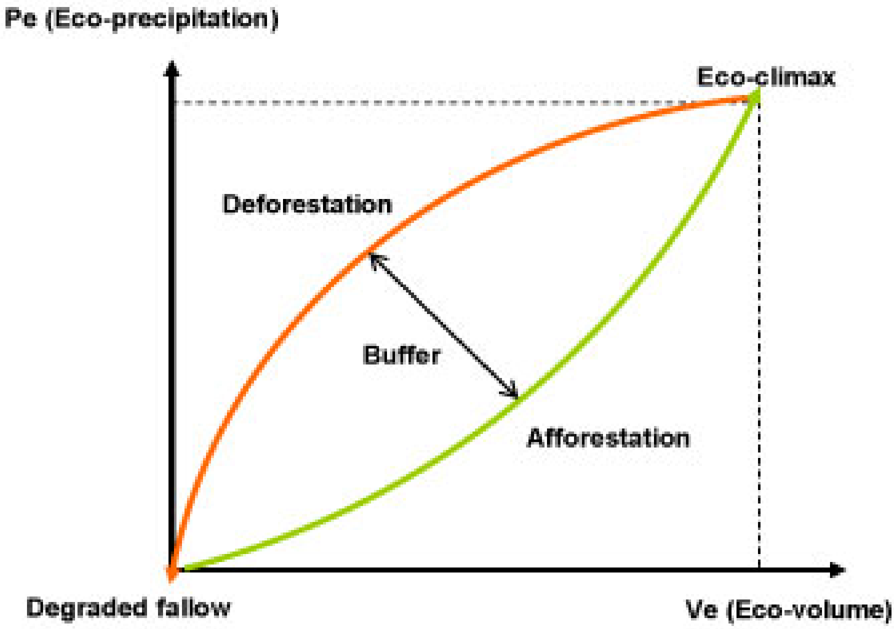
Zhixin Deng

Vegetation Dynamics in Queme Basin
Benin
West Afrika



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Korreferent:	Prof. Dr. Heiner Goldbach
	Prof. Dr. Heinrich W. Scherer
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For my sister Zhidang

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Abstract

Land use in Benin has been changed enormously since 20 years. The farming systems in the Oueme Basin are experiencing an ongoing intensifying process. Balancing the inherent trade-offs between immediate human needs and ecosystem capacity, needs comprehensive knowledge about ecosystem functions. To test the possible feedbacks between vegetation, precipitation and other environmental driving forces empirically, a new quantitative vegetation appraisal method was developed. Thus, the temporal and spatial vegetation dynamics of the Oueme Basin in Benin, West-Africa were reconstructed. The newly defined eco-volume and bio-volume concepts were used as alternative vegetation indicators in comparison with the standard biomass indicators. That portion of precipitation variability, originating specifically from vegetation variability, was defined as eco-precipitation. The *in situ* measured agro-ecological and farming system parameters of the three major vegetation types were used to validate the agricultural statistics and the satellite land cover data. Other available datasets comprising annual precipitation, vegetative duration coefficient and population density were adapted to comparable time and spatial spans, and eventually analysed together with the reconstructed vegetation dynamics. The feedback between vegetation and precipitation was evaluated at different spatial scales.

To detect possible future trends, static regional scenarios of precipitation in relation to eco-volume in 2004, as well as combined temporal and spatial scenarios of bio-volume in relation to precipitation from 1987 to 2025 have been simulated.

Zusammenfassung

Landnutzung in Benin hat sich seit rezenten 20 Jahren gewaltig geändert. Die Anbausysteme im Oueme-Einzugsgebiet erleben grade einen weitergehenden Intensivierungsprozeß. Das nachhaltige Management von den „Trade-offs“ zwischen der Lebensmittelproduktion und dem Erhalt der Ökosystemkapazität stellt eine große Herausforderung an interdisziplinären Erkenntnissen dar. Um die möglichen Zusammenhänge zwischen Vegetationsdynamiken, jährlichen Niederschläge und anderen Umweltfaktoren empirisch zu überprüfen, wurde eine neue quantitative Evaluierungsmethode entwickelt. Damit sind die temporalen und räumlichen Vegetationsdynamiken im Oueme-Einzugsgebiet in Benin, Westafrika rekonstruiert. Das neu definierte Konzept von Öko-Volumen und Bio-Volumen sind als alternative Indikatoren im Vergleich zu Standard-Indikatoren Biomasse für Vegetation eingesetzt. Der Anteil der jährlichen Niederschläge, der durch Vegetationsänderung innerhalb eines Einzugsgebiets induziert wird, ist als Öko-Niederschlag definiert. Die Parameter, die während der Felduntersuchung gemessen wurden, wurden für Validierung der Agrar-Statistiken und Satellitendaten über Landnutzung genutzt. Andere Daten von jährlichen Niederschlägen, Koeffizient der vegetativen Länge und Bevölkerungsdichten wurden in einer gleich zeit-räumlichen Skala aufbereitet. Alle Daten wurden dann zusammen analysiert.

Um die möglichen zukünftigen Tendenzen herauszufinden, wurden sowohl die statisch regionalen Szenarien des Niederschlags im Zusammenhang mit Öko-Volumen des Jahres 2004, als auch die temporal räumlichen Szenarien des Bio-Volumens im Zusammenhang mit der Niederschlagszeitreihe 1987-2025 simuliert.

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AEZ	Agro-Ecological Zone
BA	Basal Area
C_Veg	Vegetation Duration Coefficient
CIC	Cropping Intensity Coefficient
DBH	Diameter at Breast Height
ELE	Elevation (In M above Sea Level)
GDP	Gross Domestic Product
GPS	Global Positioning System
GRRE	Exponential Growth Rate in Percentage
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
H	Plant Height
IMPETUS	An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa
IPCC	International Panel for Climate Change
LC	Land Cover
MDR/DAPS	Ministère du Développement Rural (MDR), Direction de l' analyse, de la Prévision et de la Synthèse (DAPS)
MEAP/DPP	Ministère de l'Agriculture, de l'Elevage et de la Pèche (M EAP), Direction de la Programmation et de la Prospective (DPP)
P	Observed Precipitation
P_f	Predicted precipitation
P_max	Simulated concrete maximum precipitation in certain year
P_min	Simulated concrete minimum precipitation in certain year
PD	Planting Density (normally in piece/Ha)
Pe	Eco-Precipitation
Pe_ac	Concrete eco-precipitation in certain year
Pe_max	Predicted minimum eco-precipitation
Pe_min	Predicted minimum eco-precipitation
Pe'	Eco-Precipitation by its initial means
R or R_time	Ruthenberg's Value expressed either as fraction or as a percentage

R_long_area	Long-term Ruthenberg’s Value according to area share
R_short_area	Short-term Ruthenberg’s Value according to area share
Vb or Vbio	Bio-Volume
Vbc	Weighted communal Bio-Volume
Vbc_f	Predicted Bio-volume
Ve or Veco	Eco-Volume (M^3/U)
Vec	Weighted communal Eco-Volume

1 Introduction

Land use is becoming a force of global importance. In Benin, enormous changes to forests, farmlands, waterways, and air are being driven by the need to provide food, fibre, water, and shelter to rapid growing population. Croplands, pastures, plantations, and urban areas have strongly expanded in recent 20 years (Paeth 2006), accompanied by large increases in energy, water, and fertilizer consumption. Such changes in land use have enabled local people to appropriate an increasing share of the natural resources, but they also potentially undermine the capacity of ecosystems to sustain food production, to maintain freshwater and forest resources, to regulate climate and air quality, and finally to preserve soil fertility. The ecosystem responses to land use vary according to the ecological setting and the type of land-use change, and have partially differentiated local, short-term as well as global, long-term effects. On the one hand, balancing the inherent trade-offs between immediate human needs and maintaining the capacity of other ecosystem functions requires comprehensive knowledge about these ecosystem functions on regional scale (Matson, Parton, Power, and Swift 1997; DeFries, Foley, Asner 2004; Foley, DeFries, Asner, et. 2005). On the other hand, reliable data about West-Africa are not always readily available. The need for practical and efficient indicators, which can describe and relate interdisciplinary phenomena on a suitable regional scale, is not only important for biological and ecological sciences, but also for economical and political implementation. The integrative indicators eco-volume and bio-volume as vegetation indicators opposed to the standard biomass indicators generally enable to better describe the reactions between vegetation dynamics and soil nutrients variation, precipitation, population dynamics and farming intensity on the regional scale.

Since vegetation cover has been rapidly declining in Benin, the agro-ecological constraints in the whole Oueme basin have been further investigated, allowing vegetation evolution to be reconstructed on a regional scale, which, in turn and combined with other research results, would enable a realistic policy analysis. The possible feedback between vegetation and precipitation dynamics is in the focus of this study on “Vegetation Dynamics in Oueme Basin, Benin, West-Africa”.

To make the test of the feedback between vegetation and precipitation empirically possible, a suitable vegetation data compiling approach was developed together with the newly defined concepts of eco-volume and bio-volume. The portion of precipitation variability, originating specifically from vegetation variability, was defined as eco-precipitation. The *in situ* measured agro-ecological and farming system parameters of all three vegetation types were used to validate the agricultural statistics of each 62 administrative communes in the whole Oueme Basin from 1987 to 2004 and the land cover data of Global Landcover Classification (GLC2000). Thus for each of the 62 communes, the temporal and spatial dynamics of biomass, eco- and bio-volume were reconstructed. Other available datasets comprising annual precipitation, vegetative duration coefficient and population density were adapted to comparable time and spatial spans, and eventually analysed through linear multiple regressions and general linear model together with the reconstructed vegetation dynamics. The feedback between vegetation and precipitation was evaluated at different spatial scales including all 62 communes, all ten Departments (provinces), and eventually, the communal means regrouped into the south, middle and north Oueme Basin sub-regions. Moreover, the static regional scenarios of precipitation in relation to eco-volume in 2004, the temporal and spatial scenarios of bio-volume in relation to precipitation from1987 to 2025 have been simulated in order to detect possible future trends.

This study deals with interdependent processes between vegetation dynamics, precipitation variability and, on the human side, institutional arrangements, agricultural economics and population dynamics for the whole Oueme Basin. Farming systems are highlighted for their influence on the vegetation dynamics.

2 Agro-ecological Conditions in the Oueme Basin

2.1 Location and geography

Benin is located in West Africa. It is bound by Niger to the north, Burkina Faso to the northwest, Nigeria to the east, Togo to the west and the Gulf of Guinea to the south. The country has four natural topographical regions: (i) A coastal belt which has four lagoons, the Cotonou, Ouidah, Grand Popo and Porto Novo while further north the land rises slowly to a savannah plateau, (ii) The Lama which is a wide marshy depression, (iii) The Atakora Mountains in the northwest and, (iv) The eastern plains of Borgou and Kandi which slope to the Niger basin. The country is covered with different vegetation types and has many major rivers. The Oueme River is the longest river running southerly, starting from Atakora, down the middle of the country, ending till the coast. The Oueme River rises in the Atakora massif in north-western Benin. It is approximately 500 km in length and flows southward, where it is joined by its main affluent, the Okpara, on the left bank and by the Zou on the right bank. It then divides into two branches, one discharging into Lake Nokoué Abomey-Calavi, delta near Cotonou and the other one into Lagoon Porto-Novo. The Oueme Basin covers ten provinces (departments) encompassing 62 administrative Communes.

2.2 Climate

The Oueme Basin, endures a tropical climate subdivided into three climatic zones according to different rainfall regimes by the Impetus project classification; (i) The north Oueme with an unimodal rainfall regime which has two seasons: the rainy season from May to October and the dry season which is hot with very low humidity, (ii) The south Oueme with a bimodal rainfall regime which has two wet seasons, a long one between March and July and a short one between September and mid November as well as a long dry season between November and March, (iii) The middle Oueme with a transitional rainfall regime which has a rainy season between March to October, with or without a small dry season during August. Rains mostly originate from the Guinean coast. The prevailing dry season wind is the Saharan Harmattan, a hot dry dust laden wind that blows from the northeast and occurs between December and March. Average annual precipitation varies between 960 mm in the north and 1340 mm in the south. Average annual temperature ranges in

Cotonou from 23 °C in August to 28 °C in May.

2.3 Soil

The Republic Benin locates in West-Africa and geographically between 06°00’ to 12°00’ northern latitude and 01°00’ to 03°40’ eastern longitude. It has a land area of 114870 km^2 (MDR/DAPS, 1998) or around 11.5 million ha. According to GLC2000 there are only 11.43 million ha for the whole of Benin. In this study the value of land area of GLC2000 was used. Table 2-1 shows the land use classification of the three climate regions of the whole Oueme Basin used in this study. The item “Real annual crops (ha)” has been extracted from the corresponding area sum from the agriculture statistic books by the MAEP/DPP, after correction for CIC (Cropping Intensity Coefficient), as detailed in Chapter 3.

Within Oueme Basin there are four major soil types. First in North and centre, the crystalline base soils Alfisol, so called “sols ferrigineux”, are dominant. Such soils are expressed by concretion and lateritic crusts, most are sandy. Second in South, a depression with direction western to eastern separates the crystalline base soils. The soils in this depression are mainly comprised of hydromorph Vertisols, which are sandy loamy to loam soils. Third in South is a sand-stone plain (“Terre de Barre”), here the soils are dominantly deep, fertile and sandy to loamy Acrisol. Fourth after the sand-stone plain follows a coast zone, where the soils are dominated through quartz rich sand and characterized by expanded swamp zone and lagoon water (Fritz 1996, Herrmann 1996, Bohlinger 1998, van den Akker 2000).

Table 2-1 Classified land use area using remote sensing dataset (GLC2000) and corrected for CIC (Cropping Intensity Index) of the whole Oueme Basin

Depart-ment	Com-mune	IMPETUS Zone	AEZ	Total (ha)	Sum vegetation (ha)	Forest (ha)	Savannah (ha)	Real annual crops (ha)	Other (ha)
10	62	3	6	6780865	6745167	449871	5115482	1179814	35698
% to Total					99.47%	6.63%	75.44%	17.40%	0.53%
% to Sum of vegetation						6.67%	75.84%	17.49%	0.53%

- Source: Remote sensing dataset of land use in Benin in year 2000 from the GLC2000 Project, supplied by Michael Judex
- AEZ = Agricultural Ecological Zone
- Total (ha) = Total Land area in hectare of Benin according to GLC2000
- Sum vegetation (ha) = GLC2000 area of total vegetation in hectare
- Forest = mosaic forests and mangrove
- Savannah = Deciduous woodland + Deciduous shrubland with sparse trees + Sparse grassland+Swamp bushland and grassland (including perennial plantation crops)
- Real annual crops (ha) = annual crops area from Agriculture Statistics Book in year 2004 (MAEP/DPP 2004), then corrected for CIC
- Other (ha) = urban area and water bodies

2.4 Vegetation

Wezel and Bohlinger (1999) have classified Benin in four vegetation zones viz.; Coast Zone, Guinea-Congolian Zone, Guinea Zone with Southern and Northern Guinea Zone, and Sudanian Zone with Southern and Northern Sodanian Zone as shown in Figure 2-1. Northern part of Oueme Basin is mainly covered by the Southern Sudanian Zone and to a lesser extent by the Northern Guinea Zone. Northern parts of Donga and Borgou belong to the Southern Sudanian Zone, where the prevailing vegetation types are woodlands and savannahs and, *Isoberlinia* trees occur more frequently. Along rivers, gallery forests can be found. The Southern Parts of Donga and Borgou and part of Collines are dominated by the Northern Guinea Zone. The vegetation here is dominated by moist woodlands and savannahs and characterised by woodlands, tree and shrub savannahs with abundant *Isoberlinia* spp. and *Butyrospermum parkii* (Karité).

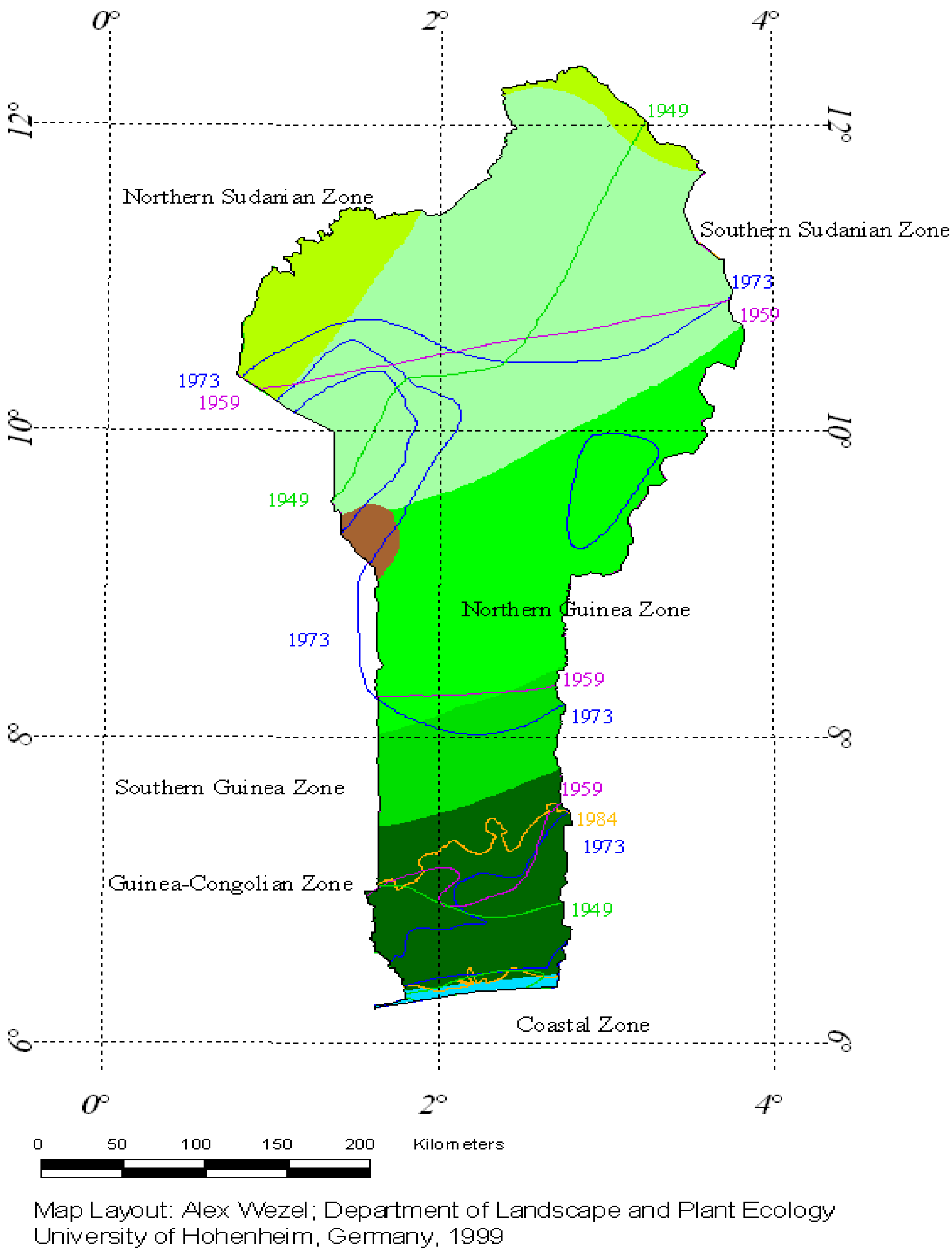

Figure 2-1 Vegetation zones of Benin

Central Oueme Basin is dominated by the Northern Guinea Zone. The separation between a Northern and a Southern Guinea Zone coincide with the northern boundary of bimodal rainfall in southern Benin.

The Southern Oueme Basin comprises three vegetation zones: (i) The Southern Guinea Zone where moister types of woodland and savannahs with abundant *Daniella oliveri* are found, (ii) The Guinea-Congolian Zone and, (iii) A Coastal Zone with a small band of coastal vegetation existing along the Atlantic Ocean. In the Guinea-Congolian and Coastal Zones mosaic forests and savannahs exist. In these two zones most of the original vegetation is replaced by secondary grasslands or savannahs due to human impact.

2.5 Population dynamics

Since the beginning of 80's Benin experiences a rapid population growth with an average annual rate of ca. 2.8%. According to the last census there were 6750000 inhabitants in Benin in the year 2002 (INSAE 2003). The figures 2-2 and 2-3 show the total national population growth and projection from 1961 to 2025.

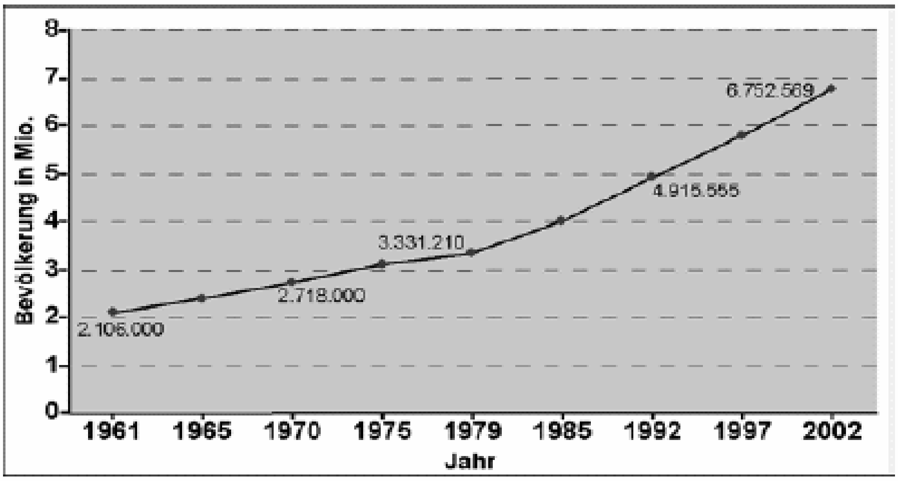

Figure 2-2 Total population growth in Benin 1961-2002 (source: Doevenspeck 2004, Bevölkerung=population and Jahr=year)

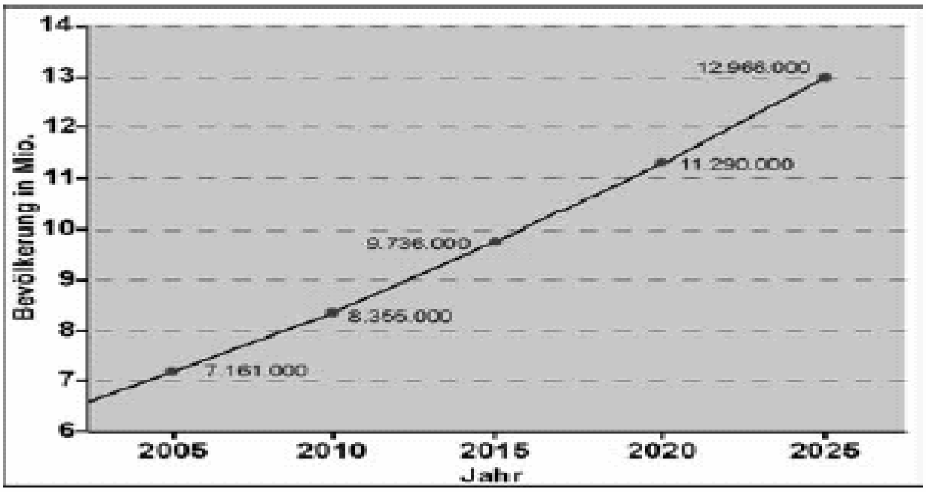

Figure 2-3 Population projection for Benin 2005-2025 (source: Doevenspeck 2004, Bevölkerung=population and Jahr=year)

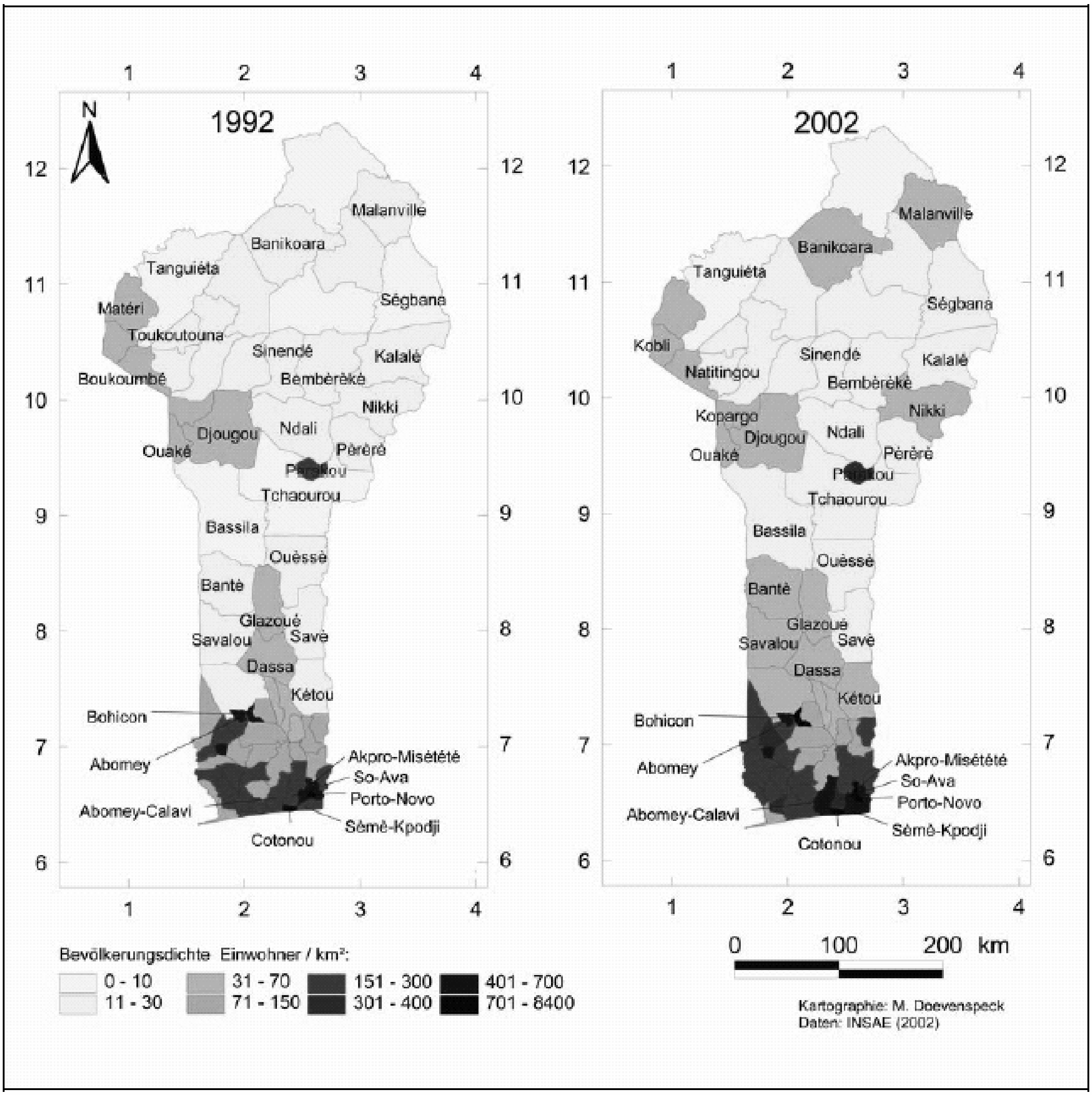

Figure 2-4 Population density (Bevölkerungsdichte) of Benin in 1992 and 2002 at communal level (source: Doevenspeck 2004) in inhabitants (Einwohner)/km²

There is obviously a gradient of population density from the south, centre to north Benin. One reason for this population distribution pattern could be as mentioned by Doevenspeck (2004) that historically the south was economically more developed than the centre and north since slave trading period and colonial time. von Oppen (2001) pointed out also the similar gradients of rainfall and topography from south to north.

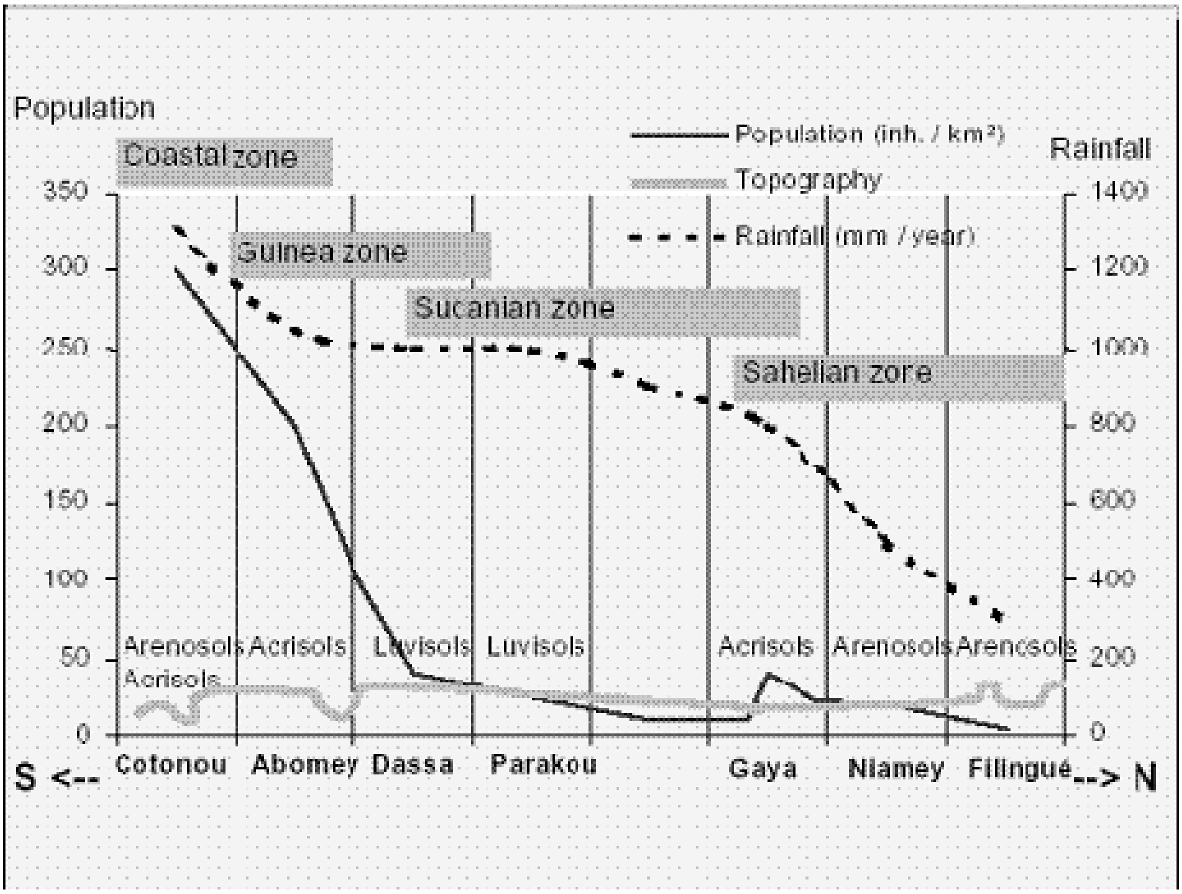

Figure 2-5 Gradients of population density, rainfall and topography (source: von Oppen, 2001)

2.6 Land property rights

Even the topic about land property rights is a complicated and sensitive issue; together with increasing population growth, climatic change, economic, institutional evolution, traditional and State land tenure play a particularly important role in the area of land use. Thus, during the field research in Benin, this issue was discussed with the farmers in all interviews and with informants (civil servants, for instance functionaries of the Service Domaine). Especially, the Pobe commune in south Plateau Province and N'dali in northern Borgou Province were selected as study sites serving as privileged observation sites for assessing previous studies in this area.

In the legislative and political land tenure practice of Benin; all land belongs to the

State.[1] It is somehow similar as the socialistic China, at least comparable with the beginning period of China's Reform. Some similar phenomena such as unclear delimitation of property rights, especially the private property rights and very high institutional costs were observed also in Benin. The costs of land transaction are very high and administrative certifications of the contracts from the State are so complicated, that most of such land transactions (including variety of tenancies) were not confirmed by the government. One of the most crucial arguments of critics is the tragedy of common property rights, which is true. For the efficiency goal, the privatization of land property rights was and is heavily discussing, but there is still no clear answer (Chimhowu & Woodhouse, 2006).

Moreover, such legal uncertainty and restrictions on access to resources, as discussed by Kirk and Adokpo-Migan (1995), endanger soil fertility up to the point of degradation. Individual private ownership also offers no guaranty of resource preserving utilization when this is only recognised and protected by the State under extremely restrictive conditions or when in addition unclear, arbitrary regulations of tenancy lead to legal uncertainty and prevent a willingness to invest in sustainable cultivation options such as agro-forestry.

Beyond these 'uncertainties', there are also optimising tendencies in Benin that the community based common property rights system is diminishing and with the decentralization process, the privatization/individualization is going deeper. More and more transaction options (=opportunities) are coming up within the land tenure

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[1] Kirk & Aokpo-Migan (1996) pointed out three points in legislation and policy of land property rights in Benin:

Even if Benin lawyers do not see a legal basis for the primacy of state ownership, land tenure practice sees it differently: it is deeply rooted in the consciousness of all levels of administration that the State is, after all is said and done, the owner of all natural resources. Autochthonous land tenure justifies if need be, only ownership-like usufructuary rights. Peasants and livestock owners with formal education have also internalised this principle.

Through the procedure of land registry, the State ensures an exclusive private land title for natural and legal persons (titre foncier).

The State has a far reaching right even since democratisation to expropriate land which is cultivated in line with customary rules in the 'interests of the general public' and to confer titles in land through urban or rural concessions. In such a case there is no right of appeal for compensation.

system especially in south. [2]

Logically and empirically, it is not a problem, whom the land ownership rights belong to, as the experience of China's reform shows. For the functioning of a private property system requires the exclusive right to use (or to decide on use), the right to freely transfer, and the right to exclusively enjoy income generated from usage. Whether the user of a property has private ownership in title is not important (Cheung, 1969, 1998). For efficient and functioning land tenure systems in Benin, the crucial concern here is a clear delimitation of these three rights.

2.7 Agro-ecological Zone

To generate more congruence between administrative areas and vegetation zones for agricultural extension and political decision purposes, the Ministry of Rural Development (MDR) defined eight agro-ecological zones (AEZ, MDR, 1998) for whole Benin, comprising sub-prefectures (after decentralization: communes) as the smallest unit having relatively homogenous soil and climatic conditions and providing statistical data (see table 2-3 and figure 2-6). The Oueme Basin spans across six AEZs, from zone 3 to 8.

The classification of the eight agro-ecological zones followed the natural conditions of these zones. In the north, there are two zones with lesser favorable conditions for agricultural production, Zone Extrême Nord Bénin (1) and Zone Ouest Atakora (4), respectively, and two zones with favorable production conditions, Zone Cotonnière du Nord Bénin (2) and Zone Vivrière du Sud Borgou (3). All are characterized by one cropping season per year and by a relatively low population density between 12 and 33 inhabitants per km². In the center, one large zone with favorable production conditions is found, Zone Cotonnière du Centre Bénin (5). In this transitional zone the cropping intensities go up from one to two cropping seasons, depending on length of

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[2] The other authors like Kirk & Aokpo-Migan(1996) described the land tenure situation in Benin more sceptically: "…endangered customary common property rights with long-term use rights of families in the North including conflicts between settled cropping farmers and livestock keepers in the face of restricted grazing lands and transhumance routes; individual private ownership, varied forms of tenancy, the beginnings of landlessness and a 'grey' land market for agriculturally favourable locations in regions with high population pressure in the South."

the local growing season, which is in turn regulated by the transition of unimodal to bimodal rainfall regimes. The population density here is still low with 28 inhabitants per km². The south has one zone with a high production potential (Zone de la Dépression (8)), one zone with a medium production potential (Zone des Terres de Barre (6)) and one zone with a low production potential (Zone des Pêcheries (7)). All these are characterized by two cropping seasons and a high population density, reaching from 135 inhabitants per km² in Zone 8, 267 inhabitants per km² in zone 6 to 416 inhabitants per km² in Zone 7 (including the urban population). In the north and in the center arable land is still available which is not yet under cultivation implying that here extended fallow periods exist. In the south all arable land is under cultivation and therefore a very high land-use ratio is prevailing (van den Akker, 1998).

Table 2-2 Agro-ecological Zone with Communes

Region	No.	Agro-ecological zone	Subprefecture
NORTH	1	Zone de l'Extrême Nord Bénin	Karimama (B), Malanville (B)
	2	Zone Cotonnière du Nord Bénin	Banikoara (B), Kérou (A), Kandi (B), Gogounou (B), Ségbana (B)
	3	Zone Vivrière du Sud Borgou	Kouandé (A), Péhunco (A), Sinendé (B), Bembèrèkè (B), N'Dali (B), Kalalé (B), Nikki (B), Pèrèrè (B)
	4	Zone Ouest-Atacora	Matéri (A), Cobly (A), Tanguiéta (A), Toucountouna (A), Boukoumbé (A), Natitingou (A), Copargo (A), Ouaké (A), Djougou (A)
CENTER	5	Zone Cotonnière du Centre Bénin	Parakou (B), Bassila (A), Tchaourou (B), Bantè (Z), Ouessè (Z), Savalou (Z), Glazoué (Z), Savè (Z), Dassa-Zoumé (Z), Djidja (Z), Kétou (O), Aplahoué (M)
SOUTH	6	Zone des Terres de Barre	Za-Kpota (Z), Covè (Z), Zagnanado (Z), Bohicon (Z), Abomey (Z), Agbangnizoun (Z), Klouékanmè (M), Toviklin (M), Djakotomey (M), Dogbo (M), Houéyogbé (M), Kpomassè (Aq), Allada (Aq), Tori-Bossito (Aq), Abomey-Calavi (Aq), Zè (Aq), Sakété (O), Ifangni (O), Akpro-Missérété (O), Avrankou (O), Adjarra (O), Porto-Novo (O)
	7	Zone des Pêcheries	Lokossa (M), Bopa (M), Athiémé (M), Comè (M), Grand-Popo (M), Ouidah (Aq), Cotonou (Aq), So-Ava (Aq), Aguégués (O), Dangbo (O), Adjohoun (O), Bonou (O), Sèmè-Podji (O), Ouinhi (Z)
	8	Zone de la Dépression	Lalo (M), Zogbodomey (Z), Toffo (Aq), Adja-Ouèrè (O), Pobè (O)

A: Atacora, B: Borgou, Z: Zou, M: Mono, Aq: Atlantique, O: Ouémé

Source: DAPS / MDR 1999

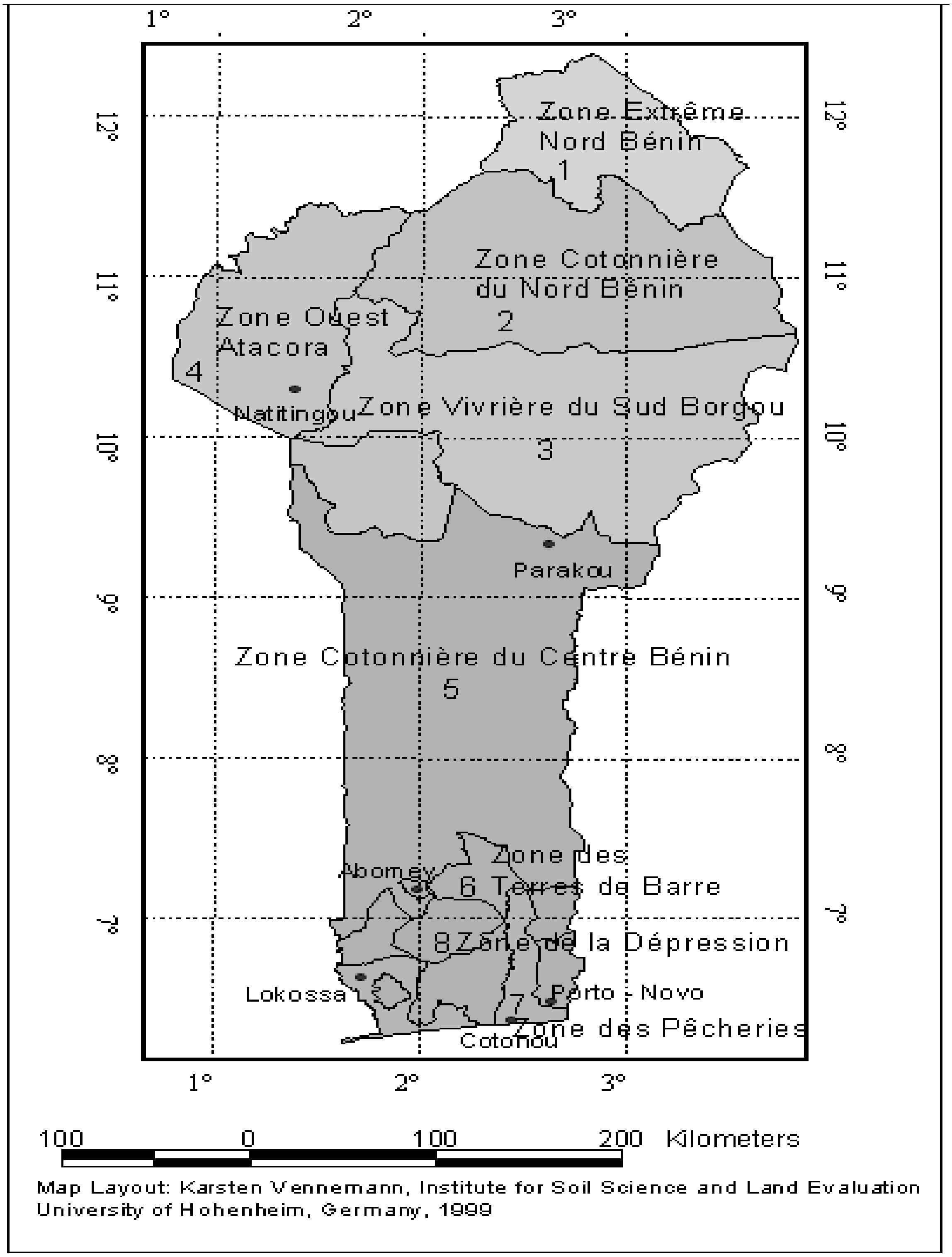

Figure 2-6 Map of 8 Agro-ecological zones in Benin

2.8 Major crops

Generally there are eight major annual crops extensively cultivated in the Oueme Basin: maize, yam, cassava (manioc), sorghum, rice, groundnut, beans, and cotton.

