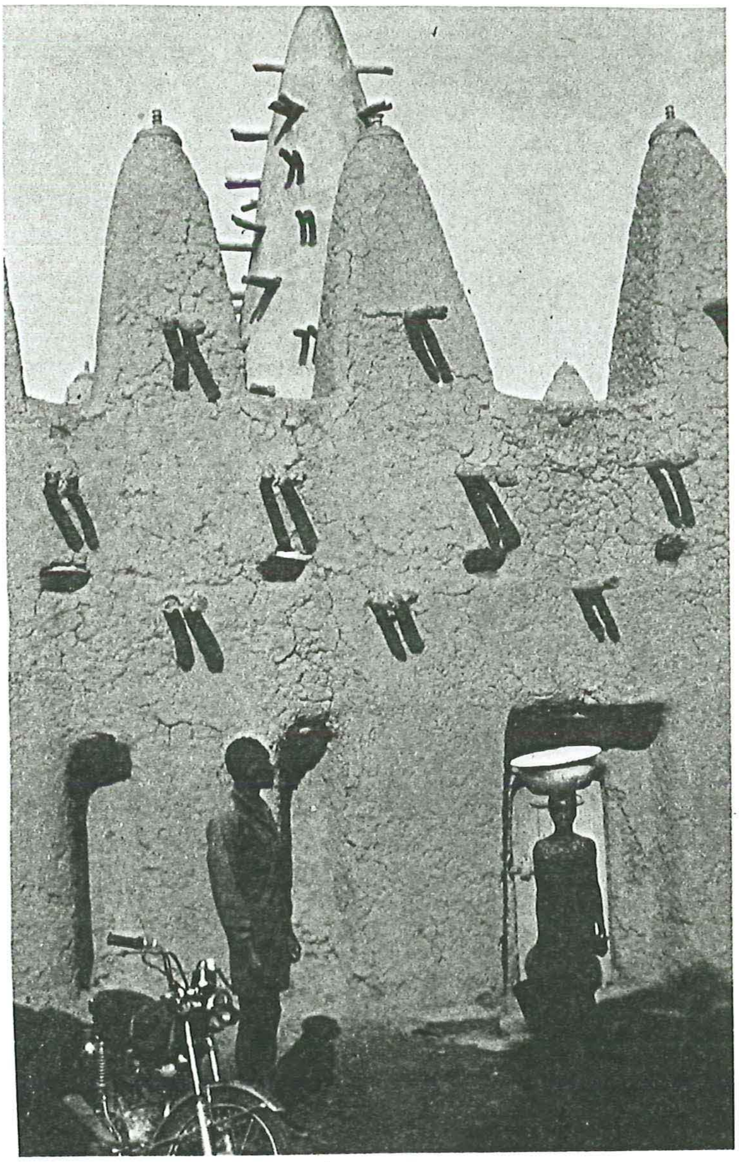
REGENERATION OF THE NITROGEN AVAILABILITY

FALLOW LANDS OF OULA, BURKINA FASO



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1990

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LA PATRIE OU LA MORT, VOOR ACHTER KOMT VOOR VOOR

> Soilscience can provide its contribution to leave the posterity a livable world
>
> C.H. Edelman, 1947

When starting this study, I was not familiar with the subjects of ecological savanna functioning, soil fertility and applicable concepts of sustainability, what I am now.

Ca c'est bien, ca.

The objective of this study was primary the assessment of the optimal fallow period, based on the regeneration of the availability of N and P.

The main conclusion about regeneration could have been expected; it is not possible to assess the optimal regeneration period, more detailled than the range already known, based on the collected data of the case study of Oula.
With a more detailled database it is possible to provide applicable relationships, valid for some scenarios in the context of the Soudan savannas of West Africa.

For essential knowledge and insight, the comprehensive PPS study book is recommended (de Ridder et al, 1982).

CHAPTER 1

1.1 Introduction

The impact of the climate on the geological determined substrate of a tract of land, combined with the overall impact of ecological interactions results in the actual dynamic state of environmental appearance. Such appearance depends thus on the site history. Characterisation of tracts of land, based on qualitative criteria, resulted in the establishment of recognisable zones at various scales. Such a zone or dynamic ecosystem is subject to long and short term changes which are constantly modifying its physiognomy, composition and ecological processes (Hopkins, 1983). The overall system may resist changes, being in a steady state situation, but it may also change gradually into a qualitative different system.

Actually, in West Africa that zonation does shift southwards. At a detailed scale, various ecosystems are recognised as degraded and the overall impact is of such intensity that forest zones evolve into savanna zones and savannas evolve into Sahel steppes (Coulibaly Issa, 1983). The West African system as a whole, is now in a succession of lowering water availability and lowering primary production.

The ministery of environment and tourism of Burkina Faso due the changes to overexploitation of the land. Primary causes are the decreased productivity as the result of a succesion of drought years (early 70's) combined with the increased number of Burkinabe, with accompaning increased exploitation of natural resources.

The FAO do recommend changes of the actual farming practise (Okigbo, 1984). These changes are perse associated with changes of socio-economic pressures. The current population pressure is the culmination of several sequential interacting historical developments. The actual pressure do threaten the existence of the system as a means of attaining economic levels of agricultural production on a sustained basis.

A concrete phenomene in the savanna zones is the natural regeneration capacity of land, being insufficient to restore the soilsurface cover. This is the result of yearly burning of the vegetation, abuse cutting of trees and the reduction of fallow periods (Coulibaly Issa, 1983).

1.2 Context: sustained forest exploitation

This study is part of a casestudy on sustained forest exploitation situated in the ecological zone of the Soudan savannas. The Soudan zone is threatened to follow the actual trend of degradation. ? The territory of Oula, Burkina Faso is selected, among others, because the area is expected not to be degraded yet. 2

A major constraint in the assessment of the overall level of sustained exploitation of land, using actual techniques, is the unknown optimal lenght of the fallow (jachère) period. 3

In the actual system of land use, soil and vegetation are allowed to regenerate from the exploitation induced by cultivation. During this fallow period, exploitation continues (wood, fruits, grazing). (Lit.)

The fallow period is an investment and meant to regenerate the soil into a cultivatable soil, with similar qualities as in the previous cropping period.
The factor determining the crop production will be treated as the primary quality the fallow must provide, while forest exploitation is of secondairy interest. It is out of the scope to consider the factors which are limiting for fallow (re)growth, which are not necessarily the same.

A long fallow period means a loss in the productivity of cultivated crops in absolute terms (kg), a too short period gives rise to a loss in productivity per surface unit (kg/ha), because of the induced degradation. Sustainability requires that no degradation occurs.

Pieri (1989) considers the incorporation of fallow periods in the course of cultivation essential to assure low but stable yields. The lenght of the cultivation period is about 10-15 year, and 5-6 year if following a herbaceous fallow (savanna).

Estimations on the actual periodicity in Oula. Fallow lenghts are actually yet shorter than before.

terrain	basfond	basglacis	residual
Cultivation	>10	6	3-4
Fallow (near)	2-4	6-10	20
Fallow (far)	6	15	30

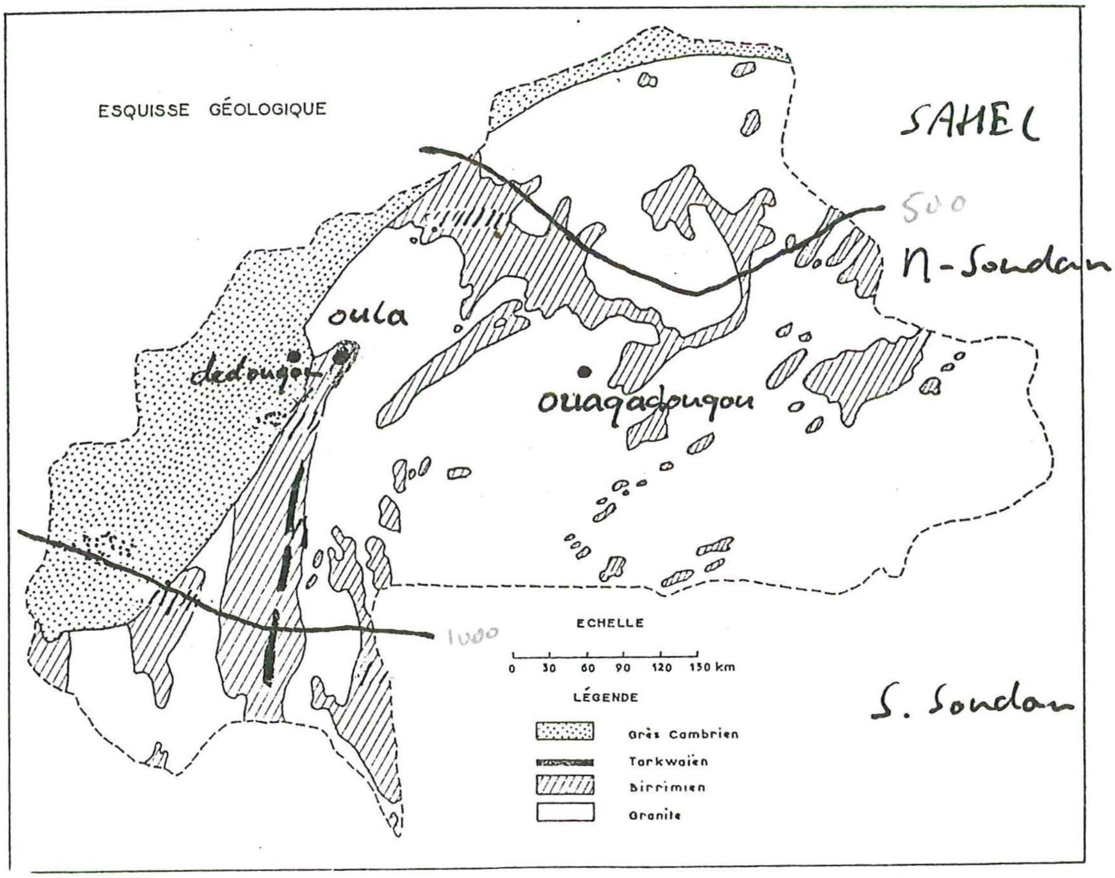
One can see that the basfonds are cultivated long while the fallow period is short. These grounds have a fallow with the highest herbaceous biomass and the poorest wood stand.
Mutual relationships are thus not as straight forward as the remarks of Pieri may suggest.

He further mentions the decrease of productivity as motive why the fields are left fallow again. Reasons are;
- intervention of an uncompetable degree of undesired grasses
- nutrient scarcity
- destruction of structural organisation of topsoil

1.3 Oula, setting

The territory of Oula, mid-west Burkina Faso, is located between 3.11' and 3.04' west of Greenwich and between 12.20' and 12.27' north of the equator.
The yearly rainfall oscillates between 700-800 mm. (The mean value in the last 5 years was 800 mm. in Tcheriba and about 700 mm. in Tigan, both at a distance of about 10 km. from Oula). The mean growing period is approx. 150 days.
The annual rainfall is about 150 mm. below the long term average since the last 15 years.
More generalised is the area part of the West African North-Soudan savannas. The agro-ecological zone is 'tropical dry sub-humid' (Okigbo, 1984).

Administrative, the village of Oula is situated east of the town Dedougou, in the department of Tcheriba, province of the Mou-Houn, western Burkina Faso.
The population density of the dept. is 18/km2.
The amount of habitants of Oula was 647 persons in 1975, and 775 in 1985. Their territory is about 12500 ha (6,5 p/km2), but has to be shared with an increasing number of 'immigrators' who settle in the neighbourhood.



1.4 Identification of the restricting factor for fallow land

Because no detailled knowledge of the area is available one must generalize. In fact one cannot distinguish only one factor which is limiting for annual crop production in the area, but generalised the dominant ones can be indicated.
The identification is however easy because DGIS has Fl 9.000.000,- on its budget, among others to study in more detail the quantification of the relevant processes determining the N availability in West African agro-systems (PPS program).

The water availability is a major soil quality as it determines the possible lenght of the cropping season and thus the risk of cultivation.

Sanchez (1976) indicates in West Africa the wateravailability as limiting factor north of the 800 mm. isohyete, nitrogen south of it.

Primary production of savanna fallow land is determined by the wood-grass competion, what depends on the wateravailability, among others modified by nutrients (Menaut et al, 1985).

Mellaart (1988) indicates for Burkina Faso the optimal sowing dates. If the lenght of the rainy season is insufficient in a certain year, the crop productivity is determined by the amount of water still in the soil, instead by nutrients.

Recent studies, like the P.P.S. studies are still focused on Sahelian situations. With the actual trend of the southwards progressing degradation, these studies form a good comparison.

Overgrazing is considered as a major initiator of actual degradation of an area, what limits the fallows to regenerate.
Exploitation of pasture (secondairy production) is limited by N and P (Penning de Vries and Djiteye, 1982, de Ridder et al. 1982) in the Sahel as well as in the Soudan savannas.
The nutient uptake (availability) is highly correlated with the water availability.
They state that beyond a rainfall of 300 mm. N and P are becoming progressively in shortage. Beyond a rainfall of 800 mm the nutrients in the plant tissue are surely diluted.
For pasture the quality is a function of the concentration of the elements, determined by the eventual relative excess of water. This is not only generalized along the north-south gradient, but also as a function of soil infiltration.
Roughly summarized is in the Soudan zone the N limiting in the lower terrains, P on the higher terrains with water run-off.

Driessen and v.Diepen (1987) provide a map of Burkina Faso.
Both N and P (nitrogen and phosphorus) are indicated as limiting factors with the application to the situation of Burkina Faso of a simplified version of WOFOST. (This is a quantitative procedure for estimating production possibilities of land use systems, what matches the crop requirements and land qualities at several hierarchical levels; 1. solar energy, 2. water, 3. nutrients etc).

In the region around Oula, the achievable annual production of millet as determined by the actual availability of (light and) soil moisture was calculated at about 1600-2500 kg/ha.
Yields in Oula are about 600 kg/ha (Guinko, 1989). The difference is primary attributed to nutrient shortage.

Implementation of QUEFTS, a quantitative soil fertility evaluation procedure, on Sahelian low natural fertility status soils indicates N and P limited yields similar and lower than the yields in Oula. This indicates that besides N and P, probably even other factors are limiting. It must however be remembered that the Millet in Oula is mainly tilted on the marginal gravelly soils, as a drought resistant supplementary cereal.

This is confirm several West African studies which indicate that generalized, the primary production of the whole Soudan savannas is limited by N and P shortage (Pieri, 1990).

Conclusion: N and P are likely to be in shortage for crop uptake thus these are the factors conserned in the following.

fig. Dominant limiting factors, from P.P.S. study in Mali.

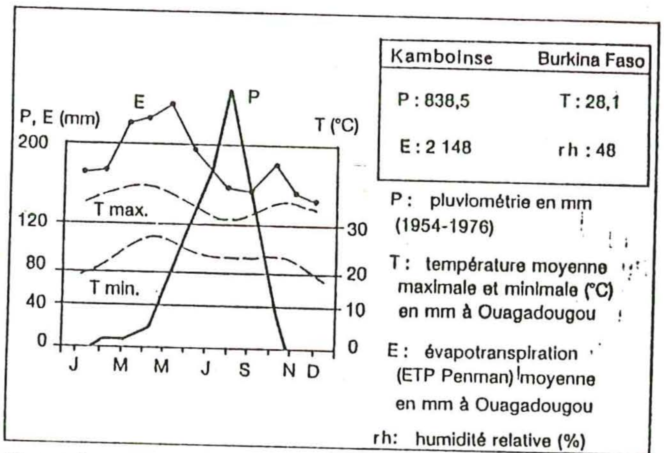


Figure 3 : Quelques caractéristiques climatiques de Kamboinse, Burkina Faso.

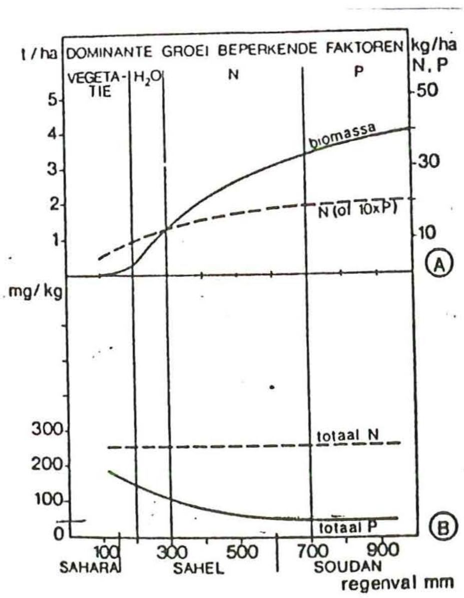


Figure . Calculated water-limited millet yields in Burkina Faso.

36 BFMILLE2 Millet (water lim.) BFASO

					coverage
		0	. . .	6507 cells	54.3%
1	1111	1	no dry matter production	16 cells	0.1%
2	2222	2	1-110 kg/ha	1 cells	0.0%
3	3333	3	110-333 kg/ha	148 cells	1.2%
4	4444	4	333-550 kg/ha	84 cells	0.7%
5	5555	5	550-775 kg/ha	168 cells	1.4%
6	6666	6	775-1100 kg/ha	190 cells	1.6%
7	7777	7	1100-1650 kg/ha	479 cells	4.0%
(8	8888	8	1650-2525 kg/ha	1476 cells	12.3%
9	9999	9	~2525 kg/ha	2931 cells	24.4%

CHAPTER 2 Sustainability

Exploitation is a temporary greater output than input, but implicit to agro-ecosystems.

Resilience:
the degree of disturbance, from what an ecosystem still can regenerate without changing into a qualitative different system

Sustained exploitation:
the disturbance caused by exploitation of the primary production may not exceed the resilience of the system.

A pragmatic definition must allow general validity, permit quantification and permit identification of feedback parameters.

Oula has been selected, among others because the vegetation is expected not to be degraded yet. This dynamic steady state situation is thus defined as a balance of;
- cropping implies an exploitation of soil nutrients (output)
- fallow is regeneration of soil nutrients (input)

Sustainability is an extremely poor defined subject and difficult to apply. It is a matter of optimalisation.
The principles of a systematic approach are:

A studied system will be considered as a homogeneous entity of time, space and quality.
The system as a whole is sustained if the system remains always the same (with implicit fluctuations). This is the case when the input and the output are balanced and also the rotating absolute quantity does not get lower or higher.
If relevant, the system can be divided into subsystems (soil-vegetation) and itself is part of a meta-system (atmosphere-landsurface).
The cycling of a considered factor passes through all defined subsystems (stores, compartments). The relative distribution changes with time, although it knows periodicities of returning to comparable situations if the system is in a steady state situation.
The considered subsystems know several qualitative subsystems with degrees of resistance or turn-over rates. A subsystem with a high turn-over rate takes part actively and dynamic in the actual processes. Subsystems with low turn-over rates form the buffer of the whole system.
The cycling pattern from the system to and from the meta-

system (atmosphere) must be 'short-cutted' and defined as seperate in and ouput figures.

