed is composed of 3 kg of straw, will produce every day:

(13 + 3) x 2 = 32 kg of excrement, or 11,680 kg per year.

- Weight of fodder is added to the weight of bed, calculated at dry state, and the result is multiplied by the following coefficients:

Work horse	1.3
Work ox	1.5
Milking cow	2.3
Adult hog	2.5
Sheep	1.2

Result is obtained in kg of excrements produced on a daily basis.

Half of dry matter of food is added to ¼ of dry matter of bed and the result is multiplied by indexes related to the animal type. Formulas are:

Bovinos $$(\frac{M.S.}{2}+\frac{M.S.}{4})x4$$

Equinos e ovinos $$(\frac{M.S.}{2}+\frac{M.S.}{4})x3$$

Suínos $$(\frac{M.S.}{2}+\frac{M.S.}{2})x3{,}7$$

Example: Suppose that a cow weighs 500 kg, is given a ration containing 1.5 kg off dry matter, and has a grass bed with a dry weight of 932 g (dry matter). By applying the formula, we have:

$$(\frac{M.S.}{2}+\frac{M.S.}{4})x4=(\frac{12{,}5}{2}+\frac{0{,}932}{4})x4$$

= 25.932 kg of manure, that is, 9,465 kg per year.

Weight of one cubic meter of manure may be calculated by the following means:

Fresh manure	500 kg
Too hardened manure	800 kg

4.9.1.3 – Manure heap

Manure heap is the manure deposit or the place where it will undergo changes until reaching the point when it should be incorporated to the soil.

Notwithstanding the care given to manure, it is always subject to nutrient loss, especially nitrogen that, because of its transformation from organic to ammoniac form, is partially lost to the atmosphere in the form of ammonia gas (NH_3).

Such losses, however, may be greatly reduced or even eliminated if the farmer shall pay attention to manure during its fermentation, that is, its decomposition by certain microorganisms.

a) **Manure deposit construction** – Manure deposit should be preferably covered to prevent head and rains from impairing the decomposition process and producing loss of nutrients. Its base should have an inclination of more or less 2% and be provided with a 5 X 10cm furrow in the lower portion, directly connected to a 2m deep well with a diameter of 1.5 - 2m to allow easy flow of liquids soaking the manure. Such liquids are very rich in phosphor and potassium. A 1m high wall should surround the base to support the first layers of manure. Both the base and well should be waterproofed by cement mass and a bitumen layer.

To prevent rainwater access, the construction of a channel around the manure deposit is recommended. Channel dimensions will depend on volume of manure produced in the year.

Calculation:

$$S = \frac{Pt}{PdxA}$$

where S = manure deposit surface area in square meters, Pt = total weight of manure to be stored, Pd = weight of one cubic meter of manure; and A = mass height, which should not exceed 3 meters.

Example: Suppose that an agricultural property has 10 cows, each one weighing in average 500 kg, one 800-kg breeding bull, and 20 sheep, each of them weighing in average 30 kg.

The quantity of manure produced annually by such animals, by applying criterion 2, where annual manure quantity is equivalent to 25 times the animal weight, will be:

10 cows	500 x 10 x 25 = 125,000
1 bull	800 x 1 x 25 = 20,000
20 sheep	30 x 20 x 25 = 15,000
TOTAL	**160,000 kg**

Taking into account the manure status, that is, semi-hardened, weighing some 700 km/m3 and mass height of 2.50 m, we will have:

$$S = \frac{Pt}{PdxA} = \frac{160.000}{700x2,5} = 91,4$$ m^2 = surface area of manure deposit

b) **Manure preparation** – Starting in the stable, manure undergoes several chemical reactions influenced by abundance of dejects, temperature and quantity and quality of material composing the beds.

In manure mass an aerobic fermentation occurs, that is, a fermentation that requires aeration, which takes place in the upper layers and generates temperatures sometimes as high as 70 - 80 degrees Celsius (°C). This fermentation will result in the formation of carbon gas (CO_2) and ammonia gas (NH3), which are essentially volatile substances that are released to the atmosphere when they do not remain in manure mass.

In lower layers, where there is no oxygen (aeration), anaerobic fermentation takes place that, different from the above, is processed in the absence of air. In such layers, temperature is around 25 to 35°C, where there is a small formation of ammonia gas (NH_3). This is the useful manure fermentation, because it puts it in conditions to be incorporated to the soil without great loss of nitrogen, what makes it a rich and efficient product. Two main precautions will allow such conditions to be obtained:

1. regularization of fermentation to reduce losses of gaseous nitrogen to the minimum; and

2. use of substances that absorb this gas and retain it in the manure mass.