Maize cultivation areas increased in the south, and then expanded more and more in north Benin. Hence, maize wins more importance, although its rapid and unsuitable cropping techniques induce soil degradation as can already be seen in the south. Diverse vegetable production is increasing in the south and will further increase up north with the ongoing urbanization process.

Among the fruit trees, cashew cultivation is expanding, followed by mango and coconut. The other tree crops: oil palm, coffee and cocoa are decreasing. Oil palm is also cropped at very high densities in the Mono in view of palm wine production. There are plans to establish huge oil palm estates in south-eastern Benin under joint-venture agreements with Asian investors. Also characteristic of Benin is the multitude of small communal or private teak plantations, generally grown at very slow revolution rates.

2.9 Animal husbandry

Animal grazing impacts obviously on the vegetation stand. Thus, the state of the animal husbandry is of interest to the vegetation dynamics. But in general the explicit information and data about animal production in Benin are scarce and difficult to obtain. Hence, animal husbandry was not included in our study. The following part is a description of this sector based on literature and own experiences during field research in Benin. According to van den Akker (2000), nationally around 75% agricultural GDP belongs to plant production and ca. 25% belongs to animal and fish production.

With rapid growing population in Benin the demands on diverse animal products are increasing. Both, the plant and animal production are typical extensive production system, the major chance for an expansion of plant as also of animal productions is using more and more land areas. Consequently, the competition for land areas is almost inevitably under actual constraints. Especially in the centre of the Oueme Basin, where there are still a lot of arable land and less population density, the animal number, - mainly cattle -, is expected to be increasing in the future. In the north, cattle’s keeping in a transhumance pattern plays an important role after annual crops cultivation. In the south, animal production systems are small but diverse and technically more intensive than these in centre and south, probably impacted bv land scarcity and easier access to capital, information, techniques and market, even if the tropical climate and animal diseases limit strongly the expansion of cattle, pig productions in south.

The south Benin is characterised through lagoon landscape with 27000 ha water surface in dry season. Traditionally the lagoons are utilised intensively for fish production, also in other seasonal water bodies in wet season. Together 42200 tonnes of fishes were produced in Benin 1995 (Cellule Macro-économique, 1997).

2.10 Farming systems

In Benin, cattle are normally kept by nomads and typical traditional character of transhumance. Otherwise, animals like poultry, goat are kept around house or combined with annual as also perennial crops. The cropping or plant production systems are characterized through natural traditional agro-forestry pattern, i.e. less or more, useful trees are left on the annual crops fields, as néré and karité in north and oil palm in south. Most annual crops fields are mixed crop fields. Different combinations are possible and with newly in Benin introduced crop varieties the new types of mixed crops are emerging.

Since this study was concentrated on the cropping systems, the term farming system was used later as synonym of cropping system. Farming systems in Benin were described as extensive subsistence farming systems. Nowadays, they have evolved from tropical shifting cultivation to relatively intensive fallow cultivation systems (Janssens, Deng and Mulindabigwi 2004, Mulindabigwi 2006).

In north the annual crops are the most important component with its farming system. Near to the Niger boundary millets and sorghum, followed by yam, groundnut and beans and increasing maize cropping are dominant, while in Donga and Borgou the yam then followed by cotton, maize, sorghum, groundnut, beans and increasing cashew and mango trees are normal cropping patterns. In central Oueme Basin almost all annual crops are cultivated, maize occupying more and more areas and perennial trees like orange, teak are common, but oil palm trees are less than these in south. In south Oueme Basin maize and cassava are dominant, while the oil palm and coco palm dominate in the coastal zone. In the pre-urban areas vegetables are produced with increasing intensive techniques.

As mentioned in the section 2.5. Agro-ecological zone, in north there is only one cropping season, in centre one season cropping is dominant but southwards two cropping seasons occurring. In south two cropping seasons are cultivated. So from north to south, the cropping intensity index (CIC; see Chapter 3) increases, whereas fallow duration decreases southwards, even if the soils in south are more degraded than those in centre and north. As a plant indicator for soil degradation, *Imperata cylindrica* (spear grass) is more widely spreading in south and induces major harvest losses.

The south is more heavily impacted by social-economic progress. The crop rotation patterns in south are more diverse, even if some of these are not proper to local agro-ecological conditions. The local farmers are trying different possibilities other than the dominating option of expanding cultivating areas under given constraints.

Whether people in the south can win this fight with more favourable technological and institutional advantages against less land per person in comparison with the centre and the north where land is more available, remains as a challenging issue.

3 Materials and Methods in General

The primary objective of the present study is to test if vegetation dynamics are influenced by climate change, land use change and population dynamics as well as agricultural farming intensity. Vegetation dynamics, however, imply two dimensions: spatial and temporal variations. The spatial variation encompasses horizontal and vertical variations. Conventionally the biomass is used to describe vegetation dynamics in plant ecology, whereas in remote sensing related geo-ecology the NDVI (Normalized Difference Vegetation Index) is the standard parameter (Rouse et al. 1973, Tucker 1979 and Myneni et al. 1995). Biomass measurement, especially at regional scale, is relatively cumbersome and takes long time, since the phytomass has to be dried in the oven at first. The destructive character of biomass approach is also a limiting factor. To test the working hypotheses the eco-volume and bio-volume concepts were designed as inter-connecting indicators.

3.1 Eco-volume and bio-volume

The *eco-volume* of a single plant is defined as the volume of a cylinder with basal area equals to the basal area of the canopy and the aboveground height at the highest point of the plant:

$$Ve = S * H \qquad \text{(Equation 3-1)}$$

where:

- Ve = Eco-volume (m^3) of a plant;
- S = Surface or canopy area (m^2) occupied by a plant;
- H = Plant height (m).

Eco-volume (Ve) of a plant community is defined as surface multiplied by the weighted average height (eco-height) of a given phytocenose or agricultural system. It is expressed as a volume in m^3. For example, when the total eco-volume amount of a commune is divided by the total surface area of this commune, the communal average eco-volume (Vec) of this commune is expressed as m^3/ha:

$$\sum Ve_i = \sum S_i * H_i \quad \textbf{(Equation 3-2)}$$

Where

- Ve_i = the partial eco-volume of each vegetation component i
- S_i = the respective area occupied by each vegetation component i at canopy closure. If no canopy closure has been reached, then this vegetation component will be treated as the sum of singular plants (e.g. the case of dispersed karite trees in a crop field).
- H_i = the respective height of each vegetation component i

Bio-volume (Vb) of a single plant in m^3 is normally defined as biomass divided by specific weight. For practical purposes an allometric formula was used to estimate bio-volume in m^3 as basal stem area multiplied by its height:

$$Vb = BA * H \quad \textbf{(Equation 3-3)}$$

where:

- Vb = Bio-volume (m^3) of a single plant;
- S = Basal stem area (m^2) of a given plant;
- H = Plant height (m).

Thus, the bio-volume of a phytocenose (vegetation community) or agricultural system can be defined as:

$$\sum Vb_i = \sum BA_i * H_i \quad \textbf{(Equation 3-4)}$$

Where

- Vb_i = the partial bio-volume of each vegetation component i
- BA_i = the respective basal stem area (subtotal) occupied by each vegetation component i
- H_i = the respective height of each vegetation component i

The communal average unit bio-volume (Vbc) in m^3/ha is obtained, when the total bio-volume amount of a commune is divided by the total surface area of this commune.

This definition of eco-volume integrates some physic details of a given vegetation comparing with conventional indicators like biomass (kg/ha), which measures explicit physic quantities of a vegetation on a dry weight basis. But any measurement has its disadvantages and advantages. The height of a plant or an average height of a vegetation type is easier to measure as biomass, which, needs to be dried at a cost of energy and time. To get a quick insight of relations between the vegetation, site stand and its socioeconomic environment, eco-volume might be a good starting point. It can be further agued that the dominant change of vegetation under rapid social economic developing process like in Benin should be first of all the surface area change of different vegetation components. Since eco-volume takes the changes of land use area into account, combined with eco-height it represents a certain dimension of the vegetation dynamics. Since not only the plant height, but also the plant density of a vegetation community reacts to different environment settings, the bio-volume is also suggested as another alternative indicator for rapid appraisal of vegetation. In this study all three indicators describing vegetation dynamics were used and compared.

3.2 Reconstructing vegetation dynamics

For estimating vegetation dynamics the land use/cover change data are needed. The annual agriculture statistics books supply spatial and temporal datasets about annual cropped areas in each commune, within the different types of land use under continuous change. But the statistic data about forests and plantations areas were scarce in Benin. Even vegetation data acquired through remote sensing could not distinguish explicitly the really complicated different agricultural cropping areas from other vegetation formations, whereas they distinguished relatively well either the forest or savannah area from other vegetation components. Thus, the annual agriculture statistics were combined with remote sensing data to estimate the land use change of whole Oueme communes assuming the forest area from remote sensing to be correct. To the contrary, cropped land area was taken from the agricultural statistics and savannah area corrected accordingly.

Before these land use change datasets from the agriculture statistics could be combined with remote sensing data, one crucial step had to be treated. The field measurements were needed to validate and justify the statistic and satellite datasets. For example, remote sensing measures geographic physic areas of different vegetations; to the contrary, annual agriculture statistics record cultivated areas of different annual crops, which are cropping areas, but not geophysical areas. Especially, when a field is cultivated twice within a year, it would be recorded twice in the official statistics. In the centre and south Oueme Basins, the cropping intensities are higher than 1, which means that a field will be cultivated more than one time within one year. Since the annual rainfall duration and thus the vegetative period length allows one to even three cropping seasons for short season crops practically, the datasets from the agricultural statistics must be corrected for CIC (Cropping Intensity Coefficient) before they are comparable with remote sensing area data.

3.3 Datasets

The own measured agro-ecological and farming system parameters are described in detail in the sections 3.6 and 3.7 and chapter 4. The personally recorded datasets in the field were completed by datasets kindly supplied by colleagues of the Impetus project as referenced hereunder.

- The agriculture statistics of Benin from 1987 to 2005 (MAEP, Benin);
- The GDP statistics for all Departments of the Oueme basin by Dr. Arnim Kuhn from the Institute for Food and Resource Economics, University of Bonn;
- The satellite land cover data of Global Landcover Classification (GLC2000) of year 2000, supplied by Michael Judex in the Remote Sensing Centre of the University of Bonn;
- The vegetative duration coefficient data from 1987 to 2004 for the 62 Oueme communes, supplied by Julia Röhrig in the Remote Sensing Centre of the University of Bonn;
- The precipitation datasets supplied by Malte Diederich in the Meteorological Institute of the University of Bonn:
- The climatologic precipitation dataset from 1987 to 2004 for the 62 Oueme communes,
- The precipitation data from 2005 to 2025 for the 62 Oueme communes, simulated by the REMO- a regional model of climate - and based on the assumptions of

IPCC-A1B with strong forcing scenarios and strong FAO land use change assumptions;

- Population projection data from 1987 to 2025 for the 62 Oueme communes, supplied by Moritz Heldmann in the Institute of Ethnology of the University of Cologne, based on projection of the census data of Benin in year 1992 and 2002.

3.4 Experimental geographical grid

Ecosystems at different levels and scales reveal different mechanisms. The micro-mechanisms determining plant physiology at the individual level can not be applied directly into regional vegetation formations. Some laws hold on throughout different levels, some do not. Since the objectives of this study is trying to find out the empirical vegetation dynamics as related to precipitation, population dynamics, farming system development across time, one ought to address first the scaling issue. The different datasets must be compiled at comparable scale, so that they can be analysed together. In this study, the **commune** (previously sous-préfecture) was selected as basic analytic unit. Accordingly, all data sets were prepared at this scale for further analyses. On the one hand, the datasets needed from the other sub-projects of Impetus could be supplied at this scale; on the other hand, the commune is the smallest administrative unit, by which most required statistical data, such as annually agricultural used cropping area, are available.

To make the agro-ecological field measurements representative, the sampling areas were subjected consistently to the Impetus zoning method approach. The project Impetus, “an integrated approach to the efficient management of scarce water resources in West Africa”, has water as its major issue. Hence, especially the precipitation stands in the centre of the project. As Impetus encompasses five gross interdisciplinary sub-projects, a consistent scale must be defined for cooperative analyses. The whole Oueme River Basin is then grouped into three zones as shown in table 3-1.

Table 3-1 Zonation of the Oueme Basin according to the Impetus approach

Zones	Rainfall Regime	Provinces	Communes	Principle Crops
North Oueme Basin	Unimodal	Borgou	Ndali, Pèrèrè, Parakou, Tchaourou	Yam, Manioc, Maize, Sorghum, Cotton, Cashew, Mango
		Donga	Korpago, Ouaké, Djougou, Bassila	
		Collines	Bantè, Ouèssè, Glazoué,	
Middle Oueme Basin	Transitional	Collines	Savè, Savalou, Dassa	Yam, Manioc, Maize, Groundnut, Sugar Cane, Orange, Cashew
		Plateau	Kétou	
		Zou	Djidja, Abomey, Za-Kopta, Bohicon, Covè, Zangnanado	
South Oueme Basin	Bimodal	Zou	Agbangnizoun, Zogbodomè, Ouinhi	Maize, Manioc, Groundnut, Beans, Vegetables, Oil Palm
		Plateau	Adja-Ouère,Ifangni, Pobè, Sakété	
		Kouffo	Aplahoué, Djakotomè, Dogbo-Tota, Klouékamné, Lalo, Toviklin	
		Mono	Athiémè, Bopa, Comè, Grand-Popo, Houéyogbè, Lokosa	
		Atlantique	Abomey-Calavi, Allada, Kpomassè, Ouidah; So-Ava, Toffo, Tori-Bossito, Zè	
		Ouémé	Adjara, Adjohoun, Aguégué, Akpro-Missérété, Avrankou, Bonou, Dangbo, Porto-Novo, Sèmè-Kpodji	
		Littoral	Cotonou	

Source: Impetus Project Document 2004 (unpublished)

3.5 Experimental farming systems grid

The farming systems along the Oueme Basin are quite different depending on social economic and agro-ecological settings. Hence, a subdivision of the basin into four zones, - each zone with three sub-zones - was made concerning farming systems variation at the beginning of the Impetus project starting phase in year 2000, as shown in table 3-2. Instead of the commune Ina up north, N'dali commune directly near to Ina was selected as sampling site following logistic capacity limitation. Additionally, the commune Abomey-Calavi was intensively interviewed, but without field measurement of the agro-biological parameters. Thus five communes: N'dali, Save, Bohicon, Pobe and Abomey-Calavi were interviewed allowing later description of crop calendar, crop rotation, and calculation of CIC and Ruthenberg's values (R).

Table 3-2 Experimental farming systems grid

Transect	West site	Middle site	East site
Upper Ouémé	Djougou (Catch) – Serou * N: 9°43' E: 1°40' Yam, Maize, Manioc Veg.Phase: 200-240 Days Rain: 1200mm Soil: Ferrugineux	General De Gaule (Impetus) –Dogué * N: 9°6' E: 1°57' Yam, Maize, Manioc Veg.Phase: 200-240 Days Rain: 1100 mm Soil: Ferrugineux	INA ** (INRAB) N: 9°59' E: 2°44' Maize, Sorghum, Cotton Veg. Phase: 130-200 Days Rain: 1000mm Soil: Ferrugineux
Middle Ouémé	Banté * N: 8°26' E: 1°54' Maize, Manioc, Yam, Groundnut Veg. Phase: 240 Days Rain: 1000mm Soil: Ferrallitique	Glazoué * N: 7°59' E: 2°15' Maize, Manioc, Yam, Groundnut Veg. Phase: 240 Days Rain: 1000 mm Soil: Ferrallitique	Savè (INRAB) ** N: 8°03' E: 2°30' Maize, Manioc, Yam, Sugar cane, Groundnut Veg. Phase: 240 Days Rain: 1000mm Soil: Ferrallitique
Lower Ouémé	Bohicon** N: 7°14' E: 2°05' Maize, Manioc, Yam, Groundnut Veg. Phase: 1000 mm Soil: Ferrallitique	Niaouli (INRAB) N: 6°45' E: 2°12' Maize, Manioc, Groundnut Veg. Phase: 210-240 Days Rain: 1200 mm Soil: Ferrallitique	Pobè: (INRAB)** N: 6°59' E: 2°42' Palme, Maize, Manioc, Vigna unguiculata Veg. Phase: 210-240 Days Rain: 1200mm Soil: Ferrallitique
Littoral Ouémé	Ouidah (Mangrove): N: 6°21' E: 2°6' Coco palm, Manioc, Vigna unguiculata Veg. Phase: 210-240 Days Rain: 1400 mm Soil: minéraux brut	Cotonou: (Peripherie) N: 6°22' E: 2°27' Coco palm, Vegetables Veg. Phase: 210-240 Days Rain: 1400 mm Soil: sE minéraux brut	Sèmè Podji: (INRAB) N: 6°24' E: 2°38' Coco palm, Manioc, Vegetables, Sugar cane Veg. Phase: 210-240 Days Rain: 1400 mm Soil: minéraux brut

N= North Longitude, E= East Latitude,
** = sites designed to be measured by former researcher (Valens Mulindabigwi) during the first Impetus project phase (2000-2003),*
*** = sites designed for own measurements during the second Impetus phase (2004-2006),*
INRAB=Institut National de la Recherche Agronomique du Bénin

3.6 Farm interview

More than 150 farmers belonging to five Communes of the North-, Middle- and South-Oueme Basin were visited, either on their fields, or at home with their families. Within them, 66 selected farmer interviews were completed during the field research from September 2003 to December 2005.

At beginning of the work in each Commune, an explorative round tour has been done, accompanied by the local agricultural technicians or civil servants. Then, farmers and villages to be interviewed were selected. Criteria to select certain farms were guided by their representative characteristics as to a particular category in a given Commune, concerning their economical and social status and for each of the important spatial subdivisions. Eventually, sampling of fields was performed. Among the 66 recorded questionnaires, ten were group interviews and the others were individual interviews. In each interview group six to 18 farmers participated (table 3-3).

Table 3-3 Farmer interviews: sampling number, spatial distribution in communes, arrondissements and villages

		Number of samples				
Commune	Date	Arrondissement	Village	Group Interview	Individual Interview	Farmer
Abomey-Calavi	2004	5	14	0	15	15
Pobe	2004	5	8	6	2	63
Bohicon	2005	3	6	0	11	11
Save	2005	5	12	4	16	58
N'dali	2003	2	9	0	12	12
Sum		**20**	**49**	**10**	**56**	**159**

The questions in the interviews concentrated in practice on farming systems, especially on the cropping systems. An example of questionnaire was attached in Annexe 1.

Crop sowing and harvest timing, crop rotation patterns, field management were repeatedly asked. Such questions allowed estimation of the cropping and fallow duration. Moreover, field management could be used to estimate the ratios of differently used crops and field areas to the whole farm land areas of farmers. Thus the Cropping Intensity Index and the Ruthenberg's value R were carried out. They were estimated for different cropping systems. Also the intercropping pattern, the farmers' perceptions about the future development of cropping systems and the most important crops were recorded.

Table 3-4 Geographic coordinates (decimal) of the interviewed villages

Commune	Village	N-longitude	E-latitude	Elevation /meter
Abomey-calavi	Yevie	6.603	2.367	29
	Dossounou	6.462	2.244	24
	Kparoun	6.683	2.485	13
	Agongbe	6.537	2.309	40
Pobe	Igana	7.038	2.705	81
	Towe	7.155	2.737	68
	Ibere	7.040	2.705	62
	Onigbolo	7.174	2.660	83
Bohicon	Madje	7.162	2.206	92
	Masse-Gbame	7.266	2.084	219
	Flely	7.188	2.093	173
Save	Okewo	8.049	2.712	173
	Dani	7.982	2.457	192
	Igbodja	7.813	2.587	170
N'dali	Mama Imorou	9.870	2.661	375

3.7 Parameters and variables

In the four selected communes: N'dali, Save, Bohicon and Pobe in the north, middle and south Oueme basin, vegetation was classified into three categories:

- Forest
- Savannah: including savannah, fallow and plantation as one category
- Annual crops: including mainly eight major crops mentioned in chapter 2

In the three regions of the whole Oueme Basin, the following standard agro-ecological parameters and data were repeatedly measured using standard methods:

- Basal Area, Height, Planting Density, Litter-fall, Soil-litter, Biomass
- Soil Chemical and Physical Indicators

- Economic yield of the principal annual crops, cultural calendars, crop rotation pattern, including fallow period, and farming management scheme
- Constraints and problems of the agriculture production from the point of view of the local farmers

For the biological parameters, a total of 150 fields were measured. Within each field a plot of 900 m^2 with a length and width of 30 m was selected in so far possible. Within each plot 5 points, comprising 1 m^2 of surface, were selected and all plants in this 1 m^2 point were measured. Where it was possible, at least three fields of each category within each commune were measured, especially in the case of different annual crops.

The measured data from these four communes in different zones were used at first to calculate the eco-volume, bio-volume and biomass of singular crops on a hectare basis. Then they were integrated into an average value of annual crops category for each commune. In turn, the eco-volume, bio-volume and biomass values of the three vegetation types were calculated for these four communes. These data were then submitted later to statistic analyses as representative values. Before the latter data were submitted for analyses, they were corrected for CIC to identify the real annual cropping areas in each 62 Oueme communes and combined with Benin Agricultural Statistics of the MEAP/DPP (MAEP: Ministere de l'Agriculture, de l'Elevage et de la Peche. DPP: Direction de la Programmation et de la Prospective).

In this study the Cropping Intensity Coefficient (CIC) is defined as a ratio of the sum of cultivated area for annual crops in big and small growing season divided by these in big growing season. Pigeon pea was excluded from this calculation being considered as a crop lasting more than one year in Benin and often perceived by farmers as fallow land. The CIC in the north Oueme Basin is 1, since there is only one growing season annually. In the middle and south, CIC ranges from 1 to 2 depending on vegetative duration and cropping intensity. All CIC values were based on the results of farm interviews during the field research. In the chapter “Farming systems in Oueme Basin” the CIC will be presented in detail. Thus the recorded areas of 62 communes in the annual agriculture statistics are divided by corresponding CIC, enabling the latter values to be combined with remote sensing data of different vegetation types in a consistent way.

The Vegetative duration Coefficient (C_veg) was defined as the number of annual rainy days plus 10 divided by 365 (Vanacker *et al.* 2005).

3.8 Interpolation

Since the selected sampling sites were only four communes and the interviewed sites were only five communes, a simple interpolation method was used to estimate the of vegetation parameters of the 62 Oueme communes for further analyses.

First, the measured eco-volume, bio-volume and biomass values in four selected communes were calculated into average unit values per hectare, and then these values were interpolated for the three Oueme Basin sub-regions. The north Oueme communes used the mean values of these from N'dali and Save, the centre Oueme communes used the mean values of these from Save and Bohicon and the south Oueme communes used the mean values of these from Bohicon and Pobe.

Secondly, the CIC values of five communes were used correspondingly for the five provinces (Departments), within which these communes are located. For the remaining five south provinces, the average CIC values from Abomey-Calavi, Pobe and Bohicon were used.

3.9 Statistical analyses

Following the data compiling process described above, the spatial vegetation dynamics in the whole Oueme Basin in the year 2004 were analyzed together with other data sets comprising geographical coordinates, the annual precipitation data, the vegetative duration coefficient, the population density, and soil nutrient indicators in 2004. Furthermore, the vegetation dynamics of these 62 communes from 1987 to 2004 were analyzed together with the annual precipitation data, the vegetative duration coefficient and the population density across time and space using multiple variable analysis methods. The statistical analyses were performed with the program STATGRAPHICS® Plus 5.1. The statistical methods used in the study include: descriptive multiple-variable analysis for numeric data, ANOVA, multiple regression, general lineal models.

4 Farming Systems in the Oueme Basin

To better understand the vegetation dynamics within the Oueme basin, it is crucial to identify the contribution and the role of agricultural land use, and particularly of farming systems, throughout the Oueme landscapes. Could agricultural development be considered as a major driving force in shaping the vegetation dynamics?

4.1 Literature review

Farming systems research in Africa dates back as far as to the standard book of de Schlippé (1956) describing traditional farming systems among the Azande tribe on both sides of the Uele River in Southern Sudan and in Northern Congo. Later on, Okigbo (1977-1993) described on-going farming systems in West-Africa. Ruthenberg (1976), Fresco and Westphal (1988) were able to hierarchize different farming systems throughout the tropics. Recent advances in African agriculture were summarized by Raemaekers (2001).

Farming systems in the north Oueme Basin were described by Mulindabigwi (2005). Most cropping systems are dominated either by yam, cassava, maize or sorghum. Among fruit trees, mango (Deng and Janssens 2004), citrus and in particular cashew trees are widely grown. Cashew trees are now becoming a booming tree crop in north Oueme, implying not only better revenues but also better protection against bush fires (Mulindabigwi, 2005).

4.2 Material and method

The material and method used in this chapter followed the same as described in the Chapter 3, sections 3.6 and 3.7.

The common Ruthenberg's R is the ratio of cropping length/area to the total rotation length/area, then multiplied by 100 (Ruthenberg 1976). Note that crop length and crop area are not always interchangeable. Therefore, R-time was defined as the ratio of number of cropping years divided by total number of years (cultivation + fallow). Moreover, "R-short area" explicitly refers to the ratio of crop area to total area (fallow + crop land).

Additionally, a modified Ruthenberg formula (R-long area) was devised such as to include both annual and perennial crops and was defined as the ratio of the total rotating annual crops area (excluding pigeon pea area), divided by the total area including pigeon pea, short fallow as well as plantation and forest areas occupied or used by the farmer. Also farmers were asked about the most important crops, the usual intercropping patterns, and their perception about the future development of cropping systems.

The original Ruthenberg's R value is a rough measure in view of grouping tropical farming systems into different classes of farming intensity i.e. permanent cultivation, ley systems, fallow systems and shifting systems, respectively. The Ruthenberg's R value becomes troublesome if it is applied as a tool for comparing the farming systems with great different vegetation length or cultivating duration and intercropping under different rainfall regimes, especially where there is more than one growing season.

4.3 Results and discussion

In this part, the farming systems in five selected communes of the south, middle and north Oueme Basin were qualitatively described with crop calendars, crop rotation patterns at first. Then quantitative analysis followed with estimation of R and CIC values of the farming systems.

4.3.1 Crop calendar and crop rotation

The detailed crop calendars and crop rotation patterns in five selected communes of the Oueme Basin were listed in the annexes 2 to 10.

4.3.1.1 South Oueme

4.3.1.1.1 Abomey-Calavi

The south Oueme commune Abomey-Calavi is becoming a new city with a total land area of 540 km^2 and a population density of 570 inhabitants per km^2 in 2002. It locates directly on the boundary of the economic capital Cotonou and is experiencing a rapid urbanizing process. The rural area here is not far from the city centre and can be taken as an extreme typical peri-urban area. The land speculations, land transactions, and different new land tenure arrangements are daily life here. A lot of autochthon farmers sell their own land and immigrate into Cotonou or move to other activities like transport, construction, seasonal labour works and trading. Meanwhile, many people from other regions are settling here. So the population density is very high comparing with other regions in Benin, even higher than the average of south Benin, which has a higher population density than that in centre and north. About half the income of local farmers, originates from such off-farm activities. The soil is sandy and relative poor. *Imperata Cylindrica* grass is widely spread, which, in most tropical regions, serves as a plant indicator for poor or degraded soils (photo 4-1).

Within the farming system here, specialization and division of labor are ongoing processes induced by turbulent social economic impacts. Traditional cropping pattern is continuing but with declining tendency, whereas the intensified vegetable productions, small animal production like rabbits and pigs are rising, indicating a newly emerging farming diversification. Farming is more and more concentrated and intensified on more suitable areas, for instance near to water, into lowland or on more fertile areas (photo 4-2, 4-3).

Maize is still the absolute dominant crop since it was introduced into Benin. It occupies more than half of agricultural cultivated land areas, followed by cassava, groundnut. In the observation year 2004, the maize field yielded obviously very poorly (photo 4-3).

The Cultivated vegetables in Abomey-calavi are especially numerous, comparing with that in the other researched four communes. Following are some examples: vernonia/amanvive, solanum/gboman, amaranth, aubergine *(Solanum melongena var. esculenta) , lettuce (Lactuca* sativa), cucumber (*Cucumis sativus*), onion (*Allium cepa*), carrot (*Daucus carota subsp. sativus*), parsley (*Petroselinum crispum*). Even mush room production exists here (photo 4-4). Tomato and chilli are widely spread over the field, mostly planted on the border of a field as is the case in whole Oueme Basin. Pineapples have been cultivated since several years here as commercial cash crop. Most vegetables are cultivated as market oriented cash crops. So the commercializing grade, and thus technical level as well as cropping intensity are relatively high. Here exist already semi-automatized irrigating vegetable gardens, as shown in photos 4-5 and 4-6.

The growing season starts at beginning of April till October. The rainfall here allows two cropping seasons for short seasonal crops likes maize, cowpea, groundnut and so on as commonly practiced in south Benin.

As shown in Annexe 9, the current crop rotation pattern in Abomey-Calavi encompasses mainly two modules (table 4-1).

Table 4-1 Crop rotation modules in Abomey-Calavi

- Main module 1: Starting with maize at beginning of first big rain season, repeated maize planting at following small rain season.
- Main module 2: Starting with maize at beginning of first big rain season, then maize planting combined with cassava at following small rain season.

On average the cultivating duration was four years with a variation range from three to four and half years; and followed by four years of fallow ranging from two to five years. So a conventional Ruthenberg R value of 50 was obtained. Nevertheless, here there are two cropping seasons with unique cropping intensity, so this R in its original mean could not be used in comparison with those from north, where there is only one cropping season. Later in this chapter this will be discussed deeper.

Seldom chemical fertilizers and manures were used for maize and cassava, and with two cropping seasons a year, both rotation modules of Abomey-Calavi had to be described as “depleting modules”. Thus overexploitation led to soil degradation as a consequence.

Photo 4-1 Widely spread *Imperata cylindrica* in south Oueme commune Abomey-Calavi

Photo 4-4 Mush room production in south Oueme commune Abomey-Calavi

Photo 4-2 Rabbit production in south Oueme commune Abomey-Calavi

Photo 4-5 Irrigating vegetable garden in south Oueme commune Abomey-Calavi

Photo 4-3 Poor maize yield in south Oueme commune Abomey-Calavi

Photo 4-6 Irrigated vegetable garden under banana in Abomey-Calavi

4.3.1.1.2 Pobe

With its about 400 km^2 total area and 207 int/km^2 Pobe is already a big commune in the south. The rainfall starts here already in March and lasts till the end of October. Part of the soil here is within the so called "depression de Lama", and belongs to the hydromorphic soils. The soils here are sandy to loamy and relatively fertile compared with the average of the soils in south. Day and night temperature differences are big and dew condenses normally at early morning. Traditional crops are intensively cultivated here; on some fertile soils even three cropping seasons are cultivated for short season crops. Commonly two cropping seasons are practiced annually.

Pobe is far from the economic and political centres but directly on the border with neighbouring Nigeria. Trading activities are highly engaged by autochthon inhabitants and local markets exist almost everywhere in the commune. Also illegal diesel oil and gasoline transport from oil rich Nigeria to Benin is relatively active. Trading of motor bikes and cars is also important for autochthon people. Food export to Nigeria is also a profitable off-farm opportunity. Many immigrants from other regions are also living here. Some local farmers have not only farms in Benin, but also in Nigeria. So share cropping is common here and land transactions are somehow easier compared with the case of the commune of N'dali in north Oueme.

Annual crops are relatively very intensively cultivated following mainly traditional patterns in Pobe comparing with those in Abomey-Calavi. Over all, oil palm trees spread widely through the whole commune. Many oil palm plantations exist here. Some of them are bigger than 50 ha. But palm fruit yield and thus oil production are declining. Many oil palm trees are increasingly been cut down for palm wine production. Most of traditional crops can be found here.

The crop rotation pattern encompasses diverse rotation modules and seems to be more traditional and intensive comparing with those in Abomey-Calavi (table 4-2). There is seldom a depleting module in Pobe as in Abomey-Calavi. Even the popular share cropping appears to be relatively sustainable. The soil here is more fertile, population less dense, social economic impact less turbulent in comparison with Abomey-Calavi. The land tenure system here is functioning as if it were a spontaneous ongoing evolution process. Hence, the rotation pattern here seems to be more sustainable.

Table 4-2 Crop rotation modules in Pobe

- Main module 1: Maize in first big rain season + cowpea (or diverse leguminous and vegetables) in following small rain season.
- Main Module 2: Maize repeatedly planted in big and small seasons.
- End phase module: maize + cassava at first big rain season, after maize is harvested in the end of big season, the cassava continues during the small

season.

- Crypto-fallow module: sometimes, after three years of main modules were repeated, three years of pigeon pea will be planted as a kind of short fallow crop. Afterwards, main modules can be continued.
- Short season module: depending on market demands or when rainfall perceived as unfavourable or soil is relative unfertile, the crops needing only short growing time likes cowpea, other vegetables can be repeatedly planted as an alternative to main modules.

The cultivating duration is normally six years with a variation range of three to ten years. The hydromorphic soils here in the "Lama depression", with its big share of compacted loam fraction, contain relatively rich contents of minerals and carbon. Hence, during the annual flooding period nutrients enrich such areas additively each year. Thus, some farmers said, on such soil one could cultivate continuously without break and fertility problem. Also the farmers with origin from Pobe are well known locally, that they like and specialize on such compacted soil in the Lama depression. After six years of cultivation on average, five years of fallow takes place with a variation range from three to six years. So the original Ruthenberg's value obtained according to time was about 55 here. In the fallow fields, oil palm trees are more densely planted. The so called oil palm fallow is characteristic here as the cashew fallow is the case in north or centre.

4.3.1.2 Middle Oueme

The communes Bohicon and Save belong to the middle Oueme Basin in accordance of Impetus zoning approach. The rainfall regime changes here from south to north direction from bimodal to unimodal. Thus the cropping seasons depend on the vegetative length varying from two to one. The dominant type of soils here are south-north-wards ferrallitic and ferruginous soils. Population density is in Bohicon higher than that in Save, the urbanization process in Bohicon is more developed than in Save.

4.3.1.2.1 Bohicon

Bohicon is a more urbanized small town with total area of 136 km^2 in comparison with Save. Its population density in 2002 was 833 inhabitants per km^2. The agricultural activities are less intensive. Most farmers have off-farm activities. The soil here is sandy and less fertile than that in Save. The traditional cropping pattern, i.e. maize plus cowpea rotation is evidently dominant here. Lots of small plantation crops are cultivated here including: orange, banana, cashew, and teak.

Two crop rotation modules dominated here as listed in table 4-3. Pigeon pea is occasionally planted as soil improving bush fallow crop. Generally the cultivation of a field takes place for five years with a range from two to ten. The fallow lasts out four years with a range from two to six years. Thus an original Ruthenberg's value was 57.

Table 4-3 Crop rotation modules in Bohicon

- Main module: Maize at first big rain season then followed cowpea (sometimes leguminous or vegetables) at small rain season.
- Short season module: Different leguminous crops through out of 2 cropping seasons annually

4.3.1.2.2 Save

Save has a total area of 2279 km^2 with a population density of 30 inhabitants per km^2. Compared to Bohicon the annual rainfall amount in most parts of Save is higher though more irregular as mentioned by farmers. So the two cropping seasons are dominant here. The uncultivated arable land here is still easily available. Here exist still certain areas of forests, even though they are continually cut down for charcoal production to be transported to Cotonou. Immigrants with different origins are establishing here renting arable land. Also the cattle keeping nomads are living here, especially during the dry season. Farming activities are the major income source for the local people. There are considerable potentials for adaptation of farming system to the climate changes but the current situation is not optimistic. On the one hand, suitable already cultivated lands cannot be intensified as the farmers have no sufficient accumulated capital to do so. On the other hand, the charcoal production for urban centre is destroying the remaining forests.

Comparing with Bohicon in the south end of the middle Oueme Basin, Save locates in the north end of the middle Oueme Basin. Here, in some parts typical semi-arid summer moist crops like yam and sorghum are cultivated. Despite the fact that maize remains the most important crop, cassava was intensively introduced into the local existing farming systems by different ways. For instance cassava has been planted with different planting densities at different periods by local farmer with belief that cassava combined with suitable crops could maintain soil fertility and simultaneously serves as food reserve where food shortage occurs, since cassava can be harvested throughout the whole year. This belief is contradicted by many authors (Raemaekers 2001).

The typical crop rotation begins with yam at first year, than followed with maize or maize + sorghum, and then cowpea, soya or groundnut. It can also be initiated with maize, cassava, leguminous crops depending on market demands and soil fertilities. Paddy rice is cultivated here at lower areas and near to water. Pigeon pea is used as fallow crop. Long term fallow is often combined with establishing cashew plantation. Mango plantations begin to occur northwards. The modules within the crop rotation here were listed in table 4-4 and the different Ruthenberg's values in table 4-4.

Table 4-4 Crop rotation modules in Save

- Main module 1: Yam at first year then followed by the other modules.
- Main module 2: Maize at first and leguminous or vegetables at second rain seasons.
- End phase module: Cassava alone or mixed with maize at first season, or maize at first then followed by cassava at second season.
- Short season module: diverse leguminous crops planted in both seasons.
- Crypto-module: pigeon pea continually for two years.

Short season module was practiced where market demands reached, or as the soil fertility was diminishing to a certain degree. End phase module here was a little different as normal. Normally after cassava cultivation in Oueme Basin, the soil fertility degrades already to a certain grade, thus only the leguminous crops followed can yield a significant harvest, or such fields have eventually to return to fallow. But as mentioned above, cassava here was planted with varying planting densities, most of those were sparse. The cultivating duration was about four year with a range from three to five years. The fallow takes place for three years with a variance from two to four years. So a typical Ruthenberg's value approximated 60 confirming the on-going intensification process of agriculture in the Oueme basin as recorded earlier on by Mulindabigwi (2006) in upper Oueme.

4.3.1.3 North Oueme

N'dali commune in the north province Borgou was selected in this study. It is a typical north commune with relative bigger area: 3759 km^2 comparing to the area of a south commune. With a population density of 28 inhabitants per km^2 in 2002 N'dali is less settled. It becomes a transport node in north Benin since most imported cars in Cotonou are transiting here on their way to Niger. Also food like yam, maize is transported both to north and to south from here. The major soil type here is sandy ferruginous soil and remains still fertile. Arable land areas are still available even though the land conflict is increasing. The administrative intervention in this point is relative weak and certification process for land property rights is less well known here and even complicated by local administration. So the traditional land property rights system is still dominant. Even against locally dominant ethnic group Bariba's tradition, the land transactions are on the rise. N'dali is becoming an immigrant target region with its relative favourable conditions considering transport, market access, available relative fertile arable lands. The expansion of government supported cotton cultivation has helped autochthon farmers accumulating certain capital.

Rainfall begins here normally from April to October but cropping season begins from May, so it allows only one cropping season. The typical yam cropping is characteristic here. Maize wins more importance, while millet, sorghum, cassava, diverse leguminous crops like cowpea, groundnut, soya and other vegetables are traditionally cultivated here.