Thus disturbance concerns the balance of N and P in and out of the whole system, as well as the relative accumulation of those in one of the defined subsystems.

Quantification of the input and output of N (and P) is only an approximation (de Ridder et al,1982). Further they discuss the degree of reality of an equilibrium situation. The actual situation is very site specific.

Summary

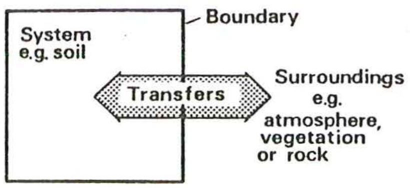
A mature or climax ecosystem may be regarded as an open system in a steady state, that is a condition independent of time in which production and consumption of each component are equally balanced, the total concentration of all components remaining constant even though there is continual change (Richards, 1974).
For the considered agro-ecosystem of Oula, inwhere management (fire, pasture and fallow-cultivation periodicity) is a major contributor to the actual restricted climax vegetation, is Richards statement applicable; it is true that over short periods of time ecosystems appear to show considerable change (like the mentioned priodicity), but if cognisance is taken of the time factor, the steady state condition is seen to apply.
The sustainability of a steady state land-use system must thus be defined over a limited period of time in order to have any significance; some tens of years to a complete inter-glacial period. But even then one can state that the whole of West-Africa is a sustained open steady state, inwhere degradation in the northern zones provides a concentration of all components in the south.

(This kind of hot-spot forming processes can be encountered at each level of detail and is observable in the terrain of Oula as well; the inner circles around the village benefit from the exploitation in the outer circle, while the whole system is 'sustained').

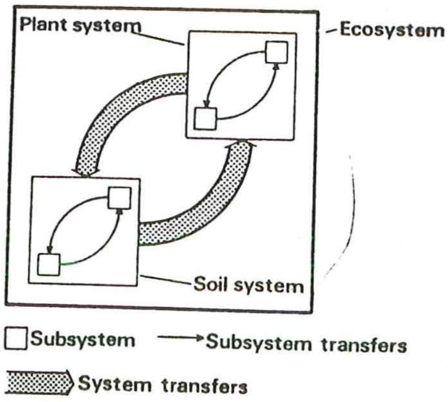
The statement of Richards is thus completely true but rather invaluable. Or as stated by Odum (1975) once a clear image of overall structure and function has been obtained, component parts and functions such as the cycling of nitrogen, can be considered; or a particular environment such as the Sudan savannas can be placed, <u>in perspective only</u>.

N and P in the ecology are like money in the economy.

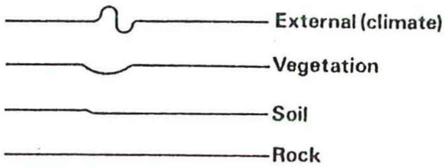
Disturbance and regeneration, two components of the agro-ecosystem.



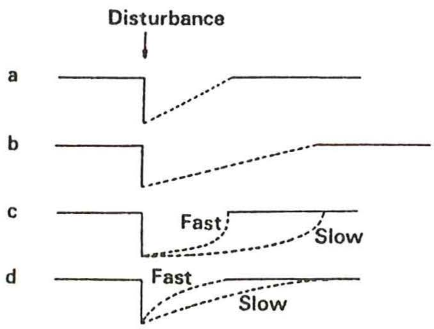
System definition

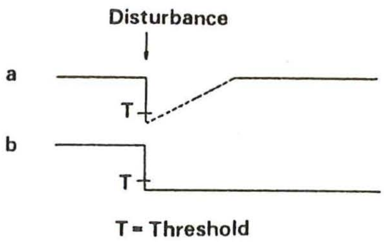


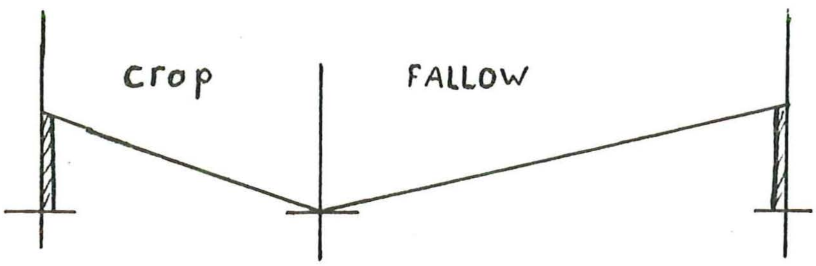
Systems hierarchy



Different degrees of reactivity of components







CHAPTER 3 Relevant determinants

The phenomenology of the savannas is determined by various factors, what together do determine the amounts and availability of N and P in the soil.

The main N source, the soil o.m., (>90% of the N) contributes significantly to the structural architecture of the soil and thus the wateravailability (length of growing season). Also because the N is more mobile (open cycle, connected with the atmosphere, and soluble in the soil, what is both not the case for P) is this study primarely concerned with N.

> Although most of the P taken up by the plants is provided by the weathering of primary minerals, is the microbial oxidation of organic substrates an important supplementary source of inorganic P. The mineralization-immobilization cycle of P is comparable to the turnover cycle of N (Richards, 1974, Kowalenko, 1978).
>
> The N% and P% of the o.m. are highly variable (Kowalenko, 1978). Ahn (1970) mentions a N content of 5%.
> Although the (C/)N/P ratios are not constant is the P% probably 1% and 10% of resp. C% and N% for humus (de Ridder et al, 1982).
> P is 0,7% and 7% of resp. C% and N% for the whole soil o.m. (Penning de Vries and Djiteye, 1982).
> Jones and Wild (1975) mentions even wider org.C/org.P weight ratios of about 250 (P% is 0,4% of C%).

P/N ratio

An interaction of N and P uptake from the soil exist as they are both involved in the same processes in the active cells of plants. Both are present in nucleic acids, N is present in enzymes and P in the molecules that transport energy for enzymatic reactions, The P/N ratio in plants is an indication of the relative availability of one of those elements but it doesn't indicate if an absolute lack of P,N or both exists in the soil store. There may be differences among species but as a first estimate the limits of P/N of 0.04 and 0.15 may be considered as a general characteristic (de Ridder et al, 1982, Pieri, 1989). The N uptake rises with P application and vice versa. The P requirements are 0,1* N requirements as the optimal ratio in grains is 1/10 (v. Keulen, 1983).
Plant requirements for N and P vary according to their stage of development. Observed is in Sahelian conditions that P is in relative shortage in the first half of the growing season and N in the second half. This depends probably highly on the relative amount of P, not bound at organic compounds. The P/N ratio changes during that period and is high during flowering.

3.1 Site-specific dynamics dominate the expected relation between total amounts in the soil and vegetative uptake.

Degradation of a landsurface is best shown by the vegetation (one must know which stade in the fallow succesion is observed). Degradation in the Soudan savannas is actually scattered and mainly an accumulation of circumstances, initiating the loss of the soil cover (overgrazing along sides of streams in Oula). The structural trend, yet hardly visible, of degradation may be approached with N (or associated P) balances.
The N and P providing capacity of the soil is best shown by the annual amount taken up by the vegetation.

* Measurement of the amounts of N and P stored in the soil, eventually having taken into account more detailled cycli, are of very limited value as one wishes to correlate these data with crop production. Such correlations are obscured by exogeneous conditions which differ each year. The variability and complexity of indigeous and exogenous factors which influence the uptake of nutrients from an unfertilized soil (as in Oula) makes it virtually impossible to predict crop production on theoretical considerations only (Driessen, 1983).
* An example is from de Ridder et al.(1982) who mention the existence of the relation between production and rainfall, and the absence of a relation between rainfall and the amount of soil N. Thus what about the dynamics from the soilstore to the vegetative store an vice versa (?)
* The inherent fertility of the soil, the zero N and P level, knows differences between years. At the basis of that are presumably the differences in environmental conditions, especially rainfall. The moisture balance of the soil can varie between years what has a significant effect on rate and duration of soil o.m. mineralization, on magnitude of losses through denitrification and leaching, etc.(v.Keulen, 1983). This variation can only be caught statistically.
* Stoorvogel and Smaling (1990) state that at any one time, a certain amount of N, P (and K) is present in the soil, either in stable or labile, plant available forms. When measured one year later, these amounts are not necessarily the same. This is due to various processes that cause nutrients to flow into and out of the rootable soil layers.

This reaches the core of the problem of the calculation of site specific balances with respect to the availability, provided by the fallow. Availability is thus not only related with total amounts, (what is not primary related with crop uptake (de Ridder et al.1982), but also with the biochemical processes determining the release (which are highly variable along temporal sequences, essentially being fallow periodicity and the seasonal periodicity) and with 3 dimensional redistribution patterns as well.

3.2 Fertilisation

The most simple solution to solve the problem of N and P shortage is mineral fertilisation.
In Oula, mineral fertilisation is rarely applicated, and only in small amounts for cotton in the basfonds. In fact little is known about optimal fertilisation on 'Soudanian' soils. Similar concepts are applied throughout Burkina Faso, with little attention to site specific conditions (pers.com. Compaore)

-- The N recovery fraction (relative amount of supplied N which has been taken up by the plants) is higher with higher uptake of native N (zero N level). It is thus more economic to fertilize fields already relative rich in nutrients. Areas which receive run-off water have a higher urea (ammoniacal, NH_4^+) recovery fraction than the nitrate (NO_3^-) recovery fraction. Because nitrification is lower under these circumstances the NH_4^+ remains in the system, and NO_3^- is lost by leaching and/or denitrification (v.Keulen, 1983; heavy clay soil in the Sahel).
-- The recovery fraction of P may be highly variable and difficult to predict. Optimal release is at PH of about 6-6,5 (v.Diest, 1983, Ahn, 1970).

Extra input does not neccesarily improve their availability.
Results of fertiliser experiments in the West African savannas are summarised by Pieri (1989) and indicate that the general processes following mineral fertilisation are an acidification of the soil and a loss of organic matter.
Experiments in Saria (800 mm., Burkina Faso) indicate that a supply of mineral N (for example 100 kg/ha) induces an 'over mineralisation' of the soil o.m. and loss of about 300-400 kg humus /ha. The reason is the excess of N in comparison with the C as energy source for microbial life (low C/N ratio). This system buffer is the soil N store which will have to be restored in a subsequent fallow period, or fertilisation have to be continued with an increasing intensity.

The above is especially valid for sandy soils (mineralisation during cropping is yet 4%/year, while under fallow the rate is about 0,5-1,2% in high-grass savannas (Greenland and Nye, 1960). On more clayey soils the results of only mineral fertilisation can increase the yields while no acidification occurs, but o.m. is still lost. The loss however is of no real importance in soils with inherent high fertility and accompanied high organic matter content

(Pieri, 1989). (?)
An advantage is that the interannual variability of crop yields may be reduced in the first few years. In Oula, the cropping period is short.

Combined fertilisation by both mineral as organic (cattle) manure stabilises yield at an increased level. The effectivity of the mineral manure remains stable over the years and the o.m. content increases with increased organic manure supply. Acidification is stopped.
Organic manure is derived from outer circles further away from the village. It can assure contineous cropping in the inner circle, but is no assurance for sustained land use.

The increased output during the cropping period goes thus accompanied with a net mineralization of the organic stock. The expected extra input during fallow should thus be restored in that humic stock (net immobilisation).

The destruction of organic matter is structurally higher than the formation. The last implies however not a net loss of N, but of C. (CO_2 loss, respiration compensates the CO_2 gain, assimilation).

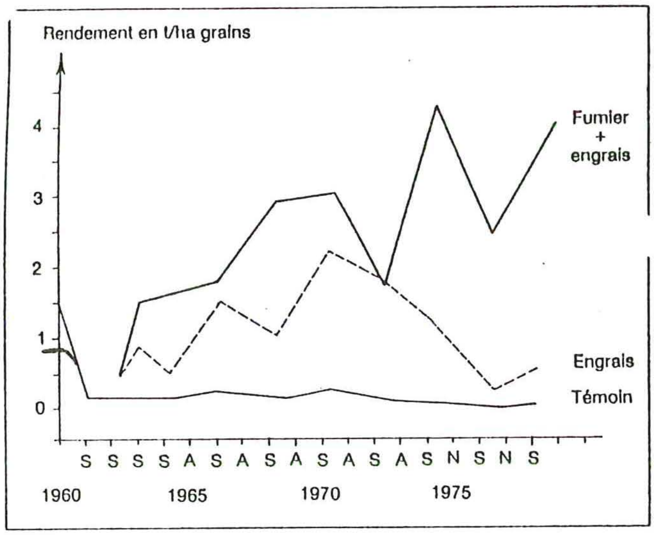


Figure : Rendements du sorgho dans un essai de longue durée au Burkina Faso. La diminution des rendements dans les traitements avec engrais est due à l'acidification (d'après Pichot et al., *1981).*

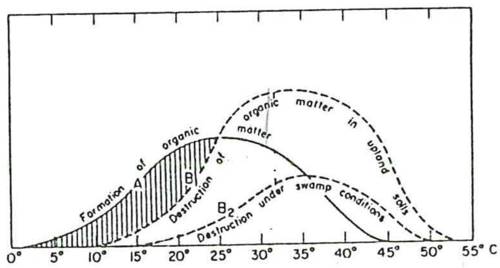


Fig. Comparative rates of production (A) and decomposition (B) of organic matter as a function of mean annual temperature and aeration of the soil. Source: Van Dam, 1971.

3.3 Soil characterisation

One should thus at least specify its situation, for better understanding. The following is a qualitative summary of some essential determinants. Considered is primary the soil.

According to local conditions (p.m.) particular soil types may occur. Vertisols (typified by their structure derived from alternating swelling and shrinking of the clay) occupie the valleys in areas where basic rocks occur (Menaut et al, 1985). These soils, associated with 'sols bruns eutrophes', must be rather common and are considered as the most fertile soils of Burkina Faso. (pers. comment Bunasols, by Blokhuis (LUW), Boulet, 1971, 1976, 1978, Jenny, 1965). These soils may especially be expected in areas with Birrimien geological substrate.

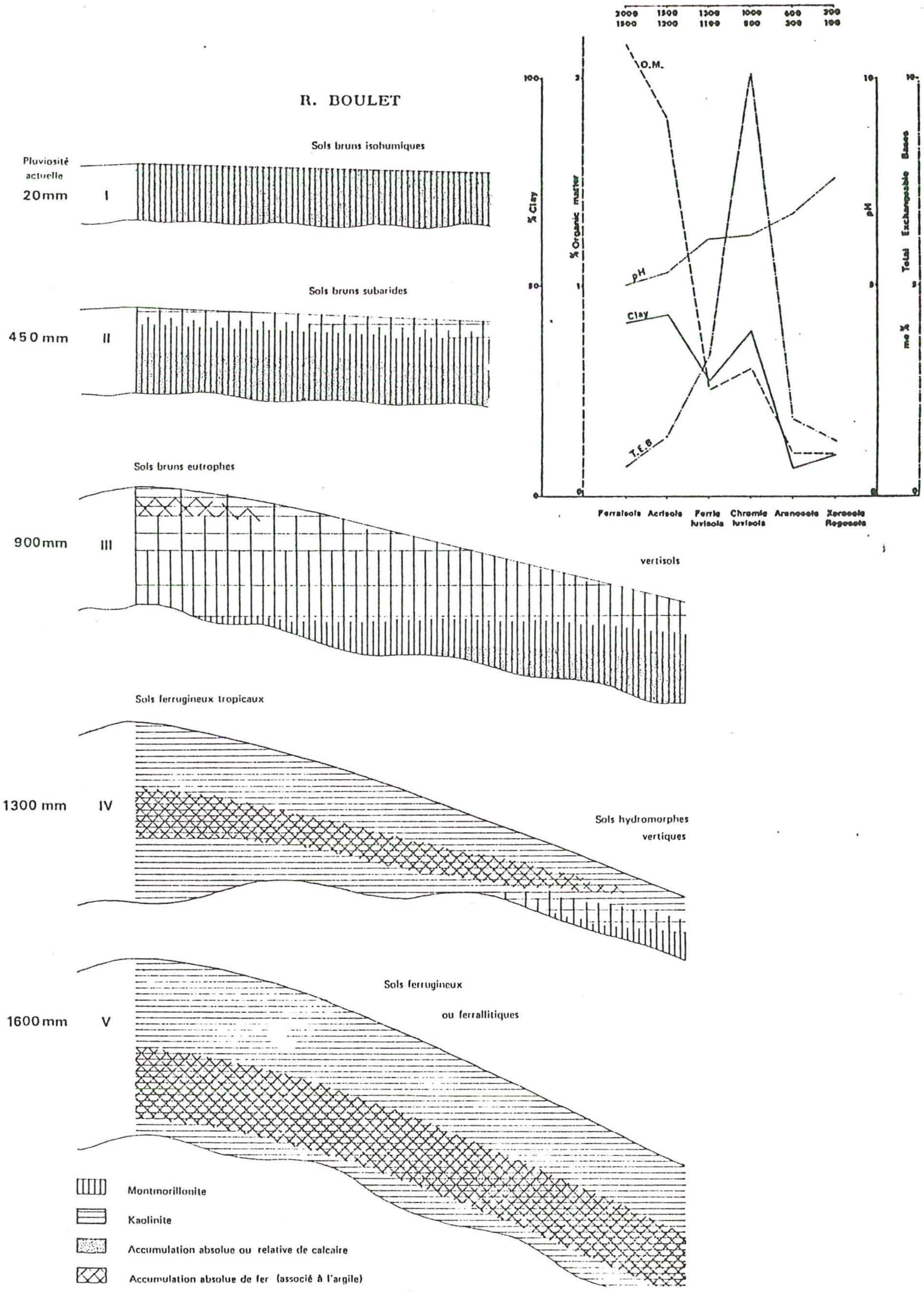
The most extended areas contain soils with ferruginous (lateritic) material (sols ferrugineux tropicaux (ORSTOM), alfisols (USDA) and luvisols (FAO). The material can be present as an ironpan, and/or is transporated and deposited as gravelly colluvium. Plateaux covered with ironpans are a very common phenomene in especially this zone of West Africa (Boulet et al, 1971).
Typical for savannas are the concave forms as the landscape is adapted to surface run off (pediment) (Nye and Greenland, 1960). Slopes are gentle but of a great lenght (Roose, 1985).
The soils on these colluvial plains are thus structurally in a degrading trend.