Mass compression and its irrigation are the processes used to obtain those conditions.

After collected from sheds and stables, excrements should be immediately heaped in manure deposit, which should be compressed and at all times irrigated with the own liquid in the well. By acting that way, fermentation will occur regularly and put manure in the state of full decomposition.

Mass compression should not be very strong or very weak, but moderate. By compressing manure strongly, fermentation will be very fast and vigorous, thus increasing nitrogen losses; on the other hand, by compressing it weakly, fermentation will occur slowly and hardening is not perfect.

Irrigation, which facilitates and established fermentation regularity, should take place whenever necessary to maintain the mass always humid, but not soaked.

Lack of irrigation will make manure dry up, resulting in losses of nitrogen for volatilization and promoting the proliferation of fungi that also consume gaseous nitrogen.

Manure irrigation has the following advantages:

- provides conditions for combination of carbon gas with ammonia to form ammonium carbonate, which dissolves in the actual liquid and is evenly distributed over the whole mass;

- makes compression easier, which is so necessary for a good manure fermentation process; and
- maintains the temperature in upper heap layer constant, thus controlling aerobic fermentation.

When the manure deposit has no attached well, ordinary water may be used for irrigation.

Heap height should not exceed two meters.

Liquids from manure deposit that are collected in the well (nitre bed) ferment easily and quickly, and releases gaseous nitrogen to the atmosphere. To reduce nitrogen losses, the farmer may provide the well with a wooden cover to prevent the contact between internal and external atmosphere.

Some authors also recommend the use of substances that impede nitrogen volatilization. These include sulfuric and chloridic acids mixed at equal proportions and diluted with water. To each liter of mix of such acids, 10 liters of water should be added. At dilution, care should be taken to add water to acids in small portions, as, at making contact, mix temperature increases. Therefore, acids should never be added to water.

Once in a while, that mix should be poured into the well. When a pump is used to remove liquid (purine) this is not advisable.

Likewise, adding gypsum or simple superphosphate to manure mass in the proportion of 50 kg per ton of material is recommended. The following reaction occurs:

$$2CaSO_4 + Ca(H_2PO_4)_2 + 2(NH_4)_2CO_3 = Ca_3(PO_4)_2 + 2(NH_4)_2S0_4 + 2H_2O + CO_2$$

This way, nitrogen becomes stable and not subject to losses mentioned above.

Krantz Process – A German agronomist, Krantz, showed that nitrogen transformation into the form it is lost is the result of the work of several microorganisms that to not resist to high temperatures exceeding 60ºC.

Based on that fact, Krantz proposed the following process:

- manure is heaped uncompressed in the manure deposit, in layers;
- after two days, microbial fermentations increase mass temperature to above 60ºC. At that temperature, aerobic microorganisms die and fermentation of upper layers stops. The mass is strongly and daily compressed for more or less three days without irrigation. By compression, air is expelled and the remaining aerobic microorganisms die from the lack of aeration; and
- a new manure layer is placed on the first layer and the same procedure indicated above is followed.

New layers are deposit on the heap like the first layer. When the mass is 2.5 – 3.0 high and is well compressed, it is covered by stable earth.

Experiments made in Europe showed the supremacy of this process over the others, by producing high quality manure able to promote higher agricultural yields.

After two-three months fermentation ends and manure is well hardened, ready to be incorporated to the soil. Its hardening is easily recognized by its dark color and homogeneity and consistent of its mass that becomes pasty.

4.9.1.4. Manure application

Upon unloading manure from deposit for application, because the several layers do not have the same hardening level, it is advisable to cut the mass in 50 to 80-cm thick vertical sections. The chemical composition of such layers is quite variable, as can be seen in data below:

Table 13 – Chemical Composition of Manure per Layer

	MANURE COMPOSITION IN LAYERS		
	LOWER	INTERMEDIATE	UPPER
Water	75.9	79.3	75.8
Nitrogen (N)	0.58	0.63	0.56
Phosphor (P2 O5)	0.37	0.54	0.46
Potassium (K2O)	0.59	0.71	0.77
Calcium (CaO)	0.40	0.63	0.69
Magnesium (MgO)	0.17	0.15	0.15

Source: Kiehl (1985).

Manure quantity to be applied per hectare is quite variable. Some factors that determine that quantity are: crop, type of soil, and content of soil organic matter. In general, according to the quantity applied, manuring may be classified as:

	kg/ha
Strong manuring	60.000
Regular manuring	40.000
Weak manuring	20.000

In practice, manure can be placed in 7-m spaced heaps. Quantity in each heap is calculated as follows:

Suppose that quantity to be applied is 40,000 kg/ha. Area occupied by each heap is: 7 X 7 = 49 square meters. One hectare, or 10,000 m2, will have 10,000 ÷ 49 = 204 heaps. By dividing 40,000 kg of manure by 204 heaps, each heap will have 191 kg or approximately 240 liters of manure.