The crop rotation pattern begins normally the first year with yam after land clearing. As cotton was intensively extended here, it took sometimes also the leading place as first crop after clearing a land. The second year followed by maize or maize mixed with sorghum or millet, and is then repeated till year four. In the fifth and sixth year leguminous crops are planted. Afterwards, depending on soil fertility and market demand, this field would be given up to fallow or yam, sorghum or cassava would be planted for the further two years. Fallow has been increasingly combined with establishing cashew plantation, so called cashew fallow. One important reason is that trees are generally recognised as a sign of land property rights; only the land lord/owner is allowed planting and occupying trees.

Combined with the data about cultivation and fallow duration of another Impetus project colleague Julia Röhrig, the average cultivation duration was four years with a range from two to eight years. The average fallow duration was four years with a range from one and half to ten years. Thus the Ruthenberg's value is about 56.

4.3.2 CIC and modifying Ruthenberg's value

There are very scarce data about estimation of fallow areas and duration for Benin. Even such estimation could not be used directly in this study, for the other studies such estimation is useful, also for further research of the interplay between vegetation dynamics and agro-ecological settings.

For this purpose, several modifications of R coefficient are proposed, for instance combining it with CIC. To be able to calculate R and CIC values in five selected representative communes, farmers were asked to estimate the percentage share of different annual and perennial crops, fallow and forest land that they occupied or used during the same year. Where there are two cropping seasons, the percentage estimations were done separately.

The CIC was calculated as a ratio of the sum of cultivated area for annual crops excluding pigeon pea in big and small growing season divided by these in big growing season, as mentioned in chapter Materials and Methods in General.

Table 4-5 Ruthenberg's R values and its modification with CIC

Commune	R-time	R-time x CIC	R-short-area	R-short-area x CIC	R-long-area	R-long-area x CIC	CIC	C_veg 2004	C_veg 03-05
Abomey-Calavi	0.51	0.80	0.57	0.90	0.52	0.82	1.58	0.49	0.45
Pobe	0.55	1.02	0.89	1.73	0.76	1.42	1.86	0.59	0.53
Bohicon	0.61	0.99	0.75	1.21	0.54	0.88	1.61	0.55	0.53
Save	0.59	1.02	0.75	1.31	0.57	1.00	1.75	0.54	0.54
North(=N'dali)	0.56	0.56	0.66	0.66	0.43	0.43	1.00	0.47	0.48

The CIC and R values for five selected communes are shown in table 4-5 and figure 4-1. In the second column R-time values are the original Ruthenberg's values expressed as arithmetic mean (average) without multiplying by 100, which were obtained through farmer interviews by asking how long their cultivation and fallow duration are. The R-time values of the Bohicon, Save and north coincide with the observation by the other author (Mulindabigwi, 2006). C_veg 2004 values were the vegetative duration coefficient of year 2004, and C_veg 03-05 values were the average of vegetative duration coefficients from 2003 to 2005, where field research took place.

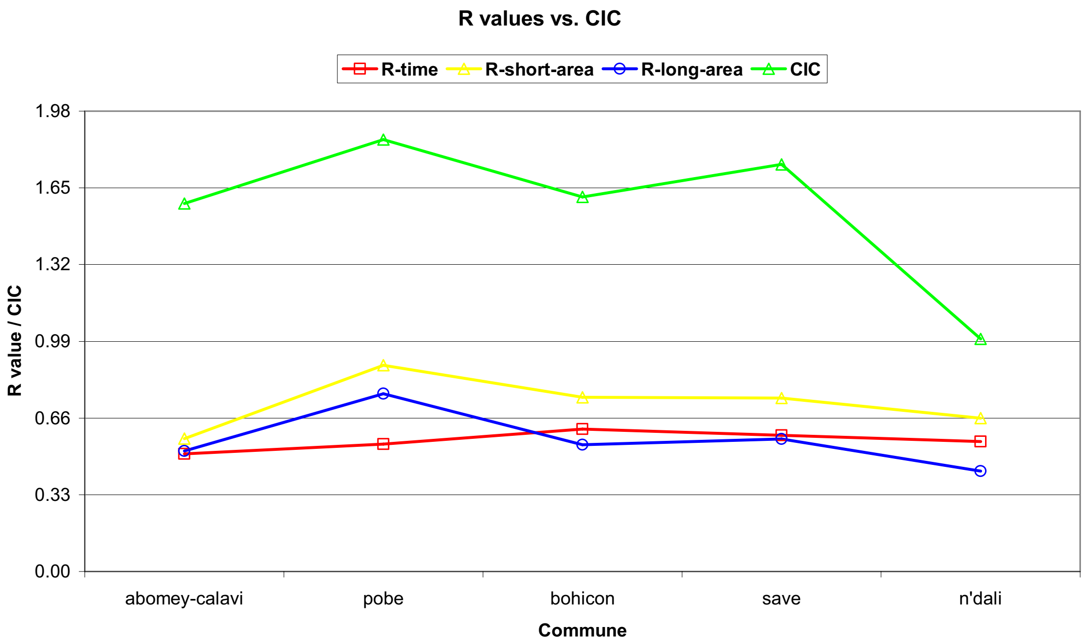

Figure 4-1 Cropping Intensity Coefficient (CIC) and Ruthenberg's values (R) according to time and area

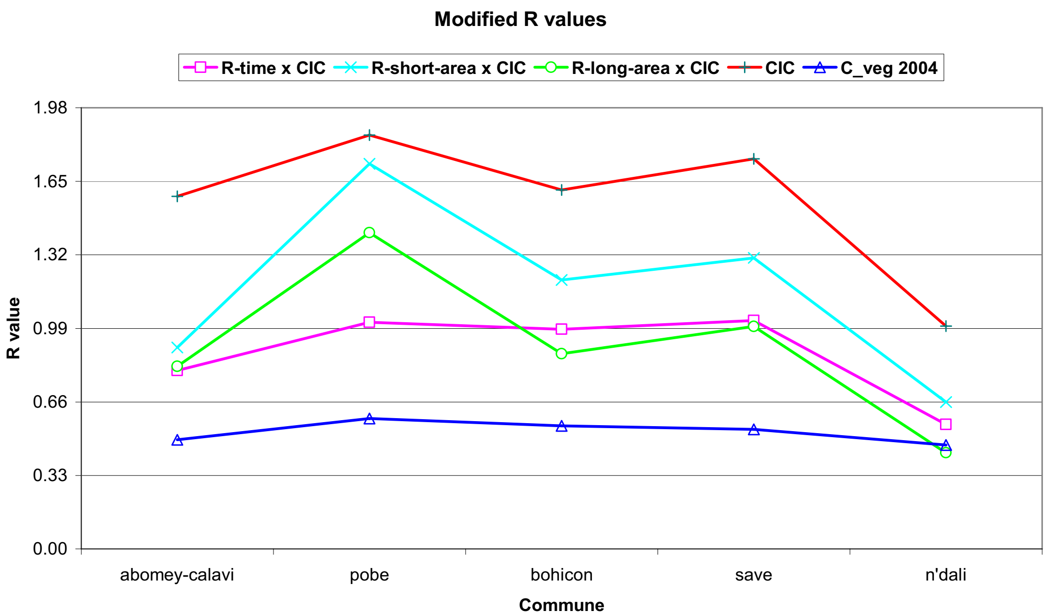

Figure 4-2 Ruthenberg's values (R) modified by Cropping Intensity Coefficients (CIC) vs. CIC and Vegetation Duration Coefficient (C_veg)

The R-time and R-short-area values could be considered as short-term rotation intensity, while the R-long-area values could be considered as long-term rotation intensity, since in the long run, theoretically all kinds of land use types could be changed into other kinds, for instance into annual crops fields. The practices of oil palm fallow in the south and cashew fallow in the centre and north Oueme Basin supported this consideration about the long-term R definition. Such definition of R-long-area implies that all other land areas of a farm, excluding annual crops areas, have been considered as fallow areas.

In accordance to the agro-ecological and social economic conditions in the five communes, the R-long-area was considered as more suitable indicator and discriminator responding to the proportion of the area under annual crops cultivation to the total arable area. The R-time has not clearly distinguished the differences between five communes, thus it was relative unsuitable. One reason might be that the vegetative length and thus cultivation duration in north, centre and south regions are clearly different. Since tree crops like oil palm and cashew were more and more used to sign the ownership rights, the R-short-area was also not very suitable to distinguish the different farming systems under different conditions. The unclear delimitation of land caused by unclear land property rights systems in Benin contributed also to the unsuitability of R-short-area as a good indicator.

It is interesting that all R values modified by CIC could yield a better indicator for distinguishing different farming systems intensities. Figure 4-2 showed a visual example that CIC and CIC modified R values were varying congruously with C_veg 2004, but more explicit quantitative evaluation will need more sampling data.

It would be ideal to describe a cropping system, if an integrative indicator could measure simultaneously the cropping intensity, soil fertility, area allocation upon space and parcel management across time. Even better, if it could respond to the rainfall influence, for example, the length of vegetative period, and, respond to the impact of population dynamics. But the interplay between these events is not linearly correlated, even though logically they are related. Thus for the study goal, for the whole Oueme Basin, CIC was taken as a responding indicator to cropping intensity, length of vegetative period. As the Oueme Basin has been zoned into three different zones, CIC could also be a good responding indicator to soil fertility and population dynamics.

To test the relationships between cropping intensity index and population indicators, different social, biological and environmental parameters, a preliminary cluster analysis was performed CIC and R values, biological and soil indices, coordinates and precipitation parameters (figure 4-3). The modified R by CIC (R_time justified) was closely associated with vegetation duration coefficient (VR_1) and to a lesser extent with population density (P_dens02). Even so, CIC should prove useful for justifying agricultural used land area in the official statistics. This topic remains a very interesting issue for further research.

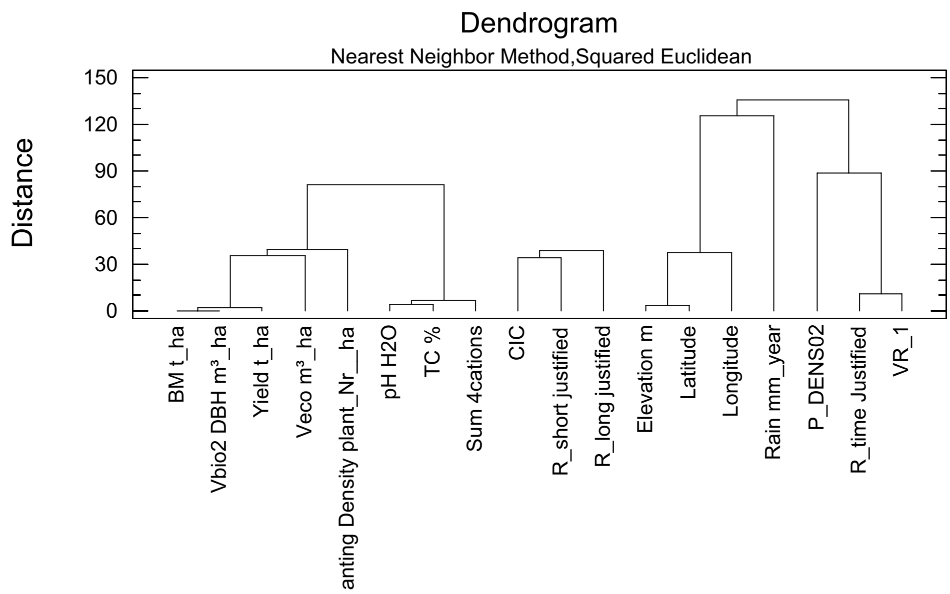

Figure 4-3 Result of cluster analysis with three datasets across the Oueme basin: Cropping Intensity Coefficient (CIC) and Ruthenberg R values, biological and soil indices, coordinates and precipitation parameters

4.3.3 Intercropping

Annual cropping practice in Benin is often assorted with intercropping. Only commercialized cotton is planted in pure stand. Moreover, many plantation crops (mainly fruit trees) become also pure stands, at their adult stadium. Different annual crops are planted in the same field, for example, maize + cowpea pattern is popular in whole Benin, where maize is cultivated. Further patterns, maize + sorghum, yam + cassava, cassava + maize, maize + groundnut/beans and maize/cassava + vegetables exist. More characteristic in Benin and also in other African countries, one can find useful trees with varying distances in most annual crop fields. Up north one observes inter-planted Karitè and Nérè trees (Vermeersch 2005). In newly established young cashew or mango plantations annual crops are usually planted. In the centre and south regions, the oil palms are customary to many annual crops, and near to urban areas the vegetables under banana trees are typical of the landscape. This intercropping practice is on the one hand a risk management strategy in response to local climate uncertainties (irregular rainfall amount and temporal distribution); on the other hand, it is a response of farmers to increase productivity of the same area. In north and centre regions there are still arable lands which are not cultivated. In the south the intercropping with different annual crops could be induced by the fact that in the dense settled south, share-cropping occurs increasingly, even though the institutional arrangements are relatively weak. Moreover, land tenure systems encompass legislative and traditional uncertainties as mentioned in chapter 2. So the tenants are tempted to overexploit their fields.

4.3.4 Case study mango

In order to illustrate the importance of controlling biomass development, biomass partitioning and crop intensification at micro-scale, a pilot study was initiated with Mango farmers of the N'dali commune, in the north Oueme sub-region.

Mango (*Mangifera indica L., Anacardiaceae*), is the most widely known cultivated fruit tree in the Sahel and one of the most important tree crops of the tropics. As shown in table 4-6, the global mango production revealed a growing trend worldwide during the 1990-2003 periods. For Africa, Western Africa and the world as a whole, a similar exponential growth rate (GRRE) of about 3% has been recorded for total mango production, mainly due to the harvesting area expansion, with GRRE values of 4.10%, 3.65% and 3.91% for the whole world, Africa and Western Africa, respectively. At the same period, the differentiated yield levels (Mt/ha) showed a slightly diminishing trend: GRRE were -0.34%, -0.19% and -0.54% for world, Africa and Western Africa, respectively. In Benin, the total mango production, harvesting area and yield per hectare were 12 000t, 2 300 ha and 5.2 t/ha since 1985 (FAO, 2004).

Table 4-6 Production trend of mango in the world, West Africa and neighbouring countries of Benin

Production (Mt)	1990	2001	2002	2003	GRRE %
World	16902707	25140500	26478497	25562469	3.41
Africa	1728677	2641090	2619204	2629800	3.45
Western Africa	672711	1008351	1040217	1046405	3.35
Benin+	12 000	12 000	12 000	12 000	0.00
Burkina Faso	5 000	5 000	5 000	5 000	-0.00
Cape Verde	4 761	4 500	4 500	4 500	-0.49
Côte d'Ivoire	14 000	15 000	15 000	15 000	2.62
Gambia	250	554	560	560	4.68
Ghana	4 000	4 000	4 000	4 000	-0.00
Guinea	50 000	120 000	155 812	160 000	5.81
Guinea-Bissau	3 700	4 700	4 700	4 700	1.05
Mali	14 000	33 097	29 145	29 145	7.51
Nigeria	504 000	730 000	730 000	730 000	3.14
Senegal	56 000	73 000	73 000	75 000	2.11
Sierra Leone	5 000	6 500	6 500	6 500	2.20

**: Calculation based on the FAOSTAT. www.fao.org, FAO 2004.*
***: GRRE = % exponential growth rate.*
+: Benin data based on FAO estimation.

The mango tree originates in India and the adjacent Southeast Asian region. Early explorers brought the tree to other regions, such as East Africa in the 14th century and 200 years later Portuguese sailors brought the tree to West Africa. Today the species is cultivated in almost every tropical region but preferably in zones with a dry season because fruiting becomes irregular in other regions (von Maydell, 1986). Consequently, the irregular, alternating fruiting, so recognised as on-off fruiting phenomenon, induces the income instability of mango growers and more undesirably, it hinders the development of commercialising mango production at its starting stage. The on-off fruiting phenomenon should be also one of the reasons, why the worldwide mango production was estimated at e.g. 17 million tons in 1992 although only 0.102 million tons (0.6 %) were internationally traded (THE HINDU, 1997).

Indeed, in Benin mango trees distribute in whole country but mostly concentrate in the arid north region. Even though, during the field research in September 2003 - May 2004, the on-off fruiting phenomenon of mango production was identified in N'Dali and Sérarou of North Benin, - where an obvious dry season dominates the region from October to April -, only 49% trees were bearing fruits at that time as shown in the figure 4-4. The explanation for the on-off fruiting phenomenon in North

Benin, and more particularly in the Northern part of the Oueme Basin, needs further thinking.

Considering the agro-ecological constraints and technological level of mango production in West Africa, the following hypothesis was put forward: the on-off fruiting phenomenon is due to the trade-off between the reproductive and vegetative growth cycles of mango tree. The biomass partitioning pattern within different plant organs of an individual plant varies under different conditions. When a plant partitions more net photosynthate to leaf, branch and stem, it remains less to the reproductive organs like flower and fruit. This implies that:

- The fruit yield of mango should quantitatively correlate with the leaf area index (LAI), crown diameter, basal area and tree height;
- There should be a threshold value of LAI, which could predict the on or off fruiting of individual mango trees;
- Further more, the pruning could increase the quantity as well as the quality of mango yield since it rebalances the biomass partitioning.
-

Table 4-7 Primary Parameters of Mango Tree Biomass Productivity of N'Dali-103 (Average Value)

Parameter	LAI	Basal Area	DBH cm	Crown Diameter m	Surface m²	Height m	Biomass	Fruit Yield
Average/tree	1.58	844 cm²	8.45	8.53	57.15	7.18	246.2 kg	26.2 kg
On ha basis**	0.90	8.44 m²	-	-	5715	-	24.62 t	2.6 t

**Co-ordinates (GPS-data): Elevation:1262 ft; N: 09°47,446´; E: 002°42,351´.*
***: Planting density: 10 m X 10 m, which means 100 trees/ha*

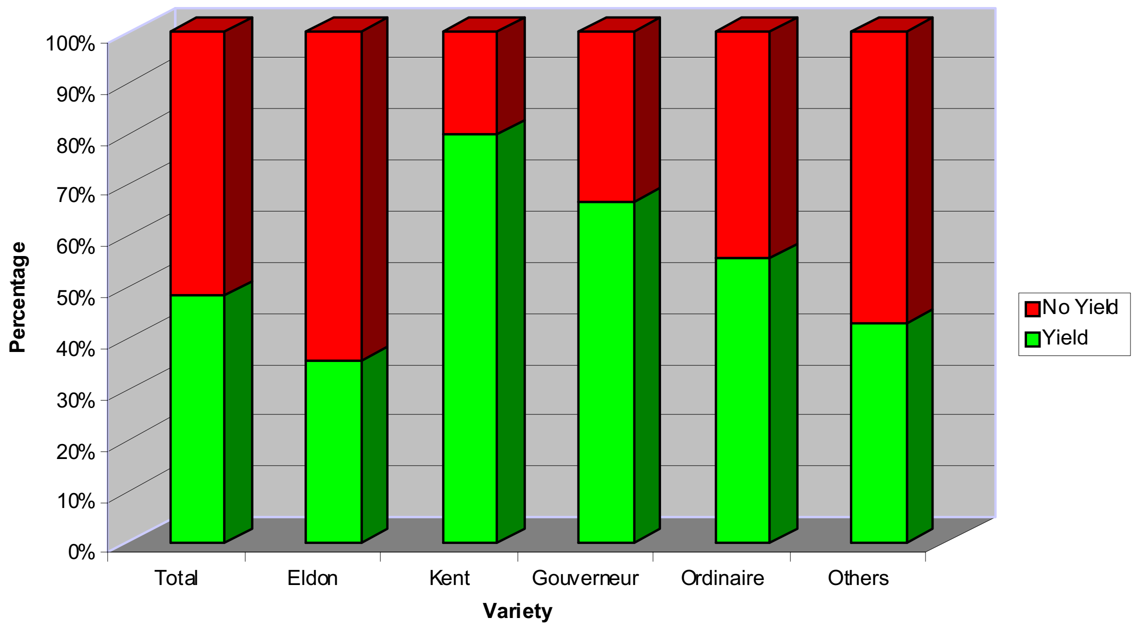

Figure 4-4 Fruit loading difference between different mango varieties in the north Oueme

** "Others" includes the following varieties: Brooks, Keitt, Smith, Ifac, Dabtcha, Ruby, July, Palmer, Zill, Irwin, Haden, Tomy Atkins …*

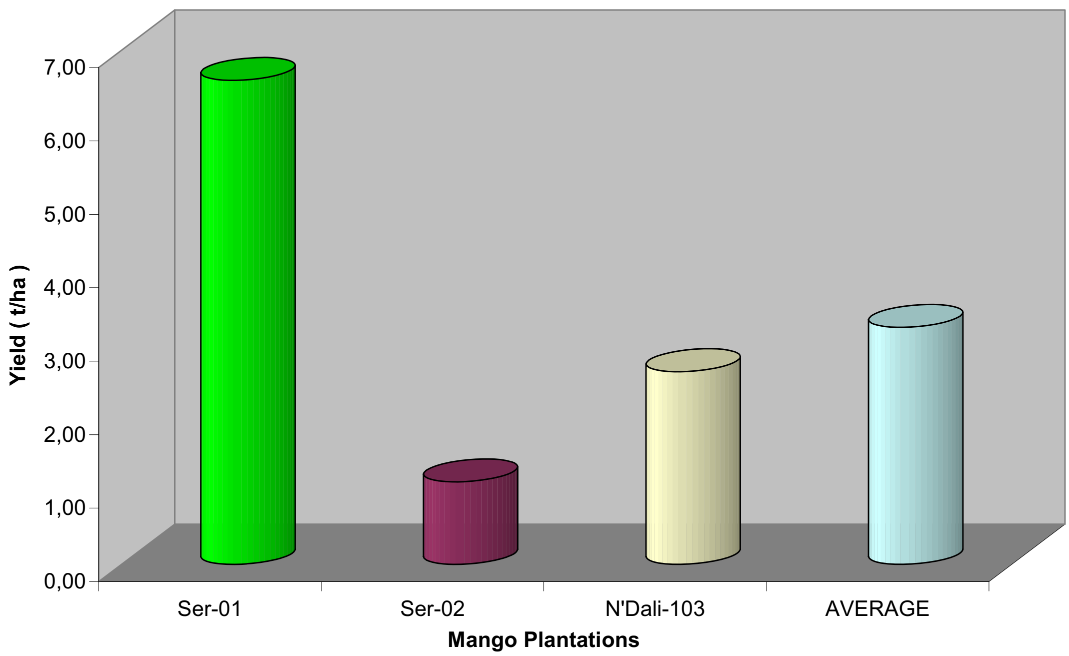

Figure 4-5 Difference of yield level between mango orchards in the north Oueme

To test the hypotheses the necessary parameters have been measured at a mango orchard in N'Dali (table 4-7), and a small survey was done in four mango orchards in

North Benin (figures 4-6, 4-7 and 4-8). First results are documented here. The harvested and exported products (2.6 t of fruits/ha) amount to $1/10^{th}$ of the total biomass, which remains within the sustainable potential of these orchards. When possible, the research measurement is to be completed during the coming years. Or it could be a potential collaborative research with GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit).

Considering the figures 4-4 and 4-5, one can recognise a technological potential present in Serarou (ca. 7 t/ha) which could improve mango production in North Benin. Of course, if it is worth to improve mango production, is an economic and political choice.

Under the West African sub-humid i.e. vigorously growing conditions, pruning does remain the most effective and feasible technique. Hence, there is a need of an *in situ* experiment to quantify the relationships between the different pruning approaches, pruning intensities and fruit yield levels of mango production. Indeed, the pruning could double the current average fruit yield of 3.2 t/ha to ca. 7 t/ha (see Figure 4-5), particularly when choosing productive clones like cultivar Kent (Figure 4-7). And more important, it could stabilise the fruit yield between the different years, which is a prerequisite to integrate mango production into the market economy and into the international trade, since market mechanisms need predictable production information to price building, which in turn facilitates the market transactions and enable an efficient resource allocation (Alchian, and Demsetz. 1972). Otherwise, the too high information costs caused by the production uncertainty will disable a certain amount of mango transactions.

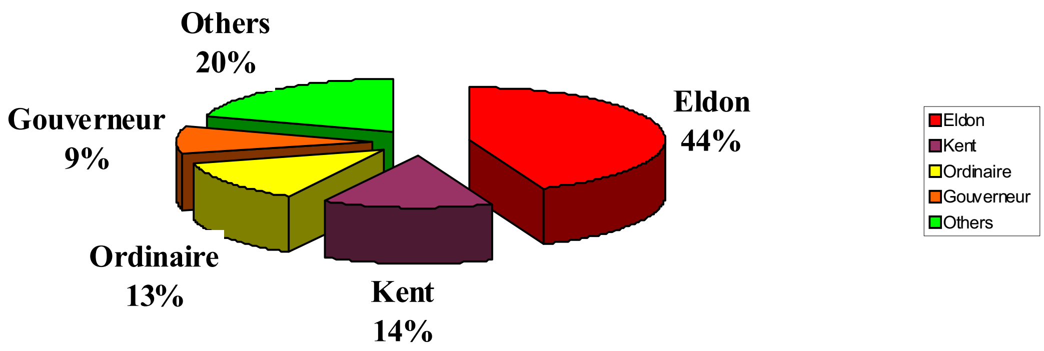

Figure 4-6 Mango Varieties composition in N'Dali and Sérarou, north Oueme

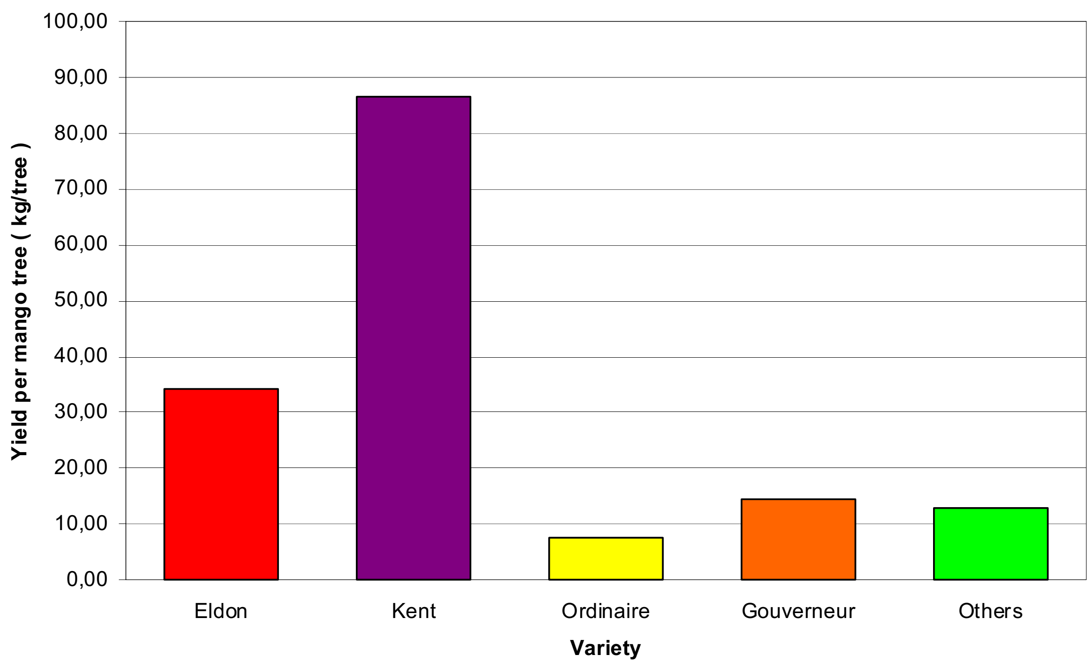

Figure 4-7 Yield difference between the mango varieties in the north Oueme

Loosening the other technological, institutional and economical constraints. the further developing of mango sector can be reasonably imagined: beyond the orchard management strategy with pruning as critical technique, assuming that mineral fertilizer would be available through liberalized market access upon governmental intervention, and if modern weeding and plant protection measures could be used, if so, the yield level could reach ca. 15 t/ha, which is four times the current average yield level. If additionally, irrigation, - preferably drip irrigation -, could be realized, a yield level of 30 t/ha could be reached together with the development in other sectors.

4.4 Partial conclusion

Farming systems are experiencing an on-going intensifying process reshaping vegetation dynamics in the Oueme basin. Crop production can easily be intensified by appropriate techniques. The case of mango production is illustrated. The Ruthenberg coefficient modified as R-long-area coefficient, and particularly combined with CIC, was considered as a more suitable indicator and discriminator of overall cropping intensity as annual crops are related to the total arable area. Above indicators point to systems where long-term fallows become nearly extinct and where short-term fallow period tends to be shorter than the cropping period. Hence, vegetation dynamics rely more and more on human management, if not, influence.

5 Litter Fall in Forest and Plantation

5.1 Introduction

Tree litter fall is the major above-ground input of carbon (and nutrients) into the forest and plantation floor. Such litter layer protects the underlying humus and mineral soil against drought and represents a considerable buffer for the on-going vegetation dynamics and eventually contributes to the sustainability of ecosystem capacity. However, on a regional scale, litter fall data are scarcely available on sufficient stands as it is a cumbersome task. These are to be collected and analyzed, when estimating carbon budgets and accounting green house gas as requested by international agreements.

To predict litter fall annual quantity of forest and plantation in Benin, West-Africa, vegetation stand parameters like biomass were measured. Previous studies by Sonwa (2004) in Cameroon and Mulindabigwi (2006) in Benin indicated that litter fall depended on factors like latitude, precipitations, basal area and age. Yearly litter fall fluctuated around 6-8 t/ha in Northern Ouémé, Benin (Mulindabigwi 2006) and between 8-14 t/ha under several types of cocoa based agro-forests in Cameroon (Sonwa 2004).

The biological stand parameters, however, will not change as strongly as variation of litter fall over time and across regions in Benin, where unimodal and bimodal Guinean Coast climate rainfall regimes dominate differently in North and South. For predicting regionally more generalized and temporal dynamics of litter fall, climate change should be taken into account. Moreover, the micro-site parameters, like soil characters, vary throughout the regions in Benin and could contribute to predict litter fall more precisely.

5.2 Material and method

Litter fall amounts of six sites in forest and plantations along the whole North, Middle and South Oueme River Basin (10°N, 2°E—6°N, 2°E), were collected at monthly interval for a whole year. Additionally, litter fall data of other seven sites within the same project IMPETUS in Benin were used. The biological stand parameters like diameter at breast height (DBH), basal area (BA), height of tree (H), and planting density (PD) were measured in situ. Between 10 and 20 litter traps of 1m² were allocated to each of the 13 sites. The soil samples in the same sites were taken and analyzed either in Germany for chemical characteristics or in Benin for physical characteristics. Climate parameters like 20 years average annual and monthly precipitation amount (1985-2004), number of rainy days, were supplied by Mr. Malte Diederich (2006) from the same project.

Data were analyzed with the statistic program STATGRAPHICS Plus 5.1 in three steps. Firstly, the time series analyses were done with two variables: the monthly litter fall quantities and the average monthly precipitation quantities of 13 sampling sites. Secondly, the multiple regressions with 13 sites data were done. Thirdly, the simple regression analyses were performed with above mentioned stand, site and climate parameters from own measurements taken in the six sites. Finally, the multiple regression analyses with the six sites data set were performed for determining the most suitable predicting model for litter fall. More general methods are described under Chapter 3.

5.3 Results and discussion

The data shown in table 5-1 are relatively similar to those collected formerly by John (1973) in Ghana. The regression analyses show the results of time series analyses of 13 sites data set (Table 5-1) with two variables “Monthly total dry litter fall quantity vs. Monthly precipitation”: Over all the 13 sites, there is a statistically significant relationship between two variables at the 99% confidence level. The correlation coefficient equals -0.51, indicating a moderately strong relationship between the two variables in agreement with Sonwa (2004) and Mulindabigwi (2006). Because of the time lag, the largest litter fall is recorded during the dry season.

Table 5-1 Litter fall (LF) data across 13 sites in Benin as related to different ecological parameters

Serial Nr.	LF t/ha	Rain mm	H cm	Veco m³/ha	N-Lat.	E-long.	Elev.
Boranglf	5.67	1137	380	37985	7.20	2.06	183
lafolf	7.88	1185	845	84516	6.98	2.13	87
latelf	8.37	1185	1767	176747	6.98	2.17	69
pofolf	8.00	1214	1176	117579	6.97	2.68	104
nfolf	7.81	1160	688	68831	9.76	2.35	317
nmglf	3.58	1160	760	76000	9.79	2.71	394
sefolf	9.02	1283	1245	124490	9.70	1.67	439
sefalf	1.72	1283	514	51350	9.70	1.67	439
secashlf	4.55	1283	633	63330	9.70	1.67	439
dfolf	4.10	1250	670	67020	9.02	1.94	384
dfalf	3.02	1250	514	51350	9.02	1.94	384
dcashlf	2.65	1250	633	63330	9.02	1.94	384
dorlf	3.78	1250	700	70000	9.02	1.94	384

Boranglf = Bohicon: orange, lafolf = Lama: forest, latelf = Lama forest, pofolf = Pobé forest, nfolf = N'dali forest, nmglf = N'dali mango, sefolf = Sérou forest, sefalf = Sérou fallow, secashlf = Sèrou cashew, dfolf = Dogué forest, dfalf = Dogué fallow, dcashlf = Dogué cashew, dorlf = Dogué orange. Veco = eco-volume of forest, plantation or fallow.

Multiple regressions for 13 sites to determine the annual total litter fall quantity (LF in t/ha): Precipitation (mm), height (cm) or latitude alone could determine relatively strongly LF. Two or three combined parameters yielded some better models.

$$LF = 0.00117854*Rain + 0.00484474*H$$

Model 5-1 Litter fall (LF) in relation to precipitation (Rain) and plant height (H)

For example, model 5-1explains 91.1% of the variability of LF. There is a statistically significant relationship between the variables at the 99% confidence level (Figure 5-1).

As plant height is closely related to vegetation indicators like bio-volume and eco-volume, it follows that litter fall plays a major role in determining the vegetation dynamics within the Oueme basin. Moreover, its relation with rainfall should also be considered as a central element in vegetation dynamics.

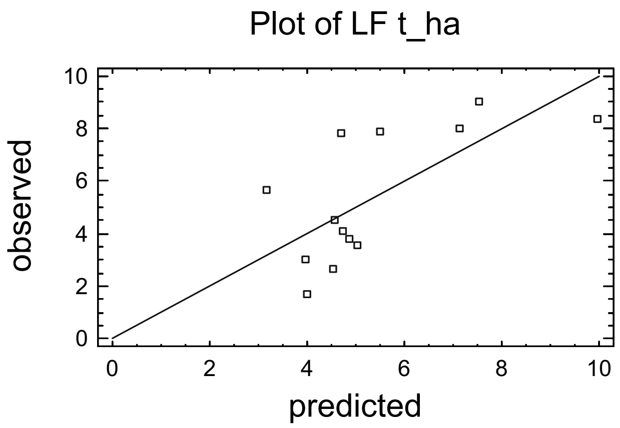

Figure 5-1 Relation between observed and predicted annual litter fall (LF in t/ha) data related to annual precipitation (mm) and tree height (cm) as independent variables

Litter fall could be related to other variables through simple regressions across six sites. The best single determining variable was a biological stand parameter: planting density (here the Nr. of trees per hectare), with a correlation coefficient = 0.98. When comparing with other site and climate parameters, the biological stand parameters like bio-volume (Vbio-m^3/ha), eco-volume, DBH could fit and explain the LF and its variation better than climate parameters like average annual precipitation. Within the site parameters, only elevation as related to litter fall was almost as good as Vbio and DBH. The soil parameter carbon percent within a 20 cm deep soil layer had relative weak relations with LF.

Table 5-2 Litter fall (LF) across 6 sites in Benin as related to important soil and growth characteristics *

Serial Nr.	LF kg/ha	Rain mm	DBH cm/tree	Sum BA m^2/ha	Height cm	PD	Vbio m^3/ha	N-Lat.	E-long.	Elev.	Soil C %
Boranlf	5675	1137	11	11	380	215	1	7.20	2.06	183	0.56
lafolf	7878	1185	15	20	845	344	6	6.98	2.13	87	2.49
latelf	8371	1185	28	62	1767	944	103	6.98	2.17	69	1.25
pofolf	7998	1214	10	111	1176	589	77	6.97	2.68	104	1.34
nfolf	7807	1160	17	39	688	656	18	9.76	2.35	317	0.91
nmglf	3583	1160	7	8	760	100	1	9.79	2.71	394	2.73

** Serial Nr. as in Table 1. BA = basal area; PD = planting density; Vbio = bio-volume; C% = carbon %*

Multiple regressions for six sites to determine LF: The annual precipitation was the best single parameter for determining LF. Even with only one parameter like precipitation, DBH, BA, Planting density, Vb, eco-height, or carbon percent, the fitted models without constant could explain the variability of LF relatively well. Among all the parameters of three categories: biology, climate and site, different combinations of parameters yielded different models with and without constant, which explained easily more than 90% of variability for LF at 99% confidence level, even only with two parameters,

LF = 6.42646*PD + 462.14*Latitude

Model 5-2 Litter fall (LF) in relation to planting density (PD) and latitude

For instance, for model 5-2 a statistically significant relationship could be found between the variables at the 99% confidence level. The R-Squared statistic indicates that the model explains 96.1% of the variability in LF.

In model 5-3 the relationship between LF and both DBH and precipitation is described.

LF = 163.629*DBH + 3.8467*Precipitation

Model 5-3 Litter fall (LF) in relation to diameter at breast height (DBH) and precipitation

Here again, there is a statistically significant relationship between the variables at the 99% confidence level and a determination coefficient as high as 97.2% (Figure 5-2).

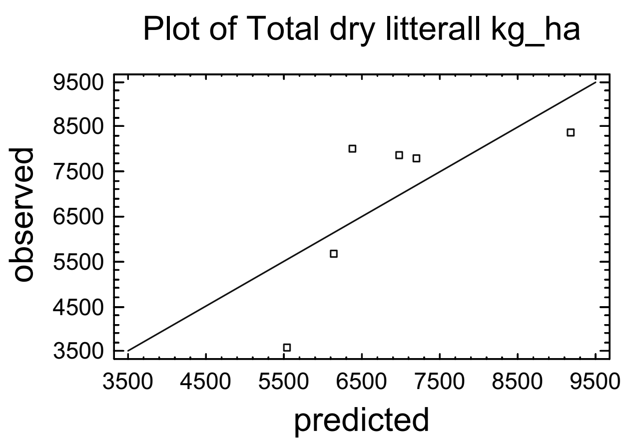

Figure 5-2 Prediction model for annual litter fall (kg/ha) using tree DBH and annual precipitation as independent variables

Caution should be taken when interpreting above regressions because of apparent low number of degrees of freedom. In fact, each recorded result was the average of 10-20 litter traps. Finally, soil carbon content (C%) as related to annual litter fall quantity showed a statistically significant relationship at the 95% confidence level.

LF = 3352.72*Soil C %

Model 5-4 Litter fall (LF) in relation to soil carbon content (Soil C%)

Model 5-4 has a determination coefficient of only 67.5% (Figure 5-3). This litter fall to soil carbon relation is central to the theory of Nye & Greenland (1960). The moderate determination coefficient points to the fact that both the humification and mineralization coefficients were different in the various agricultural and natural systems. It also follows that the mineralization to humification rates are not constant and/or that the recorded agricultural and natural systems are not at equilibrium.

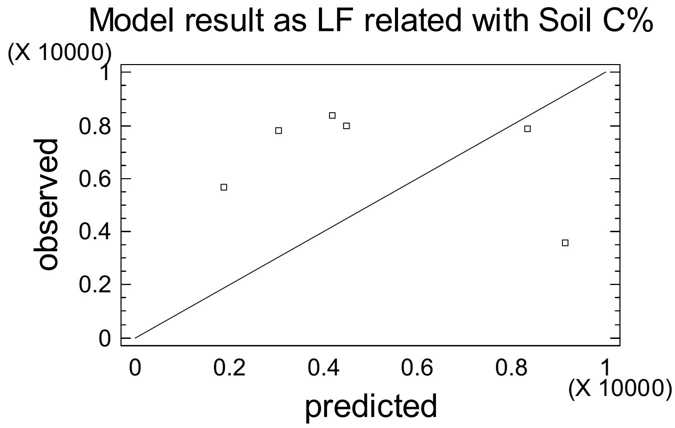

Figure 5-3 Prediction model between soil carbon (C%) and annual litter fall quantity (kg/ha)

5.4 Partial conclusions

Tree litter fall is the major above-ground input of carbon (and nutrients) into the forest and plantation floor. In our studies, the annual litter fall flux has been found to correlate with site, stand, and climate characteristics like planting density, annual precipitation, latitude, DBH, height and to a lesser degree with carbon content in the soil. Comparatively to site parameters like soil properties, the biological stand parameters are easy to measure and can be combined with large scale climate parameters to predict annual litter fall dynamics reasonably over the regions. This opens the possibility of making models for predicting tree litter fall on regional scale, both in forests and plantations where it is not measured directly.