N and P contents (kg/ha) on West African savannas

Nye and Greenland (1960)		Jones and Wild (1975)		Breman	
Ntot	1500-3100			Ntot	775
Ptot	120-1000	Ptot (ferrug)	450	Ptot	75-150
		Ptot (basic)	1000		

(see par. 4.3 for Oula values)

Diversification of relevant soil characteristics, along the north-south sequence and along the catenary sequence (clay mineralogy !) in Burkina Faso (Boulet, 1978). Chemical data as by Menaut et al, 1985).



Soils of Oula

Soils are characterised and defined on base of their geomorphological position, primary meant to improve the accessibility of the map, and compatible to soil legends earlier used in Burkina Faso (Orstom).

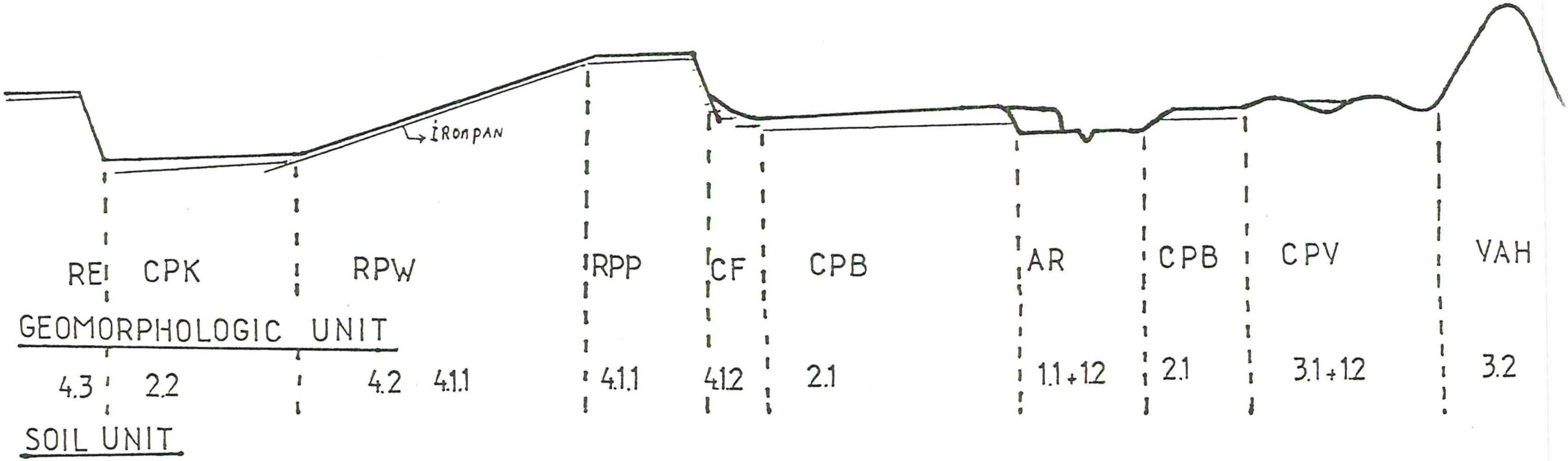
The variability within the soil units of the flat and gently sloping plains is mainly determined by the occurence of ironpans and gravelly layers at various depths, what has a major impact on intern drainage and rootability.
The dissected hills and accidented terrains know various depths to the parent material.
The variability is large within small distances.

Units are as mapped by Leenaars (1990).

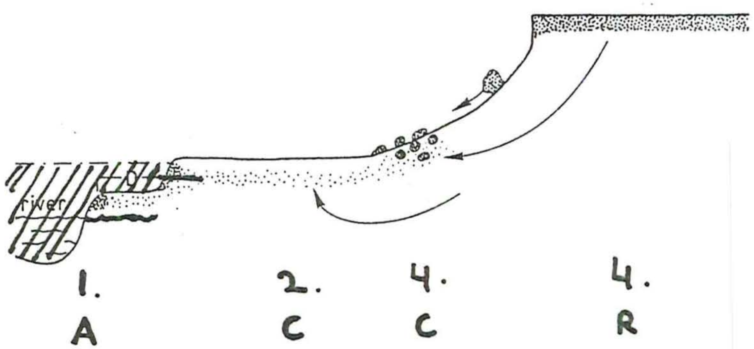
- (A) Alluvial; valleyfloor, floodplain, bas fond
  almost flat, moderate extern drainage
- (C) Colluvial; collo-fluvial plains, footslopes, basglacis.
  Boin watershed:
  almost flat, surface run off
  accidented terrains, water accumulates in small depressions
  Karouka watershed:
  almost flat, imperfect extern drainage
- (R) Residual; abrasion plains, lateritic plateaux
  long gentle slopes, moderately extern drainage, parts very poor
- (V) Volcanic; hilly terrains, greenschists and basalts
  well extern drainage

Associated soil types (French classification system)
Mean rooting depth, drainage

- (A) Type 1.1 (vertisols)
  80 cm. imperfect intern drained
  Type 1.2 (sols bruns eutrophes)
  > 80 cm. moderately well drained
- (C) Type 2.1 (Sols ferrugineux tropicaux),
  80 cm. well to moderately well drained
  Type 2.2 (sols ferrugineux tropicaux)
  80 cm. imperfectly to moderately drained
  Type 3.1 (Sols bruts d'erosion)
  40 cm. well to moderately well drained
- (R) Type 4.1 (Sols ferrugineux tropicaux; gravel overlying an ironpan)
  30 cm. moderately well drained
  Type 4.2 (Sols ferrugineux tropicaux; gravel overlying an ironpan)
  20 cm. imperfectly drained
- (V) Type 3.2 (Sols bruts d'erosion)
  very variable depths, somewhat excessively



SIMPLIFIED EAST-WEST SECTION



The following is mainly concerned with type 2 (basglacis) and type 1 (basfond)

3.4 Agriculture of Oula

The agriculture is based on self sufficiency. Food staple are cereals, notably sorghum and millet. Cash crops are cotton and peanuts. Roughly summarised is Cotton tilted in the basfond, Sorghum in the basfond and the bas glacis and Millet on the bas glacis and the terrains with more relief.
Modern implements are hardly used. Fertilisation of the cotton is rare, and has thus only a slight positive effect on the nutrient balance of the cropping sequence, like it has in comparable regions (v.d. Pol, 1990).
During the year 1987, 729 ha were cultivated as follows (Guinko, 1989):

Culture	Production (in tons)	Rendement (kg/ha)	Surface (ha)
Sorghum	400	800	500
Millet	135	600	225
Cotton	6	800	7,5
Maize	4	850	5
Rice	4	950	4

Exploitation consists further the collection of fruits, fire wood, construction wood and pasture.

The exploited area knows 4 types of terrain, roughly relaterd with increasing distance from the village.
-village grounds (permanent; enriched by manure and household refuse)
-intermediate grounds (semi permanent; short regeneration period)
-brousse grounds (shifting cultivation pattern)
-hardly accessible grounds

The people are forced to extent their exploiting activities to more marginal terrains. There is a structural transportation of resources (N and P) to the inner circles. At more detailled level this is always the case, like the tendence to graze on grasses, and deposit the manure in shade rich environment. Also termite activity is a good example of this tendence towards desequilibrium; 'hotspot' forming.

Vegetation:
Vegetation ranges from open grassland to dense bushed woodland, depending on soiltype and stage of fallow development.
Basfond soils would be characterised as open bushland (Grass with scattered Acacia Seyal). The large yearly uptake means a large fuelload, and the intense fireregime limits the vegetation to regenerate.
The fallow vegetation of the basglacis would be characterised as bushed woodland, because some trees are left during cropping (karitee). Otherwise all observed fallows (2-29 year) would be characterised as bushland.

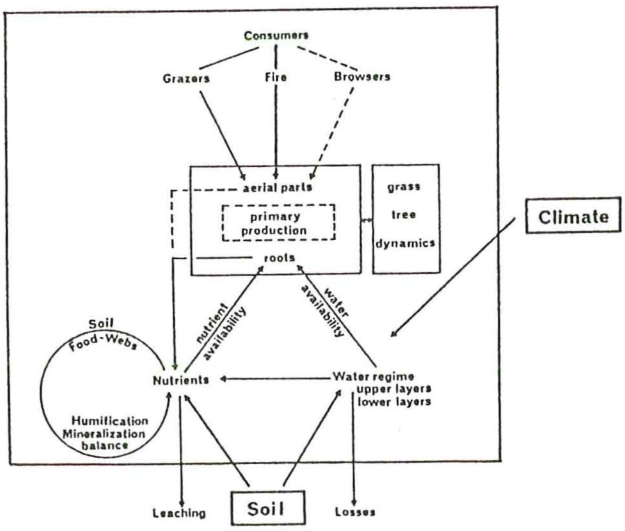
3.5 Savanna functioning

The ecological actors do store N and P in various amounts and in various degrees of resistance. These interact, and determine the amounts to be released each year. This is also the case in the vegetation.

In the subhumid savannas is litter production limited because large amounts of the above ground production is consumed by cattle and burnt. Litter is the main contributor to the mineralizable part of the dead o.m. Soil organisms do live in it and decompose it. For the microbes to be able to mineralize the organic matter, the material is decomposed by soil macro fauna as earthworms and termites. The area is situated in the transition zone where earth worms disappear with lower rainfall, what makes the decomposing action of termites dominant.
At the onset of the rainy season the nutrients get released by leaking, excudates and mineralization by microbes. This biological activation is caused by wetting of the soil.

Decomposition of the rootsystem is no important contributor to N uptake. Release of nutrients from the yearly decomposed rootsystem of the grasses is incorporated in the associated microflora and an important contributor to the humification.
Most of the N in grasses and bushes in the fallow vegetation are thus likely to be lost from the system. The regrowth causes mineralisation, instead of immobilisation.
The rootsystem is however immobilised, and this growing cycle, with a high turn-over rate is thus a contributor to the fast humification of the vegetative material. This is one of the reasons that the humic stock of the dryer savannas is less resistant than the one in wet savannas. This part of the humic stock is essential as buffer in the next disturbance caused by cultivation (see next par.)

Determinants of the N and P availability in the particular situation of savannas (Menaut et al,1985).



. An overall model of savanna functioning.

3.6 N and P in the soil. Degrees of availability as determined by the used extractants.

Passing all relevant determinants, the vegetation is at last the overall reflection of the particular situation. Thus, inversily the soil is the reflection of the vegetation. The status of the soil at last determines the suitability of the land for cultivation.

Both N and P are tied up in system stores, all in various degrees of resistance to weathering or decomposition. Measurements of total soil N and P contents helps to indicate structural nutrient deficiency but provides only a poor indication of the amount which turns over through the soil-vegetation system each growing cycle; the amount available for plant uptake.

Summarised according to Pieri (1989).
During the cropping period both C1 and C2 (especially C2a) are depleted.

Relative C% of the soil organic matter is

- C1, 20-50% C/N = 20-40
  vegetative material, easily decomposed. Energy source (C) for microbes; net immobilised (important nutritive source as well !)
- C2, 50-80% C2a C/N = 15
  C2b C/N = 10
  organo-mineral complex (several degrees of humification; C2a is less resistant than C2b).
  net mineralisation; the less resistant parts are N source for plants
- C3, 2-4% C/N = 10
  regulates the the activity between C1 and C2, and with the 'outer system' (plants, fixation etc.)
  Measurement of the CO2 respiration is indication of that regulating activity, and of ecosystem stability (Odum, ?).

The most direct approach in estimating the mean yearly available amount is the use of extraction agents which mimic the action of plant roots, and whose results are correlated with plant production. For both N and P no such general applicable extractants exist (Driessen, 1983):

-- The distinction of difficult and easily soluble P stores is arbitary and determined by the used extractants. P fixation capacity of soils are correlated with so many soil-variables, who in turn depend on exogeneous factors, that it is to be expected that the correlation between extractable P and P taken up by plants varies among soils and extractants.

Locally established correlations are not transferable to other areas.
Common extractants are Bray and (modified) Olsen.
-- No generally valid guidelines exist for estimating the ability of the soil to supply N to plants, due to the extremely complicated processes of (changes in) decomposition and resynthesis of soil o.m.
-- The availability of N or P depends also on the balance or imbalance of the total total nutrient supply. Critical levels of extractable P are co-determined by the soil's total N content. An emperical rule, applicated to the soils of Oula from basfond to basglacis, is that the critical P level (modified Olsen) may be estimated at about 0,025 to 0,05 times the total N content.
Nye and Greenland (1960) mention a Ptot./Pavail. ratio of 20 - 100.

For the particular situation of Oula or more general of West-Africa, some developed methods have been tested. Pieri (1989) mentions the method of Bremner, which determines the amount of N mobilisable by the cultures, and adapted to the needs of agricultural diagnosis. (NHt = total hydrolysable N).
The IRAT finds N,KCl a good indication of a soil's suitability to provide N for uptake. N,KCl extracts the amounts of NO_3^- and NH_4^+ present in the soil solution plus the amount of N in the soluble organo-mineral fraction.
For P he mentions several methods.

The fractioning of the several o.m. compounds with different resistance to mineralisation and to extractants are also valuable for indicating the qualitative developments of the soil-vegetation system

Egoumenides et al.(1987) have established some applicable ratios, derived from several West-African soils. Both extracting methods mentioned above were used and some broad groups of the o.m. compounds (qualitative N fractions), as indicated by Greenland (1972) were determined.

Method KCl,N is used after what the remaining insoluble org.N is hydrolysed. They characterise the method of hydrolysis as an appreciation of the stability of the o.m., inwhere the eldest fractions are always resistant to the hydrolyse.
NHt is seperated into NHd and NHnd (distillable and not-distillable), and the fractions are tried to be correlated with various o.m. compounds. NHd is negatively correlated with C/N ratio of a certain substrate. (C/N is high, like straw,; NHd is low).
Second seperation method is the hydrolysis of a soil sample, resulting in NHt and residue. The NHt is treated chromatographically in order to seperate amino-acids. These

amino-acids are still an imporatant constitute of the humificated soil o.m.

```
               1.       2.     3.      4.
N total = N,KCl + NHd + NHnd + NnH   --> increasing resistance
                               amines
```

(NnH is mostly not a participant in a common Ntot. analysis).
The N in the stores with decreasing resistance takes most actively place in the actual cycling process from soil to vegetation, and is in the same order of amount as the N involved in the input and output transfers.

Their experiments follow the development of relative fractions of N with changing circumstances.
Degradation implies a relative growth of NHd (relative most easy available hydrolised org.N) in relation to the total N.
Improvement by the combined fertilization with mineral N and farmyard manure (low C/N ratio) increases yield, total N but the ratio 'NHd/total N' decreases, as well as 'NHd/NHnd'.

To provide status to the state of equilibrium of the soil N-pool, more sensitive and more pertinent is the 'NHd/amino N' ratio, as determined with the second method mentioned above.
Apport of organic material (wih low C/N) increases NHd as well as amino-N (amino-acid proteinaceous N). The ratio decreases.
The ratio could be an expression of the sensibility to mineralisation, independent to the total-N (quantity).

A conclusion of the study of Eugomenides is the phenomene of regeneration with increasing absolute amounts of moderate available N, simultaneously occuring with a relative decrease in relation to the not-available N, and to the total N.

De Ridder et al (1982) do mention comparable N stores. They divide in 3 fractions. One with a turn over rate of several hundred years, the second with a rate of several years and a third with a rate of several weeks to months.
The total soil amount is several thousands (first store), but the second contains only several hundreds kg N/ha. This is the store which is exhausted during cropping and is the one to be restored during fallow.

3.7 Regeneration

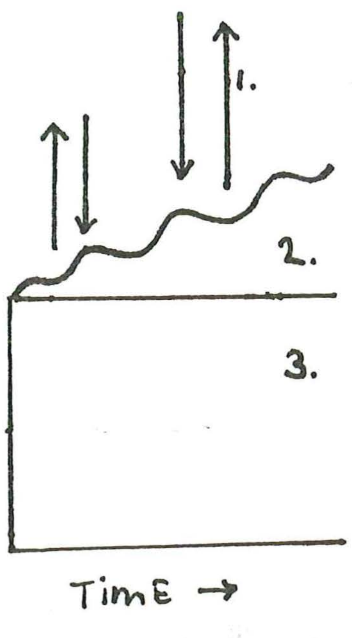
Mineralisation in high grass savannas is about 0,5-1,2 % of the o.m. (Greenland and Nye, 1960) and about 2-4% under cultivation (Pieri, 1989). The last is a net loss.

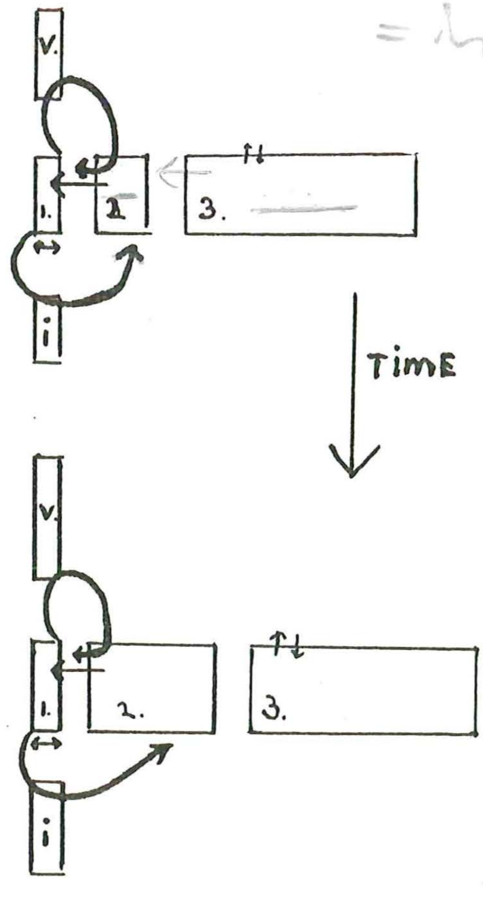
Regeneration is the increase of an 'intermediate' N store. The depletion and regeneration of this store can be considered as a slow pulsating system, comparable with the savanna pulsating system, providing the N flush.
The input-output regime determines the level of the dynamics, inside of the soil-vegetation system.
These dynamics are in first instance a <u>net</u> mineralization of the resistant humic stock, because the vegetation grows.
In the mean while the intermediate stock is formed from the recirculation of the vegetative material.
In a steady state situation, the mineralisation equals the immobilisation, but both continue (0,5-1,2 %).

Thus a disturbance by net mineralisation of the intermediate stock is compensated by a net immobilisation, but the net mineralisation of the total organic stock is not compensated by a net immobilisation.

Altogether, the disturbance has caused, in principle, a loss of the humic stock, all other variables constant. The requirement of constant variables is however an impossibility, thus sustainability can be reached within the ranges of chance.

