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Oasification: a forest solution to many problems of desertification

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Abstract

Desertification is a widespread process worldwide, particularly acute on deforested sloping lands under arid, semiarid or dry sub-humid conditions. To counteract this environmental threat, we have opted for an approach promoting the opposite process, which has been termed *oasification*. It entails the building of small earth structures to collect and infiltrate as much precipitation and runoff as possible by modifying a slope's physiography in a convenient and non-aggressive manner. As a result, better soil moisture conditions will prevail and the chances of the establishment and growth of woody vegetation will be markedly improved, thus redressing the dangerous process of desertification.

Since ancient times, many water harvesting strategies (microcatchments, ridging, terracing, etc.) have been successfully employed to check, collect and infiltrate surface runoff in those regions of the world where precipitation is scarce. All these structures can be currently designed according to enlightened hydrologic criteria based on sound knowledge of water economy, water requirements, soil erosion, building costs and landscape impacts. These criteria should help land managers and technicians in deciding the appropriate planting densities and micropond sizes that will yield the best seedling survival rates with minimal disturbance to the original physiography of the slope.

Key words: *Oasification*, desertification, water harvesting, soil harvesting, microcatchments, reforestation of arid and semiarid zones.

Resumen

Oasification: **la solución forestal a muchos problemas de desertificación**

La desertificación es un proceso muy frecuente en laderas deforestadas bajo clima árido, semiárido o seco subhúmedo. Frente a este problema se apuesta por el proceso contrario, es decir, la oasificación. Se trata de dotar a la ladera de unas pequeñas estructuras de tierra que recojan e infiltren la escorrentía, modificando levemente su fisiografía. De esta forma se consigue mejorar las condiciones de humedad del suelo y se posibilita el desarrollo de una vegetación forestal, invirtiéndose el temido proceso de desertificación.

Las estructuras que consiguen frenar, captar e infiltrar la escorrentía (por ejemplo: microcuencas, aterrazados o acaballonados), y que actúan como trampas de suelo y nutrientes a su vez, deben diseñarse con unos criterios adecuados y basados en la economía del agua, para evitar impactos ambientales excesivos y el incremento innecesario de los costes de ejecución. Estos criterios sirven para orientar al técnico encargado de la restauración sobre el tamaño de los alcorques a realizar, con vistas a aumentar la supervivencia del repoblado reduciendo la alteración del microrrelieve a lo mínimo indispensable.

Palabras clave: *Oasificación,* desertización, cosechas de agua, recolección de suelo, microcuencas, reforestación de zonas áridas y semiáridas.

Introduction

Sustained arid conditions will eventually trigger the development of desertification processes which, in turn, will steadily degrade the overall environmental status of the affected area. Desertification may be defined as a complex process whereby natural resources are limited in their productivity and value by prevailing arid, semiarid and subhumid climatic conditions as a result of climatic change or adverse human activity (UNCCD, 1994).

Martínez de Azagra (2000) has coined the neologism *oasification* to be used as an antonym of desertification by soil erosion. The aim of this process is to develop a

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thriving dense woody plant cover, in other words, to redress the hydrological, edaphic and botanical degradation affecting a slope; this is done through appropriate soil preparation and through the introduction of suitable plant species. To be successful, adequate water harvesting systems must be in place; the degradation process of the slope itself should be taken advantage of and runoff water be collected in suitably sized microponds around the microsites intended to be afforested.

The term *oasification* is closely related to concepts such as water harvesting and runoff farming but, of the multiple threads of meaning these terms share, we should underline as more relevant here those referring to ecological rather than to agricultural applications. In *oasification*, soil and nutrient harvesting are regarded as fundamental component parts in the reclamation process of a degraded slope. Besides harvesting water, *oasification* preserves and accumulates soil and nutrients helping thus control water erosion so common in arid zones. As a matter of fact, under many different situations all over the world, soil and water conservation should be considered as synonyms. Words to this effect have been expressed by Ludwig *et al*. (1997) when they reported about sloping areas under semiarid conditions in Australia where the landscape is naturally divided into source and sink zones (run-off and run-on areas) which are quickly reclaimed by plant species through the retention of water, soil and litter.

Oasification versus desertification

Deteriorating hydrological conditions on sloping lands (hydrological regression) lead to eventual vegetation and edaphic regression. It is most likely that this process will end up feeding back on itself, particularly in arid areas with torrential storms, and in a relatively short period of time it may produce bare sloping lands (with no water, no cover and no soil). This water, soil and plant cover regression characterises desertification when due to soil erosion (= edaphic aridity), not only the most common and widespread worldwide but resulting in quite deleterious effects: soil without plant cover, unproductive, without organic matter, with low infiltration capacity, with scorching sunlight exposure, wide range of temperatures, and increasing direct physical evaporation after storms.