Since vegetation adapts more to long term climate conditions than short term climate conditions, the monthly dynamics of litter fall quantity are more difficult to predict than annual litter fall quantity. The different site specific rainfall regimes should be taken into account in future research.

Vegetation dynamics have monthly and annual characteristics according to site specificity as indicated by litter fall. It is to be considered as a key factor when describing relations between soil and vegetation as well as between soil and eco-volume.

6 Spatial Vegetation Dynamics

6.1 Introduction

6.1.1 Objective

In the previous chapter the relation between litter fall and soil carbon content was only moderate but with precipitation it was stronger. Which indicators of vegetation dynamics other than litter fall (e.g. biomass, eco- and bio-volume) would present a better response to precipitation, soil nutrition and population dynamics at the regional scale?

6.1.2 Hypothesis

6-1: Eco-volume, bio-volume and biomass should correlate closely and positively among each other at different spatial levels, as all of them are comparable vegetation parameters for plant communities. That implies that knowing one of them suffices to predict the other one.

6-2: Vegetation dynamics should respond differently to the environmental parameters at different spatial levels/scales. That implies first, that correlation coefficients should differ at different levels. And secondly, the different zoning approaches should distinguish different parameters of vegetation dynamics, agro-ecological factors with different discriminating degrees.

6-3: Annual precipitation, vegetative length, soil carbon content and longitude should influence biomass, bio- and eco-volume positively and directly. But the sensibilities of these three vegetation dynamics indicators in response to the environmental parameters should be different.

6-4: Population density and GDP per capita should influence vegetation dynamics negatively.

6.2 Material and method

To test the suitability of three indicators for vegetation dynamics as interconnecting parameters, based on the own field measurements of vegetation parameters in four

Communes i.e. Pobe in South-Oueme, Bohicon and Save in Middle-Oueme and N'dali in North-Oueme Basin. Other available statistic and satellite data were also compiled at communal level. Since field research was implemented from 2003 to 2005, the year 2004 was selected as pivot year and consequently, all data used in this chapter were of year 2004. Only area estimation data from GLC2000 was from year 2000, which, were then complemented by the annual agricultural statistics of year 2004 and reconstructed as described under Chapter 3. Secondly, the parameter mean values of ten departments and six AEZs were also analyzed concerning their correlations. Then the correlations of parameters within the three Impetus zones were tested. In the following part the calculation of eco-volume value (Ve) is described in detail. The other two indicators, bio-volume and biomass followed the same compiling procedures as eco-volume.

Also, the soil litter (SL) and four selected soil parameters including: 1) Total carbon percent (=TC1% t_t), 2) Sum of 4 cations (=sum 4cations t_t), 3) PH-value in water (=pH H2O t_t) and 4) Effective phosphor (= P t_t) followed the same compiling procedures. But by compiling soil parameters, only vegetation areas were taking into account. That implied that the communal average unit soil parameters were weighted by the different area shares of vegetation types to the total vegetation areas. The assumption taken here was, that the corresponding soil parameters under these vegetation type covers do change consequently in relation to vegetation type change. The 150 sampled soil parameters were listed in the annexe 13.

For each of 62 communes of Oueme Catchments, the weighted total eco-volume values of the whole commune were calculated. Then, the communal average unit Vec values of each 62 communes were obtained, whereby the total Ve of a certain commune is divided by the whole area values of this commune.

The compiling was as follows: The first step is to carry out the average Ve values (m^3/ha) of three classified vegetation types ((i) forest, (ii) savannah+fallow+plantation and (iii) annual crops) in four selected representative Communes. Secondly, these average Ve values of three vegetation types in four communes were grouped into three categories: North-, Middle- and South-Oueme Basin in accordance with the Impetus zoning approach (Chapter 3). The average Ve values of annual crops were then weighted by the percentage share of different principle annual crops to the total annual crops area in three different sub-regions of the whole Oueme Basin, which, were obtained by the field research interviews as described in Chapter 4 dealing with Farming Systems. The weighted average Ve values of annual crops, together with the other two average Ve values of the forest and savannah (= savannah + fallow + plantation), were then used to estimate the total Ve values of all 62 communes of Oueme catchment. Thirdly, the area data of land use change from the IMPETUS Project remote sensing group and the statistics of the annual agricultural used area from the MAEP (Ministry for Agriculture Benin's) of 62 Oueme communes have to be corrected at first for CIC (Cropping Intensity Coefficient), by the results of chapter 4. Fourthly, the average Ve values in three vegetation type classes and three Oueme Basin sub-regions were weighted by the percentage shares of the three vegetation types areas to total communal area of 62 communes. The whole Ve value of a commune was divided by the total area value of this commune to obtain the communal average unit Vec value, which will be submitted to the static regression analysis in this chapter.

6.3 Results and discussion

6.3.1 Vegetation parameters in four test communes

In this part, the measured and then compiled vegetation parameters in four tested communes were presented.

6.3.1.1 Measured vegetation parameters

The table 6-1 shows the measured vegetation parameters of different plants in North-Oueme, commune of N'dali. Sorghum happened to be intercropped between maize. The table 6-2 shows the measured vegetation parameters of different plants in Middle-Oueme, commune of Save. The table 6-3 shows the measured vegetation parameters of different plants in Middle-Oueme commune Bohicon.

Table 6-1 Measured vegetation parameters of different plants in N'dali

Crop	Vb m³/ha	Ve m³/ha	BM t/ha
Manioc	18.65	23182.00	26.81
Cotton	6.07	11554.99	4.77
Maize	15.17	20831.67	7.40
Sorghum	25.30	22262.10	2.12
Soya	5.58	7136.67	7.55
Yam	1.22	2425.00	7.70
Fallow	27.31	10539.57	4.29
Plantation (mango)	61.08	72095.59	46.42
Forest	269.13	79075.00	60.91

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.

Table 6-2 Measured vegetation parameters of different plants in Save

Crop	Vb m³/ha	Ve m³/ha	BM t/ha
Manioc	10.50	23012.38	13.88
Cowpea	0.51	3511.46	1.94
Groundnut	0.16	2825.58	3.64
Maize	8.07	20888.18	3.34
Rice	10.03	10320.00	3.39
Sorghum	23.34	34016.49	21.23
Soya	0.51	3867.84	5.07
Sugar cane	133.62	26021.73	49.19
Voandzou	2.02	2275.00	3.18
Yam			3.39
Fallow	145.06	16330.00	5.99
Plantation (cashew, mango)	131.24	76668.09	76.46
Forest	283.72	109705.46	60.35

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.

Table 6-3 Measured vegetation parameters of different plants in Bohicon

Crop	Vb m³/ha	Ve m³/ha	BM t/ha
Manioc	1.55	18920.00	13.88
Cowpea	0.37	3006.91	2.26
Groundnut	0.14	2059.91	1.01
Maize	4.09	15850.42	1.76
Sorghum	30.02	34218.93	27.13
Fallow	19.80	18235.57	3.32
Plantation (cashew, orange, oil palm)	251.28	57287.49	21.44
Forest	630.08	179522.06	160.78

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare

The table 6-4 shows the measured vegetation parameters of different plants in South-Oueme commune Pobe.

Table 6-4 Measured vegetation parameters of different plants in Pobe

Crop	Vb m³/ha	Ve m³/ha	BM t/ha
Manioc	14.15	23527.08	34.75
Cowpea	1.06	4510.48	1.41
Groundnut	0.23	3048.23	0.87
Maize	17.91	18713.08	4.33
Sorghum	30.02	34218.93	18.48
Soya	1.77	3597.14	1.17
Sweet potato	0.11	1890.91	2.43
Taro	197.49	14117.78	6.28
Yam	0.32	31000.00	1.64
Pigeon pea	50.59	33753.85	14.15
Fallow	218.69	15385.93	7.16
Plantation (oil palm)	757.65	147750.00	10.46
Forest	1305.87	155623.33	92.15

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.

6.3.1.2 Weighted parameters of annual crops

The table 6-5 shows the weighted vegetation parameters of annual crops by using area percent as weighting factor in North-Oueme, commune of N'dali. The table 6-6 shows the weighted vegetation parameters of annual crops by using area percent as weighting factor in Middle-Oueme, commune of Save.

Table 6-5 Weighted vegetation parameters of annual crops in N'dali by surface percentages

Crop	Area%	Vb m³/ha	Ve m³/ha	BM t/ha	Vb_aav	Ve_aav	BM_aav
Yam	11.24	1.22	2425.00	7.70	0.137	272.625	0.865
Soya	2.53	5.58	7136.67	7.55	0.141	180.522	0.190
Cotton	12.65	6.07	11554.99	4.77	0.767	1461.423	0.602
Maize	48.48	15.17	20831.67	7.40	7.352	10099.670	3.588
Sorghum	5.34	25.30	22262.10	6.33	1.350	1188.814	0.337
Manioc	8.15	18.65	23182.00	26.81	1.520	1889.483	2.185
Ananas	0.06	6.07	11554.99	4.77	0.003	6.495	0.003
Cowpea	2.25	5.58	3400.00	3.02	0.125	76.447	0.0679
Dohi	0.00	5.58	3400.00	3.02	0	0	0
Goussi/ sesame	0.84	5.58	3400.00	3.02	0.047	28.667	0.0255
Groundnut	4.50	5.58	3400.00	3.02	0.251	152.894	0.136
Millet	1.97	25.30	22262.10	6.33	0.497	437.984	0.126
Pigeon pea	0.28	18.65	23182.00	26.81	0.052	65.154	0.0754
Rice	0.00	5.58	3400.00	3.02	0	0	0
Sweet potato	0.28	1.22	2425.00	7.70	0.003	6.815	0.0216
Taro	0.00	1.22	2425.00	7.70	0	0	0
Vegetables (tomato, chili, gombo, onion…)	1.15	5.58	3400.00	3.02	0.064	39.179	0.0348
Voandzou	0.28	5.58	3400.00	3.02	0.015	9.555	0.0085
Annual	100.00				12.331	15915.740	8.268

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.
- Area% in this table means the percentage of surface of each annual crops to whole annual agricultural used area of this site, which was calculated using the results of farmer interviews.
- The crops which were not measured directly were approximated by using the similar measured crops, for ex., soya to dohi. etc.
- Vb_aav=average bio-volume weighted by annual Area%; the rest may be deduced by analogy.

Table 6-6 Weighted vegetation parameters of annual crops in Save by surface percentages

Crop	Area %	Vb m³/ha	Ve m³/ha	BM t/ha	Vb_aav	Ve_aav	BM_aav
Ananas	0.02	0.16	2825.58	3.64	2.57E-05	0.455	0.0006
Cotton	0.00	0.16	2825.58	3.64	0	0	0
Cowpea	9.73	0.51	3511.46	1.94	0.049258	341.836	0.1889
Dohi	2.29	0.16	2825.58	3.64	0.003653	64.668	0.0833
Goussi/sesame	4.50	0.16	2825.58	3.64	0.007177	127.059	0.1636
Groundnut	10.36	0.16	2825.58	3.64	0.016541	292.828	0.3771
Maize	27.91	8.07	20888.18	3.34	2.251123	5829.973	0.9327
Manioc	13.93	10.50	23012.38	13.88	1.461635	3204.561	1.9322
Millet	0.00	23.34	34016.49	21.23	0	0	0
Pigeon pea	2.42	10.50	23012.38	13.88	0.253756	556.347	0.3355
Rice	4.42	10.03	10320.00	3.39	0.443135	455.746	0.1496
Sorghum	3.87	23.34	34016.49	21.23	0.902984	1315.812	0.8211
Soya	7.80	0.51	3867.84	5.07	0.040077	301.597	0.3956
Sweet potato	0.00	0.16	2825.58	3.64	0	0	0
Taro	0.00	10.50	23012.38	13.88	0	0	0
Vegetables (tomato, chili, Gombo, onion…)	3.00	0.16	2825.58	3.64	0.004785	84.706	0.1091
Voandzou	2.80	2.02	2275.00	3.18	0.05677	63.800	0.0893
Yam	6.96	1.22	2425.00	3.39	0.08508	168.845	0.2361
Annual	100.00				5.57599	12808.240	5.8146

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.
- Area% in this table means the percentage of surface of each annual crops to whole annual agricultural used area of this site, which was calculated using the results of farmer interviews.
- The crops which were not measured directly were approximated by using the similar measured crops, for ex., soya to dohi. etc.
- Vb_aav=average bio-volume weighted by annual Area%; the rest may be deduced by analogy.

The table 6-7 shows the weighted vegetation parameters of annual crops by using area percent as weighting factor in Middle-Oueme, commune of Bohicon.

Table 6-7 Weighted vegetation parameters of annual crops in Bohicon by surface percentages

Crop	Area%	Vb m³/ha	Ve m³/ha	BM t/ha	Vb_aav	Ve_aav	BM_aav
Ananas	0.00						
Cotton	0.00						
Cowpea	15.12	0.37	3006.91	2.26	0.055783	454.5753	0.34191
Dohi	0.00						
Goussi/sesame	0.00						
Groundnut	32.46	0.14	2059.91	1.01	0.045942	668.598	0.32848
Maize	42.91	4.09	15850.42	1.76	1.754192	6802.199	0.75471
Manioc	2.93	1.55	18920.00	13.88	0.045459	555.0819	0.40709
Millet	0.00						
Pigeon pea	0.00						
Rice	0.00						
Sorghum	4.05	30.02	34218.93	27.13	1.214839	1384.728	1.09776
Soya	1.85	0.37	3006.91	2.26	0.006844	55.76989	0.04194
Sweet potato	0.67						
Taro	0.00						
Vegetables	0.00						
Voandzou	0.00						
Yam	0.00						
Annual	100.00				3.123058	9920.952	2.97192

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.
- Area% in this table means the percentage of surface of each annual crops to whole annual agricultural used area of this site, which was calculated using the results of farmer interviews.
- The crops which were not measured directly were approximated by using the similar measured crops, for ex., soya to dohi. etc.
- Vb_aav=average bio-volume weighted by annual Area%; the rest may be deduced by analogy.

The table 6-8 shows the weighted vegetation parameters of annual crops by using area percent as weighting factor in South-Oueme, commune of Pobe.

Table 6-8 Weighted vegetation parameters of annual crops in Pobe by surface percentages

Crop	Area %	Vb m³/ha	Ve m³/ha	BM t/ha	Vb_aav	Ve_aav	BM_aav
Maize	27.66	17.91	18713.08	4.33	4.954	5175.502	1.1971
Groundnut	5.49	0.23	3048.23	0.87	0.013	167.217	0.0476
Cowpea	10.97	1.06	4510.48	1.41	0.117	494.8637	0.1549
Vegetables (tomato, chili, gombo, onion…)	20.23	1.06	4510.48	1.41	0.215	912.4049	0.2857
Manioc	9.71	14.15	23527.08	34.75	1.375	2285.488	3.3760
Goussi/sesame	7.09	1.06	4510.48	1.41	0.075	319.5995	0.1000
Yam	5.14	0.32	31000.00	1.64	0.017	1594.286	0.0841
Sorghum	0.00	30.02	34218.93	18.48	0	0	0
Pigeon pea	4.00	50.59	33753.85	14.15	2.024	1350.154	0.5661
Cotton	3.89	0.67	3651.30	1.90	0.026	141.8789	0.0737
Taro	2.63	197.49	14117.78	6.28	5.191	371.0959	0.1651
Sweet potato	1.94	0.11	1890.91	2.43	0.002	36.73766	0.0473
Soya	0.11	1.77	3597.14	1.17	0.002	4.11102	0.0013
Rice	0.69	1.06	4510.48	1.41	0.007	30.92898	0.0096
Ananas	0.46	1.06	4510.48	1.41	0.005	20.61932	0.0064
Dohi	0.00	1.06	4510.48	1.41	0	0	0
Millet	0.00	1.06	4510.48	1.41	0	0	0
Voandzou	0.00	0.67	3651.30	1.90	0	0	0
Annual	100.00	321.38	202742.91	97.79	14.020	12904.89	6.12

- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.
- Area% in this table means the percentage of surface of each annual crops to whole annual agricultural used area of this site, which was calculated using the results of farmer interviews.
- The crops which were not measured directly were approximated by using the similar measured crops, for ex., soya to dohi. etc.
- Vb_aav=average bio-volume weighted by annual Area%; the rest may be deduced by analogy.

6.3.1.3 Aggregated parameters of three vegetation types

The table 6-9 shows the aggregated vegetation parameters of three vegetation types in four tested communes. Note the poor biomass of savannah in Pobe.

Table 6-9 Aggregated average vegetation parameters of three vegetation types

Communes	Vegetation type	Vb m³/ha	Ve m³/ha	BM t/ha
N'dali	Annual crop	12.33	15915.74	8.27
	Savannah	44.20	41317.58	25.35
	Forest	269.13	79075.00	60.91
Save	Annual crop	5.58	12808.24	5.81
	Savannah	138.15	46499.05	41.23
	Forest	283.72	109705.46	60.35
Bohicon	Annual crop	3.12	9920.95	2.97
	Savannah	142.85	41229.31	24.05
	Forest	422.26	137632.10	100.52
Pobe	Annual Crop	14.02	12904.89	6.12
	Savannah	488.17	81567.96	8.81
	Forest	1305.87	155623.33	92.15

- Savannah means the average value of fallow, savannah and plantation crops.
- Vb=bio-volume of singular crop on a hectare, Ve=eco-volume and BM=biomass of singular crop on a hectare.

6.3.2 Integrated vegetation parameters of 62 communes

The following table shows the integrated average unit vegetation parameter value of 62 Oueme communes in year 2004, which were carried out with the calculation procedure described in the materials and methods of this chapter.

Table 6-10 Integrated average unit vegetation parameters of 62 Oueme Communes in year 2004

Commune	Vbc	Vec	BMc	Commune	Vbc	Vec	BMc
Abomey-Calavi	254	50625	23	Ouake	64	33976	24
Allada	271	53612	21	Cotonou	16	3041	1
Kpomasse	44	15452	8	Athieme	277	54826	19
Ouidah	319	60974	24	Bopa	277	54626	16
So-Ava	229	40968	22	Come	285	54995	21
Toffo	109	27679	10	Grand-Popo	377	70397	27
Tori-Bossito	428	78205	43	Houeyogbe	204	43236	13
Ze	266	52937	20	Lokossa	277	54519	18
Bembereke	76	38333	28	Adjara	498	89304	48
Kalale	73	37471	28	Adjohoun	403	73975	45
N'Dali	83	41145	31	Aguegue	322	59519	28
Nikki	72	37055	27	Akpro-Misserete	297	57003	35
Parakou	21	18655	11	Avrankou	446	80894	46
Perere	82	40537	30	Bonou	438	79880	42
Sinende	79	39529	29	Dangbo	328	61891	39
Tchaourou	101	46186	34	Porto-Novo	563	98981	56
Bante	92	43425	32	Seme-Kpodji	407	74822	34
Dassa-Zoume	128	40832	30	Adja-Ouere	110	27489	15
Glazoue	69	35888	26	Ifangni	422	76790	49
Ouesse	172	64644	43	Ketou	137	47631	32
Savalou	129	41308	30	Pobe	454	81800	52
Save	150	48089	35	Sakete	175	37678	22
Aplahoue	253	51162	14	Abomey	86	30914	21
Djakotomey	125	30405	9	Agbangnizoun	242	49414	14
Dogbo-Tota	257	51698	16	Bohicon	86	30755	21
Klouekanme	240	49081	14	Cove	102	34743	25
Lalo	256	51637	14	Djidja	125	40174	29
Toviklin	174	38340	11	Ouinhi	296	57827	22
Bassila	96	45066	34	Zangnanado	126	44011	30
Kopargo	75	38138	28	Za-Kpota	119	39263	28
Djougou	84	41197	31	Zogbodome	304	59334	18

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level

The other agro-ecological data sets used in followed statistic analyses were listed as Annexe 13.

6.3.3 Integrated vegetation parameters and agro-ecological factors in ten departments

The table 6-11 shows the spatially integrated mean values of vegetation, agro-ecological parameters in ten Oueme-Department.

Table 6-11 Integrated vegetation parameters and agro-ecological factors of ten Oueme departments

Departement	TC1 % t_t	Sum 4cations t_t	pH H2O t_t	P t_t	Vbc	Vec	BMc	SLc
Litorral	0.84	4.98	6.30	0.45	15.60	3041	0.81	0.18
Mono	0.94	5.77	6.42	0.46	281.09	55198	18.73	3.47
Atlantique	1.06	6.75	6.57	0.47	239.72	47951	20.67	3.27
Oueme	1.12	7.09	6.54	0.42	403.74	74033	40.59	4.00
Kouffo	0.93	5.80	6.45	0.48	235.71	48386	13.58	3.38
Plateau	1.09	6.80	6.77	0.55	198.05	50062	32.60	3.60
Zou	0.94	5.49	6.67	0.57	165.61	44183	25.49	3.29
Collines	1.15	6.22	6.95	0.84	126.56	46984	33.43	3.01
Donga	1.40	6.99	7.15	1.13	88.24	42528	31.71	2.36
Borgou	1.36	6.90	7.11	1.08	82.78	40507	29.85	2.31
Departement	**C-veg.04**	**POPD04**	**LON**	**LAT**	**ELE**	**Rain_04**	**GDP/cap**	
Litorral	0.52	8489.30	2.42	6.37	4.10	1234	2961.50	
Mono	0.52	234.49	1.83	6.55	24.06	1213	500.80	
Atlantique	0.56	273.02	2.22	6.61	46.61	1252	919.20	
Oueme	0.62	605.43	2.55	6.62	27.97	1343	942.90	
Kouffo	0.61	226.48	1.78	7.01	109.11	1242	493.60	
Plateau	0.60	132.86	2.62	7.20	110.23	1145	1337.50	
Zou	0.58	120.49	2.11	7.28	105.08	1236	522.40	
Collines	0.56	41.78	2.20	8.14	195.02	1261	920.20	
Donga	0.51	33.46	1.81	9.33	358.58	1154	823.30	
Borgou	0.48	30.90	2.77	9.80	346.46	1207	1221.10	

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at departmental level
- TC1 % t_t = total soil carbon percentage
- Sum 4cations t_t = sum of 4 cations (Na, K, Ca, Mg)
- pH H2O t_t = pH values in water
- P t_t = effective phosphorus values of soil sample

6.3.4 Relations among vegetation parameters

Correlations between vegetation indicators have been calculated at different scales of spatial arrangement.

6.3.4.1 Communal level

The table 6-12 shows simple correlations between each pair of variables at communal level. These correlation coefficients range between 0.5 and 0.9 and indicate relative strong linear relationships between the vegetation indicators i.e. bio-volume, eco-volume, bio-mass, and soil litter.

Table 6-12 Relations among vegetation indicators at communal level

	Vbc	Vec	BMc	SLc
Vbc		0.9312 (62) 0.0000	0.5214 (62) 0.0000	0.8454 (62) 0.0000
Vec	0.9312 (62) 0.0000		0.7351 (62) 0.0000	0.8492 (62) 0.0000
BMc	0.5214 (62) 0.0000	0.7351 (62) 0.0000		0.5116 (62) 0.0000
SLc	0.8454 (62) 0.0000	0.8492 (62) 0.0000	0.5116 (62) 0.0000	

Correlation
(Sample Size)
P-Value

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

The table 6-13 shows the linear regression models to estimate BMc using only Vec or Vbc. Since the P-values of ANOVA were all less than 0.01, relationships between the variables were statistically significant at the 99% confidence level. Biomass was correlated closer with eco-volume (R^2 = 54%) than with bio-volume and soil litter. From Tables 6-12 & 6-13, hypothesis 6-1 can be accepted at the communal level.

Table 6-13 Simple linear regression models estimating biomass using other indicators of vegetation dynamics at communal level (n=62)

Model	**R-squared%**	**P-value (Model)**
BMc = 3.07183 + 0.000477173*Vec	54.0	0.00
BMc = 17.0353 + 0.0452696*Vbc	27.2	0.00
BMc = 2.47104 + 7.67841*SLc	26.2	0.00

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

6.3.4.2 Department level

As shown in table 6-14, the correlation coefficients ranged from 0.27 to 0.86. But since the P value between BMc and Vbc was greater than 0.05, there was no significant correlation at the 95% level at the departmental level although there existed a highly significant correlation at communal level (R^2 = 0.52**).

Table 6-14 Relations among vegetation indicators at department level

	Vbc	Vec	BMc	SLc
Vbc		0.8626 (10) 0.0013	0.3840 (10) 0.2733	0.8226 (10) 0.0035
Vec	0.8626 (10) 0.0013		0.7451 (10) 0.0134	0.9438 (10) 0.0000
BMc	0.3840 (10) 0.2733	0.7451 (10) 0.0134		0.6369 (10) 0.0477
SLc	0.8226 (10) 0.0035	0.9438 (10) 0.0000	0.6369 (10) 0.0477	

Correlation
(Sample Size)
P-Value

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at departmental level; SLc = Soil litter

The table 6-15 shows the linear regression models to estimate the unit biomass quantity of a department (BMc: t/ha) using the other vegetation dynamics indicators such as eco-volume (Vec) or bio-volume (Vbc). Also at department level, biomass was correlated closer with eco-volume than with bio-volume and soil litter. Combining the results in above two tables, it is likely that at department level, Vec and Vbc are still positively closely correlated, but the BMc is not closely correlated with Vbc again as it was at communal level, even though BMc was still positively and closely correlated with Vec.

Table 6-15 Simple linear regression models estimating biomass using other indicators of vegetation dynamics at department level (n=10)

Model	R-squared%	P-value (Model)
BMc = 2.46505 + 0.00049199*Vec	55.5	0.01
BMc = 17.5027 + 0.0394282*Vbc	14.7	0.27
BMc = 5.066 + 6.81676*SLc	40.6	0.05

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

6.3.4.3 Within Impetus zones

Here the relations between vegetation parameters at communal level are presented as nested within North, Middle and South Oueme zones. The relationships between vegetation parameters within three Impetus zones were closer than those in the whole Oueme Basin. This implies that this zoning approach was meaningful in order to classify all Oueme communes into more homogenous groups. Based on the above results, it could be concluded that hypothesis 6-1 was confirmed.

6.3.4.3.1 North Oueme

As shown in tables 6-16 & 6-17, the relations between vegetation parameters within the North Oueme basin were closer as those in the whole Oueme Basin. There exists a very strong regression between biomass and eco-volume ($R^2 = 0.95^{**}$).

Table 6-16 Relations among vegetation indicators within North Oueme

	Vbc	Vec	BMc	SLc
Vbc		0.9927 (15) 0.0000	0.9441 (15) 0.0000	0.9962 (15) 0.0000
Vec	0.9927 (15) 0.0000		0.9769 (15) 0.0000	0.9786 (15) 0.0000
BMc	0.9441 (15) 0.0000	0.9769 (15) 0.0000		0.9122 (15) 0.0000
SLc	0.9962 (15) 0.0000	0.9786 (15) 0.0000	0.9122 (15) 0.0000	

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

Table 6-17 Simple linear regression models estimating biomass using other vegetation parameters within North Oueme (n = 15)

Model	**R-squared%**	**P-value (Model)**
BMc = 1.22346 + 0.000695354*Vec	95.4	0.00
BMc = 12.2415 + 0.204053*Vbc	89.1	0.00
BMc = -10.5831 + 17.088*SLc	83.2	0.00

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

6.3.4.3.2 Middle Oueme

Within Middle Oueme, also strong and positive correlations as well as simple regressions are observed (Tables 6-18 & 6-19).

Table 6-18 Relations among vegetation indicators within Middle Oueme

	Vbc	Vec	BMc	SLc
Vbc		0.9716 (10) 0.0000	0.9991 (10) 0.0000	0.8439 (10) 0.0021
Vec	0.9716 (10) 0.0000		0.9806 (10) 0.0000	0.9468 (10) 0.0000
BMc	0.9991 (10) 0.0000	0.9806 (10) 0.0000		0.8654 (10) 0.0012
SLc	0.8439 (10) 0.0021	0.9468 (10) 0.0000	0.8654 (10) 0.0012	

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

Table 6-19 Simple linear regression models estimating biomass using other vegetation parameters within Middle Oueme (n = 10)

Model	R-squared%	P-value (Model)
BMc = -0.278263 + 0.000717244*Vec	96.2	0.00
BMc = 2.95773 + 0.213154*Vbc	99.8	0.00
BMc = -26.8283 + 17.0832*SLc	74.9	0.00

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

6.3.4.3.3 South Oueme

Within South Oueme, the vegetation stands at communal level are relatively less homogenous as is the case in North and Middle Oueme, but the relations between vegetation parameters were still strongly and positively correlated.

Table 6-20 Relations among vegetation indicators within South Oueme

	Vbc	Vec	BMc	SLc
Vbc		0.9959 (37) 0.0000	0.9063 (37) 0.0000	0.8436 (37) 0.0000
Vec	0.9959 (37) 0.0000		0.8882 (37) 0.0000	0.8870 (37) 0.0000
BMc	0.9063 (37) 0.0000	0.8882 (37) 0.0000		0.7412 (37) 0.0000
SLc	0.8436 (37) 0.0000	0.8870 (37) 0.0000	0.7412 (37) 0.0000	

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

Table 6-21 Simple linear regression models estimating biomass using other vegetation parameters within South Oueme (n = 37)

Model	R-squared%	P-value (Model)
BMc = -9.84859 + 0.000629299*Vec	78.9	0.00
BMc = -5.27598 + 0.105625*Vbc	82.1	0.00
BMc = -22.4331 + 13.7873*SLc	54.9	0.00

- Vbc=bio-volume, Vec=eco-volume and BMc=biomass of total vegetation on a hectare, respectively at communal level; SLc = Soil litter

6.3.5 Relations between vegetation dynamics and agro-ecological factors

6.3.5.1 Communal level

To test the relationships between different vegetation dynamics parameters and environmental parameters at communal level, the statistic method “backwards selection procedure with constant” of the multiple regression module was selected to yield the comparable regression models. At beginning all the environmental parameters in Annexe 13 were put into the analysis module. This theoretic logical criterion was followed in all steps of the implemented statistic analyses. Among the different agro-ecological factors it is hoped to find the major driving forces regulating vegetation dynamics. Since the relationship between vegetation and precipitation was one of the major concerns of this study, effort was paid especially to find out such possible empirical relationship. Only a few selected models at communal level are presented.

6.3.5.1.1 Bio-volume

For the model 6-1 the followed parameters were considered: Vbc=bio-volume, TC1%t_t=total carbon in soil, C_veg_04=vegetative duration coefficient in year 2004, POPD04=population density in year 2004, Rain_04=precipitation in year 2004, ELE=elevation of communes, LAT=latitude and LON=longitude. GDP0_cap=GDP per capita was not used here since it was only available at provincial/department level. Determination approached 75% (Table 6-22).

Vbc = 3748.31 + 699.241*TC1 % t_t - 686.598*pH H2O t_t + 534.693*C_veg_04 - 0.0186086*POPD04

Model 6-1 Bio-volume (Vbc) to TC1%t_t, PH-value, C_veg_04 and POPD04

Table 6-22 Statistic results of model 6-1

Dependent variable: Vbc

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	3748.31	405.19	9.25075	0.0000
TC1 % t_t	699.241	90.9345	7.68951	0.0000
pH H2O t_t	-686.598	64.1395	-10.7048	0.0000
C_veg_04	534.693	185.67	2.8798	0.0056
POPD04	-0.0186086	0.00783157	-2.37611	0.0209

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	830091.0	4	207523.0	42.46	0.0000
Residual	278600.0	57	4887.72		
Total (Corr.)	1.10869E6	61			

R-squared = 74.8713 percent
R-squared (adjusted for d.f.) = 73.1078 percent
Standard Error of Est. = 69.9122
Mean absolute error = 50.6398
Durbin-Watson statistic = 1.8251 (P=0.1831)
Lag 1 residual autocorrelation = 0.0869172

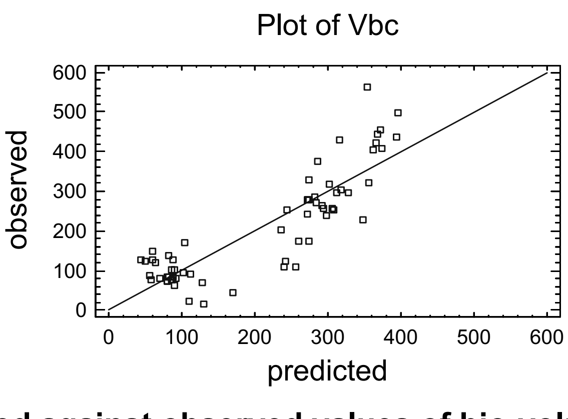

Figure 6-1 Predicted against observed values of bio-volume in model 6-1

In the model 6-2 all soil parameters were removed to check if other environmental parameters used in model 6-1 could explain the variability of Vbc. The results showed obviously that soil parameters were dominant in this context. Since the constant had P-value=0.86, it was removed and the model 6-3 was obtained.

$$Vbc = 46.6248 + 0.477849*Rain\_04 - 57.6279*LAT$$

Model 6-2: Bio-volume (Vbc) as to precipitation and latitude (LAT) without soil parameters

Table 6-23 Statistic results of model 6-2

Dependent variable: Vbc

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	46.6248	255.632	0.18239	0.8559
Rain_04	0.477849	0.171123	2.79244	0.0070
LAT	-57.6279	11.2757	-5.11082	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	507968.0	2	253984.0	24.95	0.0000
Residual	600723.0	59	10181.7		
Total (Corr.)	1.10869E6	61			

R-squared = 45.8169 percent
R-squared (adjusted for d.f.) = 43.9802 percent
Standard Error of Est. = 100.905
Mean absolute error = 73.9042
Durbin-Watson statistic = 2.01798 (P=0.4166)
Lag 1 residual autocorrelation = -0.0133092

Model 6-3 presents a simple relation between bio-volume and both rain and latitude with a determination of 84% (Table 6-24).

$$Vbc = 0.507485*Rain\_04 - 56.3513*LAT$$

Model 6-3 Bio-volume (Vbc) as to precipitation and latitude (LAT) without constant term

Table 6-24 Statistic results of model 6-3

Dependent variable: Vbc

Parameter	Estimate	Standard Error	T Statistic	P-Value
Rain_04	0.507485	0.0532542	9.52947	0.0000
LAT	-56.3513	8.76878	-6.42635	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.26164E6	2	1.63082E6	162.79	0.0000
Residual	601062.0	60	10017.7		
Total	3.8627E6	62			

R-squared = 84.4393 percent

R-squared (adjusted for d.f.) = 84.18 percent
Standard Error of Est. = 100.088
Mean absolute error = 73.9687
Durbin-Watson statistic = 2.02607
Lag 1 residual autocorrelation = -0.0175341

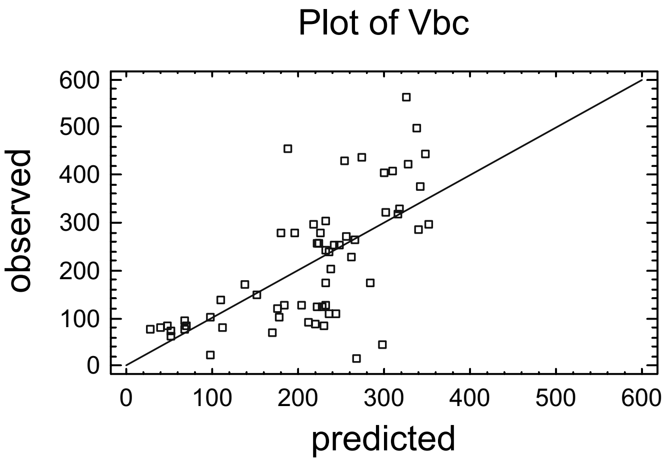

Figure 6-2 Predicted against observed values of bio-volume in model 6-3

6.3.5.1.2 Eco-volume

Using the same procedures like for bio-volume, the following regression models were obtained for eco-volume (Vec) with a lower determination of only 46%.

Vec = 500469.0 + 95273.2*TC1 % t_t - 82773.0*pH H2O t_t - 3.81358*POPD04

Model 6-4 Eco-volume (Vec) as to soil and population parameters

Table 6-25 Statistic results of model 6-4

Dependent variable: Vec

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	500469.0	64934.5	7.70729	0.0000
TC1 % t_t	95273.2	17659.1	5.39513	0.0000
pH H2O t_t	-82773.0	11885.2	-6.96439	0.0000
POPD04	-3.81358	1.51738	-2.51327	0.0148

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	9.11917E9	3	3.03972E9	16.45	0.0000
Residual	1.07175E10	58	1.84785E8		
Total (Corr.)	1.98367E10	61			

R-squared = 45.9713 percent
R-squared (adjusted for d.f.) = 43.1767 percent
Standard Error of Est. = 13593.6
Mean absolute error = 9656.03
Durbin-Watson statistic = 1.62968 (P=0.0538)
Lag 1 residual autocorrelation = 0.184161

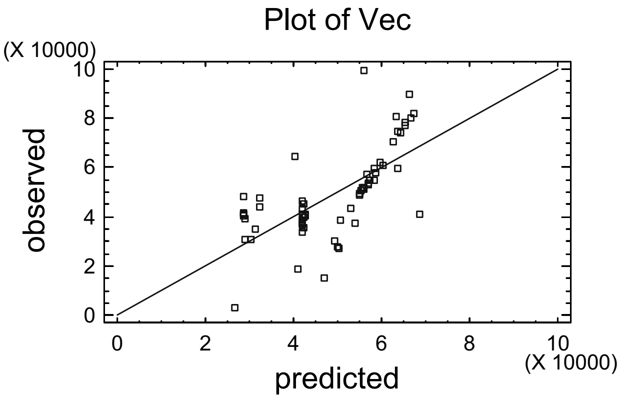

Figure 6-3 Predicted vs. observed eco-volume in model 6-4

Without soil parameters the variability of eco-volume (Vec) could only be explained for 24.9% by other environmental factors as shown in model 6-5.

Vec = -25884.2 - 44.8973*ELE + 64.9981*Rain_04

Model 6-5 Eco-volume (Vec) as to elevation (ELE) and Precipitation

Since in the model 6-5 the constant was not significant, it was removed and the following model 6-6 was obtained.

Vec = -49.7294*ELE + 44.8172*Rain_04

Model 6-6 Eco-volume (Vec) as to ELE and Rain04 without constant term

Table 6-26 Statistic results of model 6-6

Dependent variable: Vec

Parameter	Estimate	Standard Error	T Statistic	P-Value
ELE	-49.7294	15.3109	-3.24797	0.0019
Rain_04	44.8172	2.24976	19.9209	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.55233E11	2	7.76163E10	309.72	0.0000
Residual	1.50362E10	60	2.50603E8		
Total	1.70269E11	62			

R-squared = 91.1692 percent
R-squared (adjusted for d.f.) = 91.022 percent
Standard Error of Est. = 15830.4
Mean absolute error = 11091.6
Durbin-Watson statistic = 2.0467
Lag 1 residual autocorrelation = -0.0247726

Another alternative model 6-7 using Rain_04 and LAT could also explain the variability of Vec. Since the constant was not significant with a P-value of 0.85 by this simulation, it was removed. Determination of model 6-7 is about 90%.

Vec = -4029.93*LAT + 63.7345*Rain_04

Model 6-7 Eco-volume (Vec) as to Rain_04 and LAT

Table 6-27 Statistic results of model 6-7

Dependent variable: Vec

Parameter	Estimate	Standard Error	T Statistic	P-Value
LAT	-4029.93	1411.04	-2.85599	0.0059
Rain_04	63.7345	8.5695	7.43737	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.54705E11	2	7.73524E10	298.20	0.0000
Residual	1.5564E10	60	2.594E8		
Total	1.70269E11	62			

R-squared = 90.8591 percent
R-squared (adjusted for d.f.) = 90.7068 percent
Standard Error of Est. = 16105.9
Mean absolute error = 11563.4
Durbin-Watson statistic = 2.03894
Lag 1 residual autocorrelation = -0.0220197

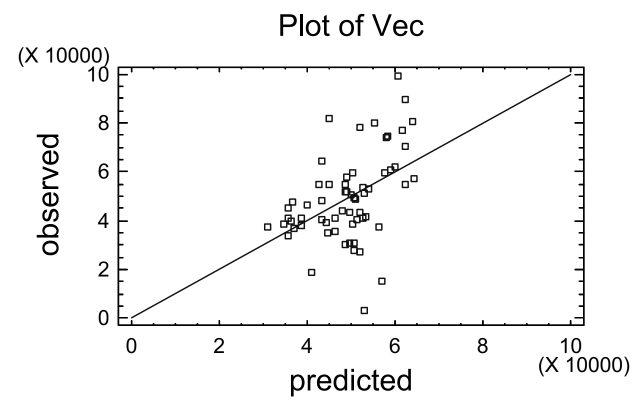

Figure 6-4 Predicted vs. observed eco-volume (Vec) in model 6-7

6.3.5.1.3 Biomass

Using the same procedures as used for eco- and bio-volume, the model 6-8 for biomass (BMc) was obtained with a poor determination of only 35%.