Principle of the regeneration of the availability of N
1. N,KCl
2. N,intermediate
3. N,resistant
v. vegetation cycle
i. immobilisation cycle





3.8 Availability: synchronised turn-over mechanism

As one could read in the previous chapters, the amounts of N and P stored in the various compartments of the nutrient cycli are a poor indication of the availability of those elements for plant uptake. Availability is determined by the turn-over rate of the stores and the synchronisation of the various processes. Especially the synchronisation is a subject what can in principle be studied by indicating the redistribution of N and P through the system for certain time intervals. In order to be able to apply such an approach, one requires an enormous calculative model, which needs data input and must be able to indicate the statistical significance.

The fluctuations of exogeneous conditions is in the soil most directly reflected in biological activation or inactivation. On the savanna grounds with a distinct dry season, mineralisation and immobilisation of org.N and org.P depend highly on the drying and wetting of the soil.
A well known reflection of this is the N flush at beginning of the rainy season (Sanchez, 1976, Pieri, 1989). The soil may get dry again during the rainy season and the release of N is stimulated every time the soil is wetted again. With the irregular rainfall pattern the N release may be considered as very economic. Menaut et al.(1985) call this a pulsating system of availability.
The biochemical processes in the soil during the dry season are practically stopped. Wetting of the soil results in the release of nutients, caused by the stimulation of the microbial activity (heterotrophic bacteria (Pieri, 1989) as mentioned in the models of savanna functioning (Menaut et al, 1985, Swift et al, 1979 in Bourliere and Hadley, 1983).

The release of inorganic N and P are taken up by plants, part of the microbes, precipitate etc. (Richards, 1974). The net balance is however a net mineraliztion in the first half and a net immobilisation in the second half of the rainy season (de Ridder et al.1982). With vegetation the immobilisation is lower and the vegetative material is thus net more mineralized in order to keep the nutrients cycling back to the living plant tissue. Net mineralization is proportional to the cumulative rainfall.

The availability (release) of especially N is thus rather complicated. The inorganic amounts varie through the year with season and from week to week. Generalisations can hardly be made but significant differences are observed in the Sahel (de Ridder et al.1982).
In the early part of the rainy season both sandy and clayey soils have total = soil amounts of inorganic N of about 15-20 kg/ha. They observe on sandy soils a relative fast growth of the amount

and fast growth in the vegetative tissue.
On clayey soils the growth of the inorganic amount starts later, followed by an even more late growth in the vegetative tissue. Both have a total and vegetative peak in aug-sep, a total of about 60 (sand) to 75 (clay) kg N/ha. At the end both have a vegetative amount of about 30 kg N/ha.

The harvest index indicates the ratio grain yield / total dry matter yield, which may become very unfavourable when moisture limitation occurs during the end of the rainy season; the reproductive phase. During that phase the N and P, which are remobilized in the plant and normally translocated to the generative parts, remain in the residual parts (straw). High amounts of N taken up in early growth stages increases the risk of moisture shortage during the reproductive phase.

A favourable rainfall pattern is thus essential for an optimal use of the easily available amount of the N (and the associated P).

General remark (citate Kudeyarov, 1980)

All processes of nitrogen transformations in the soil are harmoniously interdependent. It is therefor possible to assume that the soil presents a self-regulating buffer system of a kind in which the inputs and outputs of mineral nitrogen are kept in a relative equilibrium. This equilibrium may change due to the type of agricultural management.

The interrelationship of the soil and its environment (vegetation etc) is thus not easily systematised.

CHAPTER 4 Fallow grounds in Oula

The previous chapters are only illustrative. This chapter only contains the indication of the data which are measured in Oula.

One cannot totally rely on the following figures as the amount of data is statistically not recommended. This is particulary true for soiltype 3 and 4. If these are reported is it for relative comparison.
Striking are the large variance coefficients (root of variance divided by mean value, in %). I hope the report was able to convince the reader that it is an expectable phenomene in the way the experiments were located in this region.

Soiltype 1 (8x); sols bruns eutrophes and vertisols

plot	43	47	8	23	49	50	401	12
pit	13	7	11	25	1	27	9	8
age	2	3	6	6	9	11	12	15

Soiltype 2 (11x); sols ferrugineux

plot	38	22	14	28	15	41	34	44	31	36	13
pit	5	3	12	6	15	21	4	20	26	22	24
age	1	2	3	5	8	8	9	17	18	22	29

Soiltype 3 (2x); sols bruts d'erosion, overlying volcanic p.m.

plot	42	4
pit	10	28
age	15	17

27

Soiltype 4 (6x); sols (ferrugineux) gravillionaires

plot	3	18	402	32	19	16
pit	14	17	2	16	18	19
age	2	8	12	15	22	30

(plot 16 and 402 of type 4 have volcanic p.m. in the subsoil
plot 4 is volcanic material with only low p content
Plot 8 is a poor chemical representative for soiltype 1

3 3

4.1 Chemical fertility regeneration; related with fallow age?

It is stated is that an increased lenght of the fallow period results in an increased yield in the subsequent cultivation period or an increased possible lenght of that period.

Data can be found in the annexes or the next par.

Hypothese 1A It was expected that during the fallow period the chemical status of the soil would regenerate. This should be shown by an absolute increase of the nutrient content of the topsoils, stabilising in time.

Hypothese 1B The increase is only observable through stratification

Monitoring the changes with fallow age requires much time. Thus 28 plots were established and their age since the last period of cultivation was recorded.
Soilprofiles were described and sampled at 3-4 depths.
Over the soilsurface, compound samples of topsoils (20 cm.) were taken during the dry season (february).
Analysed was PH, C%, Ntot, Ptot, bases (Ca,Mg,Na,K) and the CEC.
To get a first impression, the data were correlated by lineair regression with the fallow age. This has been done for all 28 plots together. as well as for the data divided into strata (4 soiltypes). (The division into strata is not recommended statistically because only few figures are left available per soiltype).

None of the chemical data, or ratios of them, of the topsoils were significant correlated with fallow age (see annex 0). Stratification into soiltypes resulted in an strong reduction of the variability. Regeneration per type could however not be observed.

* Methods
As an example the results for C% are shown, which were still best correlated. The values of this parameter are hardly interpretable and it can be doubted if the figures are significant. (r= correlation coefficient)
r= 0,1 all data
r= 0,26 soiltype 1 (basfond)
r= 0,52 soiltype 2 (basglacis)
r= -0,67 soiltype 3 (accidented)
r= 0,83 soiltype 4 (lateritic)
Soiltype 1 has high absolute values for C% and receives

yearly fresh deposits, independent from the age of fallow. (n=8).
The correlation for type 2 is not significant. (n=12).
Type 3 indicates a decrease in C% with growing age. (n=5).
Type 4 shows a significant correlation but the number of values (3) is in fact far too low to permit interpretation. (n=3).

At least, the C% does not significantly increase with age. This could be expected because the C which easily mineralizes during cropping forms only a small part of the total soil organic matter.

* Conclusion

It can be concluded, from the given data and the considered relationships, that no chemical regeneration could be observed.

This conclusion can be confirmed by studies of savanna soils, under the regime of farming practises with relative short cropping periods. (Ohler, 1982, Prudencio, 1987, Pieri, 1989).

Hypothese 2 regeneration as expected exists (input exceeds output during fallow) but is obscured by other variables. Sampling stratification can reduce their effects.

The large variability in data, induced by the variability in experimental plots, was already expected (and expressed).
The original intention was to produce a soilmap, at which base (among others) the locations of the experimental plots could be selected. However, the locations of the plots were selected, based on some practical reasons as well as on environmental criteria, what has been done before arrival of the author. The intended homogenity of the parameter 'soil' was already determined using the appearance of the soilsurface as criterium.
A first sight at the soilprofiles, and at their geomorphological and hydrological context made clear that the differences among the selected plots, and number of variables involved, are too great to provide a base for a comparative study.

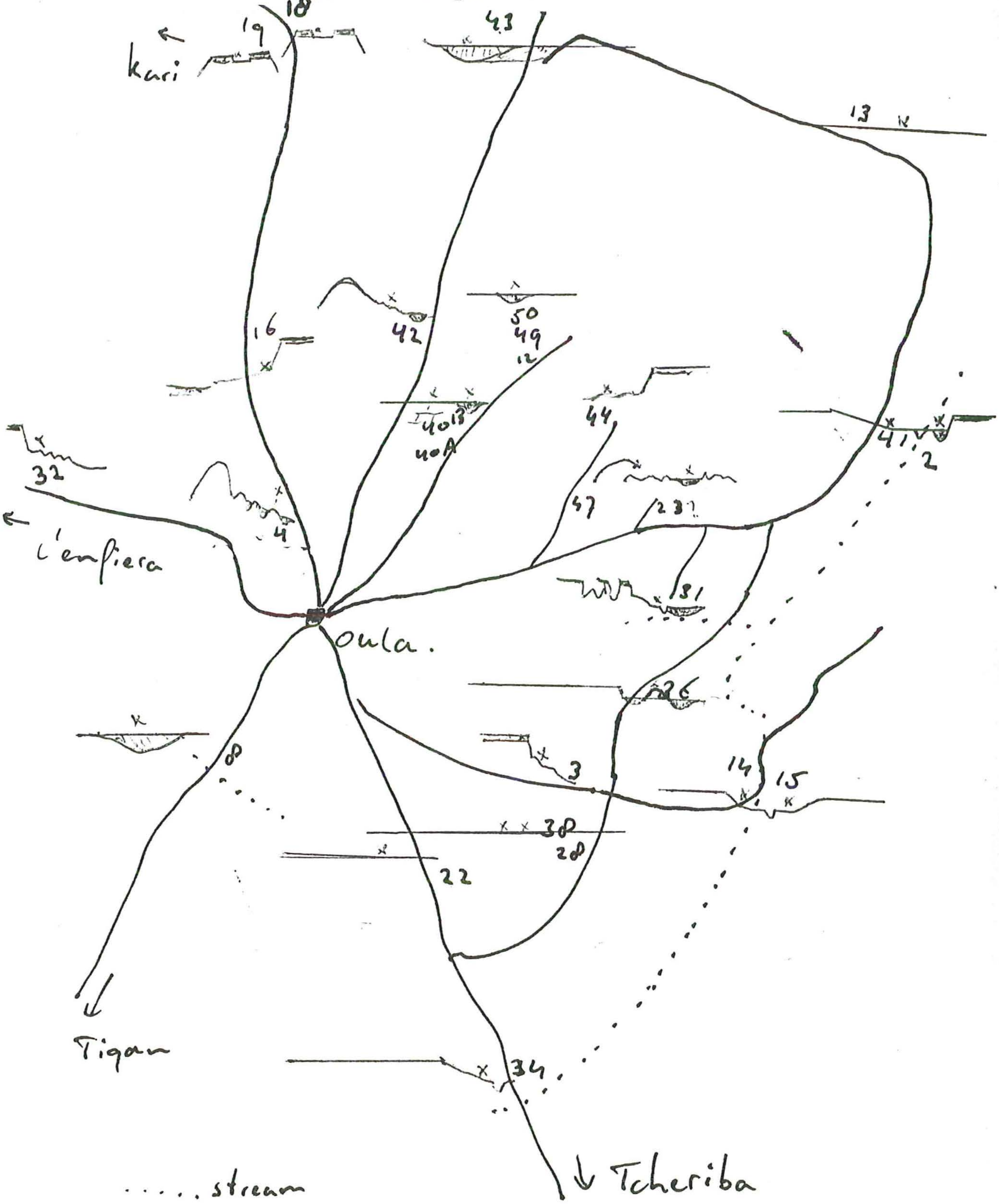
Conclusion; variability in age is very likely too be totally obscured by stronger determinants.

* The method of lineair regression is very simple and restricted. As it is unknown what contribute significantly to the variability of the chemical data, the use of statistical methods as principal component analysis or multi-variate analysis could determine some fixed parameters.
- Topsoil texture could not been used as an criterium as that was similar for practically all plots (loam to silty loam).
- Arrangement according to the clay mineralogy of the soil, determined with the rule of the thumb; sticky or non-sticky consistence, resulted in 2 groups of an acceptable amount of data. Sticky soils in the area have high values for CEC (montmorrilonite; exchange buffer).
- In the Soudan zone is the distinction along catenas recommended (Ahn, 1970, Menaut, 1985, Jenny, 1965, Boulet, 1978).
- Concentric zones, related with management intensity, is also a good base for comparison (Prudencio, 1987). Sanchez (1976) mention a decrease in absolute amounts of N with distance.

The extremely poor correlations observed in par.1.3.3, even after the main stratification determined the decision not to execute such an analysis.
For a proper experiment is it advisable to reduce the number of variables incorporated.

* Study of regeneration with age should be conducted for several years, without changing the location.

Location of exprimental plots.



Hypothese 3 regeneration can be contributed to other variables than the soil fertility

This is surely partly true. The increased soil surface cover reduces run-off and increases infiltration. According to Pieri, the risk of topsoil degradation can be assessed with the ratio (o.m.% / clay + silt %).

Conclusion: For topsoils in Oula the texture is all loam to silty loam (due to transportation processes as observed !). Because no increase in C% was observed, is this hypothese not confirmed.

The soils of especially the basglacishave a high risk or are already degraded (ratio > 9). Pieri has used this test for sandy topsoils (sand > 80%), while in Oula the sand % is 30-40.

This process of erosion is inherent to the savanna landscape, which is constructed for the greater part of long but slightly sloping plains of colluvium (Nye, 1960), but probably intensified by the management practises. The soils of the basfond are yearly eroded but also receive new deposits. The soils of the basfond do receive yearly fresh deposits.

In fact also no increase of the total soil cover%, as determined with the step-point method is observed.

Soil cover (%) on basfond (1) and basglacis (2)

			var.coef.(%)
-All trees and shrubs	1.	41	60
	2.	70	30
-Without remaining karitees	1.	24	60
	2.	50	45

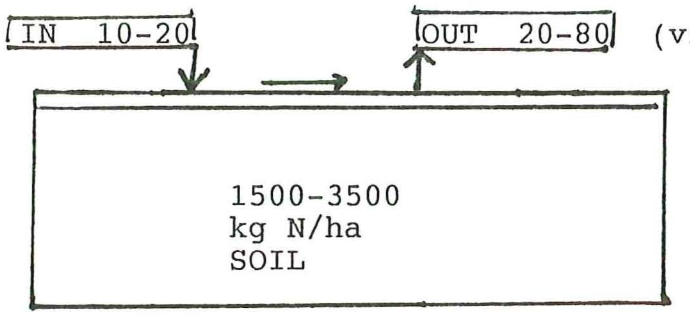
Hypothese 4 regeneration implies an increased amount of nutrients, while soil storage hardly changes

Recent input-output studies in Burkina Faso (Stoorvogel and Smaling, 1990) and south Mali (v.d.Pol, 1990) estimate net negative balances of the soil for N and P during cropping of resp. 25-60 and 3-6 kg/ha.year.

The input for Sorghum is estimated at about 12 kg, and at about 8 kg/ha.year if not manured (deposition and fixation). These input values are also illustrative for the amounts during fallow. (N and P in the above ground part of Sorgum is resp. about 25-30 and 3 kg/ha, thus a part is lost from the soil-vegetation-agriculture system.

The total amounts for N and P in the topsoil of 20 cm. are about resp. 1500-3500 kg N/ha and 400-1200 kg P/ha.

Conclusion: The amounts of input and output fall thus in the range of the analitical error of the soil amounts, and is thus not observable.
The total amounts are very site-specific.



(vice-versa in fallow)

Hypothese 5 Eventual extra input is locked in the vegetation, and the soilfertility profitates from the recirculation by an increased quality of N and P soilstorage (availability)

Although the total amounts of nutrients in soils of the zone are high, the uptake seems to be limited (Penning de Vries and Djiteye, 1982).
Probably are exhausted only the nutrients easily available, which form often only a small part of the total amounts. The total amounts are large and form the buffer of the ecosystem. Changes in nutrient content are then hardly observable.
No data are available about the several soil stores with various degrees of resistance as explained in the previous chapters. This fifth hypothese is most probably true but cannot be confirmed. It can however be checked if the amounts in the biomass increase.

It is correct that the total vegetative storage increases with time. See annex 3,4 and 6. This is however implicit to biomass production. The figures do not indicate if the increase is the result of an increased (or progessively increasing) input, or does result from the soil store (the last would implie that he system of Oula is yet in a degrading trend).

The yearly uptake figures are not reported as these are not interpretable. The woody biomass is extremely variable over the plots. No compensation could been made for the karitees which are remained during the cropping period. Thes results in an overestimation of the apparent yearly uptake.

The grasses are assumed to turn-over every year. Their contents are at least the minimum values which are taken up (ignoring N fixation). These amounts are slightly higher than crops do take up and highest in the basfond (30-35 kg/ha).
The total amount is however on the basglacis highest (trees and bush). Thus unknown is the yearly uptake.

The return can be estimated from the actual data. The amounts in the leaves are slightly lower than in the grasses.

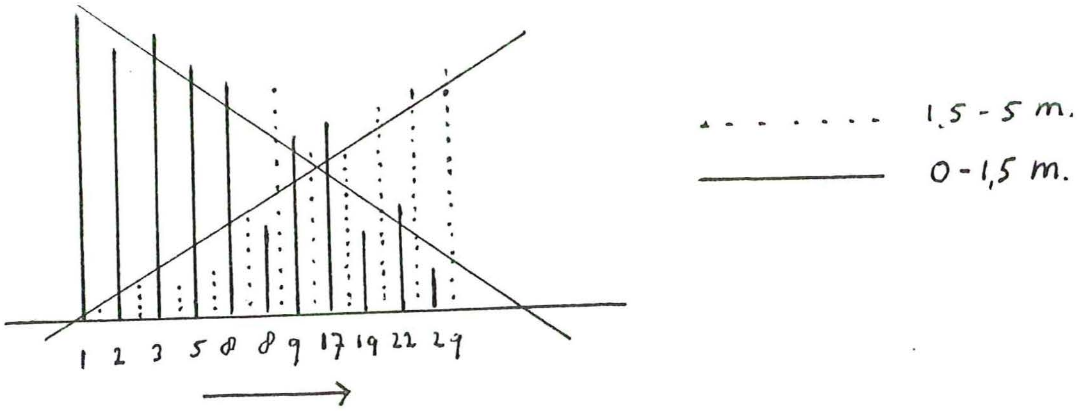
The bulk of N and P is however the amount in the wood, which is highly variable but seems slightly correlated with age. Unknown is their contribution in the recirculation. Estimations in sub-humid savannas of India (Lamotte and Bourliere, 1983) state that 120-150 kg N/ha returns to the soil, if total biomass content is 140-170 kg N/ha.