Conversely, an improvement in the hydrological conditions of sloping lands (hydrological progression) leads to an increase in infiltration (ideally all precipitation should seep into the soil), and to a steady progression in soil, plant cover and productivity (in terms of biomass) conditions. That is, the greater the amount of water seeping into the soil, the higher the level of available water for the plants and the further in their growth and development plant species will advance. These plant formations protect the soil against erosion and supply organic matter, contributing to the development of a more fertile, deep and mature soil profile. Both processes, the regression from the three above-mentioned points of view (collectively considered as desertification) and the progress towards more favourable conditions (*oasification*) are diagrammatically shown in Figure 1.

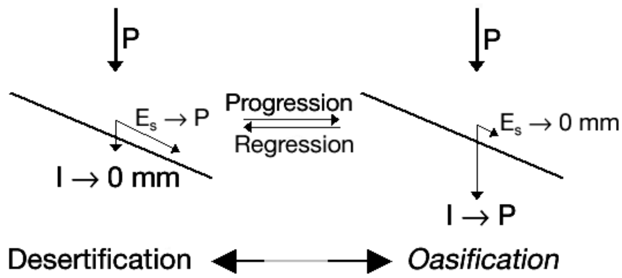

Figure 1. *Oasification* against desertification. P: precipitation. E_s: surface runoff. I: infiltration.

Oasification strategy and modelling

When starting the *oasification* process on a degraded slope, primary systematizations must be set up, basically endorheic microcatchments (Martínez de Azagra, 1996, 2000). A local water balance must be worked out, focusing on the water economy of the slope. As shown in Figure 2, the components making

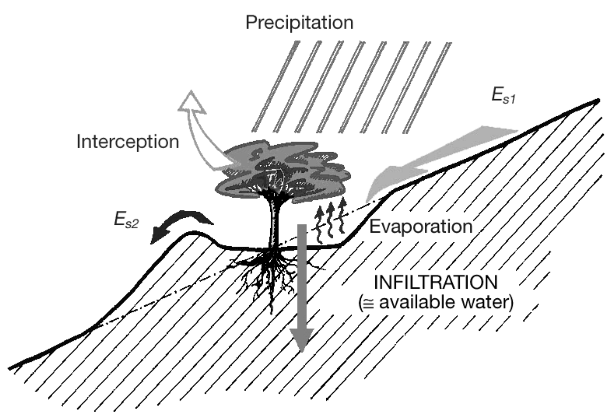

Figure 2. Basic components for a local water balance (Martínez de Azagra, 1996).

up this balance are: precipitation, interception, runoff (both incoming into the micropond and outflowing from it, E_{s1} and E_{s2}), evaporation and infiltration.

What matters when reclaiming a slope is not so much the water that escapes (the main concern of classic hydrology, traditionally focused on runoff) but the water that is being retained and infiltrated, whenever possible the total precipitation falling on the site should be harvested. The ultimate aim when reclaiming sloping lands should be that infiltration must equal precipitation. Since the slope is already degraded, we are forced to act (primary systematization) by creating runoff producing areas and runoff collecting areas (S_1 and S_2), the former will feed the latter where appropriatedly sized (in terms of their ridge height) microponds will collect runoff as it flows downhill.

In our time, the design of *oasification* processes (that is, water, soil and nutrient harvesting) can and must be carried out with better up-to-date knowledge, safety and accuracy based on specific formulae and models. Previous calculations are all the more necessary when wide tree spacing is preferred in an afforestation program, the systematized units are consequently larger and the volume of water to be accumulated is significant. To build *oasification* systems (strategies for water economy in arid areas), that is, to find out the correct size of ridges, bunds, microponds, dry-stone walls, and so forth, models such as those mentioned below will help to proceed safely.