BMc = -29.1135 + 38.2855*TC1 % t_t + 7.88057*LON - 0.0319893*ELE

Model 6-8 Biomass (BMc) as related to soil carbon, elevation and longitude

Without soil parameters the following model 6-9 explains only 24.8% of the variability in BMc.

BMc = -44.1996 + 11.5741*LON + 0.0358175*Rain_04

Model 6-9 Biomass (BMc) as to environmental factors LON and rain

6.3.5.1.4 Summary

Comparing the results of multiple regression for modelling Vec, Vbc and BMc, it could be concluded that at communal level:

- The soil parameters affected generally dominantly the vegetation dynamics at communal level.
- The bio-volume has been responding more sensitive to the soil and other selected environmental parameters, followed by eco-volume and biomass.
- Combining precipitation with only one of three geographic coordinates could yield relatively sufficient models explaining vegetation dynamics.
- Combing soil parameters, population density and vegetative length were significant for estimating static communal vegetation dynamics.

6.3.5.2 Department level

Since the soil data were strongly integrated, and at the provincial level the sample numbers were only 10, the analyses results with only soil parameters were not shown in following section, in spite of the fact that models at communal and departmental level tend to concur. Consequently, most attention was geared towards the relations between vegetation and other social, environmental factors, such as precipitation, population and coordinates.

6.3.5.2.1 Bio-volume

As models in table 6-28 shows, bio-volume could be explained well by population density and latitude at departmental level (R^2 = 74%). Also precipitation and population density could explain variability of bio-volume at department level relatively good in comparison to those at communal level. Here the vegetative duration coefficient alone could explain ca. 43% variability of bio-volume.

Table 6-28 Multiple regression models predicting bio-volume (Vbc) at department level (n = 10)

Model	R-squared%	P-value (Mode)
Vbc = 760.261 - 0.0323777*POPD04 - 72.5623*LAT	74.03	0.009
Vbc = -1247.37 + 1.18305*Rain_04 - 0.0220946*POPD04	55.90	0.057
Vbc = -695.527 + 1581.36*C_veg_04	43.54	0.038

- C_veg_04 = vegetation duration coefficient in 2004

6.3.5.2.2 Eco-volume

At department level, eco-volume could also be correlated closely with population density and precipitation as shown in Table 6-29. About 78% variability of eco-volume could be explained by population density and latitude variation. Also GDP per capita combined with longitude could explain ca 75% variability of eco-volume.

Table 6-29 Multiple regression models predicting eco-volume (Vec) at department level

Model	R-squared%	P-value (Mode)
Vec = -105064.0 + 127.033*Rain_04 - 5.62609*POPD04	81.79	0.003
Vec = 93811.8 - 6.36218*POPD04 - 5612.4*LAT	78.48	0.005
Vec = 22824.3 - 24.218*GDP/cap + 21621.3*LON	75.27	0.008
Vec = 65407.9 - 18.9058*GDP/cap	61.00	0.008
Rain_04 = 1038.61 + 0.0217435*POPD04 + 0.00370795*Vec	47.43	0.105

- GDP/cap = GDP per capita

6.3.5.2.3 Biomass

Biomass variability could be explained more by population density or GDP combined with longitude (Table 6-30).

Table 6-30 Multiple regression models predicting biomass (BMc) at department level

Model	R-squared%	P-value (Mode)
BMc = -3.70465 - 0.00353758*POPD04 + 14.3679*LON	69.83	0.015
BMc = -12.5877 + 23.2066*LON - 0.0135684*GDP/cap	61.93	0.034
BMc = -130.015 + 7.93576*LAT + 171.428*C_veg_04	52.68	0.073

Comparing the results using communal and department average unit values of compiled parameters, it could be concluded:

- At department level and without soil indicators, population density combined with precipitation could explain properly vegetation dynamics, which was consistent with those at communal level. Moreover, population density combined with latitude or longitude could explain vegetation dynamics properly too. But at department level, even if the models had higher determination than those at communal level, the variance of variables at department level was far smaller than those at communal level as only 10 departments were part of the analyses.
- At communal level:
    a. The soil parameters affected generally dominantly the vegetation dynamics.
    b. The bio-volume has been responding more sensitive to the soil and other selected environmental parameters, followed by eco-volume and biomass.
    c. Using precipitation with only one of 3 geographic coordinates, relatively satisfactory models explaining vegetation dynamics were obtained.
    d. Combining soil parameters, population density and vegetative length appears meaningful in relationship to vegetation dynamics.

6.3.5.3 Within Impetus zones

6.3.5.3.1 Bio-volume

6.3.5.3.1.1 North Oueme

Within North Oueme, bio-volume variability could be reasonably explained by only two soil parameters i.e. Sum of 4 cations and total carbon content (Table 6-31).

Table 6-31 Multiple regression models predicting bio-volume (Vbc) within North Oueme

Model	R-squared%	P-value (Mode)
Vbc = -3907.9 + 385.027*Sum 4cations t_t - 446.867*P t_t - 700.253*TC1% t_t + 390.396*pH H2O t_t	99.8	0.000
Vbc = -1829.71 + 430.225*Sum 4cations t_t - 339.803*P t_t - 503.383*TC1 % t_t	99.7	0.000
Vbc = -1651.39 + 440.745*Sum 4cations t_t - 956.705*TC1 % t_t	99.4	0.000
Vbc = -150.77 + 174.327*TC1 % t_t	30.9	0.032
Vbc = 62.2583*TC1 % t_t	90.6	0.000
Vbc = -509.856 + 86.6156*Sum 4cations t_t	50.8	0.002
Vbc = -87.5324 + 364.078*C_veg_04 - 0.206222*POPD04	51.0	0.014
Vbc = 190.686*C_veg_04 - 0.21419*POPD04	94.0	0.000
Vbc = 0.0679039*Rain_04	88.5	0.000

- n=15

6.3.5.3.1.2 Middle Oueme

Within middle Oueme the phosphor was unexpectedly negatively correlated with bio-volume. It could be explained by the more important vegetation in southern Benin where soils happen to have lower phosphorus content as up north (Annexes 11 & 12).The population density showed more strong impact on bio-volume (Table 6-32).

Table 6-32 Multiple regression models predicting bio-volume within Middle Oueme

Model	R-squared%	P-value (Mode)
Vbc = -3426.62 + 25.0643*Sum 4cations t_t + 556.326*pH H2O t_t - 585.136*P t_t	99.8	0.000
Vbc = 520.004 - 647.348*P t_t	97.1	0.000
Vbc = 131.002 - 0.0597297*POPD04	68.1	0.003
Vbc = 0.0977673*Rain_04	96.4	0.000

- n=10

6.3.5.3.1.3 South Oueme

Within South Oueme, the relationship between precipitation and bio-volume was relative weak (Table 6-33).

Table 6-33 Multiple regression models predicting bio-volume within South Oueme

Model	R-squared%	P-value (Mode)
Vbc = 114.54 + 223.652*pH H2O t_t - 2823.78*P t_t	75.9	0.000
Vbc = -1168.08 + 6604.14*TC1 % t_t - 824.044*Sum 4cations t_t	71.3	0.000
Vbc = 242.561*pH H2O t_t - 2843.11*P t_t	96.4	0.000
Vbc = 1399.3 - 2442.53*P t_t	70.8	0.000
Vbc = 275.477*TC1 % t_t	85.6	0.000
Vbc = 1515.81 - 2660.23*P t_t - 0.0264148*POPD04	81.0	0.000
Vbc = -248.757 + 1044.08*C_veg_04 - 1.47489*ELE	24.5	0.008
Vbc = 605.016*C_veg_04 - 1.31021*ELE	88.3	0.000
Vbc = 0.227817*Rain_04	86.4	0.000

- n=37

Within North, Middle and South Oueme separately, bio-volume was obviously correlated with soil parameters. Without soil parameter, bio-volume was likely more correlated with population density and vegetative length than with precipitation directly. The direct correlation between bio-volume and precipitation was non-significant with constant term but significant without constant term.

6.3.5.3.2 Eco-volume

6.3.5.3.2.1 North Oueme

Within North Oueme, again the soil parameters were dominant among relations with eco-volume. Also the population density affected the eco-volume stronger than environmental factors other than soil parameters (table 6-34).

Table 6-34 Multiple regression models predicting eco-volume within North Oueme

Model	R-squared%	P-value (Mode)
Vec = -1.07287E6 - 186905.0*TC1 % t_t + 107058.0*Sum 4cations t_t + 106604.0*pH H2O t_t - 117849.0*P t_t	99.9	0.000
Vec = -505387.0 - 133147.0*TC1 % t_t + 119400.0*Sum 4cations t_t - 88613.3*P t_t	99.8	0.000
Vec = -458884.0 - 251363.0*TC1 % t_t + 122143.0*Sum 4cations t_t	99.5	0.000
Vec = -43019.0 + 62078.2*TC1 % t_t	42.4	0.008
Vec = -158959.0 + 29099.7*Sum 4cations t_t	62.7	0.000
Vec = 44423.7 - 75.1518*POPD04	45.4	0.006
Vec = 88658.9*C_veg_04 - 73.032*POPD04	98.0	0.000
Vec = -6557.46 + 101648.0*C_veg_04 - 72.4351*POPD04	59.3	0.004
Vec = 32.9482*Rain_04	95.0	0.000

- n=15

6.3.5.3.2.2 Middle Oueme

The different regression models at communal level within the South Oueme region are summarized in Table 6-35.

Table 6-35 Multiple regression models predicting eco-volume within Middle Oueme

Model	R-squared%	P-value (Mode)
Vec = -1.02908E6 + 19100.2*Sum 4cations t_t + 157207.0*pH H2O t_t - 163829.0*P t_t	99.8	0.000
Vec = 46031.3 + 19671.6*Sum 4cations t_t - 184570.0*P t_t	99.4	0.000
Vec = 149168.0 - 176445.0*P t_t	84.8	0.000
Vec = 43149.3 - 16.3287*POPD04	59.8	0.009

- n=10

6.3.5.3.2.3 South Oueme

The different regression models at communal level within the South Oueme region are summarized in Table 6-36.

Table 6-36 Multiple regression models predicting eco-volume within South Oueme

Model	R-squared%	P-value (Mode)
Vec = 22371.9 + 35872.2*pH H2O t_t - 441027.0*P t_t	68.2	0.000
Vec = 39565.4*pH H2O t_t - 444804.0*P t_t	96.4	0.000
Vec = 191467.0 + 35584.7*TC1 % t_t - 380069.0*P t_t	67.9	0.000
Vec = 1.21641E6 + 259826.0*TC1 % t_t - 219536.0*pH H2O t_t	65.8	0.000
Vec = -170957.0 + 1.02363E6*TC1 % t_t - 127593.0*Sum 4cations t_t	63.4	0.000
Vec = 228437.0 - 379879.0*P t_t	63.3	0.000
Vec = 199501.0 - 421319.0*P t_t + 87777.9*C_veg_04 - 4.86351*POPD04	81.9	0.000
Vec = 169904.0 - 381456.0*P t_t + 101967.0*C_veg_04	69.2	0.000
Vec = 43.906*Rain_04	89.8	0.000

- n=37

Eco-volume within the North, Middle and South Oueme regions separately was obviously correlated with soil parameters. In the absence of soil parameters, eco-volume was more correlated with population density and vegetative length than with precipitation directly.

6.3.5.3.3 Biomass

6.3.5.3.3.1 North Oueme

Here biomass was more likely to be explained by vegetation length as by precipitation. Also population density affected biomass more obviously than was the case in South and Middle Oueme (table 6-37).

Table 6-37 Multiple regression models predicting biomass within North Oueme

Model	R-squared%	P-value (Mode)
BMc = -591.414 - 94.0483*TC1 % t_t + 61.4106*Sum 4cations t_t + 54.6104*pH H2O t_t - 57.343*P t_t	99.9	0.000
BMc = -300.708 - 66.5093*TC1 % t_t + 67.733*Sum 4cations t_t - 42.3664*P t_t	99.9	0.000
BMc = -278.475 - 123.029*TC1 % t_t + 69.0446*Sum 4cations t_t	99.8	0.000
BMc = -131.677 + 23.5047*Sum 4cations t_t	83.3	0.000
BMc = -43.396 + 54.1519*TC1 % t_t	63.8	0.000
BMc = -15.538 + 42.535*P t_t	62.0	0.000
BMc = -318.144 + 49.0589*pH H2O t_t	68.9	0.000
BMc = 3.41778 + 58.5231*C_veg_04 - 0.0620513*POPD04	73.3	0.000
BMc = 65.2933*C_veg_04 - 0.0617402*POPD04	98.8	0.000
BMc = 32.7697 - 0.0636155*POPD04	64.2	0.000

- n=15

6.3.5.3.3.2 Middle Oueme

Within middle Oueme and without soil parameters, population density also impacted relatively strongly on biomass (table 6-38).

Table 6-38 Multiple regression models predicting biomass within Middle Oueme

Model	R-squared%	P-value (Mode)
BMc = -734.728 + 6.88167*Sum 4cations t_t + 118.388*pH H2O t_t - 124.487*P t_t	99.8	0.000
BMc = 74.906 + 7.31195*Sum 4cations t_t - 140.107*P t_t	99.4	0.000
BMc = 66.9382 + 59.2284*TC1 % t_t - 153.825*P t_t	99.3	0.000
BMc = 113.242 - 137.087*P t_t	95.6	0.008
BMc = 159.39 + 76.2535*Sum 4cations t_t - 575.194*TC1 % t_t	95.6	0.000
BMc = 30.8647 - 0.0126518*POPD04	67.1	0.004

- n=10

6.3.5.3.3.3 South Oueme

Within South Oueme, biomass was still closely related with soil parameters. But population density alone could not explain biomass variability again as within North and Middle Oueme (table 6-39). This could be partially explained by the fact, that in South Oueme, the population densities of different communes were already relatively high compared with those in North and Middle Oueme. The positive relation of biomass with longitude was very interesting here.

Table 6-39 Multiple regression models predicting biomass within South Oueme

Model	R-squared%	P-value (Mode)
BMc = -250.176 + 67.8506*pH H2O t_t - 367.199*P t_t	90.0	0.000
BMc = 752.611 + 218.646*TC1 % t_t - 146.496*pH H2O t_t	88.5	0.000
BMc = -173.788 + 731.523*TC1 % t_t - 85.5549*Sum 4cations t_t	86.9	0.000
BMc = 67.8928 - 251.908*P t_t + 69.009*TC1 % t_t	89.6	0.000
BMc = 139.588 - 251.54*P t_t	55.3	0.000
BMc = -35.3524 + 27.1925*LON	43.5	0.000
BMc = 26.755*LON - 5.13467*LAT	86.7	0.000
BMc = -77.0896 + 94.3242*C_veg_04 + 52.7524*TC1 % t_t - 0.158363*ELE	51.0	0.000
BMc = 78.5022 - 0.00256119*POPD04 + 18.8524*LON - 205.703*P t_t	76.3	0.000

- n=37

6.4 Partial conclusions

For the spatial vegetation dynamics, the following conclusions can be made:

Relations among vegetation parameters:

- Generally, biomass as standard reference parameter had closer relation with eco-volume than with bio-volume. Eco-volume was much closer to bio-volume (correlation coefficient bigger than 90%). That implies that knowing eco-volume or bio-volume, biomass could be estimated reasonably and precisely.
- At communal and department levels, vegetation parameters were relatively closely related.
- Within three Impetus zones, the relationships between vegetation parameters were closer than those in the whole Oueme Basin. This implies that this zoning approach was meaningful in order to classify all Oueme communes into more homogenous groups.
- Hence, hypothesis 6-1 can be accepted.

Relations between vegetation dynamics and agro-ecological factors:

- At communal level:
    a. The soil parameters affected generally dominantly the vegetation dynamics. Soil carbon content correlated positively with three vegetation parameters (biomass, bio-volume and eco-volume).
    b. The bio-volume has been responding more sensitively to the soil and other selected environmental parameters, followed by eco-volume and biomass.
    c. Using precipitation with only one of three geographic coordinates could yield relatively sufficient models explaining vegetation dynamics. Precipitation, vegetation length and longitude influenced vegetation parameters positively.
    d. Combining with soil parameters, population density and vegetative length became significant in relationships to vegetation dynamics. Population density influence vegetation parameters negatively.
- At department level:
    a. Without soil indicators, population density combined with precipitation could explain properly vegetation dynamics, which was consistent with those at communal level.
    b. Population density combined with latitude or longitude could explain vegetation dynamics properly, too. But at department level, models had higher R^2 than these at communal level; the variance of variables at department level was far smaller than these at communal level, as only 10 departments were considered in the analyses.
- Within three Oueme zones:
    a. Across over all three Oueme zones, bio-volume, eco-volume and biomass could be estimated sufficiently through soil parameters.
    b. Without soil parameter, three vegetation parameters were likely more correlated with population density negatively and with vegetative length positively than with precipitation directly.
    c. For three Oueme zones, vegetation parameters in Middle and North Oueme could still sufficiently be estimated through social environmental factors without soil indicators.
    d. The direct correlation between vegetation parameters and precipitation

was relatively weak.

e. Bio-, eco-volume and biomass performed differently within different Oueme zones.

- Further hypotheses could accepted such as:
  a. Hypothesis 6-2: This hypothesis can be accepted as at different spatial levels the relations between three vegetation parameters and agro-ecological factors were different. For instance, the vegetation length itself was significant in relation to vegetation parameters within the Impetus zones, whereas it was only significant with vegetation parameters at communal level in so far combined with soil parameters.
  b. Hypothesis 6-3: Generally, this hypothesis can be accepted at all spatial levels. The bio-volume responds generally more sensitively to the other agro-ecological factors.
  c. Hypothesis 6-4: The latter hypothesis can be accepted at the Departmental level as population density and GDP impacted negatively on vegetation dynamics such as soil parameters

7 Temporal and Spatial Vegetation Dynamics

7.1 Introduction

7.1.1 Objective

From the previous chapter it appears that vegetation dynamics present a fair amount of spatial coherence across the Oueme basin. In this chapter the spatial relations will be analyzed across a time span of 18 years. Relations among three vegetation parameters, available precipitation, vegetative duration coefficient and population density will be analyzed both spatially and temporally.

7.1.2 Hypotheses

7-1: Bio-volume, eco-volume and biomass dynamics should correlate closely with each other across the region and over time.

7-2: Bio-volume, eco-volume and biomass dynamics should respond to population, precipitation and vegetative length dynamics differently across the region and over time.

7.2 Material and method

The analyses are based on four time series data sets of 18 years (1987-2004), including all 62 Oueme communes:

- three vegetation parameters (Vbc, Vec and BMc);
- annual precipitation;
- annual vegetative duration coefficient (C_veg) and
- population density.

The compiling procedures were the same as used in the chapter on spatial vegetation dynamics. During this study, only above mentioned time series data sets were available.

7.3 *Results and discussion*

7.3.1 Relations among vegetation parameters

7.3.1.1 Within the whole Oueme Basin

As shown in table 7-1, all vegetation parameters were closely correlated. BMc was more closely correlated with Vec than with Vbc. This result was consistent with the results of chapter 6 on spatial vegetation dynamics.

Table 7-1 Relations among vegetation indicators of whole Oueme Basin

	Vbc	Vec	BMc	SLc
Vbc		0.9263 (1105) 0.0000	0.4847 (1105) 0.0000	0.8447 (1105) 0.0000
Vec	0.9263 (1105) 0.0000		0.7175 (1105) 0.0000	0.8474 (1105) 0.0000
BMc	0.4847 (1105) 0.0000	0.7175 (1105) 0.0000		0.4803 (1105) 0.0000
SLc	0.8447 (1105) 0.0000	0.8474 (1105) 0.0000	0.4803 (1105) 0.0000	

The same tendency could be observed in table 7-2 as that for the static spatial models. Biomass was correlated closer with eco-volume than with bio-volume and soil litter.

Table 7-2 Simple linear regression models estimating biomass using other vegetation parameters at communal level

Model	R-squared%	P-value (model)
BMc = 3.11594 + 0.000481104*Vec	51.5	0.000
BMc = 18.3217 + 0.0424765*Vbc	23.5	0.000
BMc = 4.14936 + 7.37962*SLc	23.1	0.000

- n = 1105

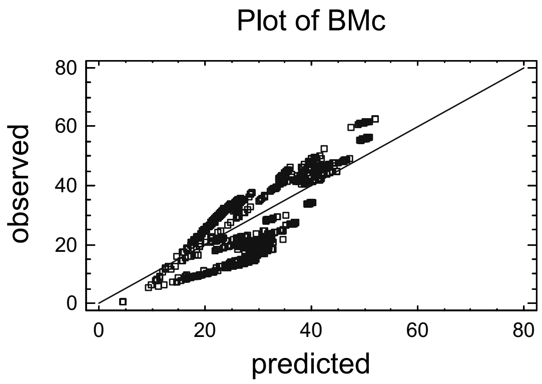

Figure 7-1 Observed vs. predicted plot of simple linear model estimating biomass using Vec

Since logically, the constant terms in above models could be removed, yielding corrected models which fitted obviously better, resulting in higher determination coefficients. Also statistically, such models could be optimized using autocorrelation option or choosing other non linear models.

7.3.1.2 Relations by General Linear Model

Using General Linear Model (GLM), it could be tested quickly if a zoning approach was meaningful or not.

7.3.1.2.1 Within Impetus zones

As shown in the following models and tables (models 7-1, 7-2 & 7-3; tables 7-3, 7-4 &7-5), a stronger relation could be found out within the whole Oueme Basin when all 62 Oueme communes are nested into 3 Impetus zones.

BMc = -2.18287 + 5.34872*I1(1) + 4.43451*I1(2) + 0.000659345*Vec
where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwise

Model 7-1 General Linear Model estimating biomass in relation to eco-volume (Vec) within Impetus zones

Table 7-3 ANOVA for biomass (BMc) in relation to eco-volume (Vec) within Impetus zone

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	126438.0	3	42145.9	1712.16	0.0000
Residual	27101.8	1101	24.6156		

Total (Corr.)	153539.0	1104

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	47403.3	2	23701.6	962.87	0.0000
Vec	120533.0	1	120533.0	4896.62	0.0000
Residual	27101.8	1101	24.6156		
Total (corrected)	153539.0	1104			

R-Squared = 82.3486 percent
R-Squared (adjusted for d.f.) = 82.3005 percent
Standard Error of Est. = 4.96141
Mean absolute error = 3.62122
Durbin-Watson statistic = 0.144581 (P=0.0000)

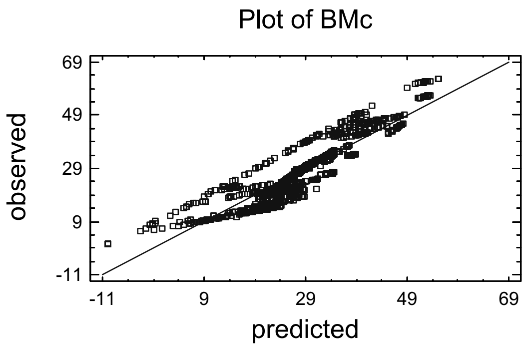

Figure 7-2 Observed vs. predicted plot of Model 7-1

BMc = 9.45869 + 11.5584*I1(1) + 5.8117*I1(2) + 0.112972*Vbc
where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwise

Model 7-2 General Linear Model estimating biomass (BMc) in relation to bio-volume (Vbc) within Impetus zones

Table 7-4 ANOVA for biomass (BMc) in relation to bio-volume (Vbc) within Impetus zones

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	129441.0	3	43146.9	1971.26	0.0000
Residual	24098.6	1101	21.888		
Total (Corr.)	153539.0	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	93368.9	2	46684.4	2132.88	0.0000
Vbc	123536.0	1	123536.0	5644.03	0.0000
Residual	24098.6	1101	21.888		
Total (corrected)	153539.0	1104			

R-Squared = 84.3046 percent
R-Squared (adjusted for d.f.) = 84.2618 percent
Standard Error of Est. = 4.67846
Mean absolute error = 3.5678
Durbin-Watson statistic = 0.172493 (P=0.0000)

BMc = -14.4476 + 11.7205*I1(1) - 2.45728*I1(2) + 14.1863*SLc
where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwise

Model 7-3 General Linear Model estimating biomass (BMc) in relation to soil litter (SLc) within Impetus zones

Table 7-5 ANOVA for biomass (BMc) in relation to soil litter (SLc) within Impetus Zone

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	89541.1	3	29847.0	513.48	0.0000
Residual	63998.3	1101	58.1275		
Total (Corr.)	153539.0	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	54116.0	2	27058.0	465.49	0.0000
SLc	83636.7	1	83636.7	1438.85	0.0000
Residual	63998.3	1101	58.1275		
Total (corrected)	153539.0	1104			

R-Squared = 58.318 percent
R-Squared (adjusted for d.f.) = 58.2044 percent
Standard Error of Est. = 7.62414
Mean absolute error = 5.6335
Durbin-Watson statistic = 0.124874 (P=0.0000)

After Impetus zoning, biomass could estimated better with eco- and bio-volume than with soil litter. Comparing the regression results according to Impetus zoning approach with those without zoning within whole Oueme Basin, the Impetus zoning yield better fitted models.

Comparing these results with those of Impetus zoning and AEZ, the classifying communes into departments yielded the similar results as Impetus zoning. Since Impetus zoning grouped all 62 Oueme communes only into three zones, such models were simpler and still included large variance of variables, so it was considered as the best zoning approach for relating vegetation parameters with each other at temporal and spatial dimensions.

Comparing the analyzed relation within vegetation parameters with and without zoning process, the follows are summarized:

- Eco-volume, then followed by bio-volume and soil litter could be used to estimate biomass properly, and this range hold on across all zoning approaches.

- The best fitted models were those obtained through classifying vegetation parameters into three Impetus zones.

Among vegetation parameters, the relation between eco-volume and biomass - as standard reference parameter - was closer than relations between bio-volume and biomass. Even if by definition, *ceteris paribus*, eco-volume contains only information about height of given vegetation, in comparison, bio-volume contains information about height and density of given vegetation.

7.3.2 Relations between vegetation dynamics and agro-ecological factors

7.3.2.1 Relations within four test communes

Using 18 years time series data of four tested communes, the results are presented in this section (Tables 7-6 up to 7-9).

Table 7-6 Multiple regression models estimating vegetation parameters of N'dali commune

Model	R-squared%	P-value (model)
Vbc = 44.1842 - 0.170496*POPD	45.2	0.002
Vec = 41310.2 - 136.209*POPD	45.3	0.002
BMc = 25.3454 - 0.0914764*POPD	45.2	0.002

- n = 18

Table 7-7 Multiple regression models estimating vegetation parameters of Save commune

Model	R-squared%	P-value (model)
Vbc = 152.059 - 0.410439*POPD	37.0	0.007
Vec = 51892.9 - 104.267*POPD	37.0	0.007
BMc = 43.5467 - 0.109901*POPD	37.0	0.007

- n = 18

Table 7-8 Multiple regression models estimating vegetation parameters of Bohicon commune

Model	R-squared%	P-value (model)
Vbc = 171.701 - 0.100456*POPD	70.0	0.000
Vec = 47695.1 - 22.5106*POPD	70.0	0.000
BMc = 28.4059 - 0.0151567*POPD	70.0	0.000

- n = 18

Table 7-9 Multiple regression models estimating vegetation parameters of Pobe commune

Model	R-squared%	P-value (model)
Vbc = 123525.0 - 116.871*POPD	47.7	0.001
Vec = 63.2793 - 0.0303712*POPD	26.4	0.029
BMc = 4.32799 - 0.00211735*POPD	49.2	0.001

- n = 18

Dependent variables are bio-volume (Vbc), eco-volume (Vec) and biomass (BMc); independent variables are population density (POPD), precipitation and vegetative duration coefficient. For statistical analyses the multiple regression module is selected. Since the precipitation and vegetative duration coefficient are statistically not significant in relationship to vegetation parameters, such models are not presented. Comparing the models for the four tested communes, it can be concluded that population is the dominant driving force for the vegetation dynamics. This is a consequence, as with growing population the demand on land exploitation has been expanding. This result is in coinciding with the results of M'Barek (2005) and Doevenspeck (2004). The commune Bohicon with the population density from 502 to 869 inhabitants per km^2 from 1987 to 2004 was the highest within four tested communes. In Bohicon the relationships between vegetation dynamics and population were also stronger than those in other three communes.

7.3.2.2 Relations by Multiple Regression

7.3.2.2.1 Within the whole Oueme Basin

The results in table 7-10 show that bio-volume could be estimated better with available data than eco-volume and biomass. According to T-statistic values, longitude was the most influencing variable among the independent variables, followed by population density. But precipitation and vegetative duration coefficient were also significant. The fourth model in the table 7-10 has been selected to predict vegetation dynamics scenarios till year 2025. It was discussed more in details in the chapter 8 on “Scenario of vegetation dynamics”.

Table 7-10 Multiple regression models estimating vegetation parameters within whole Oueme Basin

Model	R-squared %	P-value (model)
Vec = 26814.7 + 6.76903*Rain - 4.5541*POPD + 11758.2*LON - 65.9679*ELE	27.7	0.000
Vbc = 351.645 + 0.0437651*Rain - 0.0215931*POPD + 80.5633*LON - 41.2452*LAT - 0.371619*ELE	48.8	0.000
Vbc = 567.047 + 0.0382258*Rain - 0.0219657*POPD + 95.9236*LON - 80.2588*LAT	48.1	0.000
Vbc = 253.749 + 0.0565757*Rain - 0.0171858*POPD - 0.721665*ELE	44.6	0.000
BMc = -9.66523 + 0.00559963*Rain - 0.00186846*POPD + 13.9248*LON	24.6	0.000

- n = 1105

7.3.2.2.2 Within Impetus zones

Further models are presented for the three sub-regions in Tables 7-11, 7-12 and 7-13.

Table 7-11 Multiple models estimating vegetation parameters using other driving forces within North Oueme

Model	R-squared %	P-value (model)
Vbc = 262.059 - 0.188817*POPD + 8.50157*LON - 19.6173*LAT	40.6	0.000
Vec = 91076.1 - 63.5425*POPD + 2278.77*LON - 5447.42*LAT	45.6	0.000
BMc = 59.6876 - 0.0511604*POPD + 1.18975*LON - 3.09906*LAT	55.5	0.000

- n = 1105

Table 7-12 Multiple models estimating vegetation parameters using other driving forces within Middle Oueme

Model	R-squared %	P-value (model)
Vbc = 14.7263 - 0.0453753*POPD + 40.4281*LON + 0.196697*ELE	51.5	0.000
Vbc = -0.0438639*POPD + 45.7031*LON + 0.216693*ELE	98.6	0.000
Vec = 4201.2 - 11.7169*POPD + 14533.3*LON + 47.673*ELE	55.1	0.000
Vec = -11.2858*POPD + 16038.2*LON + 53.3777*ELE	98.9	0.000
BMc = 5.31765 - 0.00952697*POPD + 9.00992*LON + 0.0409011*ELE	52.2	0.000

- n = 1105

Table 7-13 Multiple models estimating vegetation parameters using other driving forces within South Oueme

Model	R-squared %	P-value (model)
Vbc = -31.6919 - 0.0288623*POPD + 164.904*LON - 0.432097*ELE	29.5	0.000
Vbc = -0.0287017*POPD + 151.971*LON - 0.485189*ELE	90.2	0.000
Vec = 6077.45 - 5.61053*POPD + 25707.0*LON - 60.3266*ELE	28.7	0.000
Vec = -5.64133*POPD + 28187.1*LON - 50.1452*ELE	92.4	0.000
BMc = -7.45359 - 0.00271598*POPD + 30.1246*LON - 4.80192*LAT	49.6	0.000
BMc = -0.00276707*POPD + 29.9104*LON - 5.83862*LAT	87.9	0.000

- n = 1105

Within three Oueme zones, population density was the most dominant driving force for the vegetation dynamics. Combining population density with normally two of coordinates could yield models to estimate vegetation dynamics reasonably. Comparing the results after Impetus zoning with those without zoning, only the models for North and Middle Oueme became some better, for the South Oueme the models were quit similar as those without zoning. Within whole Oueme communes, bio-volume was likely the best indicator, which could be estimated relatively properly by other available data of driving forces.

7.3.2.3 Relations by General Linear Model within Impetus Zones

Model 7-4 up to model 7-6 and table 7-14 up to table 7-16 present the results of the relations between three vegetation parameters and environmental driving forces by using General Linear Model (GLM). Within the three Impetus zones, the bio-volume could be estimated using GLM as a function of available agro-ecological driving forces better than for the two other vegetation parameters. Comparing the results for modelling vegetation parameters within Impetus zones, departments and AEZs (results at department and AEZ level were not presented here), it could be concluded that classifying Oueme communes into 3 Impetus zones yielded the best models, which could explain vegetation dynamics by other available environmental driving forces logically and with relatively strong relation.

7.3.2.3.1.1 Bio-volume

Vbc = 157.872 - 29.9459*I1(1) - 59.7707*I1(2) + 0.035084*Rain - 0.0237218*POPD - 21.7801*LAT + 79.9365*LON - 0.189806*ELE

where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwise

Model 7-4 General linear model estimating bio-volume (Vbc) within three Impetus zones

Table 7-14 Analysis of Variance for Vbc using other driving forces within three Impetus zones

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.20148E7	7	1.7164E6	236.01	0.0000
Residual	7.97786E6	1097	7272.43		
Total (Corr.)	1.99926E7	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	2.26455E6	2	1.13227E6	155.69	0.0000
Rain	53936.4	1	53936.4	7.42	0.0065
POPD	561041.0	1	561041.0	77.15	0.0000
LAT	30652.3	1	30652.3	4.21	0.0401
LON	809191.0	1	809191.0	111.27	0.0000
ELE	33889.0	1	33889.0	4.66	0.0309
Residual	7.97786E6	1097	7272.43		
Total (corrected)	1.99926E7	1104			

R-Squared = 60.096 percent
R-Squared (adjusted for d.f.) = 59.8414 percent
Standard Error of Est. = 85.2785
Mean absolute error = 59.0603
Durbin-Watson statistic = 0.271411 (P=0.0000)

7.3.2.3.1.2 Eco-volume

Vec = 51511.5 + 4948.46*I1(1) - 8487.8*I1(2) + 5.29748*Rain - 5.05088*POPD + 13027.3*LON - 4278.04*LAT - 31.9809*ELE

where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwise

Model 7-5 General linear model estimating eco-volume (Vec) within three Impetus zones

Table 7-15 Analysis of Variance for Vec using other driving forces within three Impetus zones

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	1.1814E11	7	1.68771E10	82.91	0.0000
Residual	2.23318E11	1097	2.03571E8		
Total (Corr.)	3.41458E11	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	2.29438E10	2	1.14719E10	56.35	0.0000
Rain	1.22971E9	1	1.22971E9	6.04	0.0140
POPD	2.54351E10	1	2.54351E10	124.94	0.0000
LON	2.14917E10	1	2.14917E10	105.57	0.0000
LAT	1.18258E9	1	1.18258E9	5.81	0.0159
ELE	9.62102E8	1	9.62102E8	4.73	0.0297
Residual	2.23318E11	1097	2.03571E8		
Total (corrected)	3.41458E11	1104			

R-Squared = 34.5987 percent
R-Squared (adjusted for d.f.) = 34.1814 percent
Standard Error of Est. = 14267.8
Mean absolute error = 10029.6
Durbin-Watson statistic = 0.257857 (P=0.0000)

7.3.2.3.1.3 Biomass

BMc = 36.0446 + 9.65129*I1(1) - 1.14388*I1(2) + 0.00526979*Rain - 0.00203514*POPD + 14.7401*LON - 5.89945*LAT

where
I1(1) = 1 if Zone=1, -1 if Zone=3, 0 otherwise
I1(2) = 1 if Zone=2, -1 if Zone=3, 0 otherwiseModel 7-6 General linear model estimating biomass (BMc) within three Impetus zones

Table 7-16 Analysis of Variance for biomass (BMc) using other driving forces within three Impetus zones

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value

Model	45180.9	6	7530.15	76.30	0.0000
Residual	108358.0	1098	98.6871		
Total (Corr.)	153539.0	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Zone	7341.2	2	3670.6	37.19	0.0000
Rain	1228.76	1	1228.76	12.45	0.0004
POPD	4131.42	1	4131.42	41.86	0.0000
LON	34914.5	1	34914.5	353.79	0.0000
LAT	5658.07	1	5658.07	57.33	0.0000
Residual	108358.0	1098	98.6871		
Total (corrected)	153539.0	1104			

R-Squared = 29.4263 percent
R-Squared (adjusted for d.f.) = 29.0406 percent
Standard Error of Est. = 9.93414
Mean absolute error = 7.62574
Durbin-Watson statistic = 0.218655 (P=0.0000)

Different zoning approaches yielded different models estimating vegetation dynamics. Impetus zoning approach classifies 62 Oueme communes into North, Middle and South zone, which yielded already relatively proper models estimating relations among vegetation parameters and relations between vegetation dynamics and other available environmental driving forces such as population dynamics, precipitation dynamics and variation of vegetative length combining with geographic coordinates.

Throughout all analyses, population has been the dominant driving force among factors such as precipitation and vegetative length. Since spatial rainfall pattern affects the population distribution over the region, one part of effect of population on vegetation might refer back to rainfall. By the former chapter, it was observed that when combined with soil parameters, precipitation became statistically significant in relationship to vegetation dynamics, as precipitation alone was not statistically significant to vegetation dynamics. So it was expected that if some temporal information about soil could be put in the analyses, such models should predict vegetation dynamics more precisely.

In this study, bio-volume was more suitable to indicate vegetation dynamics across time and space than eco-volume and biomass, since it responded more sensitively to population and precipitation dynamics.

Theoretically, vegetation should correlate more directly with evapotranspiration (EP).

Such data were not available during the period of this study, but for the further research this could be a very interesting point to test if bio-volume dynamics correlate with EP dynamics better than eco-volume and biomass dynamics with EP. As observed in the chapter 6, depending on data compiling and zoning approaches, eco-volume, bio-volume and biomass as indicators have responded differently to other driving forces. It is interesting to know, how those vegetation dynamics indicators would respond to more specific compiled driving forces likes EP and plant available water.

As described in Material & Methods, the calculation of vegetation dynamics was based on several observed data sets, i.e. the agro-statistics, LUC-satellite data, climatologic data and measured data. But considering its compiling procedures, it has also a reconstructive character. This was treated as observed vegetation dynamics. But theoretically, by each step of compiling processes, there were different possibilities to reconstruct the vegetation dynamics with different approaches, which might yield different reconstructed vegetation scenarios. Even if a vegetation dynamics scenario, based on a model selected in chapter 8, showed relative moderately strong coincidence with the observed vegetation dynamics, the need for fine-tuning the model does remain.

7.4 Partial Conclusion

In accordance with above results and discussion, the *a priori* stated hypotheses:

(i) Hypothesis 7-1: Bio-volume, eco-volume and biomass dynamics correlated closely with each other across the region and over time. Among vegetation parameters, the relations between eco-volume and biomass were closer than those between bio-volume and biomass.

(ii) 7-2: Bio-volume, eco-volume and biomass dynamics responded to population, precipitation and vegetative length dynamics differently across the region and over time. In this study, bio-volume was more suitable to indicate vegetation dynamics across time and space than eco-volume and biomass, since it responded more sensitively to population and precipitation dynamics.

8 Scenarios of Vegetation Dynamics and Eco-precipitation

8.1 Introduction

8.1.1 Objective

Temporal and spatial vegetation dynamics is a crucial issue in relationship with climate change and regional water cycle in the tropical Oueme Basin Benin, as is the case in the Sahel. Globally, the function of vegetation, especially the possible contribution of forest to precipitation is an old debate (Kerfoot O. 1968, Stone P. H. and Quirk W. T. 1975, Lee R. 1978, Huang B.W. 1981, Charney J G. Anthes A.1984, Sandstrom K. 1998, Shi P.L. Yan J.Zh. 2001). There are controversies about possible influences of forest on horizontal (occult) and vertical precipitation processes. There are large observations used as contrary evidences, - even about the possible influences of forest on the surface runoffs -, but still there is no simple answer of “yes” or “no” (Hewlett J.D., Helvey J.D. 1970, Bosch J.M. 1979, Bosch J.M., Hewlett J D. 1982, Hewlett J D, Bosch M. 1985, Scott. F 1997, Giambelluca. W, Fox J, Yarnasarn S, et al. 1999, Calder 2000, Kiersch 2000, Los, S. O. & Weedon G. P., et al. 2006).