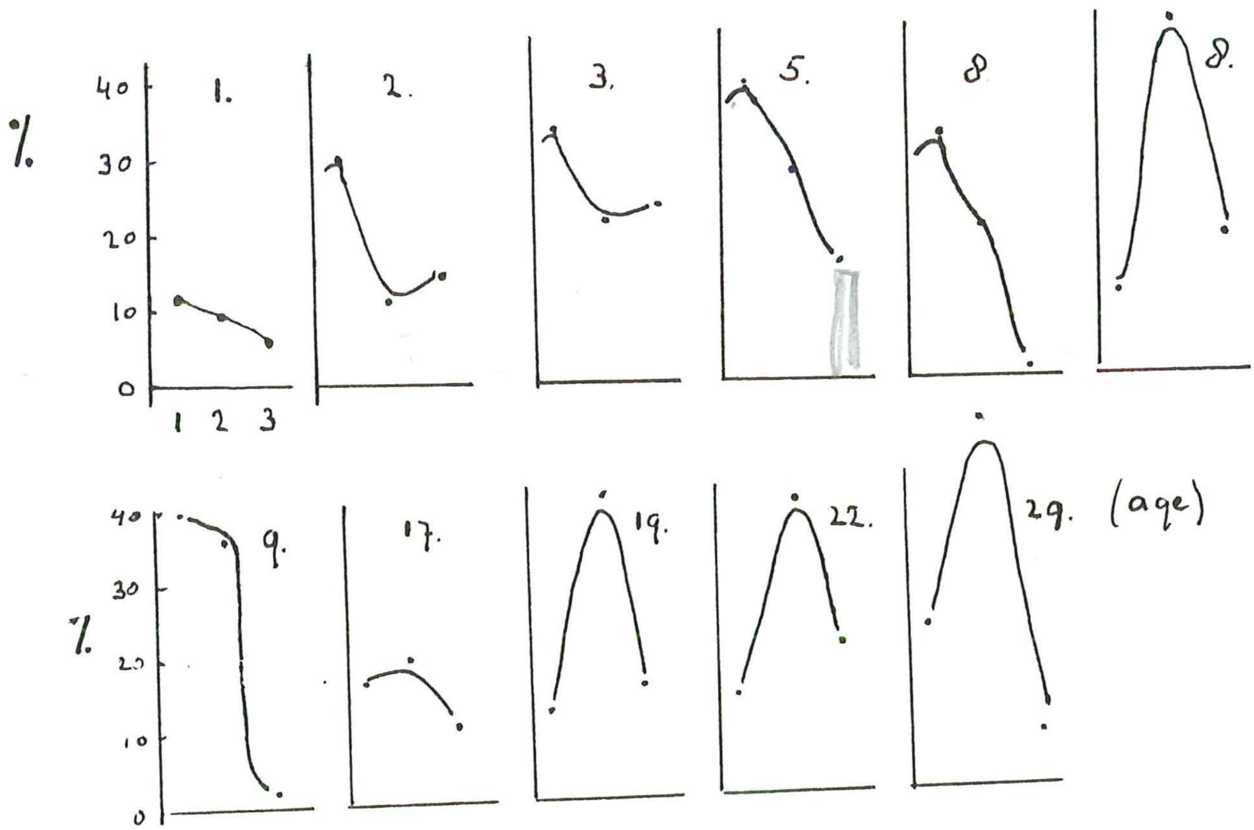
The P return is relative less compared to the total vegetative amounts, what is very strange. (Losses with fire and volatilisation do not affect P).

The contribution of woody species depends also on grazing and fire, which differs for bushes and trees.
Relative amounts stored are unknown. With the step-point method, the relative contribution in soil cover is known.

Illustrated is the cover without karites (that differences fades away with age), on the glacis soils. The structure knows a development, which is only mature at high ages.
For the basfond this trend is slower, or even absent (due to the intense fire regime).

1. 0-1,5 m.
2. 1,5-5 m.
3. > 5 m.





Thus, the relative contribution of the woody species increases, but amounts are unknown. Independent of the total amounts, qualitative changes may be observed.

The C/N ratio of the residual material decreases thus. This ratio is often used as an indication of the quality of the soil o.m. The critical ratio in savannas may be estimated at about 20. (values in Oula, see further comments of Penning de Vries and Djiteye, 1982, de Ridder et al. 1982, Greenland and Nye, 1960, Driessen, 1983, Bolt and Bruggenwert, 1978, Dabin, 1978). Material of lower ratio is thought to know a net mineralisation, material of higher ratio is net immobilised in the microbial tissue. Thus:

Bio-chemical regeneration of the availability of N implies a lowering of the C/N ratio of the soil o.m. ?

Crops taken over by grasses (both high C/N ratio) at start of the fallow. Fire and grazing will keep the soil C/N high. Elder fallows, with relative low grass/tree-bush ratio may lower C/N ratio, because of their lower C/N ratio, low impact of fire and grazing, and the humification of the grass roots.

The topsoil parameters do not change parallel with the vegetative changes.

C/N does not decrease with age. Two comments:

- Net immobilisation only occurs at high C/N ratios, what increases the humic stock slightly (lowering C/N). Simultaneously the deposition of litter, with lower C/N ratio than grass litter, increases absolute and relative with growing vegetation. But regeneration does not significantly change the soil C/N because the C/N ratio of fresh deposits of trees is also very high.
- The soil C/N ratio does not indicate the availability of N, because it is the humus which has a low C/N value (8-15), but which is also most resistant to decomposition and thus the least available N source.

  (This resistant store is the largest and does hardly change (that has to be the intermediate store as indicated by de Ridder et al, 1982). Again, changes are not visible).

Complicated?; it is the fresh material, easily decomposed by action of soil macrofauna, which leaks nutrients, and which knows a net immobilisation. However in the mean time there is also mineralization which releases a temporary inorganic N excess. Both vegetation and microbes compete and profit. although microbes (immobilization) are apparently stronger.

Differences are found for the C% and C/N ratio among the different soil types.

Regeneration implies an increase of the relative available fraction P in the topsoil

What about the bio-chemical availability of P ?
The P in the basfond is primarily provided by weathering of minerals (low C/P ratio; 66).
The glacis topsoils have C/P ratios common for humus (90), what is still much lower than for the soil o.m. (including litter; 140).
Bas glacis soils are thus also still mainly provided by mineral weathering, instead of release from fresh deposited vegetatitive material (high C/P).
P release is optimal inbetween PH 6-6,5.

The PH hardly changes and is about optimal (6,5-7).
The vegetative cycling P seems to be a minor P source.
At high PH, due to fire, the P can precipitate as Ca-phosphates, especially in the Ca-rich basfond.
Fire results in an decrease of the C/P ratio.

conclusion: The P is very likely not to be regenerated during the fallow. The contribution from weathering minerals is dominant and result in high total P contents.

Estimation of the P, available for uptake has not been done for Oula. Greenland and Nye (1960) mention ratios Ptot./Pav. of 20-100. Eventual exhaustion during cropping must thus be easily be replaced.

conclusion:
An eventual improvement of the biochemical availability of P during fallow, is unlikely for the basfond soils, because the total amounts are large, and the PH is about optimal, although slightly too high. Similar comments for the glacis soils, although in a lesser extent.
The C/N ratio is a poor indicator of the availability of N.

Hypothese 6 Regeneration implies an increase in the topsoil-vegetation system from the subsoil

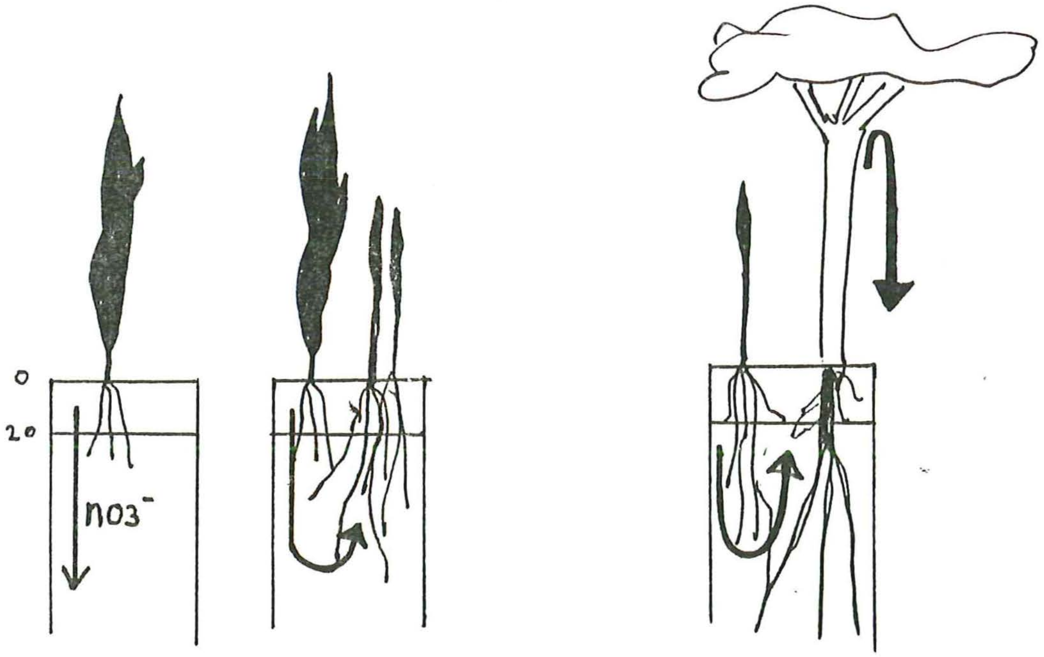
- The deep rooting natural vegetation finds its extra input from soil layers below 20 cm. This is very likely if one realise that NO3- and NH4+ are soluble, but hardly leach beyond the reach of grass and tree roots (pps, 1982). During cropping however the N gets unavailable for crops, but gets more and more available for the competing grasses.
- P is released from weathering primary minerals, presented through the soil body (especially in soiltype 1), but very insoluble. The more extended rooting system of the natural vegetation can activate this P again.

It is thus likely that the regeneration period implies, among others, an increase of the total amount of N and/or P by pumping it up vegatively (recycling), what brings it in the reach of seedlings. This redistribution through the soil is not quantified for Oula.
In fact this phenomene is an increase in the availability of N and P. Not for plant uptake, but for crop uptake specifically.

Conclusion:

It is unknown if the explanation for the vegetative increase is dominated by the pumping action of the increasing rooting system or by an increased input from out of the soil-vegetation system.

A. crop B. crop-grass competition C. fallow
--->
time



Hypothese 7 Regeneration implies an increased availability of N and/or P, either from atmosphere, subsoil, erosion/deposition or biochemical

The concentrations of the vegetation can be followed. No reliable data are available for trees and bushes. The grasses however do regenerate yearly.

Many comments can be made about the ecological competing interactions of grasses and trees, competing for water and in a later stadium for light, as well as the variable soil surface cover and sequence of changing vegetation structures concerning height classes, but the concentrations do seem to increase (see annex 8).
In the basfond both N% and P% increase. The rest shows rather constant but fluctuating values. The P% of the haut glacis seems to increase too.
The P/N ratios are high, even exceeding the max. ratio mentioned for grains and grasses (0,16). This indicates relative N shortage in especially the basfond.

- The effect in the basfond can be the result of the deposition by lateral water movement. The topsoil does not increase its content, but the material is simply depostited on top of the former soil body. Also is the impact of the fire regime very strong, what limits tree regeneration.
- more likely is that the P is in relative excess during the latter phase of the growing season, because much of the released N is then immobilised. The P uptake is limited by N shortage.

conclusion 7: although the regeneration seems to be visible by an increased % in the grassy tissue of the basfond, these are the terrains which are left in fallow for short periods only, actually.

CONCLUSION

- The tests have not been able to provide a conclusion about the eventual increase of the availability of N and P during fallow.
- The available parameters are not suitable to test the hypotheses.
- Amounts in the topsoil are very high, compared with the amounts in the total input-output balance and with the amounts which cycle through the soil and vegetation system. Although these small amounts are surely significant makes it a quantitative evaluation of total soil N very difficult to interprete. Recent balance studies indicate this complexity (see par. 4.2).
- Trends were strongly obscured by local differences, and stratification is necessary. More data are necessary for statistical relevance.

4.2 Regeneration, assessed with balance principle

The results of the hypotheses of par. 4.1 are hardly interpretable.

4.2.1 Input and output transfers

The calculation of the nutrient balance can give an indication of the total amounts lost during the cropping period. The fallow period should restore this amount in principle.

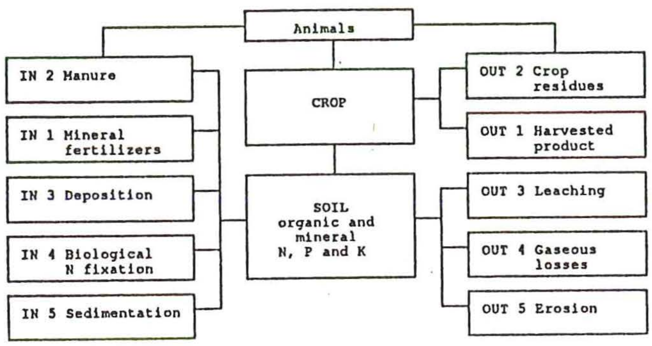
Because of the extreme variance in data in literature, balances derived from recent balance studies are indicated.
These balances are primarily focused on the cropping period.
v.d.Pol (1990) indicates ranges from optimistic to pessimistic scenarios.
The yearly balance of fallow is only calculatable within even more wide ranges and more assumptions have to be made.

An example of a semi-quantitative characterisation of the nutrient balance of a homogeneous entity in time and space is the study of Stoorvogel and Smaling (1990).
The study comprises the assessment of the soil nutrient depletion of the Sub-Saharan countries, Burkina Faso included. The calculation per country is based on their agro-ecological zones (what they call the land/water classes, which provide an indication of the general water availability to crops over large regions), which are divided into Land Use Systems (LUS). The LUS is the well defined tract of land (Land Unit, LU) with its pertinent Land Utilisation Type (LUT), and is thus the spatial homogeneous entity. In order to prospect the nutrient depletion are the balances calculated for two intervals of time; 1983 and 2000.

They state that in spite of the relative 'volatile' nature of the many factors affecting soil fertility, a relatively simple model should serve the purpose of simulating the processes.
The model of the considered processes is presented in fig. #
The eleventh process is the cropping intensity (CI), which indicate the presence of fallow land when less than 100%
However the CI is not specified per LWC in the report. The values of input of fallow (for the cropping period) are set irrespective of the LUS at fixed values of 2 kg N, 2 kg P_2O_5 and 1 kg K_2O /ha,year.

The LUS balance presented in the fig. is part of:
UR-L, indicating uncertain rainfall (120-179 growing days and a suitable soil quality), low management level 845 mm rainfall, moderate soil fertility.
This contributes to about 60 % of the land surface of Burkina Faso
The N and P balances of the Land Use System is most comparable with the situation of Oula, 1983

N	IN 1.	2.	3.	4.	5.	OUT 1.	2.	3.	4.	5.	total kg/ha
millet	0	4	4	4	0	10	9	4	9	10	-30
sorghum	1	3	4	4	0	9	6	5	9	10	-27
cotton	8	0	4	4	0	19	0	4	25	10	-42
P2O5	IN					OUT					total
millet	0	2	2	0	0	7	4	0	0	4	-11
sorghum	1	3	2	0	0	8	6	0	0	4	-12
cotton	5	0	2	0	0	22	0	0	0	4	-19



Nutrient flows in the soil.

4.2.2 Regeneration period as assessed by N and P balance

If the balance of the soilstore is positive during fallow, the loss during the cropping period can be balanced.
The above studies can be applicated to indicate the balance of 6 year cropping (without mineral and organic fertilisation, and a loss of crop residues; an apadation to the particular situation of Oula).
Application of the balance study of v.d.Pol (1990), conducted in the south of Mali and comparable in respect of climate, soil and agricultural management is seperated in 3 strata.
Both pessimistic and probable value do incorporate similar low amounts of fertilisation.

* The balance of 6 year cropping (basglacis) is:

(sorghum *4) + (millet *2) = negative balance (kg/ha)

N	31	*4	+ 34	*2	= 190	
P_2O_5	16	*4	+ 13	*2	= 90	= 10P
N	23	*4	+ 34	*2	= 156	(optimistic)
N	32	*4	+ 47	*2	= 222	(probable)
N	44	*4	+ 61	*2	= 398	(pessimistic)
P	1,0	*4	+ 1,3	*2	= 6,6	(optimistic)
P	2,8	*4	+ 3,2	*2	= 17,6	(probable)
P	5,4	*4	+ 5,1	*2	= 31,8	(pessimistic)

* Fallow balance

Stoorvogel and Smaling:
Fixed input of 2 kg N /ha.year, and 2 kg P_2O_5 /ha.year.
This requires a regeneration period of resp. 100 years and 50 years.

v.d.Pol:
4 kg N /ha.year, and 2,3 kg P /ha.year (optimistic)
Regeneration of the 'probable cropping balance' requires resp. 55 and 8 years

5 (neg.) kg N /ha.year, and 0,5 kg P /ha.year (probable)
Regeneration of the 'probable cropping balance' requires resp. infinitive and 35 year.

Tried was to calculate the balances, estimating input and output based on data from literature.
These show however an enormous variance. (Therefor the balances were simply copied, what gives at least an indication of possible values). Detailled reportage on the subject of N cycling is out of the scope of this study.

To base the calculations on the actual data of Oula (soil and vegetative content) proved to be difficult. The amount of assumptions to be made is high. The impact of the assumptions is also high and influences the balances significantly.
The following is based on mean values for the whole succesion of the fallow on the basglacis. Most values will change in reality, especially the amounts lost by fire and the residues returning to the soil. I was however not able to estimate the contribution of the amounts in bushes and trees.
The following is thus only an indication of the order of amounts of the balance of the soil solution (is not the soil balance).
Still a net mineralisation.
These figures cannot be used!

	kg N/ha.year	kg P/ha.year
INPUT	95	18
fixation	5	0
deposition	5	2
residu, manure	5	2
residu, rest	25	5
mineral weathering	0	5?
mineralisation	55	4
OUTPUT	80	5,5
fire	20	0
volatil, manure	5	0
volatilisation	5	0
exploit.+ growth	10	2
leaching	0	0
denitrification	2	0
erosion	3	1
immobilisation	35	2,5
Net	+15	+12

The calculation of the values in the basfond are probably more easy, because the situation is more stable.
Both input and output will be higher.

Now the regeneration of N and P would require resp. a lenght of

Stoorvogel and Smaling		probable variant of v.d.Pol	
N	13 year	N	15 year
P	10-15 year	P	1,5 year

Data from Penning de Vries (1980) indicate rates of outflux during cropping on savanna lands of 23 kg N/ha.year. Influx during grazing 6 kg N/ha.year.
6 year cropping means a loss of 140 kg/ha.
Balancing this loss, the lenght of the fallow period should be 23 year.