Two models about oasification

Martínez de Azagra (1994a) has developed some general equations to calculate water availability in *oasification* systems:

$$DESP = P + E_{s1} - E_{s2}$$

$$PIMP = P - E_{s1}$$

$$PROM = \frac{S_1 \cdot PIMP + S_2 \cdot DESP}{S_1 + S_2}$$

$$\frac{dV}{dt} = I(t) - Q(t)$$

where:

P = precipitation of the analysed downpour;

$DESP$ = infiltration or availability of water in the collecting area;

$PIMP$ = availability of water in the contributing area;

$PROM$ = average availability of water in the systematized unit (≈ in the slope);

E_{s1} = effective rainfall or surface runoff generated in the contributing area;

E_{s2} = surface runoff that escapes from the unit area;

S_1 = surface corresponding to the contributing area;

S_2 = surface of the collecting area;

S = size of the unit area ($S = S_1 + S_2 = 1$/density of the afforestation);

$\frac{dV}{dt}$ = variation of the water volume accumulated in the micropond during dt;

$I(t)$ = inflow rate;

$Q(t)$ = outflow rate.

Two particularizations for these equations were developed and computerized by the same author: models MODIPÉ and HYDNUM (Martínez de Azagra, 1994b; 1995). The former is based on the curve number method (SCS, 1991) while the latter on Horton's infiltration equation (Horton, 1940).

— Curve number uniparametric model (if $P_0 = 0.2 \cdot S$ just one parameter is left: P_0; otherwise a biparametric model):

$$E_s = \frac{(P - P_0)^2}{P + 4 \cdot P_0}$$

— Horton's infiltration equation (triparametric model: f_0, f_c, and α being its three parameters):

$$f(t) = f_c + (f_0 - f_c) \cdot e^{-\alpha \cdot t}$$

Table 1 compares both particularizations which serve the same purpose: to calculate water availability for plants being artificially established when reclaiming sloping lands. The available curve number tables allow for the precalibration of the MODIPÉ model and thereby this model gains a clear advantage over the HYDNUM model.

As seen in Figure 3, input data for MODIPÉ are: curve number for the actual slope (*NAC*), surface of the contributing area (S_1) and of the collecting area (S_2), curve numbers for both areas (*NI* and *NR*, respectively) and the capacity of the water trap (*CAPA*).

Progressive and regressive series

By using curve number tables as reference (for instance in Ponce, 1989; or in Martínez de Azagra, 1996), the range of natural options for a particular geographic area becomes apparent. If a particular site is supposed to reach a climax stage as a forested or wooded area through natural succession, the range within which the curve number may fluctuate could be

Table 1. Summary of the two particularizations

Input data	Hydnum model	Modipé model
Contributing area	S_1	S_1
Collecting area	S_2	S_2
Storage capacity of the micropond	H	$CAPA$
Characteristics of the infiltration in the contributing area	f_0 , f_c and α	NI
Characteristics of the infiltration in the collecting area	g_0 , g_c and β	NR
Water excess discharge equation	$F(h) = c \cdot L \cdot h^{1,5}$	Instant spillage
Original situation (undisturbed slope)	—	NAC
Rainfall	$i(t) =$ constant	1) A single storm 2) A series of rainfalls 3) A year

determined. The concept of progressive series of the curve number may be of some assistance here (Figure 4). To the progressive series of the curve number, a progressive series of the availability of water on the slope can also be associated (Figure 5). By just being aware of the relationship between curve numbers and runoff thresholds the process will be readily understood.

The range of the curve number fluctuation may be quite wide when starting from a highly degraded slope and when a full restoration is finally achieved over the years. According to the curve number tables, a maximum interval of 94-15 is obtained. Nevertheless, a more realistic interval, within a standard time span (about 50 years), might be 94-54, which would correspond with a fallow on a type D soil ($NAC = 94$) transformed into a forest in good hydrological condition on a type C soil ($N_{min} = 54$). Hence, it would not be appropriate to create water traps generating an equivalent curve number below 54 ($NEQ \geq 54$).

Since each curve number (N) may be coupled with a runoff threshold (P_0) through the equation:

$$P_0 = 0.2 \cdot \frac{25,400 - 254 \cdot N}{N} \quad \text{(mm)}$$

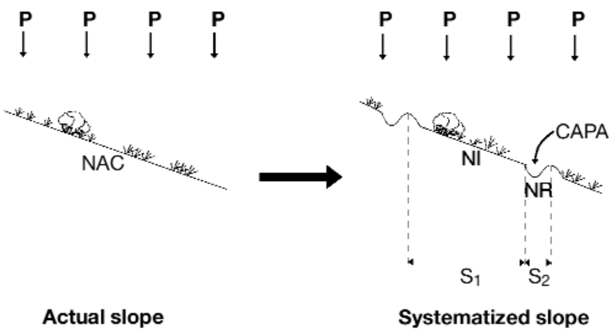

Figure 3. Input data for MODIPÉ.

runoff thresholds for both the degraded actual slope (PAC) and the restored slope ($P_{máx}$) may be obtained. These values can be related with rainfall data for the region and the corresponding return periods (see Table 2).