However, the former research results about this issue, especially about the feedbacks of vegetation and precipitation of a catchment region, made following agreements possible: beyond the analytic methods (empirical or modelling), the research results about the feedbacks between vegetation and precipitation depend specifically on selected regional climate regimes, ground surface roughness, soil-hydro-atmospheric water cycles, thermal dynamics, human activities, bio-physiological characters of vegetation stands, spatial scales of catchment and forest area, and finally on the temporal scale of datasets. The results obtained from a region could not be transferred easily to other regions and still most theories about this issue are hardly to be generalized.

Even so, as described by Sandstrom (1998) for a semi-arid tropical region, the feedback between vegetation and precipitation might be strong enough to be identified. This was the reason, why the Oueme Basin in Benin, West-Africa is selected to study the feedback between vegetation and precipitation dynamics. Since the interaction between vegetation and precipitation should be affected, -even covered-, by a complex of other influencing factors, for instance climate and geographic conditions, it is crucial for the study to extract possibly the evidence of feedback between vegetation and precipitation.

8.1.2 Hypothesis

To test the relationship between vegetation, precipitation and population dynamics within the Oueme Basin, the following hypotheses were tested with two built up scenarios:

8-1: Temporally and spatially, bio-volume should correlate positively with precipitation but negatively with population dynamics in the Oueme Basin.

8-2: Micro-climate, especially the eco-precipitation, should be influenced by eco-volume dynamics in the Oueme Basin, as shown in figure 8-1.

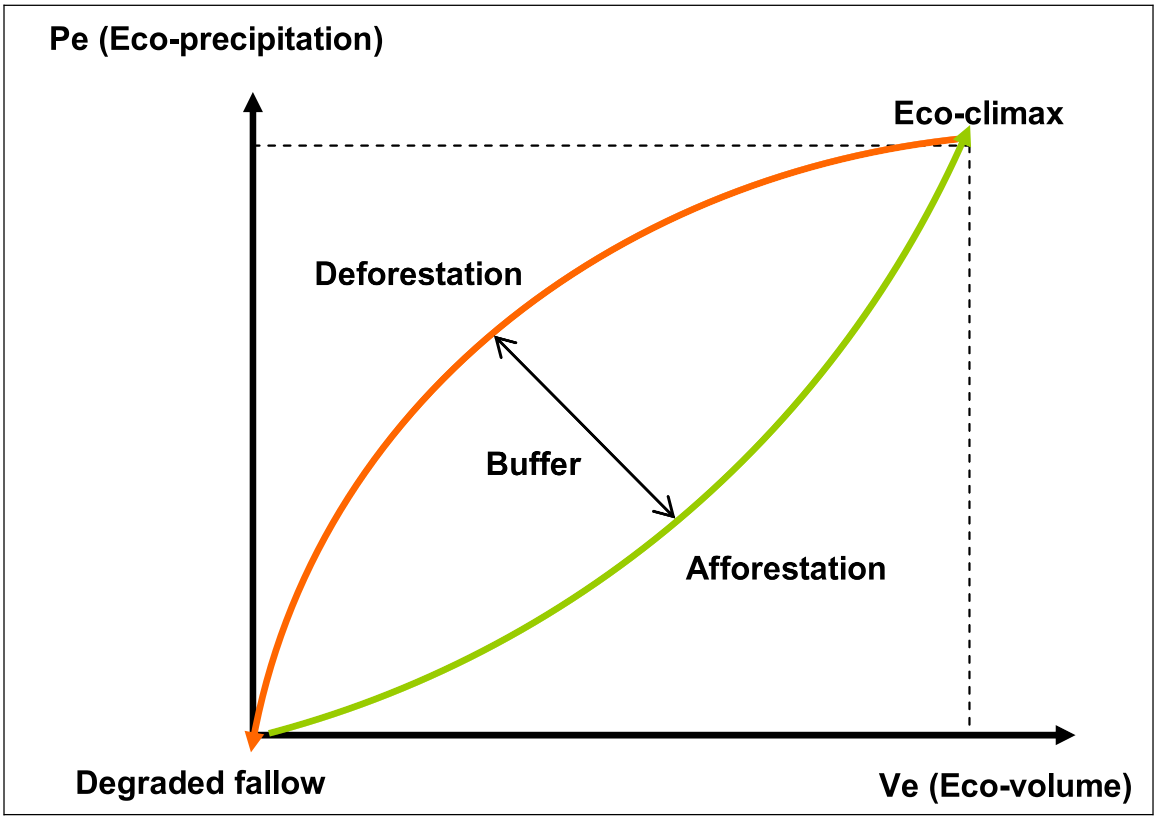

Figure 8-1 Hypothesis of eco-volume as related to eco-precipitation

8.2 Material and method

Based on the results of chapters 7 and 8 and using the same data sets (1987-2004), the model predicting vegetation dynamics was discussed more in detail in this chapter using the vegetation dynamics indicator bio-volume as an example and using datasets as described under Chapter 3. The scenario of eco-precipitation was discussed in relationship with eco-volume.

Initially, Janssens, Deng and Mulindabigwi (2004) defined eco-precipitation (Pe') as the difference between observed and minimum precipitation (Pe'=P-P_min; P=observed precipitation in a concrete year; P_min=simulated precipitation, whereby vegetation = zero). In this study the Eco-precipitation (Pe) is defined as the difference between the predicted precipitations, which are caused by variation of vegetation dynamics, from bare (zero) fallow vegetation up to eco-climax vegetation. Together with the definition of eco-volume, it is an attempt to extract the direct feedbacks between vegetation and precipitation. A concrete eco-precipitation (Pe_ac) in a certain year is defined as the simulated precipitation (P_f) in a certain year minus predicted precipitation at minimum/zero vegetation cover (P_min) in equation 8-1.

Pe_ac = P_f – P_min **Equation 8-1**

The theoretic maximum eco-precipitation (Pe_max) could be obtained as: predicted maximum precipitation at maximum eco-volume (P_max) minus predicted precipitation by minimum eco-volume (P_min) in equation 8-2.

Pe_max = P_max – P_min **Equation 8-2**

Since the maximum eco-volume should theoretically be obtained from an eco-climax stand, the measured forest eco-volume values in the tested sites were used as maximum eco-volume values, as eco-climax stands could only be approximated in one single case in this study.

8.3 Scenarios of vegetation dynamics

8.3.1 Model description

The followed selected model to estimate temporal and special bio-volume dynamics based on the facts, that the time series of soil and economic indicators were not available for this study, but the geographic distribution of such indicators were relative regular by the preliminary explorative descriptive statistic analyses. The ANOVA for bio-volume as an example shows the mathematic details about the relationship between vegetation dynamics and climate, anthropogenic driving forces and elevation variation in space and time. As can be recognized in the model 8-1 and figure 8-1, temporally and spatially, bio-volume correlates positively with precipitation but negatively with population dynamics in the Oueme Basin.

Vbc = 253.749 + 0.0565757*Rain - 0.0171858*POPD - 0.721665*ELE

Model 8-1 Selected model to predict bio-volume (Vbc) dynamic scenario

Table 8-1 ANOVA for bio-volume (Vbc) estimated by precipitation (Rain), population density (POPD) and elevation (ELE)

Dependent variable: Vbc

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	253.749	17.8324	14.2297	0.0000
Rain	0.0565757	0.0150455	3.7603	0.0002
POPD	-0.0171858	0.00311086	-5.52443	0.0000
ELE	-0.721665	0.0243136	-29.6816	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	8.91694E6	3	2.97231E6	295.44	0.0000
Residual	1.10767E7	1101	10060.6		
Total (Corr.)	1.99936E7	1104			

R-squared = 44.599 percent
R-squared (adjusted for d.f.) = 44.448 percent
Standard Error of Est. = 100.302
Mean absolute error = 73.4598
Durbin-Watson statistic = 1.69361 (P=0.0000)
Lag 1 residual autocorrelation = 0.153018

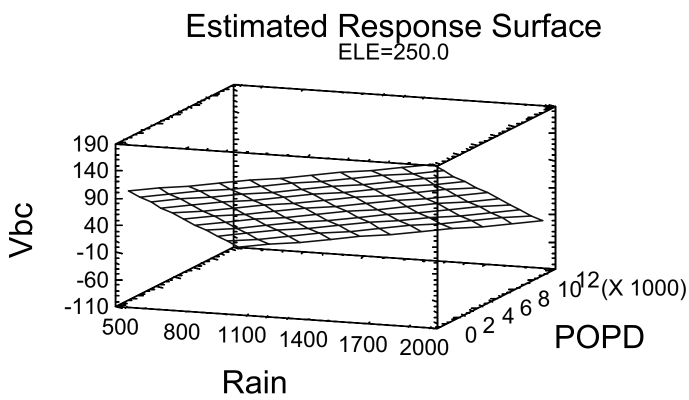

Figure 8-2 Estimated surface diagram using model 8-1

8.3.2 Observed vegetation dynamics

The figure 8-3 shows the trend line of observed bio-volume dynamics of all Oueme communes from 1987 to 2004. Since for each year the 62 communes were ranged from South to North, it could be seen that within the observation period, bio-volume values were diminishing south-north-wards. Across time, bio-volume values were slightly diminishing, too.

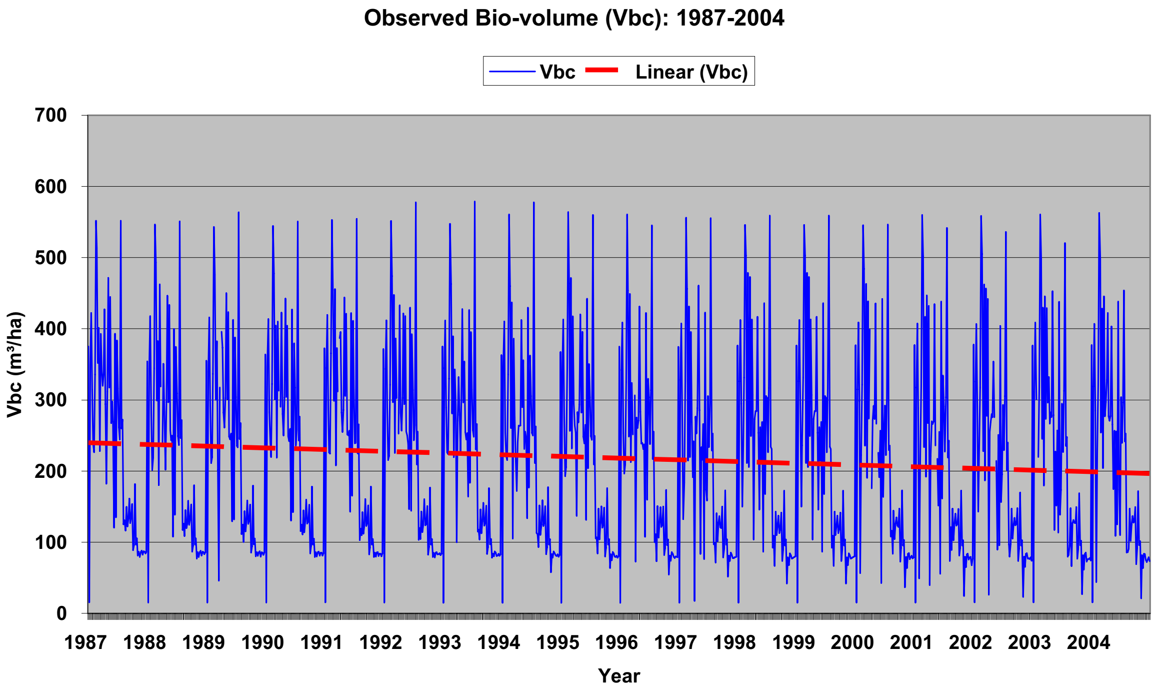

Figure 8-3 Observed bio-volume dynamics (Vbc) of 62 Oueme communes: 1987-2004

Figure 8-4 showed the same trend lines as shown in the figure 8-3, but only with five year's interval data.

The trend line of bio-volume in year 2004 (figure 8-5) showed clearly that bio-volume was diminishing along a south-north gradient.

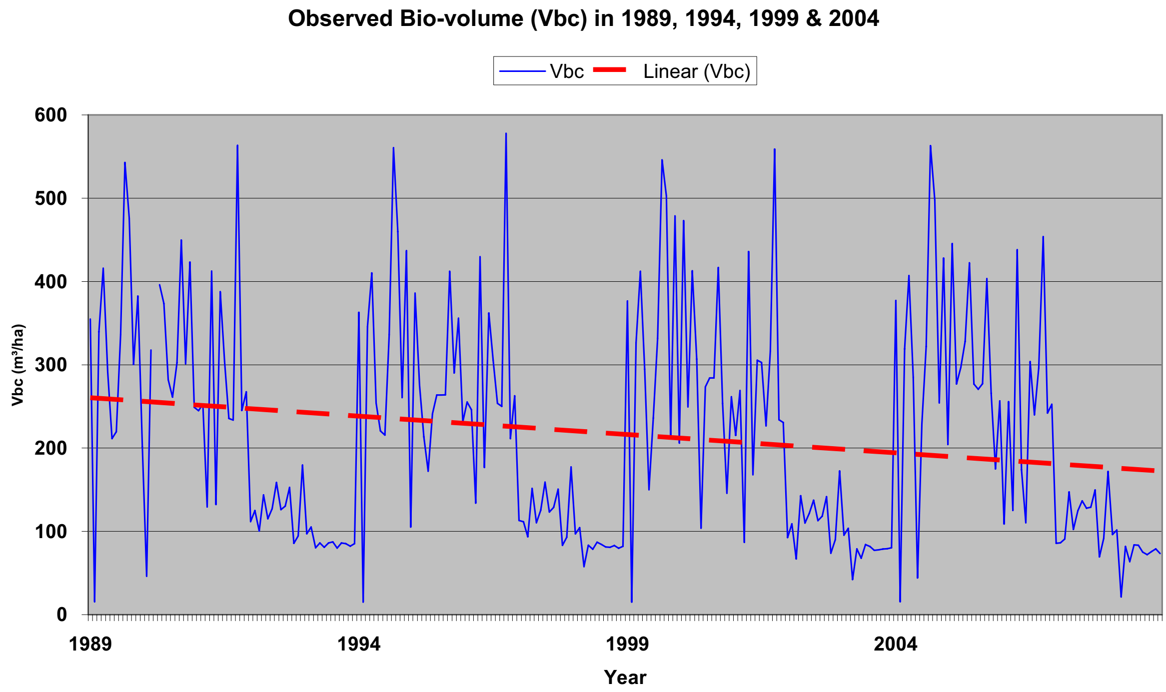

Figure 8-4 Observed bio-volume dynamics (Vbc) of 62 Oueme communes in five years interval: 1989-2004

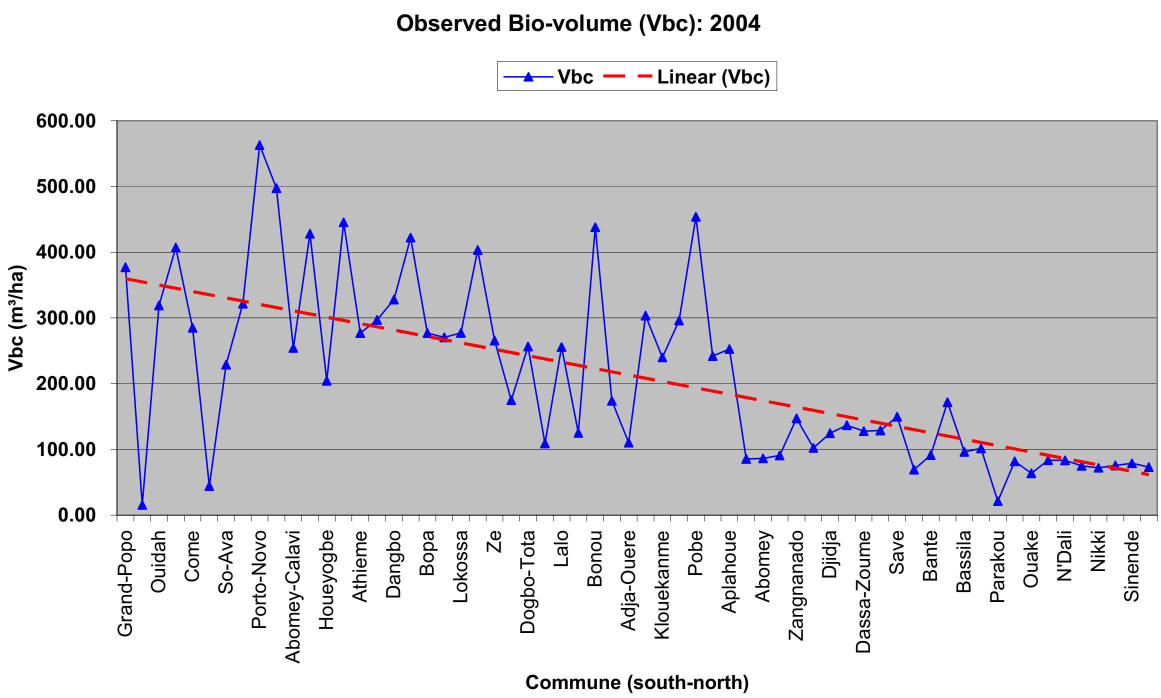

Figure 8-5 Observed bio-volume dynamics (Vbc) of 62 Oueme communes in year 2004

8.3.3 Predicted vegetation dynamics

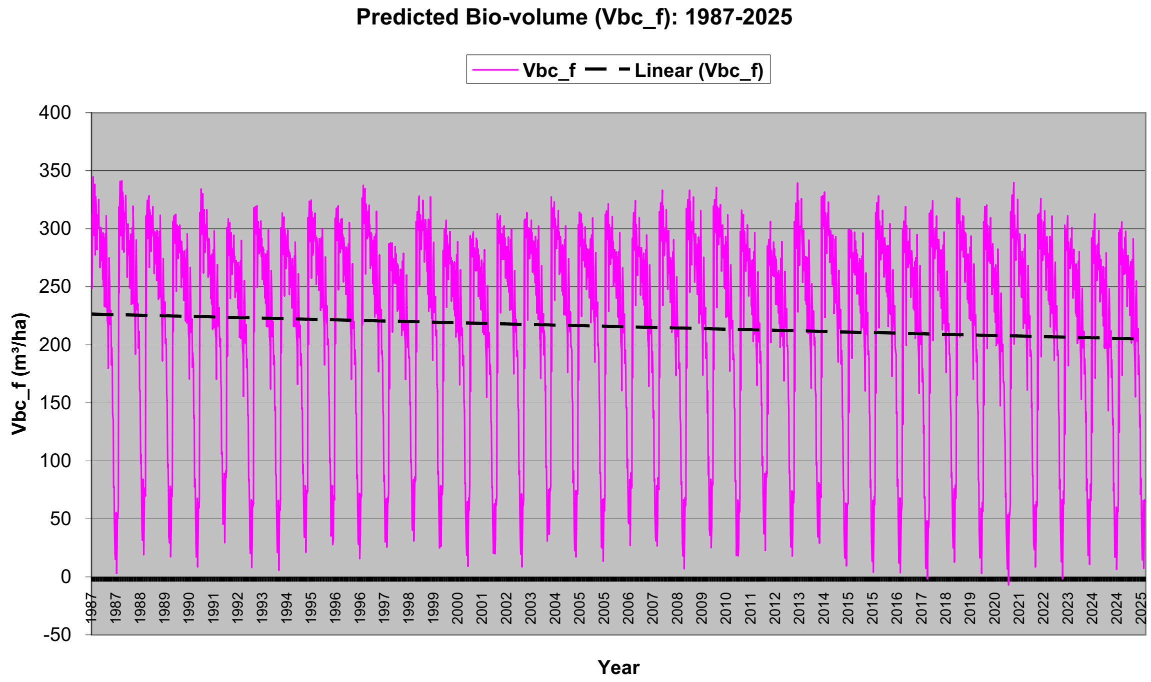

Figure 8-6 Predicted bio-volume dynamics (Vbc_f) of 62 Oueme communes: 1987-2025

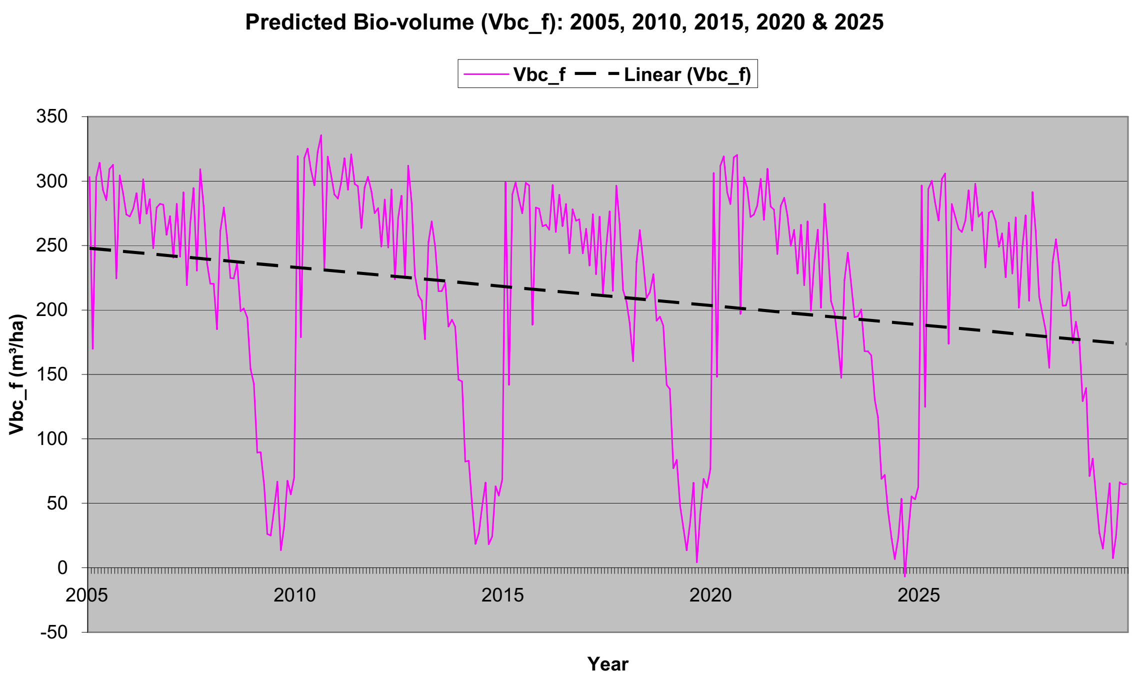

Figure 8-7 Predicted bio-volume dynamics (Vbc_f) of 62 Oueme communes in five years interval: 2005-2025

As shown in the figures 8-6 and 8-7, the bio-volume dynamics were diminishing over time and along a south-north trend. Within the predicted values, in the north department Donga, two communes Ouake and Kopargo would firstly become negative in year 2017. The south-north trend could be seen more clearly in figure 8-8.

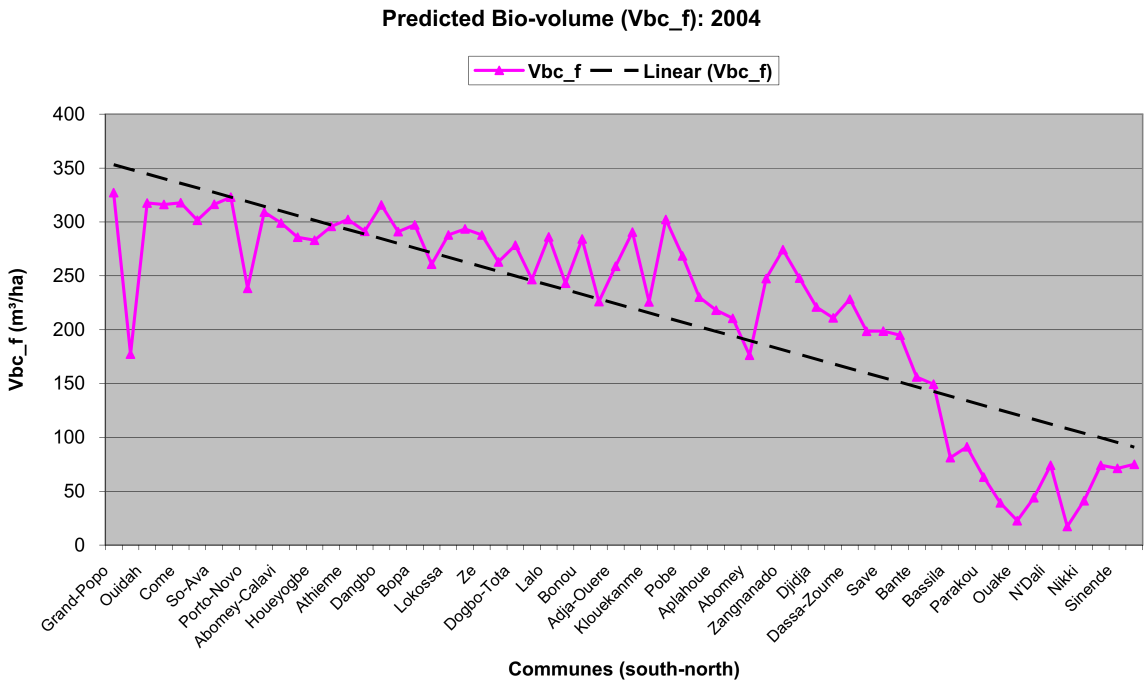

Figure 8-8 Predicted bio-volume (Vbc_f) dynamics of 62 Oueme communes in year 2004

8.3.4 Observed vs. predicted

The figure 8-9 shows the observed versus predicted bio-volumes from 1987 to 2004. The figures 8-10 and 8-11 show more clearly the details of the observed versus predicted bio-volumes. Even if the predicted bio-volume values were higher than observed values in middle and lower than those in north Oueme Basin, and the model did not take soil and economic dynamics into account, the scenario of bio-volume based on hypothesis 8-1 showed identical trends in comparison with observed values. Bio-volume was diminishing both for observed and predicted values, within the observation period (1987-2004), along a south-north-wards gradient. And across the time, observed and predicted bio-volume values were coincidently diminishing, too. Thus it can be concluded that the hypothesis 8-1 was confirmed: temporally and spatially, bio-volume correlated positively with precipitation but negatively with population dynamics in the Oueme Basin.

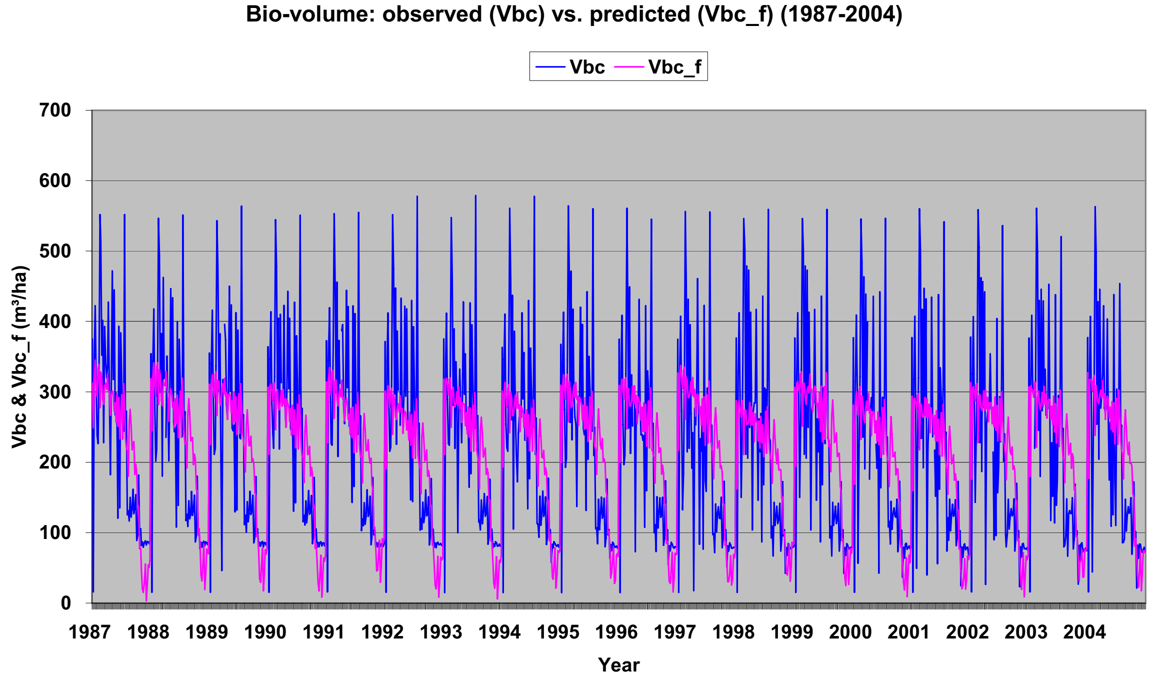

Figure 8-9 Observed and predicted bio-volume of 62 Oueme communes: 1987-2004

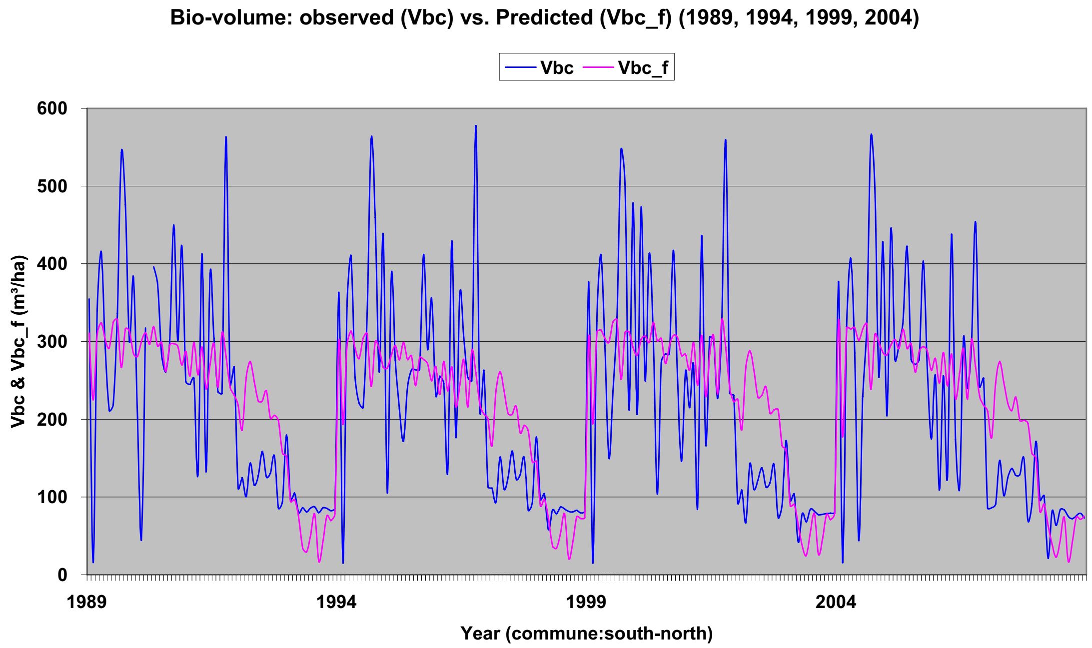

Figure 8-10 Observed and predicted bio-volume of 62 Oueme communes in five years interval: 1989-2004

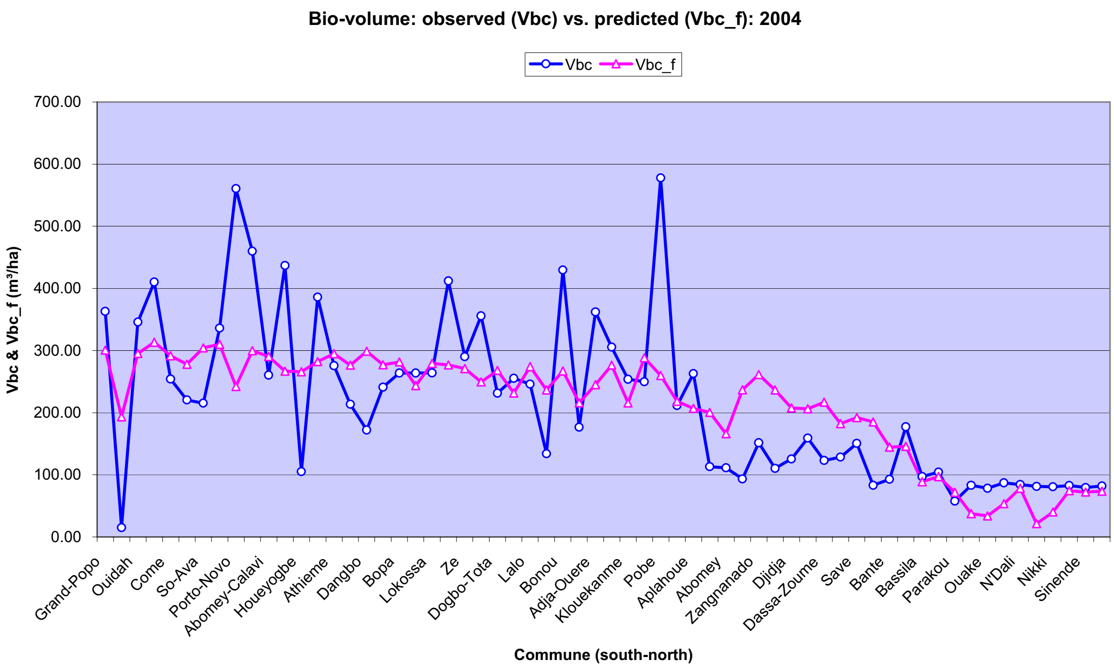

Figure 8-11 Observed and predicted bio-volume of 62 Oueme communes in years 2004

8.4 Scenarios of eco-precipitation

8.4.1 Model description

8.4.1.1 Static regional model

The following model 8-2 was selected to estimate spatial precipitation variability throughout 62 Oueme communes, which used eco-volume and three geographic coordinates as independent variables. In the analyses each commune was put into simulation as one unit. Even if the model could explain only 26.5% variability of precipitation, the model was statistically significant with a P-value of 0.001.

Rain_04 = 1543.11 + 0.00133381*Vec - 73.2149*LAT + 51.7085*LON + 0.529908*ELE

Model 8-2 Selected model predicting regional precipitation variability at communal level

Table 8-2 ANOVA for precipitation (Rain_04) estimated by eco-volume (Vec) and three geographic coordinates

Dependent variable: Rain_04

Parameter	Estimate	Standard Error	T Statistic	P-Value
CONSTANT	1543.11	186.157	8.28932	0.0000
Vec	0.00133381	0.000573837	2.32437	0.0237
LAT	-73.2149	32.9114	-2.2246	0.0301

LON	51.7085	26.6283	1.94186	0.0571
ELE	0.529908	0.309212	1.71374	0.0920

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	105027.0	4	26256.8	5.15	0.0013
Residual	290569.0	57	5097.71		
Total (Corr.)	395596.0	61			

R-squared = 26.5491 percent
R-squared (adjusted for d.f.) = 21.3946 percent
Standard Error of Est. = 71.3982
Mean absolute error = 52.034
Durbin-Watson statistic = 1.84352 (P=0.2007)
Lag 1 residual autocorrelation = 0.0706761

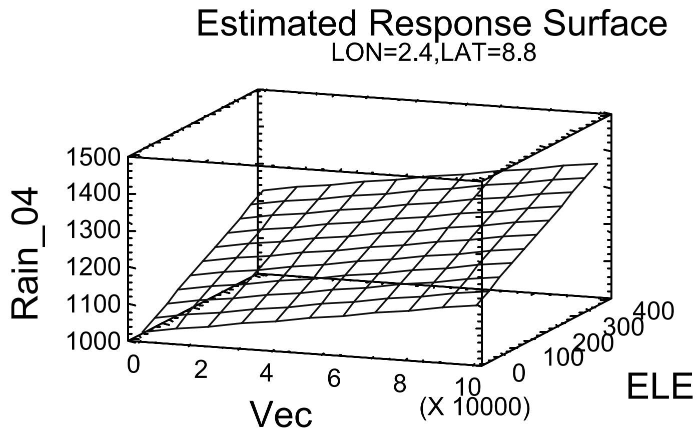

Figure 8-12 Estimated response surface using model 8-2

As defined in the section 8.2 Material and Method, the actual eco-precipitation (Pe_ac) is proportionally identical with the coefficient of eco-volume in the model 8-2, which implies that by calculating Pe_ac, the effects of geographic variation on precipitation are removed and the final effects show directly the precipitation variability induced by eco-volume variation.

There are lots of studies on the relations between vegetation dynamics and rainfall variability, but most of them are about the vegetation response to the rainfall (Klein & Roehrig, 2006, Zhang et, 2005, Vanacker et, 2005, Budde et, 2004, White et, 1997). There are few studies about the interactive feedback between vegetation and rainfall variability. Wang et al (2006a & 2006b) analysed relations between the normalized difference vegetation index (NDVI) anomalies early in the growing season and the precipitation and surface temperature later in summer over the North American Grasslands. They concluded that vegetation may influence summertime climate variability via the land–atmosphere hydrological cycles over these semi-arid grasslands. In comparison to other research, the model 8-2 in this study estimates only the feedback of the *spatial* vegetation dynamics to the regional precipitation variability. More differently in this study, the eco- and bio-volume are used instead of NDVI in most other studies. The eco- and bio-volume have different physical means as NDVI. Moreover, eco- and bio-volume are carried out by combining data of field measurement, agricultural statistics and satellite observation. Hence, eco- and bio-volume are validated indicators that might be more suitable to test the feedback between vegetation and precipitation. Even though in this study the precipitation variability was estimated only by eco-volume variability and geographic coordinates. There remain several steps to yield a better estimation. The thermal dynamics, i.e. the temperature variability, thus the variability of evapotranspiration should contribute to estimating precipitation variability. Also the precipitation data are known as containing unaccounted "noises", which could be normalized and standardized and should improve estimating the relation between precipitation and vegetation.

8.4.1.2 Temporal and regional model

Using General Linear Model (GLM) the following model (model 8-3) was obtained, as year was set as a categorical variable, which means that the relationship between precipitation, eco-volume and three geographic coordinates was analyzed within each of the 18 years (1987-2004). The same relationships were found by using only the data of year 2004 as presented in model 8-2. That implies that the relationship between precipitation, eco-volume and three geographic coordinates held on throughout the period of 18 years. As can be identified in table 8-3, throughout 18 years, 55.02% variation of precipitation could be explained by the variability of eco-volume and three geographic coordinates. The figure 8-3 shows that throughout 18 years the precipitation was influenced by eco-volume dynamics in the Oueme Basin.

Rain = 1369.12 + 80.3592*I1(1) + 227.48*I1(2) + 142.964*I1(3) -
79.7901*I1(4) + 104.593*I1(5) - 214.046*I1(6) - 54.5553*I1(7) -
105.733*I1(8) + 91.5283*I1(9) + 2.13254*I1(10) + 133.447*I1(11) -
222.388*I1(12) + 215.699*I1(13) - 189.722*I1(14) - 247.902*I1(15) - 19.4445*I1(16) +
54.2362*I1(17) + 0.000763527*Vec + 51.3034*LON - 59.9905*LAT + 0.703544*ELE

where
I1(1) = 1 if Year=1987, -1 if Year=2004, 0 otherwise

I1(2) = 1 if Year=1988, -1 if Year=2004, 0 otherwise
I1(3) = 1 if Year=1989, -1 if Year=2004, 0 otherwise
I1(4) = 1 if Year=1990, -1 if Year=2004, 0 otherwise
I1(5) = 1 if Year=1991, -1 if Year=2004, 0 otherwise
I1(6) = 1 if Year=1992, -1 if Year=2004, 0 otherwise
I1(7) = 1 if Year=1993, -1 if Year=2004, 0 otherwise
I1(8) = 1 if Year=1994, -1 if Year=2004, 0 otherwise
I1(9) = 1 if Year=1995, -1 if Year=2004, 0 otherwise
I1(10) = 1 if Year=1996, -1 if Year=2004, 0 otherwise
I1(11) = 1 if Year=1997, -1 if Year=2004, 0 otherwise
I1(12) = 1 if Year=1998, -1 if Year=2004, 0 otherwise
I1(13) = 1 if Year=1999, -1 if Year=2004, 0 otherwise
I1(14) = 1 if Year=2000, -1 if Year=2004, 0 otherwise
I1(15) = 1 if Year=2001, -1 if Year=2004, 0 otherwise
I1(16) = 1 if Year=2002, -1 if Year=2004, 0 otherwise
I1(17) = 1 if Year=2003, -1 if Year=2004, 0 otherwise

Model 8-3 General Linear Model for estimating precipitation variability (Rain) using eco-volume (Vec) and three geographic coordinates from 1987 to 2004

Table 8-3 ANOVA for precipitation (Rain) in relation to eco-volume (Vec) and three geographic coordinates from 1987 to 2004

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.47019E7	21	1.17628E6	63.09	0.0000
Residual	2.01925E7	1083	18644.9		
Total (Corr.)	4.48943E7	1104			

Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Year	2.36197E7	17	1.3894E6	74.52	0.0000
Vec	155121.0	1	155121.0	8.32	0.0039
LON	325969.0	1	325969.0	17.48	0.0000
LAT	303068.0	1	303068.0	16.25	0.0001
ELE	481805.0	1	481805.0	25.84	0.0000
Residual	2.01925E7	1083	18644.9		
Total (corrected)	4.48943E7	1104			

R-Squared = 55.0222 percent
R-Squared (adjusted for d.f.) = 54.1501 percent
Standard Error of Est. = 136.546
Mean absolute error = 100.963
Durbin-Watson statistic = 1.81885 (P=0.0013)

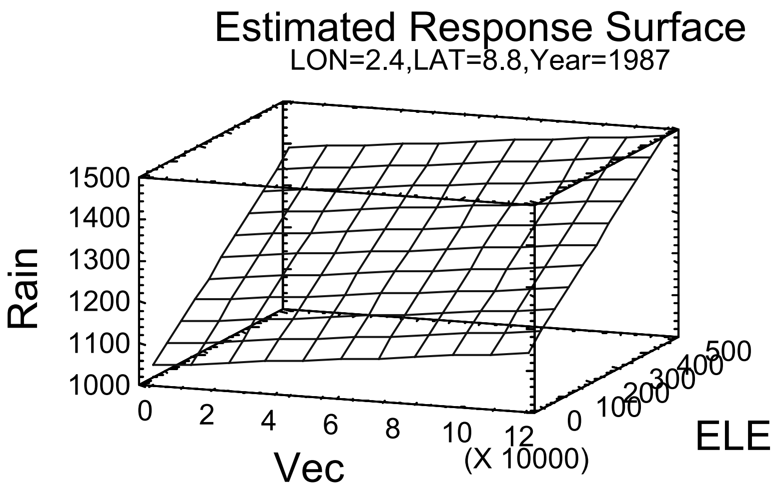

Figure 8-13 Estimated response surface using model 8-3

8.4.2 Observed vs. predicted precipitation 2004

In followed section, the results based on model 8-2 are presented.