4.2.3 Regeneration period, assessed by the compensation for the intermediate store

When assuming a steady state situation, from the onset of the fallow, the mineralisation, immobilisation, growth, residues etc are of no importance, and only total input-output figures are esential.
With the estimated figures (see above) the total input in the vegetation system would be lower than the total output during fallow. This is a net loss !

Singh et al (1980) indicate in Nigerian savannas a net total gain of 5,4 kg N/ha.year (in= 52,4 out =47 kg) for a LUS of rotational bush-fallow.
For semi-intensive LUS the total balance is negative; -4,5 kg N/ha.year (in= 75 out= 79,5).

The values of Penning de Vries (1980) do also indicate values for Sahelian conditions. Both cultivation and fallow (grazing) implies a net negative balance (resp. -12 and -6 kg N/ha.year).

Penning de Vries had made much assumptions, which are unknown. One can see that the balance during fallow can be negative as well. With the actual trend of degradation it is evn expectable.

Independent of the impossibility to compensate the loss induced with cultivation, is it still possible to regenerate the land under a degrading trend. The system is then not sustained (?) but the nutrients store, necessary for cropping is restored.

Using the figures from Pieri (1989), adapted to the Oula situation, the intermediate store contains about 400 kg N/ha. (See next par.).
The mineralisation and the immobilisation are assumed to be 1,8 times as high as in the p.p.s diagrams, because the soil amount is 1,8 times as high. The yearly immobilisation is then about 35 kg N/ha (Mineralization is then 55).

That requires 400/35 = 11,5 year to regenerate.

This method must be possible to be approached more detailled. Unknown is the start amount in this store, and also not the amount which can be reached in a reasonable time.
Independent of all processes, one can measure these stores, the mineralisation rate, and estimate the related immobilisation. Principle as explained in par. 3.7

4.3 Mean values per land unit

soil data

Although the soil samples were originally analysed in order to contribute the variability in data to the eventual change with age, is it possible to contribute that variability with other (soil) parameters, independent of the fallow age.
The correlations with other parameters than age are mostly stronger and can form a base for a seperated approach of the age-soilparameter evolution per distinguished soiltype.
Mean values and variance coefficient per soiltype and per layer are given. (Layer 1= 0-20 cm., 2= 20-50 cm., 3= >50 cm. approx.).

	SOILTYPE 1 (n=8)		SOILTYPE 2 (n=11)		SOILTYPE 3 (n=2)		SOILTYPE 4 (n=6)		ALL (n=28)	
layer										
	PH									
1.	6,7	3%	6,5	4%	7,4	0,1%	6.6	6%	6,6	5%
2.	6,6	3%	6,1	6%	7,2	0,7%	6,1	8%	6,3	7%
3.	6,9	7%	6,3	6%			6,4	7%	6,6	9%
	C%									
1.	2,0	25%	1,3	26%	1,1	33%	1,7	26%	1,6	30%
2.	0,9	29%	0,7	23%	0,4	15%	0,6	32%	0,7	32%
3.	0,5	19%	0,6	36%			0,5	34%	0,5	33%
	N%									
1.	0,10	31%	0,07	30%	0,09	45%	0,09	31%	0,08	33%
2.	0,05	21%	0,04	35%	0,03	42%	0,05	50%	0,04	37%
3.	0,04	28%	0,03	79%			0,03	60%	0,03	58%
	P%									
1.	0,04	54%	0,01	29%	0,05	90%	0,03	30%	0,02	70%
2.	0,02	28%	0,01	23%	0,06	103%	0,02	19%	0,02	88%
3.	0,02	40%	0,01	33%			0,02	26%	0,02	122

CV = SD/mean

CEC The cation exchange capacity depends mainly on the type of organic matter (humus) and claymineralogy. The difference among locations is more pronounced determined by the clay mineralogy (as determined by the parameter 'sticky-ness') than for organic matter content (C%).
CEC= 20-25 meq/100 gr. for sticky soils (type 1 and 3)
CEC= 5-10 meq/100 gr. for not sticky soils (type 2 and 4)

- The CEC is moderately correlated with C%, N%, P% for the non-sticky soils (soiltype 2 and 4),
C% - CEC, r2 = 0,60
N% - CEC, r2 = 0,44
P% - CEC, r2 = 0,40
Sticky soils do not have any correlation.

- C% - CEC correlation per soiltype
1. r2 = 0,001
2. r2 = 0,64
3. r2 = 0,60 r = -0,8 (!)
4. r2 = 0,83

Organic matter (C%) does significantly contribute to the CEC for the basglacis and haut glacis soils (type 2 and 4). The CEC for type 1 and 3 is primary determined by the presence of 'active 2:1 clays' as montmorrilonites.
The negative correlation for the shallow soiltype 3 is probably due to the strong impact of erosion in that terrains. C of the topsoil is washed away, what brings up the newly formed montmorrilonites.

C/N The correlation of C% with N% is strong for all 4 soiltypes, what seems to indicate that the N is released (mineralized) in order to keep the C/N ratio constant (Morris et al, 1982). They state however that this is the case with low C/N values.
1. r2 = 0,96 C/N = 20
2. r2 = 0,90 C/N = 20
3. r2 = 0,74 C/N = 13
4. r2 = 0.98 C/N = 18

The high values of C/N do indicate a large amount of the N immobilized in microbial tissue, or a relative high portion of not decomposed dead vegetative material (C/N of the stable end product of humus = 8-15), probably for the greater part litter of grasses. This forms the easily decomposable but also easily immobilisable N source in the next rainy season.

Amounts in the intermediate form

Figures obtained from Pieri (1989) and Egoumenides et al (1987) of ferrugineux soils soils of Burkina Faso are adapted to the data of Oula. This procedure is not possible for the basfond soils as no comparable data are available.

NHd is rather constant (100-150 ppm)
- If the total amounts are high then NHnd > Nhd.
NHnd increases proportionally with total content
- If total amounts are low NHnd slightly > Nhd

Estimation during fallow

Ntot	= 2000 (kg/ha)	(not hydrolisable part is not measured)
NHnd	= 1500	(about constant)
Nhd	= 450-550	(intermediate; increases in principle)
N,KCl	= 0-60	(released with wetting)

not intermediate.

Organic P is 0,7% of C% in the total soil organic matter (Penning de Vries and Djiteye, 1982).

kg/ha	Basglacis;	Basfond;
Porg.	270	400
Pmin.	180	750

The organic cycling P on the basglacis soils is thus an important P source for cropping.
The basfond contains still large amounts of weatherable minerals.

basglacis	Basfond	
Ptot = 450	1150	
Pass = 75		(Olssen in Pieri, 1989)
Pav. = 4,5-20	12-55	(Nye and Greenland, 1960)
Pcrit= 40-90	80-160	(tov. Ntot, Driessen, 1983)

vegetative data

As described above are the classic soildata difficult to interprete in respect of availability of soil nutrients. Vegetation data however are the reflection of the state of the nutrient providing capacity of the soil. Relative qualitative statements can be given.

Amounts minimal stored in grain crops at a yield of 800 kg/ha. derived from v.Keulen (1983) are;
In the grains 8 kg N/ha and 0,9 kg P/ha
In the straw 3 kg N/ha and 0,4 kg P/ha
This amount can rise what implies an improvement of the quality. Beyond an annual precipitation of about 800 mm. (about the situation of Oula) the concentration lowers.

It would thus be very interesting to sample grains at young and elder fields, during generative and flowering stage, in order to check if N (and P) are uberhaupt in shortage or do get in shortage, or do loose competion with grasses.
These data are more reliable and interpretable (see Guinko, 1989).

The total amounts of N and P transfered in, out and through the system determine the absolute quantities cycling within the system. Quantification allows relative comparison.
(var.coeff. in%)

Soiltype	20 cm		veg.		grass	bush	sorghum	millet
N (kg/ha)							25	27
1	3200	(21)	84	(68)	26	58		
2	1850	(26)	155	(110)	17	138		
4	2600	(23)	106	(82)	14	92		
P (kg/ha)							2,7	3
1	1150	(48)	20	(72)	8	12		
2	450	(37)	33	(100)	3	30		
4	650	(25)	20	(87)	2	18		

biomass grass (kg/ha)	
1	3550
2	3500
4	2000

It can be seen that the total amounts in both vegetation and soil differ among soiltypes. Higher amounts in the soil is not related with higher amounts in the vegetation.
The total vegetative uptake is difficult to interprete because of the unreliability of the data on woody vegetation. The grasses indicate the annual uptake.

The soils of the basfond are considered as one of the most fertile of Burkina Faso.
The regeneration of the vegetation on these soils takes a very long time, but the fallow period is short and seems to be able to regenerate the soil properties.
The biochemical availability seems to be contineously enriched by the annual flooding, on the cost of the productivity of the higher grounds (the ferruginous soils of the basglacis).

Although the amounts stored in the topsoil of the shallow lateritic soils (4) is higher than in the basglacis soils (2) is the amount in the vegetation lower, as well as the annual uptake by the grasses.
This is probably simply due to the lower water-uptake possibility in the shallow soils, but especially because of the lower real amounts in the gravelly soils (data are in mg/kg fine earth).
High annual uptake in the basfond may indicate that the annual uptake for crops is also favourable for crops. Nothing can be said about this, because the crops can be dominated by weeds as well.

The biomass of grass is about equal to the figures mentioned by Breman (2600 kg/ha), and is equal for both basfond as basglacis soils. Yield of cereals may thus be similar too. This is however also a conclusion which is based on assumptions. Millet for example yields 600 and sorghum yields 800 kg/ha, what is much lower than for grasses and apparently determined by their lower suitability in the area. The particular conditions of the basfond and basglacis may differ significant to determine relevant differences in yield of cereals.
This indicates the false pretention of the simple interpretation of balances.

De Ridder et al.(1982) estimate a N content in the aireal biomass, in the region with 800 mm.rainfall of 19 kg N/ha. Probably they mean the herbaceous biomass because the total amounts are much higher.

The P/N ratio during flowering indicates relative shortages, and range from 0,04-0,16 (de Ridder et al, 1982). (see annex 5)

	P/N	N/P	st.dev.	var.c.	n
soiltype 1					
leaves	0,17	5,8	2,7	46%	5
grass	0,3	3,3	1,2	35%	7
layer 1	0,30	3,3	0,8	24%	8
2	0,41	2,5	1,1	43%	8
3	0,47	2,1	0,9	44%	8
soiltype 2					
leaves	0,09	10,8	0,8	7%	3
grass	0,17	5,7	2,4	43%	9
layer 1	0,20	4,9	1,5	31%	11
2	0,29	3,5	0,9	26%	11
3	0,49	2.0	1,1	56%	10
soiltype 3					
leaves	0,18	5,5	-	-	1
grass	0,43	2,3	0,2	9%	2
layer 1	1,53	0.6	-	-	1
2	5,56	0,2	-	-	1
3	10,00	0,1	-	-	1
soiltype 4					
leaves	0,08	12,8	3,8	30%	2
grass	0,12	8,2	0,5	6%	4
layer 1	0,24	4,2	1,0	23%	5
2	0,48	2,1	0,8	38%	5

Conclusion: The P/N range as found for cereals must be different for fallow vegetation because the ratios do fall out of that range (0,04-0,16)

The relative relation between the soiltypes can be indicated very roughly.

Type 1
-soil:
relative high P/N ratio, ratio increases slowly with depth. Probably is a relative large portion of the topsoil P provided by inorganic (mineral) compounds.
-vegetation:
relative high P/N ratio; strongly out of balance, relative strong N shortage
Fertilize with N in the second half of the growing season

Type 2
-soil:
high P/N ratio, lower than for type 1. Increases more strongly with depth. Topsoil P is for a greater part bounded at organic material than in type 1
-vegetation:
rather high P/N ratio; slightly out of balance.
Fertilize both with N and P

Type 3
-soil:
extremely out of balance. An excess of P
-vegetation:
out of balance, the P/N ratio is relative low compared to the soil ratio. P uptake is thus limited by N shortage.

Type 4
-soil:
about as for soiltype 2
-vegetation:
P/N is comparable with soiltype 2, grass is even more in balance and here the P merges to be the primary limiting element.
Both N and P fertilization.

Generalities:
P/N ratio is lowest for the topsoils. This is due to higher the amount of organic material at what the N is bounded. The ratio increases to comparable values in the subsoils.
Higher P/N ratios in the topsoils go accompanied with higher P/N ratios in both the grasses and the leaves.
The grasses have higher P/N ratios than the leaves, probably because of the lower N% in grasses (lignine). This however implies a P/N uptake behaviour of trees more comparable with cereals than of grasses, what is strange, or a more efficient translocation of especially N in the trees than in the grasses, during the end of the rainy season. (Probably both; see figures

mean P/N grass = 0,25, leaves = 0,14, wood = 0,21).

Conclusion: N is primary limiting factor in the basfond for both grasses as trees.
The basglacis as well as the haut glacis (residual terrains) do have both elements limiting.
The grasses have an increasing shortage of P from the lower to the higher grounds with shallow soils. This is conform the concept of Penning de Vries and Djiteye (1982).

CONCLUSION

Objectives cannot be reached because data are not suitable. Use of data from literature, in order to quantify the N and P cycli in Oula, can only provide satisfactory results for persons, not familiar with the subject and the region.

It proved necessary to diversificate the land surface into 'homogeneous' units. This has two reasons:
- strong reduction of the variance of the data
- the context of the subject, the study of A.Compaore, requires a tool to evaluate landsurfaces, common in the region.

Ecological behaviour of the fallow vegetation, determinating the suitability of the soil for subsequent crops, cannot yet be characterised based on nutrient balances only.
However, careful use of nutrient balances will prove valuable for practical pragmatic purposes. Quantification in the region is still in its infancy, but also complicated.

Tried was to assess the regeneration period with 3 methods:
1. regression (increase of absolute amounts with time, stabilising when regenerated).
2. input during fallow must compensate the output of the soil-vegetation system during cultivation (N and P balance)
3. input during fallow must compensate the output of the soil, in order to make it cultivatable again (determination of the significant soilstore).

Quantification in this subject is best directed to the relevant system buffers (method 3), instead of all variables involved which are very fluctuative and site-specific.
The distinction of 3 or 4 forms of N in the soil is correlatable with resistance classes. These can be used to give an indication of the stability of an eco-system.
Within the ranges of pragmatic application, one may measure the intermediate N store, which amount in a fallow succession must stabilize in time (equilibrium in input and output of that store). Changes are significant in the periodicity of cultivation and fallow.
This assessment optimalises the possibility to meet the requirement of sustainability, as defined - chap. 2

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All

(0)

age , base saturation

Regression Output:

Constant	98.19610
Std Err of Y Est	10.50257
R Squared	0.185353
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	-0.56822
Std Err of Coef.	0.233623

age , cec

Regression Output:

Constant	13.14022
Std Err of Y Est	8.474551
R Squared	0.031828
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	0.174284
Std Err of Coef.	0.188511

age , C/N

Regression Output:

Constant	20.64697
Std Err of Y Est	2.299488
R Squared	0.064687
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	-0.06859
Std Err of Coef.	0.051150

age , %C

Regression Output:

Constant	1.550836
Std Err of Y Est	0.550885
R Squared	0.010190
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	0.006339
Std Err of Coef.	0.012254

age , N

Regression Output:

Constant	733.1939
Std Err of Y Est	294.8787
R Squared	0.057641
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	8.272014
Std Err of Coef.	6.559400

age , P

Regression Output:

Constant	229.8412
Std Err of Y Est	209.0273
R Squared	0.033536
No. of Observations	28
Degrees of Freedom	26
X Coefficient(s)	4.416457
Std Err of Coef.	4.649687

SOIL TYPE 1

age , base saturation

Regression Output:

Constant	87.97678
Std Err of Y Est	5.894509
R Squared	0.125818
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	0.246904
Std Err of Coef.	0.245984

age , cec

Regression Output:

Constant	23.40901
Std Err of Y Est	2.912459
R Squared	0.160793
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	-0.14075
Std Err of Coef.	0.121540

age , C/N

Regression Output:

Constant	23.40901
Std Err of Y Est	2.912459
R Squared	0.160793
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	-0.14075
Std Err of Coef.	0.121540

age , [redacted] N

Regression Output:

Constant	842.2753
Std Err of Y Est	215.0736
R Squared	0.519704
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	24.70129
Std Err of Coef.	8.975261

age , [redacted]

Regression Output:

Constant	22.02496
Std Err of Y Est	1.427401
R Squared	0.560347
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	-0.17792
Std Err of Coef.	0.059567

age , P

Regression Output:

Constant	404.4210
Std Err of Y Est	177.9968
R Squared	0.053450
No. of Observations	9
Degrees of Freedom	7

X Coefficient(s)	-4.67010
Std Err of Coef.	7.428006

Age / C %

C =	1,924
Std. err =	0,489
R Squared	0,0690
No. obs	8
D. Fr.	6
X Coef.	0,0272
St. ER. Coef.	0,040

SOIL TYPE 2

age , base saturation

Regression Output:	
Constant	101.1429
Std Err of Y Est	9.865095
R Squared	0.246583
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	-0.58666
Std Err of Coef.	0.341823

age , cec

Regression Output:	
Constant	7.525861
Std Err of Y Est	5.240548
R Squared	0.046614
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.120455
Std Err of Coef.	0.181584

age, C/N

Regression Output:	
Constant	20.18799
Std Err of Y Est	1.722571
R Squared	0.206145
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.091246
Std Err of Coef.	0.059686

age , %C

Regression Output:	
Constant	1.179672
Std Err of Y Est	0.337788
R Squared	0.043505
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	0.007488
Std Err of Coef.	0.011704

age , N

Regression Output:	
Constant	582.6505
Std Err of Y Est	160.3908
R Squared	0.006283
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	1.325769
Std Err of Coef.	5.557518

age , P

Regression Output:	
Constant	149.6127
Std Err of Y Est	57.27406
R Squared	0.003386
No. of Observations	11
Degrees of Freedom	9
X Coefficient(s)	-0.34705
Std Err of Coef.	1.984536

soil type 3 + 4

age , base saturation

Regression Output:	
Constant	108.4134
Std Err of Y Est	12.30973
R Squared	0.508950
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s) -1.36617
Std Err of Coef. 0.547843

age , cec

Regression Output:	
Constant	6.518313
Std Err of Y Est	9.281204
R Squared	0.297047
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s) 0.657714
Std Err of Coef. 0.413059

age , C/N

Regression Output:	
Constant	18.63807
Std Err of Y Est	1.555930
R Squared	0.155431
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s) -0.07276
Std Err of Coef. 0.069246

age , %C

Regression Output:	
Constant	1.440027
Std Err of Y Est	0.349172
R Squared	0.009034
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s) 0.003634
Std Err of Coef. 0.015539

age , N

Regression Output:	
Constant	788.0000
Std Err of Y Est	193.2779
R Squared	0.042905
No. of Observations	8
Degrees of Freedom	6