Once spread out on soil surface, manure should be immediately incorporated by plough to reduce the loss of its properties to the minimum. Its application, when well hardened, should be made one month before cultivation. If it is half hardened, it should be applied two months before cultivation.

When crop spacing is great, it can be applied on in cultivation furrow and well mixed with earth to save manure.

For perennial crops, manure should be applied around the plants in strips and then incorporated. Another method is to incorporate the manure in 15-20-cm deep holes, covering ¼ of plant. In this case, the following application would be in a different place so that, after four applications, the whole area surrounding the plant is covered by manure. When soil has a great declivity, manure can be applied only on the upper portion for better utilization.

About its beneficial effects, we highlighted in several chapters the importance of organic matter. In addition, 10 tons of manure per hectare give the soil the following average nutrient quantities:

60 kg of nitrogen (N)

50 kg of phosphor (P2O5)

70 kg of potassium (K2O)

60 kg of calcium (CaO)

15 kg of magnesium (MgO)

Chicken manure. This is the richest manure, but its price is high. Its average composition is 2% N, 2% P2O5 and 1% K2O.

4.9.2 - Compost

Compost is a mixture of waste or residues of organic matte of any kind with mineral material such as ashes, which is used as organic fertilizer. Thus, it includes ashes of every kind, fallen leaves, cleared wood, tank mud, rubbish, kitchen waste, maize and coffee straw, bones, blood, sawdust, animal remains etc.

Compost importance to improve soil productivity has been recognized by many generations. Compost application to the soil is known to improve its physical conditions, including its water storage capacity and the supply of great quantities of nutrients for plants.

4.9.2.1 – Inoculating material

Compost production and manure production require the addition of a producer of microorganisms responsible for material decomposition. Several inoculating materials are used for compost production, among which the following stand out:

a) **Inoculating mixture.** In the literature, we find the following mixture recommended for compost preparation:

25-30 liters of fresh animal excrements;

30-36 liters of excrements at fermentation stage;

5-6 liters of wood ashes; and

5-6 liters of stable urinous earth.

b) **Fresh excrement.** This is widely used as a source of microorganisms for material decomposition at compost preparation;

c) **Artificial inoculants.** This is a bacterial leave containing a diversified bacterial flora able to promote material fermentation. Inoculants are found in concentrated form, and their use consists of their dilution in water and application in material to be fermented. In the Brazilian market, one of them is found under the name of "humus solo", but its efficiency is unknown.

4.9.2.2 – Compost preparation

Location for compost preparation may be same as for manure preparation. Process consists of:

- spreading the mixed, accommodated material (straw, leaf, grass, ashes, etc.) by treading on it without compressing it to create an approximately 25-cm thick layer;
- wetting it in such a way that the lower portion becomes moistened without any excess of water flowing on the ground;

- spreading on that material a 4-finger thick fresh excrement layer. If it is a little dry, it should be watered until water reaches the lower manure layer portion; and
- spreading a new material layer by repeating the initial operations, and then successively until the heap reaches the maximum height of 2 meters. The last layer should be constituted of remains of compost preparation.

Irrigation. Heap irrigation is an important factor for a successful compost preparation. Abundant water, non-excessive water is necessary, that is, heap material should be kept humid, rather than soaked. A practical process to determine whether material should be wet or is at a good moisture state consists of taking a small sample of several parts of heap and squeeze it in the hand; if moisture is sufficient, water will appear between fingers, otherwise the heap is dry. In general, doing this two times a week is sufficient.

Ventilation. Microorganisms, as mentioned above, need air to perform their job. As such, heap material should not be compressed. Further, every 4-5 weeks it should be turned around to allow air for microorganisms. In addition, turning it around makes the mass at fermentation stage uniform.

Turning around consists of disarranging the heap to allow material existing in the upper part of heap to mix with material existing in the middle and lower part of heap, thus making all material uniform.

Temperature. As it is known, whenever material used for compost preparation is gathered together into a heap, heap gets hot. Its heating is an indication that microorganisms are working.

When heap temperature is high, 50 - 60ºC, all care should be taken to avoid lack of water. If the temperature reaches 70 - 75ºC, it is advisable to press the heap a little to reduce heating.