The figure 8-14 shows the values of predicted versus observed annual precipitation of all 62 Oueme communes in year 2004. The residues of precipitation in the figure 8-15 mean the predicted precipitation minus the observed precipitation. Even the selected model 8-2 explained only ca. 26% variability of precipitations across the Oueme communes with positive precipitation residues could mean that these were the communes where eco-volume had been diminishing faster than recorded statistic or monitored satellite data.

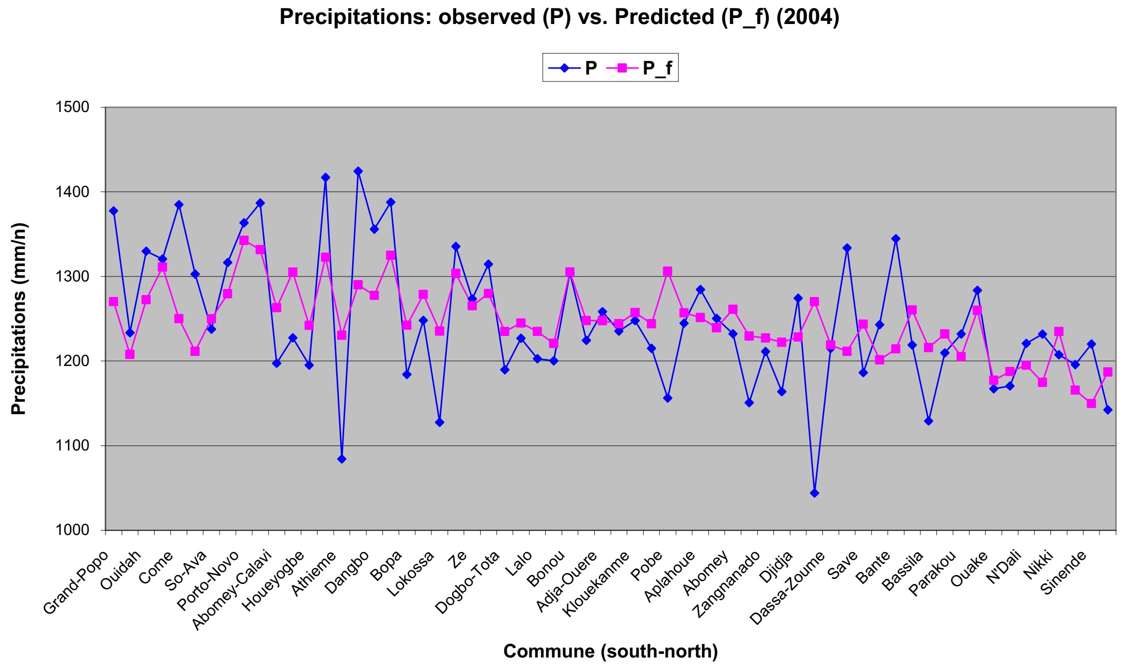

Figure 8-14 Observed precipitation (P) versus predicted precipitation (P_f) in years 2004 of 62 Oueme communes

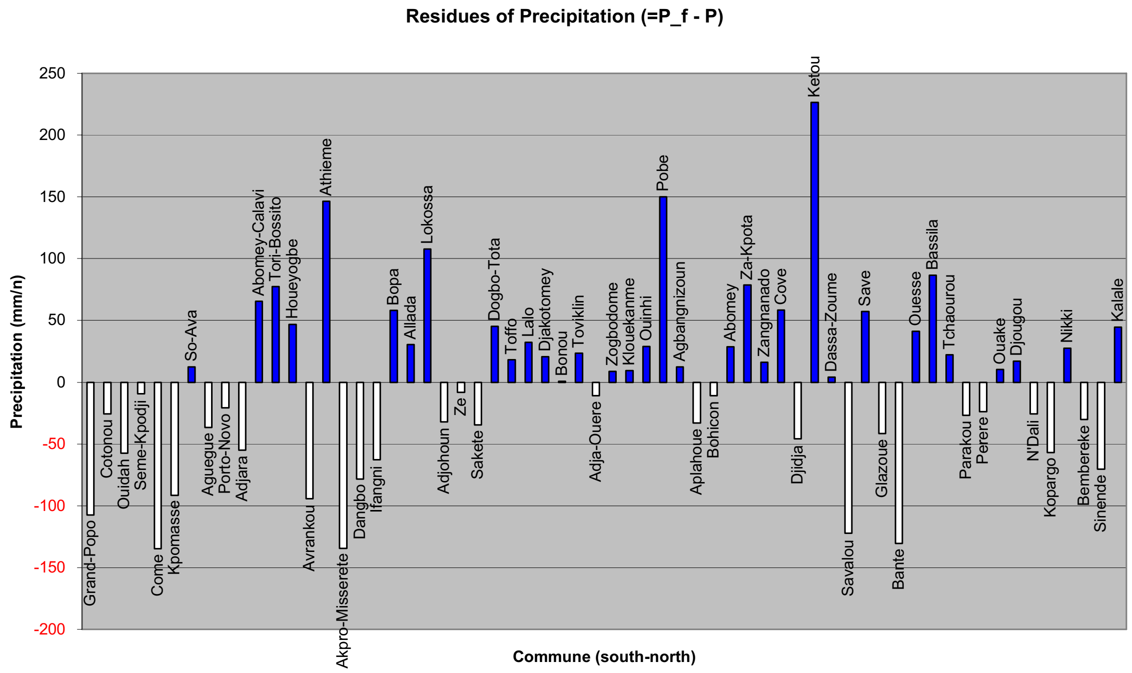

Figure 8-15 Residues of precipitation when subtracting observed precipitation (P) from predicted precipitation (P_f) in year 2004 of 62 Oueme communes

It could be seen in the figure 8-16, that the observed precipitation values were out of the range of predicted precipitations with minimum and maximum eco-volumes, since the model did not take atmospheric circulation into account.

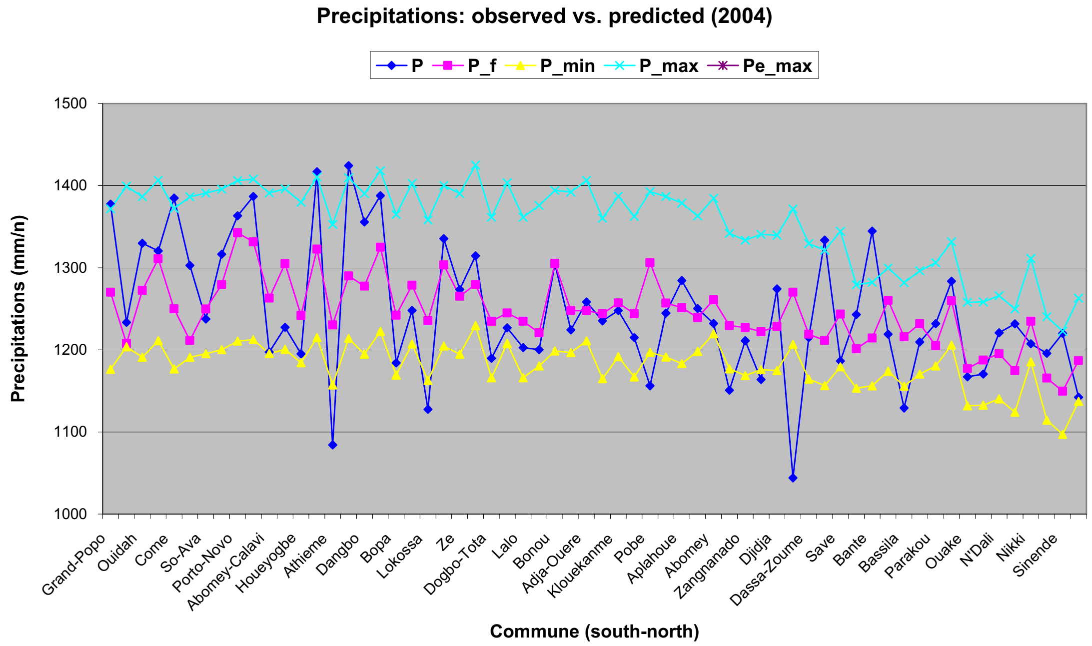

Figure 8-16 Observed (P) and predicted (P_f), minimum (P_min) and maximum (P_max) precipitations in year 2004 of 62 Oueme commune

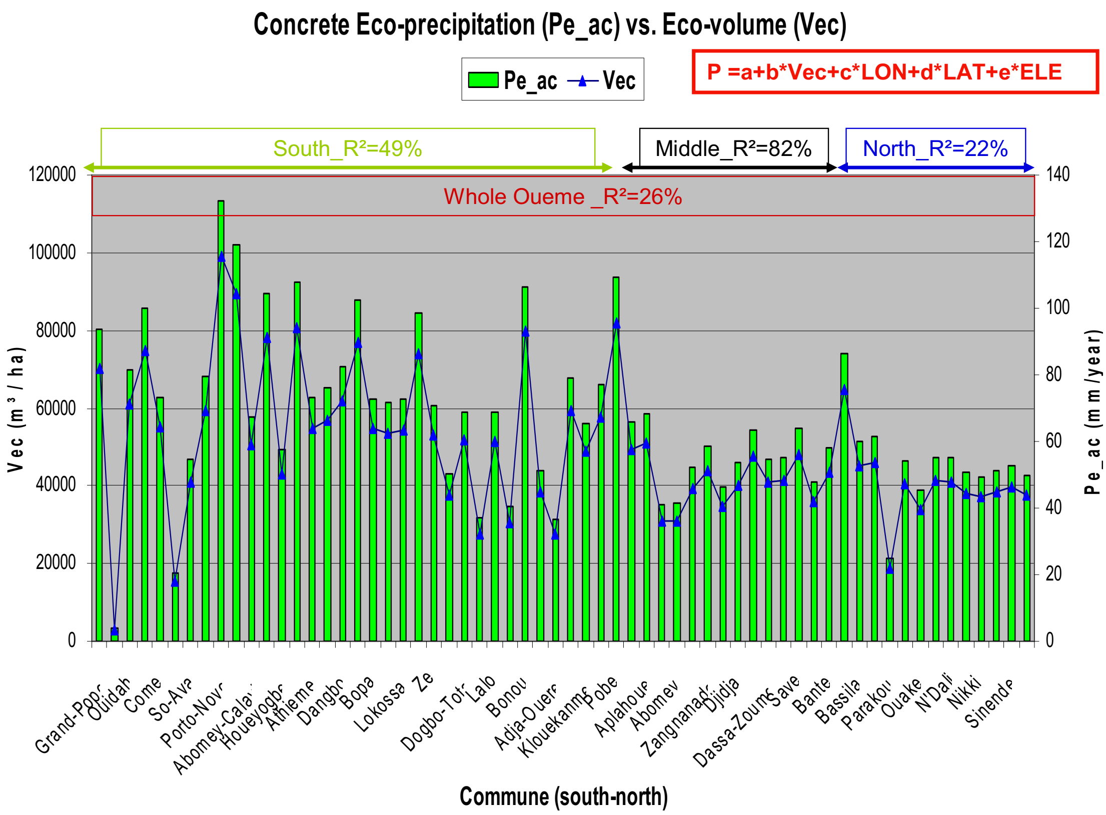

Figure 8-17 Predicted concrete Eco-precipitation (Pe_ac) vs. observed eco-volume (Vec) in year 2004 of 62 Oueme commune

According to model 8-2, the figure 8-17 shows clearly that predicted concrete eco-precipitations varied consistently with observed eco-volume in 2004 throughout the whole Oueme Basin. Even if for the whole Oueme Basin, only 26% variability could be explained, using the same multiple regression module as for model 8-2, the specific models for South-, Middle- and North-Oueme Basin show the difference (table 8-4). The sub-regional models show generally higher determination grades as this for the whole Oueme Basin (model for South-Oueme: R^2=49%, Middle-Oueme: R^2=82%, North-Oueme: R^2 = 22%). According to model 8-2, over all communes in the Oueme Basin, 10000 m^3/ha eco-volume mean 13.34 mm precipitation, which means that 1 m of eco-height would contribute to a supplement of 13.34 mm precipitation.

Table 8-4 Sub-regional models estimating relationship between precipitation (Rain_o4) and eco-volume (Vec) in year 2004

Sub-region	**Model**	**R^2 (%)**	**P-value (model)**
South	Rain_04 = 2599.66 + 0.00115957*Vec + 118.083*LON - 256.036*LAT + 1.23222*ELE	49.5	0.000
Middle	Rain_04 = 817.5 - 0.00267803*Vec - 261.194*LON + 152.105*LAT - 0.462239*ELE	81.8	0.043
North	Rain_04 = 1629.97 - 0.000819803*Vec + 17.2942*LON - 47.8743*LAT + 0.0873224*ELE	22.3	0.559

Contrary to figure 8-17, the figure 8-18 shows the relationship between eco-precipitation by its primary means (=Pe', Janssens et al 2004) and eco-volume (Vec) in year 2004 of 62 Oueme commune. The fitted regression model for whole Oueme Basin (**Pe' = 0.00133291*Vec**) has a determination of 51%. The sub-regional models are **Pe' = 0.00140099*Vec** for South-Oueme, **Pe' = 0.000514667*Vec** for Middle-Oueme and **Pe' = 0.00150874*Vec** for North-Oueme (Figure 8-18).

The figure 8-19 shows, the predicted communal maximum precipitations with maximum eco-volumes ranged from 126.9 to 195.6 mm north-south-ward. The actual eco-precipitations in 2004 ranged from 4.0 to 132.0 mm in Cotonou und Porto-Novo, especially.

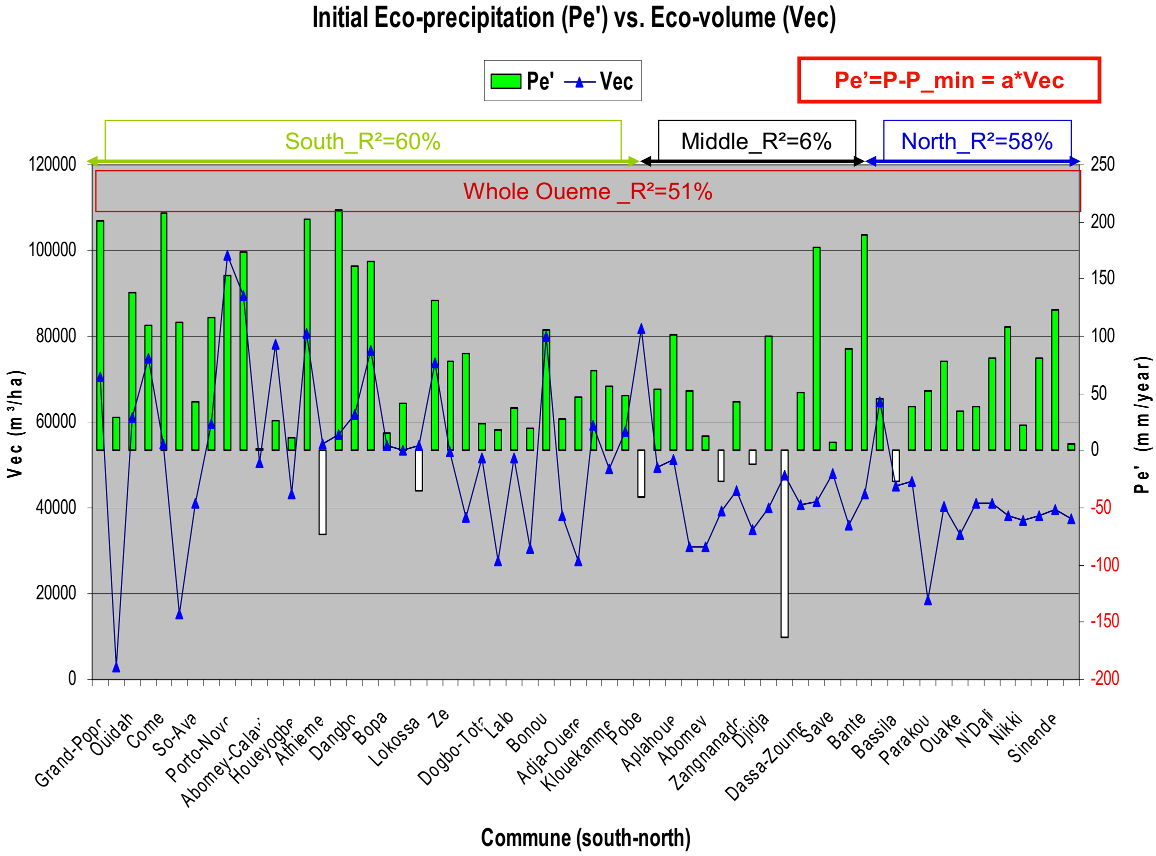

Figure 8-18 Initial eco-precipitation (Pe') vs. eco-volume (Vec) in year 2004 of 62 Oueme commune

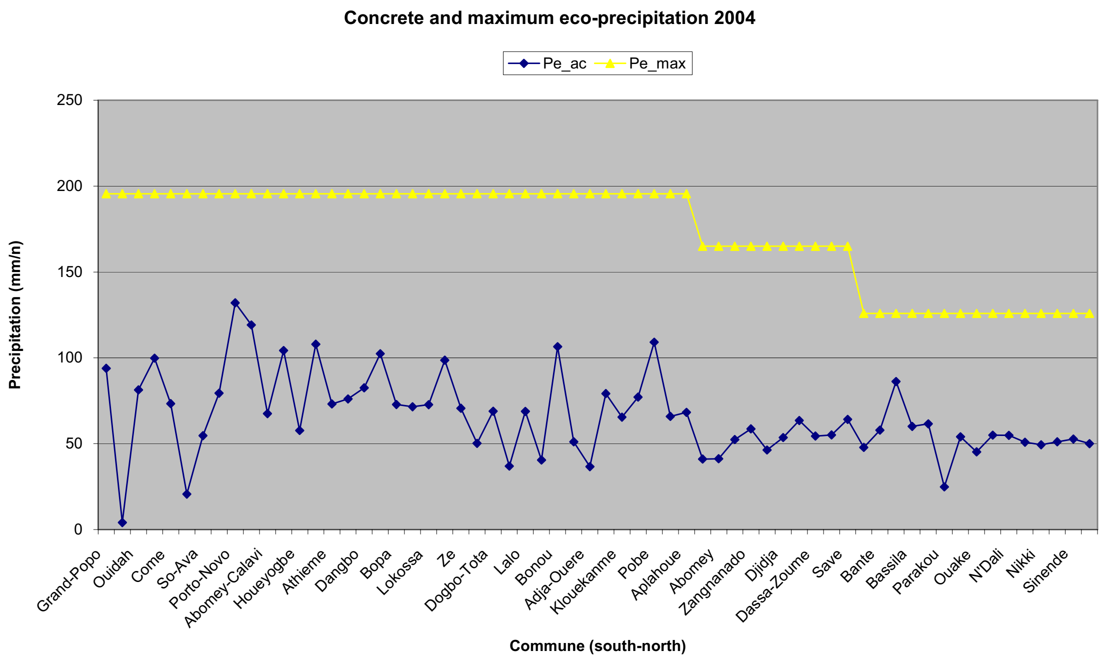

Figure 8-19 Concrete (Pe_ac) versus maximum (Pe_max) eco-precipitation in year 2004 of 62 Oueme communes

The figure 8-20 shows, the ratios of concrete eco-precipitation (Pe_ac) to predicted precipitation in year 2004 in 62 Oueme communes ranged from 0.3% to 9.8% in Cotonou and Porto-Novo, respectively. The ratios of actual to maximum eco-precipitation ranged from 2.1% to 68.5% in Cotonou and Ouesse; to the contrary, the ratios of maximum eco-precipitation to predicted precipitation in 2004 ranged from 10.0% to 16.2% in Ouesse and Cotonou. The ratios of the average concrete eco-precipitation to the average observed and average predicted precipitation were 5.25% and 5.23%, respectively.

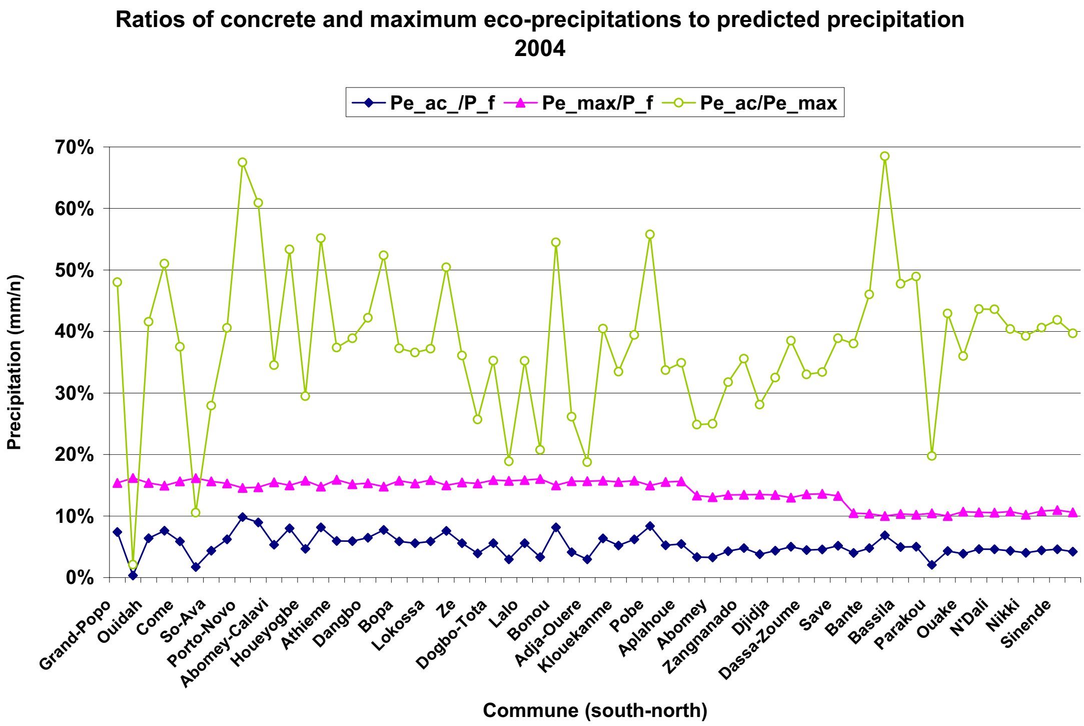

Figure 8-20 Ratios of concrete (Pe_ac) to maximum (Pe_max) eco-precipitations and these to predicted precipitation (P_f) in 2004

Even if only 26.5% variability of precipitation across whole Oueme Basin in year 2004 could be explained by the static regional model 8-2 using eco-volume and three geographic coordinates as independent variables, the model was statistically significant with a P-value of 0.001. Moreover, the sub-region models had generally higher determination grades than that of the whole Oueme Basin (model for South-Oueme: R^2=49%, Middle-Oueme: R^2=82%). The model 8-3 showed, 55.02% variation of precipitation could be explained by variability of eco-volume and three geographic coordinates across Oueme Basin and throughout 18 years. The results in this empirical study are similar as the results of Paeth (2006) and Wang et. (2006a and 2006b) using modelling approach applied in tropical and northern Africa, and North-America grasslands, respectively. The notion of eco-precipitation (Pe) defined as the predicted precipitation (P_f) minus predicted precipitation by minimum/zero vegetation cover (P_min) supplies a promising tool together with the notion of eco-volume to detect the relationship between precipitation and vegetation for empirical study, which base on the field researches and combine field, statistic and satellite data sets. Since by this definition the concrete eco-precipitation (Pe_ac) is proportionally identical with the coefficients of eco-volume in the model 8-2 and model 8-3, which implies that by calculation of Pe_ac, the effects of geographic variation on precipitation are removed and the final effect shows the precipitation variability induced only by eco-volume variation. In this study the precipitation variability was estimated only by eco-volume and geographic coordinates. Further steps remain to provide a better estimation. The thermal dynamics, i.e. the temperature variability, thus the variability of evapotranspiration should contribute to estimate precipitation variability. Also the precipitation data was known as containing "noise", which could be normalized and standardized and should improve estimating the relation between precipitation and vegetation. Distinguishing precipitation data into "wet" and "dry" years might improve also deeper understanding of feedback between vegetation and precipitation. Considering above results, the Hypothesis 8-2 can be accepted: micro-climate, especially the eco-precipitation, was influenced by eco-volume dynamics in the Oueme Basin.

8.5 Partial Conclusion

Results agreed largely with the initial hypotheses:

According to Hypothesis 8-1: Temporally and spatially, bio-volume correlated positively with precipitation but negatively with population dynamics in the Oueme Basin.

According to Hypothesis 8-2: Micro-climate, especially the eco-precipitation, was influenced by eco-volume dynamics in the Oueme Basin.

9 General Conclusion

To investigate “Vegetation Dynamics in Oueme Basin, Benin, West-Africa”, and more particularly the possible feedback between vegetation and precipitation empirically, a new quantitative vegetation appraisal was developed. The newly defined concepts of eco-volume and bio-volume were used as alternative vegetation indicators as opposed to the standard biomass indicators. The portion of precipitation variability originating from vegetation variability was defined as eco-precipitation. The *in situ* measured agro-ecological and farming system parameters of all three vegetation types were used to validate the agricultural statistics and the satellite land cover data. Accordingly, the temporal and spatial vegetation dynamics of the Oueme Basin in Benin, West-Africa were reconstructed. The general conclusions are as follows:

- The farming systems in the Oueme Basin are experiencing an ongoing intensifying process according to observed CIC and R values.
- Regarding litter fall the relation with rainfall was only moderate but strong with soil carbon content.
- Spatial vegetation dynamics in 2004 were characterized in a twofold way:
    a. All three vegetation indicators were positively and closely correlated across time and space. That implies that knowing one of them suffices to reasonably and precisely predict the other one. Among them, biomass correlated more closely with eco-volume than with bio-volume.
    b. Among all considered environmental parameters, soil parameters determined almost dominantly the vegetation, followed by geographic coordinates, population density, precipitations and vegetation length.
- Temporal and spatial vegetation dynamics from 1987 to 2004 showed similar tendencies as the spatial vegetation dynamics in 2004:
    a. The different zoning approaches (= different scaling methods) affected the relationships between vegetation and other environmental driving forces. Generally, the Impetus zoning was more satisfactory than both the Department and the AEZ zoning approaches. The Impetus zoning yielded already relatively proper models estimating relations within vegetation parameters and relations between vegetation dynamics and other available environmental driving forces such as population dynamics, precipitation

dynamics and variation of vegetative length combining with geographic coordinates. However, within IMPETUS zones, the relationship between vegetation and precipitation became statistically not significant whereas the relationship between vegetation and vegetative length (C_veg) became significant.

   b. Within vegetation parameters, the relation between eco-volume and biomass -as standard reference parameter - was closer than the relation between bio-volume and biomass.
   c. Throughout all analyses, population has been the dominant driving force among factors such as precipitation and vegetative length.
   d. Bio-volume responded better to environment driving forces than eco-volume and biomass across time and space. Bio-volume, as well as eco-volume and biomass correlated positively with precipitation but negatively with population density and showed negative trends along the latitude and altitude gradients.

- Prospective development scenarios were simulated:
   a. The scenarios of bio-volume in relation to precipitation and population dynamics showed that within the observation period (1987-2004), bio-volume diminished spatially from South to North, and temporally from 1987 to 2004. From simulation runs, this trend extended through to 2025. In the northern department Donga, two communes, Ouake and Kopargo would firstly reach zero bio-volumes in the year 2017.
   b. The scenarios of precipitation versus eco-volume showed that from a static regional approach, eco-volume together with three geographic coordinates could explain 26% of the variability of precipitation in the whole Oueme Basin in year 2004 by the model 8-2. By adding a temporal dimension to the latter model, the GLM model 8-3 could explain 55.02% of the precipitations by the independent variables eco-volume and three geographic coordinates across Oueme Basin and throughout 18 years. When relating eco-volume directly with initial eco-precipitation, determination reached 51% for the whole Oueme basin.

Based on the vegetation dynamics and on the significant relation between eco-volume and eco-precipitation across the Oueme basin, the major hypothesis as to the positive reciprocal feedback between vegetation and precipitation could be accepted, even if R-squared values of models were generally low.

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11 Annexes

Annexe 1 Example of interview questionnaire in Abomey Calavi

1. Family and Labour

Householder	Name		
	Gender		
	Age / Religion	/	
	Number of Wives		
	Number of Sons		
	Number of Girls		
Number of Family member			
Number of persons in household			
Labour		Female	Male
Number of regular labour	under 16 years		
	16-55		
	older than 55		
Number of season labour			

2. Location

Name of Village			
Name of Arrondissement			
GPS-Village	Elevation (feet)	E.:	N.:
GPS-Farm	Elevation (feet)	E.:	N.:
Distance from Farm to:	City (km)	Main Road (km)	Local Market (km)

3. How much land areas have you used for the last small rainy season (09—11.2003)? For which crops?

Crop	Land Area (hectare)	Soil Type 1=F+sableux 2=H+deltaique 3=F+colluvial 4=F+H	Soil Quality 1=very good 2=good 3=poor 4=very poor	Chiendent Imperata cylindrica Yes / No	Land property rights: Own Non-own	Yield (Kg)
Mais local						
Mais improved						
Manioc						
Patate douce						
Taro						
Rice						
Arachide/ groundnut						
Haricot/ cowpean						
Voandzou						
Soja						
Onion						
Amaranthus						
Solanum/ Gboman						
Vernonia /Amanvive						
Sésame/ cucurbitacee						
Gombo/Fevi						
Piment						
Concombre						
Laitue						
Tomato						
Carotte						
Aubergine						
Autre épice						
Oil Palm						
Manguier						
Banane						
Oranger						
Ananas						
Bread Fruit Tree						
Fallow						

4. How much land areas have you used for the last big rainy season (03—07.2004)? For which crops?

Crop	Land Area (hectare)	Soil Type 1=F+sableux 2=H+deltaique 3=F+colluvial 4=F+H	Soil Quality 1=very good 2=good 3=poor 4=very poor	Chiendent Imperata cylindrica Yes / No	Land property rights: Own Non-own	Yield (Kg)
Mais local						
Mais improved						
Manioc						
Patate douce						
Taro						
Rice						
Arachide/ groundnut						
Haricot/cowpean						
Voandzou						
Soja						
Onion						
Amaranthus						
Solanum/Gboman						
Vernonia / Amanvive						
Sésame/ cucurbitacee						
Gombo/Fevi						
Piment						
Concombre						
Laitue						
Tomato						
Carotte						
Aubergine						
Autre épice						
Oil Palm						
Manguier						
Banane						
Oranger						
Ananas						
Bread Fruit Tree						
Fallow						

5. Which additive new cultures are you going to plant in the following 1 –5 years? Why?

6. Which cultures are principal for you? Why?

7. Which mixing culture patterns do you use?

1	
2	
3	
4	
5	

8. When do you usually sow and harvest the following cultures?

Cultures		January	February	March	April	May	June	July	August	September	October	November	December
Mais local	Sowing												
	Harvest												
Mais improved	Sowing												
	Harvest												
Manioc	Sowing												
	Harvest												
Patate douce	Sowing												
	Harvest												
Taro	Sowing												
	Harvest												
Rice	Sowing												
	Harvest												
Haricot/cowpean	Sowing												
	Harvest												
Arachide/groundnut	Sowing												
	Harvest												
Voandzou	Sowing												
	Harvest												
Sésame/cucurbitacee	Sowing												
	Harvest												
Onion	Sowing												
	Harvest												
Amaranthus	Sowing												
	Harvest												
Solanum/Gboman	Sowing												
	Harvest												
Vernonia /Amanvive	Sowing												
	Harvest												

Cultures		January	February	March	April	May	June	July	August	September	October	November	December
Gombo/Fevi	Sowing												
	Harvest												
Piment	Sowing												
	Harvest												
Concombre	Sowing												
	Harvest												
Laitue	Sowing												
	Harvest												
Tomato	Sowing												
	Harvest												
Carotte	Sowing												
	Harvest												
Aubergine	Sowing												
	Harvest												
Autre épice	Sowing												
	Harvest												
Oil Palm	Sowing												
	Harvest												
Manguier	Sowing												
	Harvest												
Banana	Sowing												
	Harvest												
Ananas	Sowing												
	Harvest												
Orange	Sowing												
	Harvest												
Bread Fruit Tree	Sowing												
	Harvest												

9. Which crop rotation do you use?

Season	Big rainy Season	Small rainy season	Big rainy Season	Small rainy season	Big rainy Season	Small rainy season	Big rainy Season	Small rainy season	Big rainy Season	Small rainy season	Big rainy Season	Small rainy season			
Year															
Ä															
Year															
B															
Year															
C															
Year															
D															

10. For men: Which off-farm activities concerning income have you done during September 2003 to September 2004? How much have you earned from each activity?
Zemidjan:

House Building:

Sodabi-processing:

Animal keeping:

Kpaka:

Other:

11. For women: What are your main sources of income?
Food processing

Farming

Animal husbandry

Retail selling:

12. For women: Activities description:
Activity 1:
How much carrying capital are you using now?

What is the rhythm of your carrying capital?

What are the purchasing prices of inputs?

What are the selling prices of your processed products?

Activity 2:
How much carrying capital are you using now?

What is the rhythm of your carrying capital?

What are the purchasing prices of inputs?

What are the selling prices of your processed products?