X Coefficient(s) 4.461153
Std Err of Coef. 8.601821

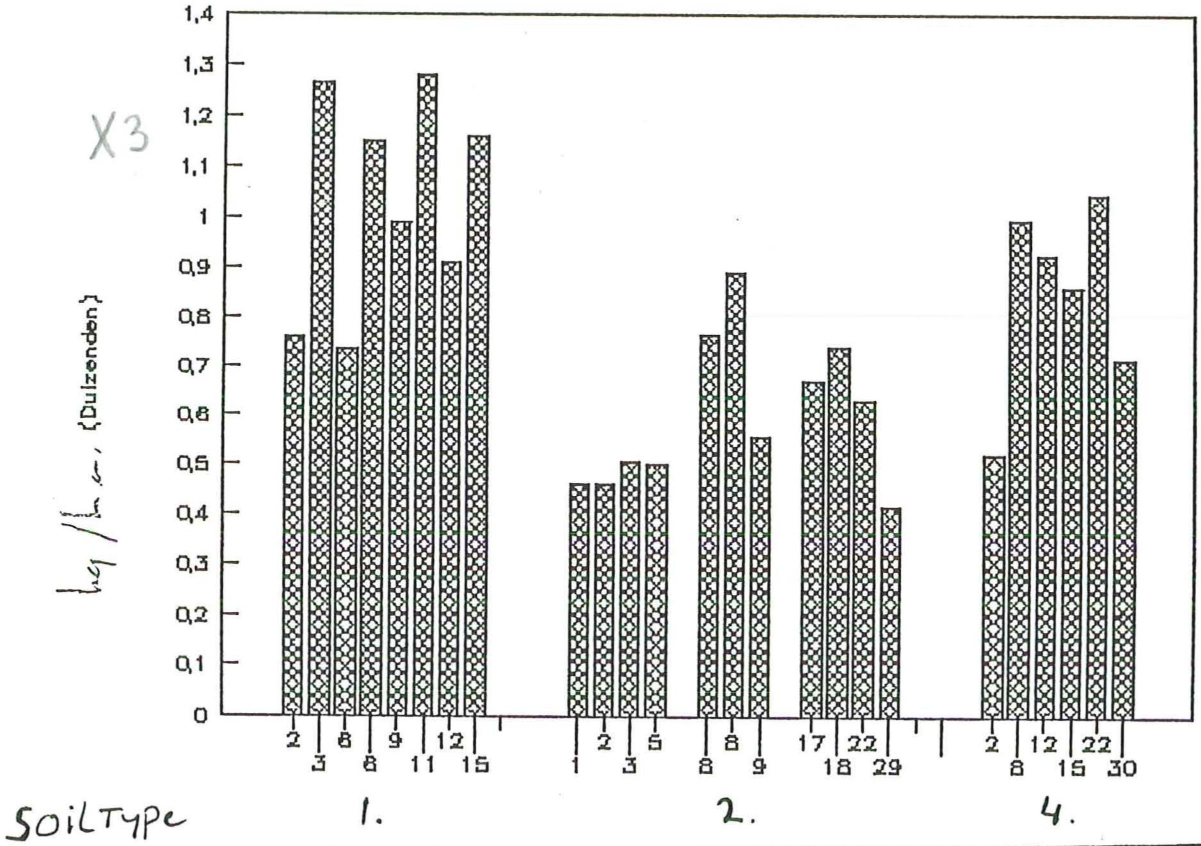
age , P

Regression Output:	
Constant	124.3305
Std Err of Y Est	261.2716
R Squared	0.275469
No. of Observations	8
Degrees of Freedom	6

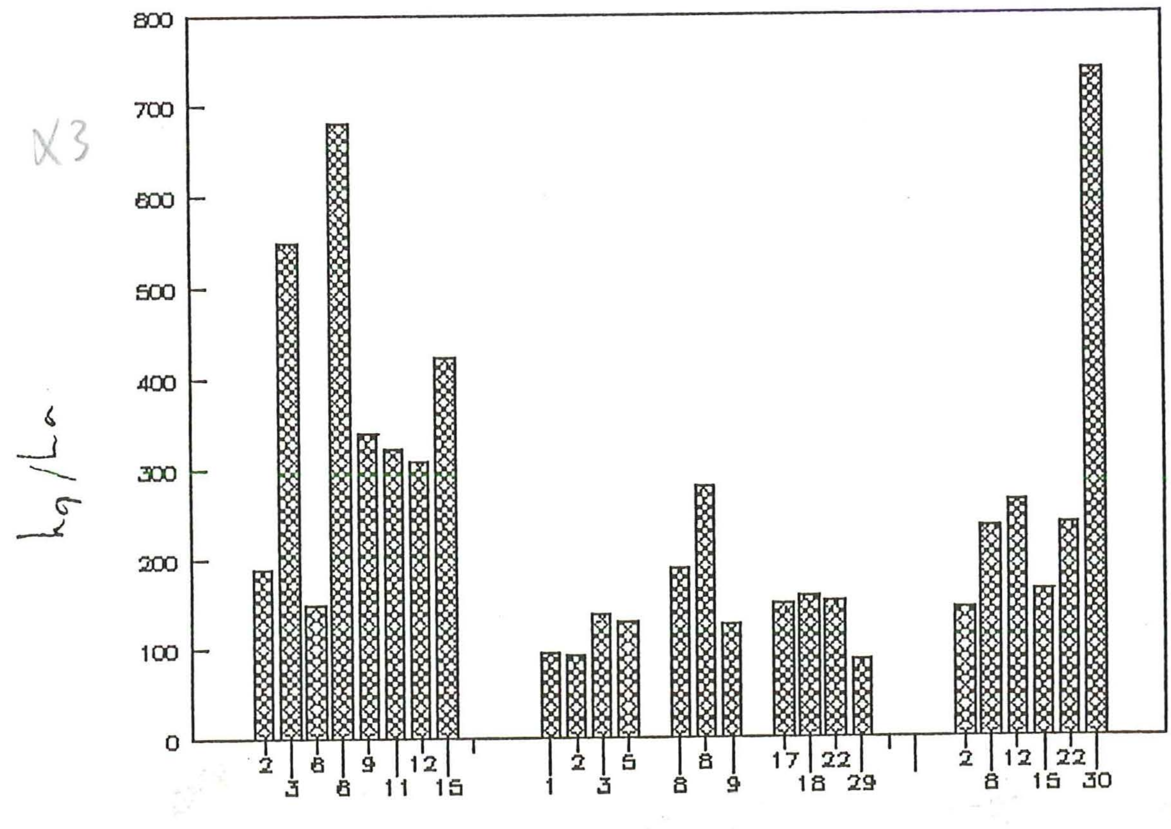
X Coefficient(s) 17.56244
Std Err of Coef. 11.62787

①

N soil

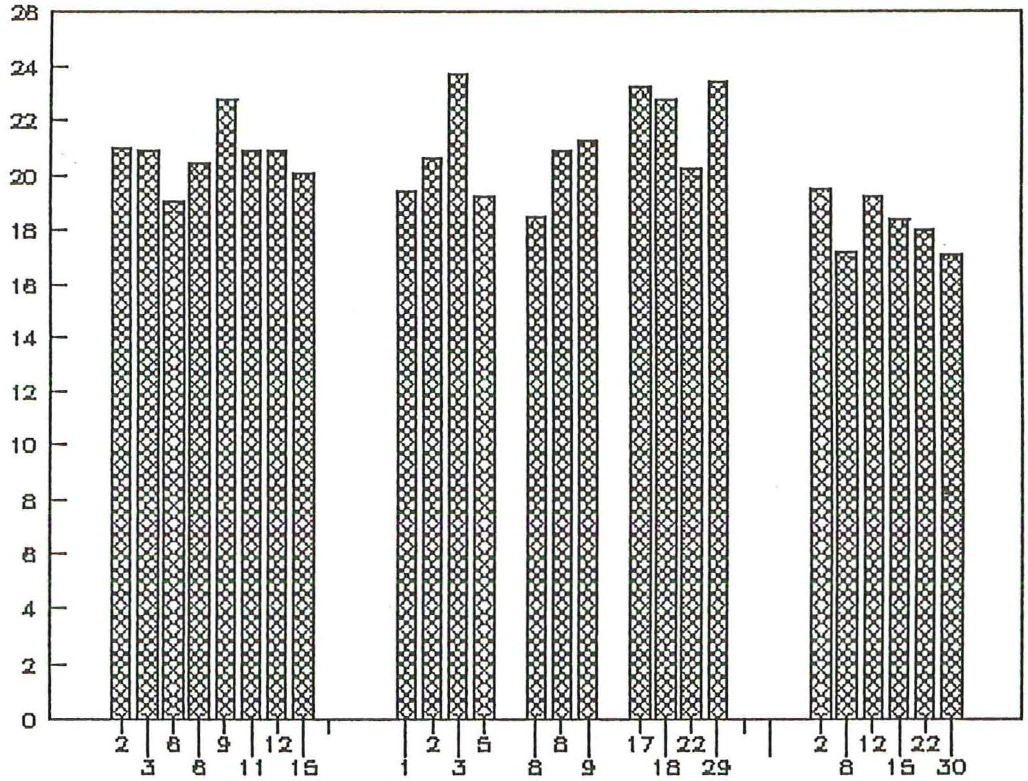


P soil

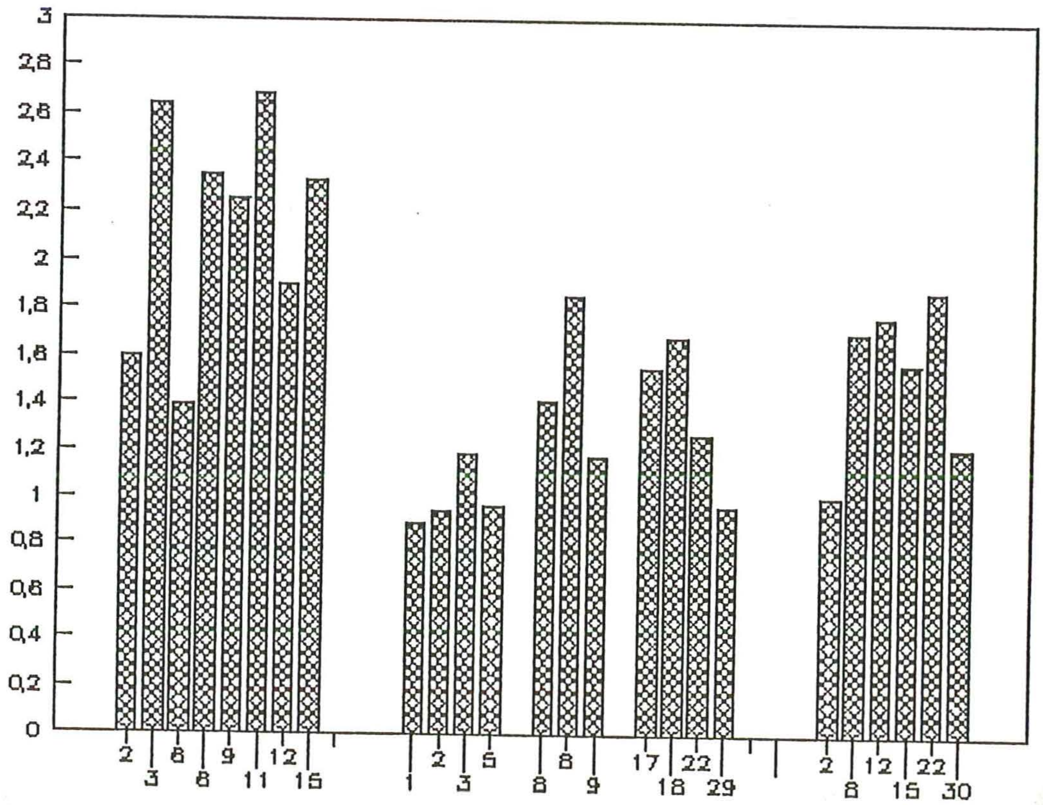


②

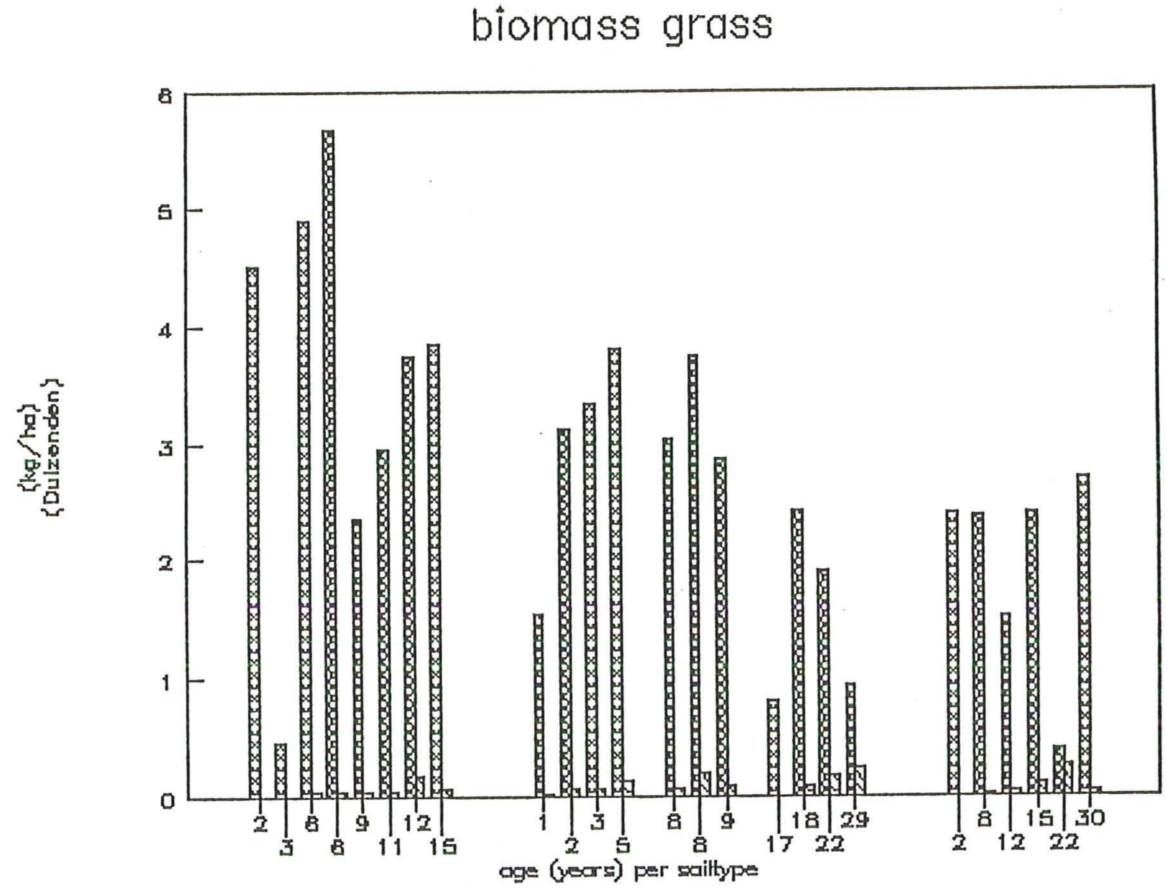
c/n soil.



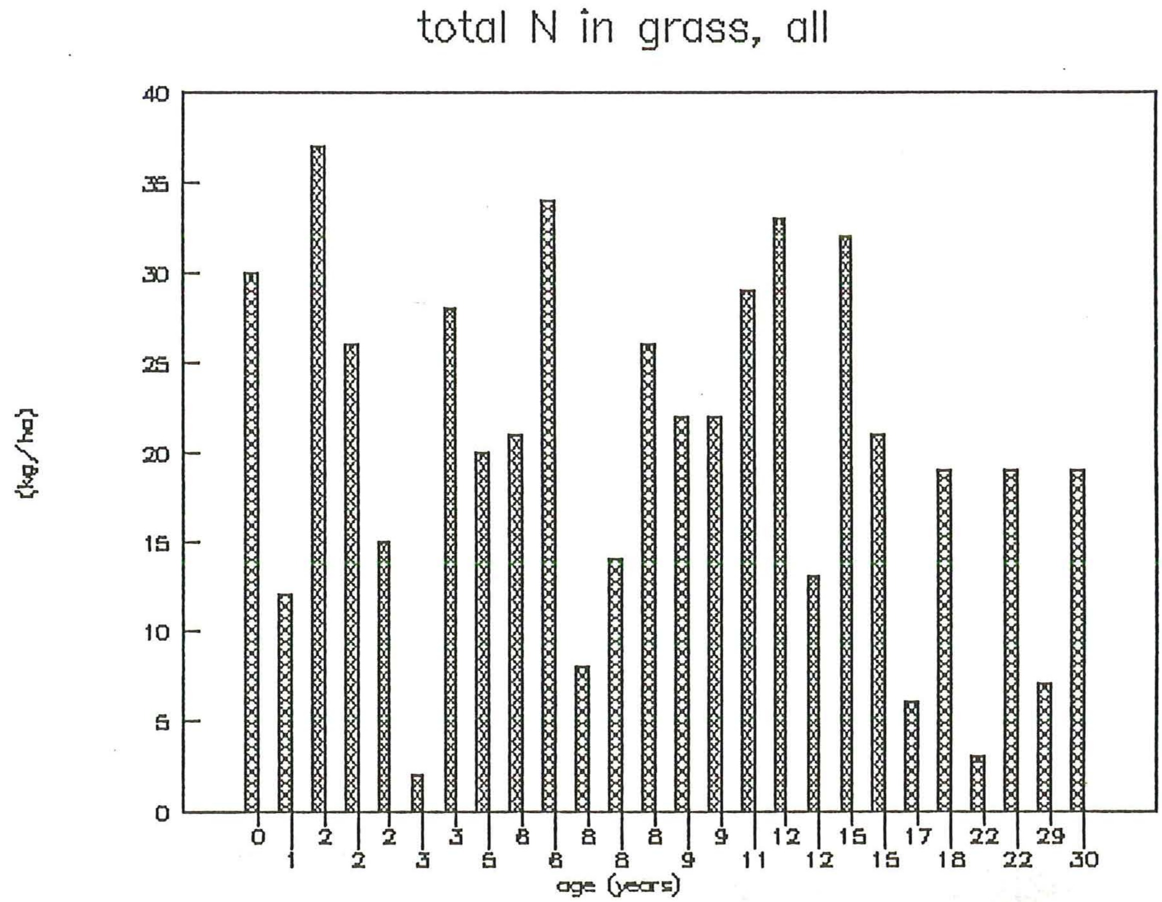
c% soil.