If the slope is too degraded, the threshold will be so low that t represents the number of times runoff occurs in a year. On the other hand, T may correspond to a very long period of return. It may be concluded then that the restored slope is acting as a perfect sink hole; that is, all precipitation is infiltrated (or intercepted), aquifers are being recharged, groundwater levels improved and the ecosystem is benefiting.

An improvement in the hydrological characteristics of the soil

Soil preparation practices commonly used by Spanish foresters (digging with microponds, micro-catchments, ridging by deep cultivation, ridging with the topsoil, reverse-sloped terraces, contour subsoiling, full subsoiling, full contour tillage) shift the curve

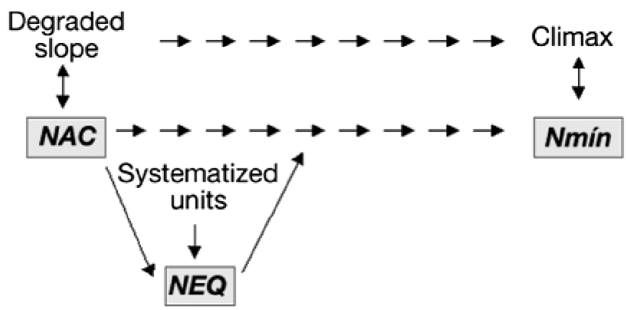

Figure 4. Progressive series of the curve number (Martínez de Azagra, 1996). NAC: curve number on the actual slope. $N_{mín}$: end curve number on the restored slope. NEQ: equivalent curve number on the systematized unit.

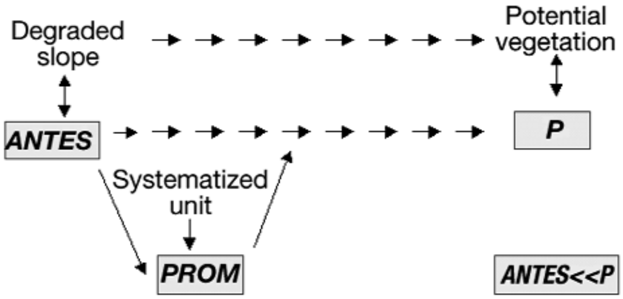

Figure 5. Progressive succession of infiltration and available water on a degraded slope (Martínez de Azagra, 1996). ANTES: available water for the slope without primary systematization. PROM: average available water for the systematized units. P: quantity of rainfall.

number for both the runoff producing area and the runoff collecting area. Table 3 shows a comparative analysis of all these practices.

Conclusions

The concept of *oasification* has been chosen for its positive connotations in the fight against desertification processes. The term refers not only to water harvesting but also to soil and nutrient conservation.

Table 2. Curve numbers, runoff thresholds and return periods relationships

Site	Curve number	Runoff threshold	Return period
Actual slope	*NAC*	*PAC*	*t*
Restored slope	N_{min}	$P_{máx}$	*T*

If degraded sloping lands under arid conditions are to move forward towards water, plant and soil progression, a careful preparation of the soil is required; endorheic or quasi-endorheic microcatchments must be set up. A hydrological model (MODIPÉ) has been developed to assist in the design of these small structures destined to collect and infiltrate runoff. For the forecast of future developments, a model of soil loss (for example: USLE) can be applied as well as a model of nutrient migration. It is thus possible to model the entire *oasification* process.

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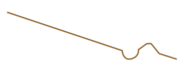
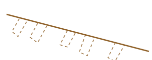
Table 3. Hydrological effects of some current procedures followed in the preparation of the soil for reforestation in Spain (according to MODIPÉ)

Soil work	Scheme	Curve numbers[1]	CAPA[2]
Undisturbed slope		NI = NR = NAC	0
Microcatchments		NI = NAC NR ≠ NAC	> 0
Ridging (by deep cultivation)		NI = NAC NR ≠ NAC	> 0
Ridging (with the topsoil)		NI > NAC NR ≠ NAC	> 0
Reverse-sloped terraces		NI > NAC NR ≠ NAC	> 0
Contour subsoiling; full subsoiling		NI = NAC NR < NAC	≈ 0
Full contour tillage		NI = NR > NAC	≈ 0

(1): NI = curve number of the contributing area. NR = curve number of the collecting area. NAC = curve number on the actual slope. (2): CAPA = storage capacity of the collecting area.

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