Annex 2 Cropping Calendar in the south Oueme: Abomey-Calavi: sowing and harvest periods

Commune	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Abomey-Calavi	Bush fire						Rainy season					
				Maize					Maize			
								Maize			Maize	
				Cassava								
				Cassava								
				Groundnut					Groundnut			
								Groundnut				Groundnut
				Sweet potato					Sweet potato			
							Sweet Potato					Sweet potato
				Tomato					Tomato			
							Tomato					Tomato
						Cowpea						
								Cowpea				
				Ananas								
	Ananas											
	Vegetables											
	Vegetables											

(Yellow means harvesting season and green means sowing season. Manioc is harvested after 12-18 months of sowing)

Annex 3 Cropping Calendar in the south Oueme: Pobe

Commune	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pobe	Bush fire					Rainy season						
				Maize				Maize				
							Maize				Maize	
			Cassava									
			Cassava									
			Cowpea					Cowpea				
					Cowpea						Cowpea	
			Groundnut					Groundnut				
						Groundnut				Groundnut		
			Rice									
								Rice				
				potato		potato						
						potato			potato			
			Taro									
											Taro	
									Goussi			
												Goussi
			Pigeonpea									
	Pigeonpea											
												Yam
								Yam				
			Amaranth			Amaranth			Amaranth			
				Amaranth			Amaranth			Amaranth		
					Onion			Onion				
						Onion			Onion			
				Solanum								
					Solanum							
			Gombo					Gombo				
						Gombo					Gombo	
			Peper				Peper					
					Peper				Peper			
			Tomato				Tomato				Tomato	
						Tomato				Tomato		
			Gbolo									
				Gbolo								
					Ananas							
					Ananas							
			Banana									
											Banana	
			Papaya									
									Papaya			
						Orange						
										Orange		
						Oil palm						
	Oil palm											
					Teak							

Annex 4 Cropping calendar in the middle Oueme: Bohicon and Save

Commune	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bohicon	Bush fire						Rainy season					
				Maize				Maize				
								Maize			Maize	
				Cowpea			Cowpea					
					Cowpea						Cowpea	
				Groundnut			Groundnut					
							Groundnut				Groundnut	
				Sorghum								
											Sorghum	
						Soya					Soya	
	Pigeonpea			Pigeonpea								
Commune	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Save	Bush fire						Rainy season					
												Yam
							Yam					
				Maize				Maize				
							Maize					Maize
				Cassava								
					Cassava							
				Groundnut				Groundnut				
						Groundnut						Groundnut
				Cowpea				Cowpea				
							Cowpea				Cowpea	
				Goussi				Goussi				
							Goussi					Goussi
						Soya						
											Soya	
					Sorghum							
											Sorghum	
						rice						
										Rice		
							Cashew					
												Cashew

Annex 5 Cropping calendar in the north Oueme: N'dali

Commune	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
N'dali	Bush fire						Rainy season					
						Coton						
										Coton		
	Yam											
								Yam				
					Maize							
										Maize		
					Cassava							
											Cassava	
					Groundnut							
									Groundnut			
						Sorghum						
											Sorghum	
								Millet				
											Millet	
						Soya			Soya			
						Rice					Rice	
						Cowpea						
								Cowpea				
						Tomato						
										Tomato		
					Goussi							
									Goussi			

Annex 6 Crop rotation pattern in different villages of the Commune Abomey-calavi

Village / Arrondissment	Soil	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
		Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season
Yevie													
ZINVIE	black	[Maize	Maize+ Cassava	---->]	[Maize	Maize+ Cassava	---->]						
Dossounou	ferralitic, sandy	[Maize	Maize]	[Maize	Maize]	[Maize + Groundnut+ Cassava	Cassava-->]	Fallow 2-3 years					
HEVIE													
Kpanroun	ferralitic, sandy	[Maize]	[Maize]	[Maize]	[Maize]	[Maize]	[Maize]	[Maize + Cassava	---->]	Fallow 5 years			
KPANROUN													
Agongbe	ferralitic, sandy	[Maize]	[Maize]	[Maize]	[Maize+ Cassava	Cassava--> + Maize]	[Maize+ Cassava	Cassava--> + Maize]	[Maize+ Cassava	Cassava--> + Maize]	Fallow 5 years		
GLO-DJIGBE													

Means of the different symbols and colours:

- **Main module** (light blue)
- **End phase module** (grey)
- **Short season crops (culture derobee)** (pink)
- **Crypto-fallow** (yellow)
- **Fallow** (green)
- **Deplete module** (orange)

Annex 7 Crop rotation pattern in different villages of the Commune Pobe

Village / Arrondissment	Soil	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7		Year 8	
		Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season
Igana	sandy	[Maize	Cow pea, Groundnut]	continually repeat				[Maize	Cow pea, Groundnut]	Fallow for 4 years (+Oil palm)							
Igana																	
	loamy	[Maize	Maize]	continually repeat				[Maize	Maize]	After 10 years maize 5 years fallow							
Towe	sandy	[Maize	Cow pea, Groundnut, Goussi]	continually repeat						[Maize	Cow pea, Groundnut, Goussi]	Fallow					
Towe																	
	sandy loam	[Maize	Cow pea, Goussi, Groundnut, Gombo, Tomato, Pepper]	continually repeat				Pigeonpea		Pigeonpea		Pigeonpea		[Maize	Cow pea, Goussi, Groundnut, Gombo, Tomato, Pepper]	[Maize	Cow pea, Goussi, Groundnut, Gombo, Tomato, Pepper]
	ferrugineus	[Maize	Cow pea, Goussi]	continually repeat													
Okeita	ferrugineus	[Maize	Maize]	[Maize	Maize]	[Maize+ Cassava	--->	[Yam	---> +Groundnut, Maize	Oil palm + Cow pea---->Fallow for 5 years							
Ahouyeye																	
	ferrugineus	[Tomate, Pepper	Maize]	[Maize+ Cassava	--->	Maize	Cassava +Oil palm	--->	Fallow for 5-6 years								
	hydromorpheux	[Maize	Cow pea, Goussi, Groundnut, Gombo, Tomato, Pepper]	continually repeat													
Ibere	hydromorpheux	[Maize	Cow pea, Combo]	continually repeat													
Ahouyeye		Rice	-->														
Onigbolo		[Maize	Maize]	continually repeat				Maiz continually repeat + chemical fertilizer						6 years fallow			
Issaba		Cow pea	Maize														
	ferrugineus	Cassava	--->														
	hydromorpheux	[Maize	Cow pea, Combo]	continually repeat till 10 years. Than, 3-4 years fallow													

Annex 8 Crop rotation pattern in different villages of the Commune Bohicon

Village / Arrondissment	Soil	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6		Year 7	
		Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season
Madje		[Maize	Cow pea, Groundnut]	continually repeats till 10 years, then 6 years fallow (Teak,Orange)											
SODOHOME		Groundnut, Cow pea,	Groundnut, Cow pea,												
	laomy	Cotton	--->												
Avogbanna	ferralitic	Groundnut, Cow pea, Dohi	Groundnut, Cow pea, Dohi	[Maize	Groundnut, Cow pea]	[Maize	Groundnut, Cow pea]	[Maize	Groundnut, Cow pea]	[Maize	Cow pea, Groundnut]	Pigeonpea		Pigeonpea	
AVOGBANNA															
Masse-Gbame	ferralitic	Groundnut, Cow pea,	Groundnut, Cow pea,	[Maize	Groundnut, Cow pea]										
PASSAGON															
Flely	ferrugineus	Groundnut, Cow pea,	Groundnut, Cow pea,	[Maize	Cow pea]	[Maize	Cow pea]	[Maize	Cow pea]	Fallow of 4 years					
AGONGOINTO															

Annex 9 Crop rotation pattern in different villages of the Commune Save

Village / Arrodissment	Soil	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
		Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season	Big season	Small season
Okewo	sandy	[Yam]		[Mais	Cow pea + Groundnut, Goussi, Dohi, Vouanzou]	Mais	[Cassava	--->	--->	Groundnut	Groundnut]	Fallow for 4 years	
OKPARA				Groundnut	Cow pea + Cassava	--->	--->						
							Cashew						
	bar fon	[Rice	-->]										
Dani	sandy	[Cow pea, Groundnut, Vouanzou, Dohi	Maize]	Maize + Sorghum	---->	[Goussi	Maize + Groundnut]	Pigeonpea		Pigeonpea		Repeats modules for further 3 years, than fallow with cashew	
OFE				Maize + Cassava	---->	--->	Goussi, Cow pea, Groundnut, Vouanzou, Dohi	Pigeonpea		Pigeonpea			
		[Yam]								Fallow with cashew			
Igbodja	after old fallow	[Yam]		[Mais	Groundnut, Cow pea, Goussi]	continually repeat till 5 years						Fallow with Cashew	
BESSE		Cassava	---->	Groundnut, Cow pea, Goussi	Groundnut, Cow pea, Goussi								
		Groundnut, Cow pea, Goussi	Groundnut, Cow pea, Goussi										
	forest plateau	[Mais	Groundnut, Cow pea, Goussi]	continually repeat till 3 years				Pigeonpea		Pigeonpea		Repeats modules for further 3 years, than 10 years of fallow	
		[Yam] + Goussi	-->										
		Goussi	Groundnut, Tomato										
		Cassava	---->+ pepper										
	valley	[Mais	Mais]	continully repeat till 15 years									
		[Rice	-->]										

Annex 10 Crop rotation pattern in different villages of the Commune N'dali

Village / Arrodissment	Soil	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Mama Imorou		[Yam	Maize, or Maize + Soghum]	[Yam	Maize, Sorghum, Millet]	Groundnut, Soya	Cowpea, Soya	3 years fallow, or cashew, mango		
N'DALI										
	ferrugineus	[Yam, Cotton	Maize]	[Cotton	Maize, Sorghum, Millet]	Groundnut	Cowpea, Soya	Yam, Cotton	Maize, Cassava	Fallow, Cashew, Mango

Annex 11 Chemic and physical parameters of soil samples in Oueme Basin-1

Serial Nr.	LAT	LON	ELE m	Texture	0-2µ	2-20µ	20-50µ	50-200µ	200-2000µ	TC %	TN %	mval K/ 100g	mval Na/ 100g	mval Mg/100 g	mval Ca/ 100g	PH H2O	PH KCl	K_av mg/100 g	P_eff mg/100g
1	7.27	2.09	172.52	Sandy	4.53	5.03	2.17	66.97	24.78	0.29	0.03	0.03	0.01	0.30	0.73	6.14	5.18	6.46	0.15
2	7.25	2.07	217.32	Sandy	5.20	0.00	2.24	72.59	19.88	0.49	0.04	0.02	0.00	0.72	0.94	6.75	5.91	1.56	0.13
3	7.23	2.13	202.39	Sandy	5.49	0.00	2.01	70.83	21.59	0.48	0.04	0.02	0.00	0.45	1.04	6.46	5.56	1.26	0.12
4	7.17	2.07	136.25	Sandy loam	11.46	4.84	3.18	54.39	26.01	0.69	0.05	0.06	0.03	0.55	1.87	6.32	5.39	4.02	0.42
5	7.23		205.13	Sandy	1.58	3.68	2.52	66.41	25.72	0.48	0.04	0.05	0.02	0.42	0.83	6.62	5.62	4.44	0.20
6		2.14		Sandy	5.45	0.78	2.49	66.77	24.41	0.53	0.04	0.02	0.01	0.47	1.14	6.52	5.64	1.46	0.09
7	7.19	2.13	138.68	Sandy	5.12	7.93	5.90	44.62	36.19	0.80	0.05	0.03	0.02	0.97	2.70	6.45	5.61	1.60	0.87
8	7.17	2.07	111.25	Sandy loam	13.09	0.79	2.76	54.88	28.37	0.60	0.05	0.03	0.00	0.40	1.14	5.83	4.73	1.22	0.19
9	7.23	2.09	205.13	Sandy	6.98	1.29	1.99	68.35	21.30	0.43	0.03	0.02	0.00	0.30	0.73	5.99	4.90	1.34	0.13
10	7.24	2.17	194.77	Sandy	5.46	2.60	2.00	65.85	24.01	0.61	0.04	0.05	0.01	0.55	1.56	6.43	5.58	3.50	0.91
11	7.16	2.08	151.18	Sandy	4.92	1.81	0.99	74.52	17.71	0.51	0.04	0.04	0.00	0.67	1.66	6.70	5.91	2.64	0.25
12	7.27	2.39	219.46	Sandy	6.94	2.57	0.99	64.94	24.53	0.57	0.04	0.02	0.01	0.62	1.46	6.42	5.55	1.40	0.12
13				Loamy sand	8.96	0.79	5.57	47.77	36.68	0.69	0.05	0.10	0.17	1.79	3.33	6.65	5.42	5.48	1.74
14				Loamy sand	2.49	8.20	5.49	46.82	36.78	0.61	0.05	0.11	0.03	0.87	3.12	6.44	5.56	7.40	0.20
15				Loamy sand	8.37	0.79	6.03	53.09	31.47	0.91	0.07	0.10	0.27	1.47	3.85	6.81	5.38	6.56	0.16
16				Loamy sand	8.62	3.40	6.77	50.63	30.31	1.50	0.10	0.28	0.03	1.77	5.41	6.56	5.73	21.20	0.43
17				Loamy sand	4.62	5.13	4.19	46.55	39.33	1.02	0.07	0.12	0.02	0.87	3.95	6.54	5.82	11.12	0.20
18				Loamy sand	6.31	2.37	3.79	58.24	29.14	0.66	0.05	0.12	0.01	1.05	3.53	6.40	5.55	11.10	0.15
19				Sandy loam	11.12	5.95	5.22	40.13	37.36	0.86	0.06	0.11	0.02	1.27	4.78	6.49	5.43	9.50	0.15
20				Sandy loam	12.40	9.30	9.67	23.03	44.57	0.87	0.06	0.11	0.10	1.62	5.51	6.55	5.47	10.04	0.35
21				Sandy loam	13.82	8.19	9.83	28.83	39.49	0.93	0.06	0.12	0.21	1.50	6.45	6.70	5.53	9.56	0.47
22				Sandy loam	13.31	5.89	10.57	30.51	40.15	1.04	0.07	0.15	0.09	1.79	6.13	6.50	5.38	12.98	0.48
23	7.99	2.39	143.26	Sandy loam	9.86	3.29	7.04	47.90	31.31	1.83	0.11	0.39	0.04	1.40	9.88	7.63	7.02	28.68	6.05
24	7.94	2.40	117.04	Loamy sand	5.55	2.77	5.81	51.33	34.45	1.12	0.07	0.17	0.02	0.95	4.89	7.83	7.16	14.96	0.62
25				Loamy sand	9.05	1.76	7.96	41.99	39.38	1.11	0.07	0.19	0.02	1.12	6.65	7.95	7.22	16.86	1.26
26	7.99	2.39	131.06	Sandy loam	12.86	5.40	10.87	22.92	46.57	1.50	0.09	0.27	0.04	1.32	6.76	6.91	6.13	20.52	0.74
27	7.94	2.39	129.54	Loamy sand	3.54	6.32	5.83	47.64	36.19	0.78	0.06	0.14	0.03	1.10	3.53	7.22	6.28	13.70	0.35
28	7.94	2.62	112.17	Loamy sand	7.07	0.51	5.81	49.62	36.15	0.91	0.06	0.12	0.02	0.90	4.16	7.38	6.50	12.94	0.31
29	8.04	2.57	176.17	Sandy	5.04	0.51	4.13	69.57	19.55	1.05	0.08	0.15	0.02	0.67	3.12	6.96	6.28	14.26	0.45
30	7.94	2.40	167.03	Sandy	4.30	1.77	4.12	69.67	19.39	1.02	0.07	0.10	0.01	0.47	1.77	6.23	5.57	11.22	0.23
31				Sandy loam	9.36	1.01	9.23	32.35	46.90	0.95	0.07	0.11	0.02	1.00	4.05	6.71	5.91	9.38	0.15
32				Sandy loam	10.13	0.51	6.81	39.49	42.65	0.83	0.06	0.19	0.03	1.10	3.43	6.82	5.96	17.16	0.30
33	7.95	2.53	126.19	Loamy sand	6.35	0.51	4.63	60.24	27.72	1.15	0.07	0.07	0.02	0.72	2.70	6.16	5.24	8.04	0.12
34	7.99	2.39	182.27	Sandy loam	10.26	11.72	10.55	33.48	33.54	1.61	0.10	0.16	0.06	1.02	3.85	5.86	4.88	33.14	6.66
35	7.99	2.39	145.08	Sandy loam	14.35	5.13	8.61	39.36	32.20	2.04	0.12	0.45	0.04	1.37	11.02	7.56	6.77	13.40	0.52
36	7.98	2.39	144.78	Sandy loam	7.11	6.10	8.05	46.74	31.67	0.97	0.07	0.19	0.01	1.99	5.72	6.94	6.10	9.60	0.19
37	7.96	2.57	123.75	Sandy loam	9.12	4.82	9.24	24.79	51.64	0.92	0.08	0.20	0.03	1.12	3.85	6.93	5.97	10.78	0.19
38	7.94	2.46	171.60	Sandy	3.60	1.03	4.93	58.19	32.06	0.83	0.07	0.26	0.00	0.80	2.60	7.38	6.65	21.68	0.62
39	7.92	2.46	170.69	Loamy sand	5.04	4.03	5.08	50.28	35.35	0.75	0.03	0.19	0.02	0.65	2.81	7.04	6.31	16.06	0.37
40	7.92	2.57	171.60	Sandy	3.02	4.53	4.35	58.58	29.55	0.78	0.02	0.19	0.03	0.67	2.50	6.84	6.15	15.82	0.32
41	7.94	2.59	181.66	Sandy	4.04	3.79	3.39	65.81	23.90	0.71	0.02	0.13	0.01	0.75	2.60	6.73	6.09	11.28	0.33
42	8.16	2.66	231.65	Sandy loam	7.68	6.65	14.25	19.79	49.79	0.90	0.03	0.16	0.05	0.85	1.98	5.80	4.70	14.16	0.23
43	8.09	2.70	402.89	Sandy	5.27	2.01	2.65	76.39	12.75	0.91	0.02	0.15	0.01	0.85	3.22	6.87	6.07	12.50	0.23
44	8.04	2.59	169.77	Loamy sand	6.86	1.53	5.84	62.21	23.73	0.91	0.01	0.15	0.01	0.97	4.05	6.65	5.72	12.68	0.44
45	8.14	2.62	235.31	Loamy sand	6.84	0.51	3.41	59.69	28.59	1.22	0.01	0.13	0.02	1.27	4.78	6.85	6.18	10.86	0.36
46				Loamy sand	8.09	2.78	4.37	54.56	29.61	1.63	0.08	0.18	0.01	1.67	5.51	7.02	6.24	14.20	0.36
47				Sandy	3.03	8.83	3.87	68.37	16.57	1.46	0.09	0.32	0.02	1.40	8.11	7.79	7.18	22.68	0.71
48	8.05	2.59	172.82	Loamy sand	6.02	2.51	3.37	63.24	24.58	0.96	0.06	0.12	0.02	1.02	3.43	6.76	5.94	11.32	0.19
49	8.16	2.55	211.53	Sandy	5.05	0.51	2.42	76.95	14.26	1.22	0.08	0.13	0.32	0.77	5.61	6.92	6.20	11.42	0.23
50	8.03	2.39	207.26	Loamy sand	6.31	1.26	3.63	64.21	23.38	1.39	0.08	0.17	0.32	1.30	7.28	7.02	6.25	15.04	0.47
51	7.98	2.46	140.82	Loamy sand	7.78	4.27	6.27	47.20	32.85	0.77	0.05	0.10	0.31	0.72	3.53	6.86	5.88	11.28	0.13
52	7.92	2.46	172.52	Loamy sand	4.76	2.25	3.84	65.69	21.73	0.77	0.05	0.25	0.33	1.00	4.89	7.47	6.84	23.54	1.36
53	7.91	2.09	160.02	Loamy sand	8.15	0.51	5.38	53.10	30.98	0.98	0.06	0.17	0.33	0.82	4.68	6.38	5.30	14.58	0.35

Annex 12 Chemic and physical parameters of soil samples in Oueme Basin-2

Serial Nr.	LAT	LON	ELE m	Texture	0-2µ	2-20µ	20-50µ	50-200µ	200-2000µ	TC %	TN %	mval K/100g	mval Na/100g	mval Mg/100g	mval Ca/100g	PH H2O	PH KCl	K_av mg/100g	P_eff mg/100g
76	7.97	2.40	124.97	Loamy sand	6.14	4.09	7.12	32.87	49.49	0.68	0.05	0.10	0.35	1.25	4.68	6.56	5.34	5.38	0.16
77	7.99	2.67	141.43	Sandy loam	6.51	9.02	10.82	28.84	44.35	0.75	0.05	0.12	0.35	0.72	3.01	6.20	4.88	6.44	0.27
78	7.18	2.66	88.09	Loamy sand	6.25	1.82	4.00	62.81	24.95	1.26	0.09	0.10	0.33	1.42	4.26	7.21	6.57	6.40	0.75
79	7.17	2.67	86.56	Sandy loam	11.08	7.81	12.09	15.29	53.25	0.89	0.06	0.10	0.34	1.32	7.38	6.95	6.12	5.74	0.24
80	7.20	2.75	96.01	Sandy loam	18.38	12.84	9.91	18.85	39.60	1.99	0.14	0.20	0.34	3.02	15.49	7.25	6.72	11.58	0.36
81	9.80	2.65	381.00	Sandy loam	7.68	6.93	7.85	50.59	26.62	0.62	0.05	0.09	0.31	0.45	2.70	6.17	5.79	5.28	0.23
82	7.13	2.70	56.08	Clay	56.75	17.53	7.48	5.71	12.22	2.35	0.18	2.15	0.42	4.54	11.23	7.41	6.46	53.40	10.36
83	7.04	2.12	67.97	Sandy	5.99	0.00	1.00	33.49	59.47	0.94	0.08	0.17	0.39	0.87	3.33	6.18	5.17	10.00	0.64
84	6.99	2.17	55.17	Sandy – clay loam	23.57	10.76	8.12	15.02	41.86	1.51	0.12	0.11	0.37	4.01	21.42	6.52	5.55	5.92	0.24
85	6.98	2.71	68.58	clay loam	38.77	12.65	7.66	18.68	21.94	1.25	0.11	0.19	0.33	2.54	5.82	6.57	5.35	9.68	0.24
86	7.03	2.71	67.36	Sandy	5.11	0.00	1.26	31.40	61.52	0.70	0.06	0.09	0.32	0.97	3.95	6.17	5.26	4.26	0.39
87	7.17	2.67	97.84	Sandy	4.93	6.16	4.97	55.79	28.01	0.89	0.06	0.06	0.32	1.67	6.03	7.50	6.81	3.36	0.63
88	7.20	2.67	112.47	Sandy loam	18.89	7.91	12.01	14.33	45.96	1.96	0.13	0.17	0.34	3.14	10.81	7.01	6.25	9.74	0.17
89	9.65	2.13	385.88	Sandy loam	12.50	5.61	8.57	48.03	24.93	1.99	0.10	0.18	0.35	1.45	11.33	7.02	6.32	10.04	1.23
90	6.97	2.59	79.55	Clay	53.80	21.63	7.01	5.85	11.67	2.22	0.16	0.25	0.42	3.96	10.08	6.39	5.11	12.36	0.19
91	7.18	2.59	59.13	Clay	57.17	13.34	5.75	8.80	15.18	3.77	0.24	0.43	0.38	1.97	11.44	7.24	6.21	25.64	2.29
92	7.19	2.71	41.15	Clay	60.50	8.87	6.45	3.52	20.40	3.16	0.21	0.20	0.46	1.87	14.03	7.59	6.47	9.30	0.30
93	7.18	2.66	106.07	Sandy loam	8.91	0.76	5.62	47.85	36.63	0.96	0.07	0.07	0.33	1.07	4.89	7.01	6.15	4.40	0.21
94	7.17	2.67	109.42	Sandy loam	8.83	8.83	8.48	26.96	46.50	0.99	0.07	0.07	0.32	1.35	6.97	7.18	6.37	4.04	0.15
95	7.18	2.13	104.55	Loamy sand	5.31	2.78	4.61	67.28	19.82	0.87	0.06	0.06	0.31	0.82	4.78	7.02	6.30	3.92	0.24
96	6.97	2.64	86.56	Clay	48.17	18.57	11.37	7.89	13.66	2.49	0.18	0.26	0.45	3.84	8.73	6.35	5.24	13.16	0.33
97	9.58	2.64	356.31	Loamy sand	4.76	6.01	7.94	53.65	27.55	0.58	0.04	0.09	0.33	0.40	2.08	6.52	5.46	5.44	0.07
98	9.58	2.66	360.27	Loamy sand	4.87	4.10	7.39	60.28	22.66	0.55	0.04	0.12	0.34	0.40	1.98	6.59	5.59	6.28	0.08
99	9.88	2.75	363.63	Sandy loam	7.31	7.81	10.64	50.58	23.26	0.94	0.07	0.16	0.34	0.82	4.99	6.73	5.94	9.08	0.25
100	9.80	2.66	384.05	Sandy loam	11.36	6.17	10.90	41.51	29.61	0.92	0.06	0.19	0.34	0.65	5.93	6.70	6.08	11.32	0.17
101	9.88	2.70	369.11	Sandy loam	5.95	7.93	8.56	53.54	23.67	1.06	0.07	0.14	0.33	0.62	6.97	6.40	5.88	6.62	0.41
102	9.78	2.71	383.74	Sandy loam	8.85	2.60	10.99	47.92	29.21	0.76	0.06	0.17	0.31	0.60	4.89	6.15	5.35	9.06	0.13
103	9.79	2.71	394.41	Sandy loam	11.68	10.13	7.98	50.04	19.84	2.73	0.17	0.18	0.33	1.42	7.80	8.09	7.40	10.10	3.52
104				Sandy loam	14.44	11.91	9.24	37.18	26.78	2.16	0.13	0.32	0.33	1.37	15.07	7.11	6.37	19.64	0.75
105	7.17	2.71	107.29	Loamy sand	6.23	0.52	6.48	47.56	38.95	0.77	0.06	0.09	0.29	0.87	5.61	7.05	6.28	5.02	0.27
106	7.18	2.68	123.14	Loamy sand	6.93	0.51	5.42	45.25	41.67	0.77	0.06	0.06	0.29	0.95	4.26	6.85	6.06	3.58	0.25
107	6.97	2.67	103.63	Sandy loam	7.38	8.40	3.67	29.91	50.88	1.34	0.13	0.07	0.30	1.37	6.34	6.21	5.54	3.56	0.23
108	6.96	2.67	101.80	Loamy sand	11.44	3.12	1.75	29.31	54.30	0.85	0.09	0.07	0.30	0.87	3.85	6.01	5.23	2.90	0.19
109	6.96	2.75	114.30	Sandy loam	15.92	4.70	2.26	33.25	43.69	1.84	0.18	0.21	0.31	1.74	13.83	7.21	6.71	12.28	0.75
110	9.80	2.72	378.87	Sandy loam	10.17	7.88	10.98	44.50	25.85	0.57	0.04	0.13	0.27	0.45	4.26	6.52	5.73	8.22	0.08
111	9.80	2.70	391.36	Sandy loam	7.76	8.53	11.91	41.72	29.55	0.94	0.06	0.10	0.24	0.60	2.39	6.12	5.17	5.10	0.07
112	9.78	2.70	377.34	Sandy loam	12.32	7.96	10.59	40.23	28.45	0.90	0.06	0.30	0.29	1.10	5.20	6.86	5.83	17.72	0.10
113	9.78	2.71	380.70	Sandy loam	11.60	10.57	9.65	40.97	26.83	1.71	0.11	0.45	0.30	1.55	11.54	7.02	6.16	24.52	0.39
114	7.18	2.70	110.64	Loamy sand	6.28	7.49	4.18	41.76	40.12	0.71	0.05	0.06	0.30	0.87	4.99	6.93	6.18	2.90	0.15
115	7.04	2.67	61.87	Sandy	5.67	1.29	1.73	26.43	64.74	1.27	0.10	0.24	0.29	1.27	8.21	6.63	5.87	12.56	0.64
116	7.18	2.65	97.54	Loamy sand	7.34	5.32	6.08	52.94	28.02	1.35	0.10	0.11	0.30	1.77	7.28	7.02	6.33	5.88	0.48
117	7.04	2.73	73.76	Clay	54.55	22.30	3.87	6.40	12.73	2.04	0.17	0.20	0.39	3.24	10.40	5.91	4.57	9.32	1.22
118	7.04	2.67	74.68	Loamy	17.76	24.81	9.03	12.20	35.84	1.53	0.10	0.09	0.34	1.07	4.05	4.89	3.85	3.92	0.24
119	6.99	2.64	114.60	Loamy sand	8.05	6.03	2.90	33.42	49.59	0.58	0.05	0.05	0.28	0.27	0.52	5.18	4.04	1.88	0.10
120	6.98	2.64	137.16	Sandy loam	11.20	3.49	2.87	27.12	55.21	0.59	0.05	0.04	0.30	0.92	3.85	6.86	6.03	1.68	0.15
121	7.05	2.62	73.46	Clay	74.74	17.07	2.96	2.05	3.06	2.25	0.19	0.21	0.54	7.30	13.51	5.99	4.57	10.00	0.67
122	8.04	2.35	182.88	Loamy sand	7.73	3.86	5.44	17.76	64.99	0.63	0.06	0.07	0.31	0.90	7.07	7.47	6.63	2.88	0.31
123	9.76	2.71	304.19	Sandy loam	10.54	11.83	15.55	24.58	36.84	1.64	0.09	0.35	0.29	1.97	7.90	7.08	6.30	22.14	0.25
124	9.81	2.70	392.58	Sandy loam	8.10	8.60	10.45	42.95	29.45	1.38	0.08	0.24	0.27	1.15	6.55	6.81	6.03	13.92	0.19
125	9.75	2.71	382.83	Sandy loam	14.12	4.44	8.28	41.66	31.13	0.88	0.06	0.14	0.29	0.77	3.74	6.63	5.39	8.22	0.08

Annex 13 Data sets of vegetation, environmental and demographic parameters used in chapter spatial vegetation dynamics

Departement	Commune	Zone	AEZ	TC1 % t_t	Sum 4cations t_t	pH H2O t_t	P t_t	Vbc	Vec	BMc	SLc	Vbc_M	Vec_M	BMc_M	SLc_M	C-veg.04	C-veg.3-6	POPD04	LON	LAT	ELE	Rain_04	GDP/cap.	Rain04 _veg	Rain04 _eff
ATLANTIQUE	Abomey-Calavi	3	6	1.07	6.87	6.58	0.47	254	50625	23	3.43	132	26207	12	1.78	0.52	0.45	681	2.32	6.50	16	1197	919	1104	773
ATLANTIQUE	Allada	3	6	1.01	6.39	6.51	0.47	271	53612	21	3.53	155	30619	12	2.02	0.57	0.47	250	2.12	6.68	82	1248	943	1127	789
ATLANTIQUE	Kpomasse	3	6	1.20	8.09	6.85	0.55	44	15452	8	2.28	24	8361	4	1.24	0.54	0.39	198	2.01	6.46	31	1303	919	1213	849
ATLANTIQUE	Ouidah	3	7	0.96	5.89	6.41	0.44	319	60974	24	3.58	171	32714	13	1.92	0.54	0.43	232	2.13	6.38	10	1330	919	1222	855
ATLANTIQUE	So-Ava	3	6	1.07	6.62	6.43	0.39	229	40968	22	2.00	117	21005	11	1.03	0.51	0.47	388	2.44	6.48	1	1238	919	1135	794
ATLANTIQUE	Toffo	3	8	1.10	7.24	6.70	0.53	109	27679	10	2.91	67	16921	6	1.78	0.61	0.52	159	2.18	6.85	102	1227	919	1103	772
ATLANTIQUE	Tori-Bossito	3	6	1.12	7.09	6.54	0.42	428	78205	43	4.16	224	40888	22	2.18	0.52	0.41	141	2.15	6.54	48	1228	919	1131	792
ATLANTIQUE	Ze	3	6	0.99	6.20	6.49	0.47	266	52937	20	3.50	155	30961	11	2.05	0.58	0.50	118	2.33	6.76	50	1274	919	1148	804
BORGOU	Bembereke	1	3	1.35	6.85	7.09	1.07	76	38333	28	2.23	34	17039	13	0.99	0.44	0.46	31	2.75	10.27	342	1196	1221	1083	758
BORGOU	Kalale	1	3	1.33	6.81	7.07	1.05	73	37471	28	2.21	35	17896	13	1.06	0.48	0.51	31	3.38	10.37	337	1142	1221	1012	708
BORGOU	N'Dali	1	3	1.40	6.97	7.14	1.12	83	41145	31	2.31	40	19735	15	1.11	0.48	0.48	19	2.47	9.74	344	1221	1221	1126	788
BORGOU	Nikki	1	3	1.33	6.80	7.07	1.04	72	37055	27	2.20	34	17672	13	1.05	0.48	0.47	34	3.19	9.95	388	1207	1221	1115	781
BORGOU	Parakou	1	5	1.02	6.01	6.71	0.65	21	18655	11	1.69	10	9200	5	0.84	0.49	0.52	353	2.61	9.35	352	1232	1221	1117	782
BORGOU	Perere	1	3	1.39	6.95	7.13	1.11	82	40537	30	2.29	41	20134	15	1.14	0.50	0.50	23	2.99	9.59	397	1284	1221	1190	833
BORGOU	Sinende	1	3	1.37	6.90	7.11	1.09	79	39529	29	2.27	36	18026	13	1.03	0.46	0.46	30	2.35	10.27	348	1220	1221	1125	788
BORGOU	Tchaourou	1	5	1.40	7.02	7.15	1.13	101	46186	34	2.52	52	23463	17	1.28	0.51	0.50	17	2.50	9.17	320	1210	1221	1100	770
COLLINES	Bante	1	5	1.40	7.00	7.15	1.13	92	43425	32	2.41	50	23927	18	1.33	0.55	0.51	34	1.87	8.34	240	1345	920	1215	850
COLLINES	Dassa-Zoume	2	5	0.94	5.38	6.78	0.60	128	40832	30	3.18	74	23632	17	1.84	0.58	0.48	54	2.25	7.69	129	1215	920	1123	786
COLLINES	Glazoue	1	5	1.30	6.73	7.03	1.00	69	35888	26	2.18	39	20124	15	1.22	0.56	0.48	56	2.23	8.18	178	1243	920	1112	778
COLLINES	Ouesse	1	5	1.33	7.02	7.09	1.03	172	64644	43	3.41	95	35674	24	1.88	0.55	0.51	37	2.48	8.53	239	1219	920	1078	754
COLLINES	Savalou	2	5	0.94	5.39	6.78	0.60	129	41308	30	3.20	71	22886	17	1.77	0.55	0.52	45	1.85	7.89	180	1334	920	1255	879
COLLINES	Save	2	5	0.94	5.47	6.78	0.57	150	48089	35	3.47	87	27921	20	2.01	0.58	0.54	32	2.56	8.00	169	1186	920	1070	749
KOUFFO	Aplahoue	3	5	0.91	5.59	6.41	0.47	253	51162	14	3.44	154	31278	9	2.10	0.61	0.54	130	1.69	7.18	147	1285	494	1138	796
KOUFFO	Djakotomey	3	6	1.06	6.90	6.65	0.52	125	30405	9	2.97	76	18419	5	1.80	0.61	0.53	433	1.70	6.87	99	1200	494	1057	740
KOUFFO	Dogbo-Tota	3	6	0.93	5.77	6.43	0.47	257	51698	16	3.46	151	30374	9	2.03	0.59	0.48	255	1.76	6.78	53	1190	494	1080	756
KOUFFO	Klouekanme	3	6	0.92	5.72	6.43	0.47	240	49081	14	3.39	146	29919	8	2.07	0.61	0.53	255	1.84	7.04	130	1248	494	1120	784
KOUFFO	Lalo	3	8	0.91	5.60	6.41	0.47	256	51637	14	3.45	156	31595	9	2.11	0.61	0.53	202	1.97	6.87	45	1203	494	1082	757
KOUFFO	Toviklin	3	6	1.00	6.39	6.56	0.50	174	38340	11	3.15	106	23372	7	1.92	0.61	0.53	527	1.82	6.90	122	1224	494	1088	762
DONGA	Bassila	1	5	1.43	7.07	7.18	1.16	96	45066	34	2.45	51	23668	18	1.29	0.53	0.51	14	1.86	8.97	327	1129	823	1028	720
DONGA	Kopargo	1	4	1.35	6.84	7.09	1.06	75	38138	28	2.23	36	18499	14	1.08	0.49	0.53	62	1.55	9.88	423	1232	823	1141	798
DONGA	Djougou	1	4	1.40	6.97	7.15	1.13	84	41197	31	2.31	41	20200	15	1.13	0.49	0.54	49	1.85	9.68	381	1171	823	1076	753
DONGA	Ouake	1	4	1.28	6.66	7.01	0.97	64	33976	24	2.12	31	16706	12	1.04	0.49	0.48	75	1.44	9.60	410	1167	823	1078	755
LITTORAL	Cotonou	3	7	0.84	4.98	6.30	0.45	16	3041	1	0.18	8	1583	0	0.10	0.52	0.46	8489	2.42	6.37	4	1234	2962	1112	779
MONO	Athieme	3	7	0.96	5.95	6.45	0.46	277	54826	19	3.54	147	29040	10	1.88	0.53	0.44	151	1.70	6.57	14	1084	501	985	690
MONO	Bopa	3	7	0.89	5.45	6.37	0.46	277	54626	16	3.44	144	28311	8	1.78	0.52	0.44	200	1.93	6.67	28	1184	501	1086	760
MONO	Come	3	7	0.96	5.91	6.43	0.45	285	54995	21	3.32	150	28929	11	1.75	0.53	0.39	371	1.90	6.43	11	1385	501	1260	882
MONO	Grand-Popo	3	7	0.91	5.50	6.33	0.42	377	70397	27	3.82	178	33138	13	1.80	0.47	0.51	154	1.84	6.33	3	1378	501	1250	875
MONO	Houeyogbe	3	6	0.98	6.23	6.52	0.49	204	43236	13	3.26	108	22743	7	1.72	0.53	0.39	271	1.85	6.55	47	1195	501	1106	774
MONO	Lokossa	3	7	0.93	5.71	6.41	0.46	277	54519	18	3.43	146	28753	10	1.81	0.53	0.46	324	1.76	6.68	34	1128	501	1039	727
OUEME	Adjara	3	8	1.09	6.78	6.46	0.39	498	89304	48	4.43	314	56274	30	2.79	0.63	0.54	842	2.68	6.49	12	1387	943	1250	875
OUEME	Adjohoun	3	7	1.20	7.76	6.64	0.43	403	73975	45	4.08	253	46389	28	2.56	0.63	0.52	207	2.50	6.71	45	1336	943	1204	843
OUEME	Aguegue	3	7	1.03	6.37	6.45	0.42	322	59519	28	3.23	192	35467	17	1.92	0.60	0.50	270	2.53	6.48	1	1316	943	1196	837
OUEME	Akpro-Misserete	3	6	1.23	8.08	6.73	0.47	297	57003	35	3.67	191	36700	23	2.36	0.64	0.53	997	2.58	6.58	36	1425	943	1279	895
OUEME	Avrankou	3	6	1.14	7.20	6.55	0.41	446	80894	46	4.23	281	50974	29	2.67	0.63	0.53	948	2.65	6.57	30	1417	943	1274	892
OUEME	Bonou	3	7	1.09	6.81	6.49	0.41	438	79880	42	4.20	278	50773	27	2.67	0.64	0.56	126	2.48	6.87	57	1304	943	1173	821
OUEME	Dangbo	3	7	1.23	8.08	6.72	0.46	328	61891	39	3.79	177	33348	21	2.04	0.54	0.55	448	2.49	6.58	9	1356	943	1223	856
OUEME	Porto-Novo	3	6	1.11	6.86	6.43	0.36	563	98981	56	4.54	347	61016	35	2.80	0.62	0.53	4717	2.61	6.49	14	1364	943	1228	860
OUEME	Seme-Kpodji	3	7	0.98	5.97	6.38	0.41	407	74822	34	3.93	251	46123	21	2.42	0.62	0.51	577	2.61	6.40	4	1321	943	1170	819
PLATEAU	Adja-Ouere	3	8	1.21	8.09	6.82	0.53	110	27489	15	2.94	71	17761	10	1.90	0.65	0.55	208	2.60	7.00	87	1258	1338	1126	788
PLATEAU	Ifangni	3	6	1.25	8.07	6.68	0.42	422	76790	49	4.16	267	48622	31	2.64	0.63	0.42	313	2.72	6.66	50	1388	1338	1251	875
PLATEAU	Ketou	2	5	0.98	5.73	6.78	0.60	137	47631	32	3.62	78	27143	18	2.06	0.57	0.47	62	2.60	7.44	140	1044	1338	877	614
PLATEAU	Pobe	3	8	1.25	8.07	6.66	0.41	454	81800	52	4.29	279	50201	32	2.63	0.61	0.53	226	2.68	7.09	65	1156	1338	1023	716
PLATEAU	Sakete	3	6	1.22	8.09	6.79	0.51	175	37678	22	3.19	110	23811	14	2.02	0.63	0.55	167	2.65	6.78	86	1314	1338	1184	829
ZOU	Abomey	2	6	0.97	5.52	6.77	0.67	86	30914	21	2.96	46	16657	12	1.59	0.54	0.54	568	1.98	7.19	190	1232	522	1119	783
ZOU	Agbangnizoun	3	6	0.92	5.70	6.43	0.47	242	49414	14	3.40	135	27527	8	1.89	0.56	0.52	229	1.96	7.10	125	1245	522	1133	793
ZOU	Bohicon	2	6	0.97	5.52	6.77	0.67	86	30755	21	2.95	52	18706	13	1.80	0.61	0.53	889	2.10	7.19	137	1250	522	1119	783
ZOU	Cove	2	6	0.96	5.46	6.77	0.64	102	34743	25	3.04	60	20381	14	1.79	0.59	0.46	83	2.29	7.34	98	1164	522	1005	704
ZOU	Djidja	2	5	0.94	5.39	6.78	0.61	125	40174	29	3.17	70	22680	17	1.79	0.56	0.53	42	1.93	7.44	144	1274	522	1151	805
ZOU	Ouinhi	3	7	0.97	6.05	6.45	0.46	296	57827	22	3.62	183	35647	13	2.23	0.62	0.55	118	2.48	7.07	25	1215	522	1082	758
ZOU	Zangnanado	2	6	0.98	5.68	6.78	0.62	126	44011	30	3.47	73	25448	17	2.01	0.58	0.55	70	2.39	7.27	65	1211	522	1025	718
ZOU	Za-Kpota	2	6	0.95	5.45	6.78	0.62	119	39263	28	3.18	69	22948	16	1.86	0.58	0.53	223	2.20	7.23	94	1151	522	1065	745
ZOU	Zogbodome	3	8	0.89	5.36	6.36	0.45	304	59334	18	3.63	178	34842	11	2.13	0.59	0.52	91	2.18	7.02	44	1235	522	1114	780

- Column 5-8 were soil parameter: total carbon percent, sum of 4 cations (Ca, Mg, K, Na), PH and phosphor.
- Column 13-16 were vegetation parameters multiplied by C-veg.04 (=Vegetative duration coefficient of year 2004), respectively.
- POPD04 was population density of communes in year 2004.

CURRICULUM VITAE

Name: Zhixin Deng

Date of birth: 16.02.1970

Nationality: Chinese

Civil status: single

Email: deng_zhi_xin@yahoo.com.cn

Education

09.1988-06.1992	Bachelor study in the Department of Plant Protection in Southern China University of Tropical Agriculture
04.1993-10.1993	MBA correspondence courses of China University of Science and Technology
04.1998-09.2001	Scholar of the DAAD (German Academic Exchange Service), Master study in the Institute of Tropical Technology of University of Applied Sciences Cologne, Germany: Master of Engineering in the field of Project Management (including Geography and Area Planning in the Tropics, Economic and Social Systems, Instruments of Planning and Deciding, Economy and Marketing, Development and Technology Transfer and Languages) and a selective field in Principles of Agricultural Production and Food Technology; Study language: German
2001.09 – 2002.09	Student in the Department of Economic Computer Science of University of Applied Sciences Cologne, Germany. Reading literatures about New Institutional Economics (Steven N.S. Cheung, Ronald Coase, Armen Alchian, Harold Demselz, Douglas North, Joseph E. Stiglitz, Xiaokai Yang, Yifu Lin, Qiren Zou)
09.2002-08.2003	Master study in University Bonn, Germany: ARTS (Agriculture Sciences and Resource Management in the Tropics and Subtropics), Master of Science; Study language: English
09.2003-07.2007	Ph.D. in the Institute of Crop Science and Resource Conservation of University Bonn, Germany

Professional experiences

03.1992-03.1994	Staff in the Hainan Food Industry development Company of the Hainan Provincial Development and Construction Inc. (the biggest state owned company in Hainnan Province), China
04.1994-09.1994	Project leader of the First Experimental Botanical Garden in the Hainan Company of the Washington Investment Group of USA, in charge of the designing, building up and managing the whole garden, China
06.1995-08.1995	Consultant in the Hainan Company of the Washington Investment Group of USA and responsible for planning and technicians training of the 1000 ha Mango Plantation Project in Hainan, China
09.1994-04.1998	Researcher of Mango Research Institute of Hainan Hengtai Mango Industry Corporation (the first private agricultural joint-stock company coming into the Shanghai Stock Market); Vice director of the Experimental Plantation; Vice director of Dongfan County's Comprehensive Technological Renovation Plantation; Manager of the Technical Service Department (independent contractor with responsibility); Participated in planning and implementing the Mango and Passion Fruit Comprehensive Project, China
10.2000-02.2001	Practice in the GTZ Project "Rehabilitation and Protection of Forests in Hainan, southern Yunnan; and Sichuan", China
11.2001-09.2003	Scientific assistant in the Institute for Fruit and Vegetable Cultivation of the University Bonn, Germany
09.2003-06.2007	Scientific staff in the Institute of Crop Science and Resource Conservation of the University Bonn. Research Fellow in the Social Economic Group of the IMPETUS-Project (an integrated approach to the efficient management of scarce water resources in West Africa), Benin and Germany

Membership

Since Sep. 2006	Chairman of Rhine Academic Forum (NGO), Germany
Since Oct.2006	Member of Chinese Association of Environment and Energy, Germany