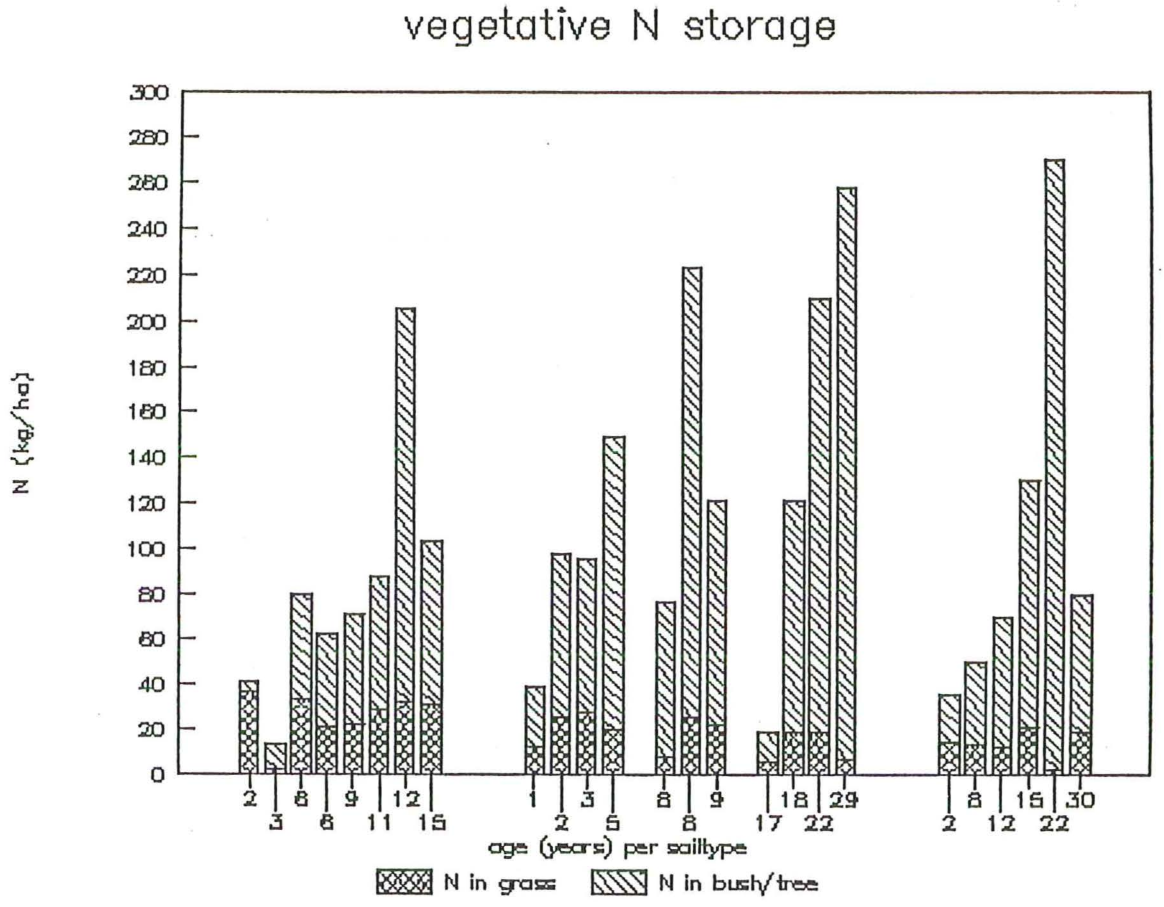
3

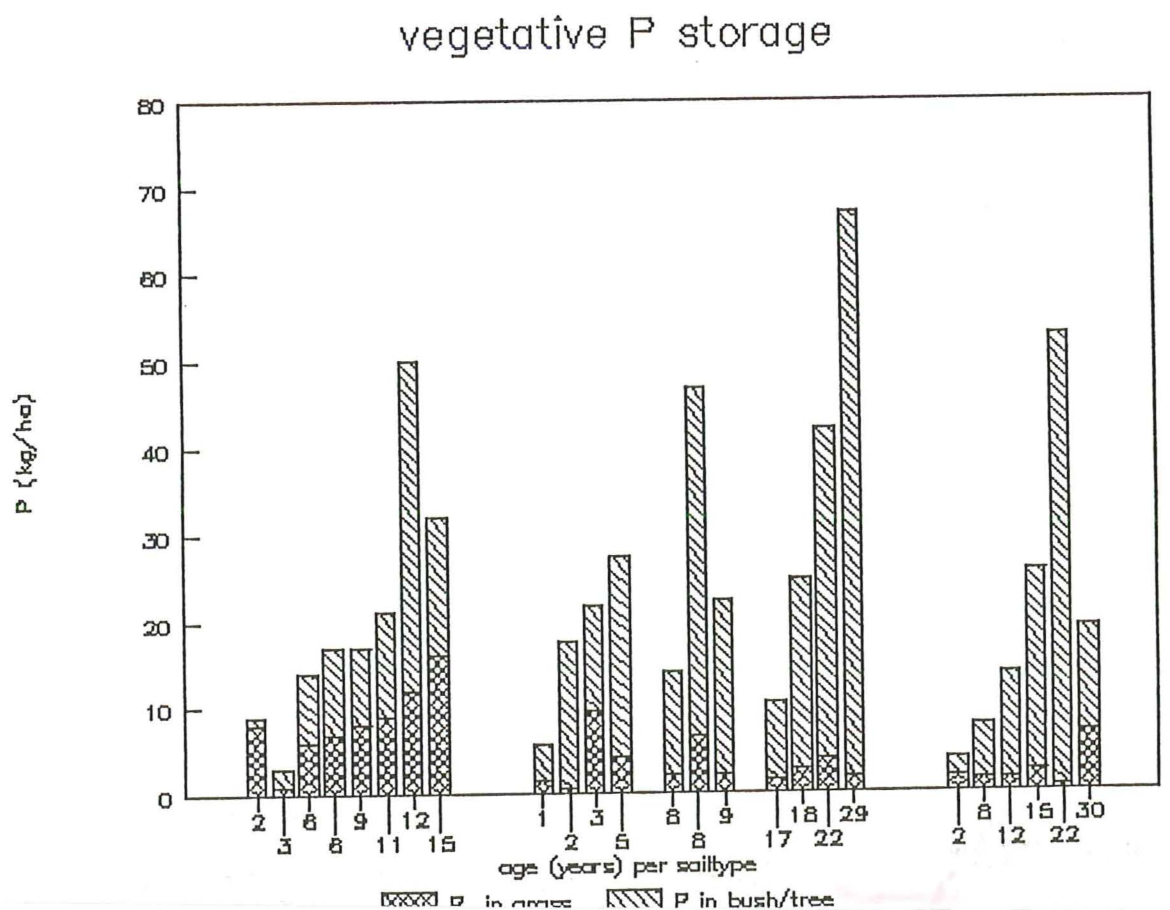


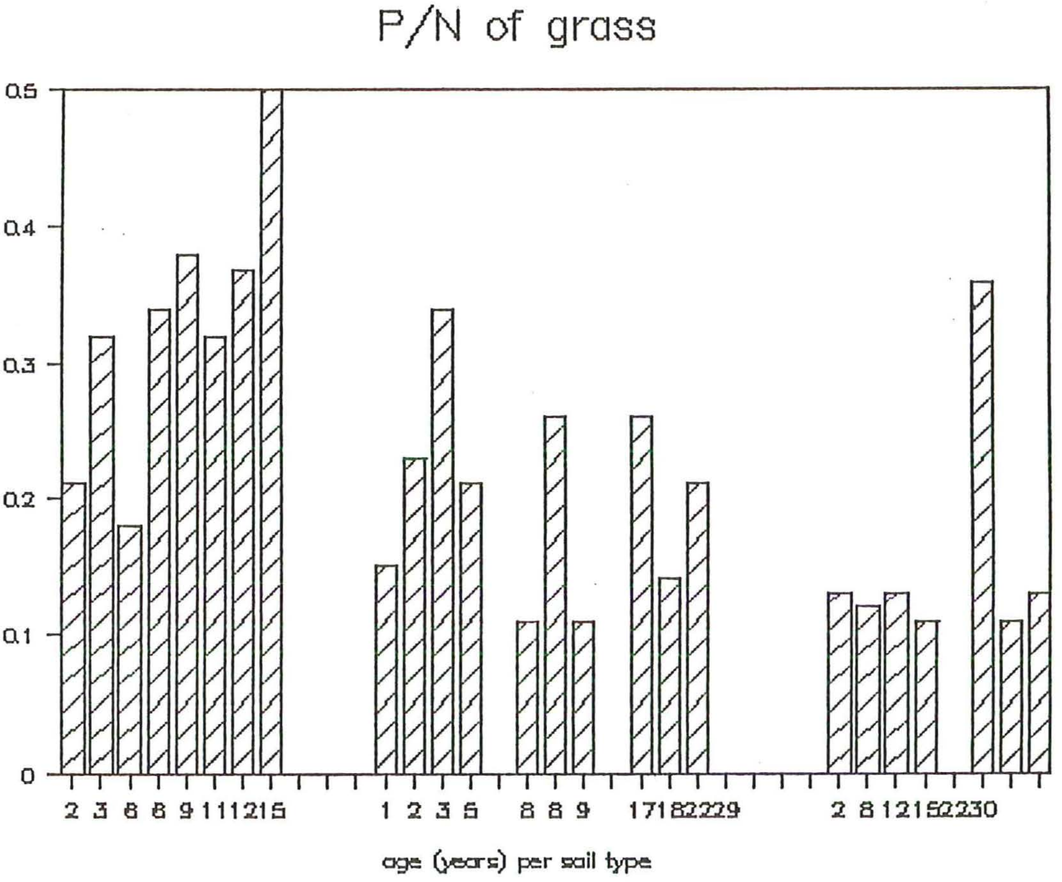
biomass grass
(kg/ha)
(Duizenden)
age (years) per soiltype



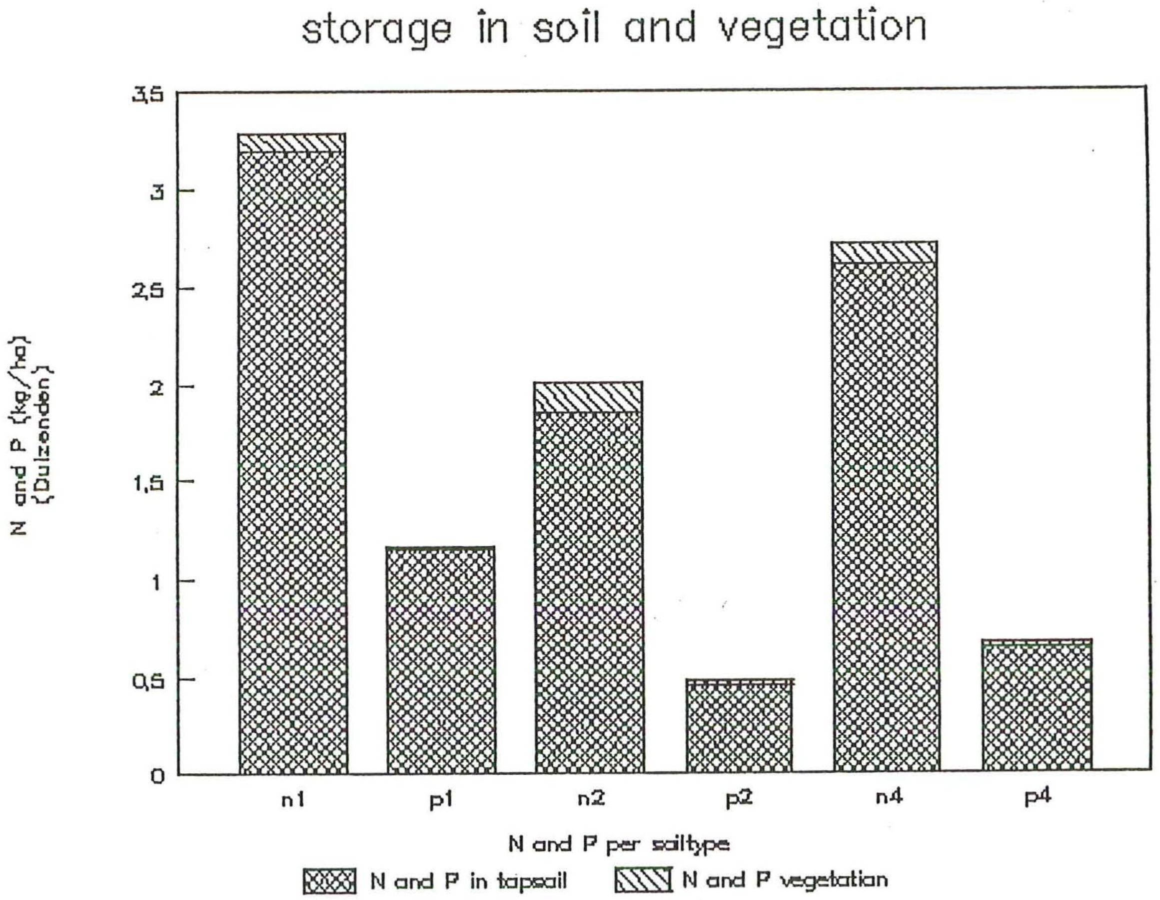
total N in grass, all
(kg/ha)
age (years)


vegetative N storage
N (kg/ha)
age (years) per soiltype
N in grass
N in bush/tree


vegetative P storage
P (kg/ha)
age (years) per soiltype
P in bush/tree


P/N of grass
0.5
0.4
0.3
0.2
0.1
0
2 3 6 6 9 1 1 1 2 1 5
1 2 3 5
6 8 9
1 7 1 8 2 2 2 9
2 8 1 2 1 5 2 2 3 0
age (years) per soil type

6.


storage in soil and vegetation
3,5
3
2,5
2
1,5
1
0,5
0
N and P (kg/ha)
(Dulzenden)
n1
p1
n2
p2
n4
p4
N and P per soiltype
N and P in topsoil
N and P vegetation

pit	NO	AGE	TYPE	B.SAT %	CEC meq/100g	C/N	C %	Ntot mg/kg	Ptot mg/kg	PH
13	43	2	1	88	25.57	21.0	1.6	760	190	6.7
7	47	3	1	96	20.51	20.9	2.64	1264	548	6.7
11	8	6	1	93	22.86	19.0	1.39	732	150	7.1
25	23	6	1	91	21.02	20.4	2.35	1150	679	6.5
1	49	9	1	84	21.79	22.8	2.25	988	341	6.5
27	50	11	1	93	24.84	20.9	2.68	1279	324	6.5
9	401	12	1	86	17.29	20.9	1.9	911	309	6.8
8	12	15	1	83	25.23	20.1	2.33	1159	423	6.7
5	38	1	2	85	6.55	19.4	0.89	458	96	6.7
3	22	2	2	114	5.15	20.6	0.94	457	94	6.8
12	14	3	2	88	5.83	23.7	1.19	502	139	6.4
6	28	5	2	105	5.41	19.2	0.96	499	129	6.7
15	15	8	2	108	9.61	18.5	1.41	762	190	6.6
21	41	8	2	96	14.67	20.9	1.86	890	280	6.5
4	34	9	2	92	5.24	21.3	1.18	555	127	6.2
20	44	17	2	90	21.25	23.2	1.55	667	149	6.5
26	31	18	2	90	9.62	22.8	1.68	737	158	6.5
22	36	22	2	96	9.44	20.2	1.27	629	152	6.7
24	13	29	2	77	4.71	23.4	0.96	410	87	6.5
14	3	2	4	95	5.41	19.5	1.01	517	145	6.5
17	18	8	4	90	8.42	17.2	1.71	993	234	6.3
2	402	12	4	89	14.84	19.2	1.77	922	265	7.0
16	32	15	4	106	7.62	18.4	1.58	857	165	6.4
18	19	22	4	83	12.0	18.0	1.88	1047	239	6.5
19	16	30	4	51	24.51	17.1	1.22	713	737	7.0
28	4		3							
10	42		3							

soil	plot type	age	Nsoil kg/ha	Ngrass	Nbush	Psoil	Pgrass	Pbush
1.	43	2	2360	37	5	590	8	1
	47	3	3920	2	12	1700	1	2
	8	6	2270	34	46	470	6	8
	23	6	3570	21	42	2110	7	10
	49	9	3070	22	49	1060	8	9
	50	11	3970	29	59	1010	9	12
	401	12	2820	33	172	960	12	38
	12	15	3590	32	72	1310	16	16
2.	38	1	1420	12	27	300	1.7	4
	22	2	1420	26	72	290	0.6	17
	14	3	1550	28	68	430	9.7	12
	28	5	1550	20	129	400	4.2	23
	15	8	2360	8	69	590	2.1	12
	41	8	2760	26	197	870	6.7	40
	34	9	1720	22	100	400	2.3	20
	44	17	2070	6	13	460	1.5	9
	31	18	2290	19	103	490	2.7	22
	36	22	1950	19	190	470	4	38
	13	29	1270	7	250	270	1.8	65
4.	3	2	1600	15	21	450	1.9	2
	18	8	3080	14	36	725	1.7	6
	402	12	2860	13	57	820	1.7	12
	32	15	1660	21	109	510	2.4	23
	19	22	3240	3	267	740	0.8	52
	16	30	2210	19	61	2280	7	12
	sorghum			25			2.7	
	millet			27			3	

	N%grass	P%grass	biom.gras	P/Ngrass
1.	0.83	0.18	4520	0.21
	0.46	0.15	450	0.32
	0.43	0.15	4900	0.18
	0.61	0.11	5670	0.34
	0.95	0.36	2340	0.38
	0.99	0.32	2950	0.32
	0.88	0.33	3740	0.37
	0.83	0.41	3850	0.5
2.	0.75	0.11	1530	0.15
	0.83	0.19	3120	0.23
	0.83	0.29	3330	0.34
	0.53	0.11	3810	0.21
	0.62	0.07	3030	0.11
	0.69	0.18	3740	0.26
	0.77	0.08	2870	0.11
	0.75	0.19	810	0.26
	0.77	0.11	2420	0.14
	1.01	0.21	1900	0.21
	0.75	0.19	930	
4.	0.63	0.08	2400	0.13
	0.58	0.07	2370	0.12
	0.85	0.12	1510	0.13
	0.89	0.11	2400	0.11
	0.75	0.19	400	
	0.70	0.25	2690	0.36
sorghum				0.11
millet				0.13