Heap temperature may be measured twice a week by a thermometer graduated from 0ºC to 100ºC, adapted to a ¼" pipe. A metallic pointer is adapted to the pipe end where thermometer bulb is attached. Temperature should be measured in three different points of heap.

When a thermometer is not available, an iron pipe should be inserted in the heap and, after 5-10 minutes, it should be quickly removed and held with the hand by the heated portion. Kin the pipe heat is insupportable, temperature is probably close to 70º C; otherwise, if the heat is supportable, temperature is below 70º C.

Temperature will start to rise in the third day, will remain high for more or less 10 days, and then will drop slowly. After each turnaround, material restarts to heat. At the end of fermentation, heap is expected to be cold.

After three to four months of fermentation, compost is in conditions to be applied to the soil.

4.9.2.3 – Compost composition

Given the diversity of material used for its preparation, compost composition if quite variable. Analyses of a compost disclosed the following nutrient content:

Nitrogen (N)	0.82%
Phosphor (P2O5)	2.20%
Potassium (K2O)	0.13%

Application – Compost application is similar to that of manure, and therefore may follow the same procedures.

4.10 – Pasture management

Pasture is an important component of soil preservation, as by providing a good cover, it prevents soil disaggregation and reduces erosion risks. However, to be completed as an option for soil occupation, pasture should be managed to minimize surface water runoff, a factor that is decisive to aggravate soil erosion.

Physical pasture management should be considered as a series of procedures aimed to ensure conditions to allow herds to use the available forage resources. On one side, it allows hers to be divided per categories, by establishing differentiated animal management conditions; on the other side, it allows forage management to be adjusted, by observing its physiological characteristics and allowing a better control of time of use and rest of pasture, its utilization uniformity and intensity, as well as separation of different species. For that, a set of facilities to allow its achievement, such as fences, sheds, corridors, watering places, salt places and feeding places, etc. are required.

Land division implanted in the State, soil characteristics and the way how properties have been colonized, led pasture exploration to a model that does not allow an adequate pasture management program. Land division into few relatively-large pastures predominates, where water is available from natural slopes at the back of pastures.

In that system, cattle if forced to walk every day to slopes, what brings negative effects on pasture exploration and animal performance, in addition to promote the opening of grooves tat cross terraces, canalize water and end by creating gullies.

Any attempt aimed to reestablish adequate pasture management procedures should include the isolation of natural water sources and water disposition in the highest parts or property to allow its distribution as an important management component.

4.10.1 – Number and size of pastures

Number of pastures in a particular property will depend on rest period (PD) in days and the occupation period (PO) that can be obtained by the following equation:

$$\text{Number of pastures} = \frac{PD}{PO} + 1$$

Example: For a particular category of cattle, such as fattening oxen, for which a rest of 42 days and an occupation of 7 days are intended, number of pastures should be:

$$N = \frac{42}{7} + 1 = 7$$

Total number of pastures in the property should be the sum of pastures intended for each cattle category.

Pasture size will depend on the available area divided by the number pf pastures.

Number and consequently the size of pastures are important to allow their better utilization. Relatively large pastures, in addition to cause both overgrazing and undergrazing zones, end by allowing the cattle flow toward slopes, thus resulting in lower water retention in the soil.

4.10.2 – Form and disposition of pasture

Pasture should be preferably rectangular, the largest axis of which should be perpendicular to slope, to allow animals to walk on level ground and therefore protect terraces and prevent water canalization. For soft topography properties, square pastures may be used, provided that pastures are not excessively large.

Photo 37 – Pasture Management in a Revolving System (Voisin)
Source: www.ircolac.com/Irco/FOTOS%20IRCO-VOISIN.htm

Photo 38 – Pasture Management in a Revolving System (Voisin)
Source: www.e-fazendas.com.br/site2/detalhe.asp?refer...

4.10.3 – Location and protection of corridors

Corridors are important for animal flow between pastures and to stables, but they generally cause or aggravate erosion. They are typically disposed parallel to the slope, continuous, narrow, naked and free of retained water. For their best use as a management component, they should be leveled or discontinuous and partially leveled. They should be vegetated, preferably by creeping grasses that are aggressive and tolerant to intensive treading, such as running carpet grass, Brachiaria humidicola, or African star grass. When vegetated by pasture, corridors should be wider to avoid reducing the pasture area. They should also be provided with dikes to retain water, which should be linked to terraces, if any.

4.10.4 – Distribution of salt and watering places

Such structures are very important for pasture management, as they are daily visited. As such, they should be arranged to allow the continuous flow of cattle to establish for a good use of pastures and walking on flat surfaces to the extent possible. So, each of them may be at a leveled end, and their allocation to pasture corners should be avoided.

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