Journal of Hydrology 375 (2009) 114–127

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Sahelian rangeland response to changes in rainfall over two decades in the Gourma region, Mali

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ARTICLE INFO

Keywords:
Sahel
Mali
Gourma
Vegetation dynamics
Patchiness
Yield variability

SUMMARY

Twenty-five rangeland sites were monitored over two decades (1984–2006) first to assess the impact of the 1983–1984 droughts on fodder resources, then to better understand ecosystem functioning and dynamics. Sites are sampled along the south–north bioclimatic gradient in Gourma (Mali), within three main edaphic situations: sandy, loamy-clay and shallow soils. In addition, three levels of grazing pressure where systematically sampled within sandy soils. Located at the northern edge of the area reached by the West African monsoon, the Gourma gradient has recorded extremes in inter-annual variations of rainfall and resulting variations in vegetation growth. Following rainfall variability, inter-annual variability of herbaceous yield increases as climate gets dryer with latitudes at least on the sandy soils sites. Local redistribution of rainfall explains the high patchiness of herbaceous vegetation, especially on shallow soils. Yet spatial heterogeneity of the vegetation does not buffer between year yield variability that increases with spatial heterogeneity. At short term, livestock grazing during the wet season affects plant growth and thus yield in direction and proportions that vary with the timing and intensity of grazing. In the longer term, grazing also impinges upon species composition in many ways. Hence, long histories of heavy grazing promote either long cycle annuals refused by livestock or else short cycle good quality feed species. Primary production is maintained or even increased in the case of refusal such as *Sida cordifolia*, and is lessened in the case of short cycle species such as *Zornia glochidiata*. These behaviours explain that the yield anomalies calculated for the rangelands on sandy soils relative to the yield of site less grazed under similar climate tend to be negative in northern Sahel where the scenario of short cycle species dominates, while yield anomalies are close to nil in centre Sahel and slightly positive in South Sahel where the refusal scenario is more frequent. Because grazing promotes short cycle species, grazed rangelands respond faster to droughts. Year to year changes in species composition are abrupt as expected from the transient soil seed stock. However, some decadal trends in species composition are identified, with a wave of pioneer species following the 1983–1984 droughts, and a more progressive diversification and return to typical Sahel flora from 1992 onwards.

Introduction

Major droughts occurred through out the Sahel in 1972–1973 and again in 1983–1984. They followed a relatively wet period of 20 years 1948–1968 (Nicholson, 2001) and were included within a 25 years dry period 1968–1993. Since 1994 rainfall vary around the overall average. Both droughts had severe impact on the vegetation, crops, livestock and the population of the Sahel. The disturbances on vegetation and soils by the first drought were studied and monitored over a few sites in the Gourma by Boudet (1972, 1977, 1979) and Leprun (1992). First reports (e.g. Boudet, 1972) were alarming and warning on the risks of rapid desertification. The following reports (Boudet, 1977, 1979, 1984; Coulibaly, 1979) were less pessimistic, herbaceous layer had rapidly recovered, at least on sandy soils, and some of the decimated woody plant populations had started to regenerate soon after the drought. However, the desertification trend was confirmed, and responsibility for a larger fraction of vegetation and land degradation attributed to natural resource management, especially to pastoralist through grazing livestock at rates believed unsustainable (Gallais,

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✠ Deceased 10/02/2007.

0022-1694/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.jhydrol.2008.11.005

1975). Then occurred the second drought that peaked in 1984 with repeated crop failure for two or three years in a row, spectacular losses in vegetation cover that triggered wind and run-off soil erosion and massive losses in livestock, famine, impoverishment and emigration of the population (Hiernaux, 1996). In the framework of the impact assessment of that drought, 25 rangeland sites were sampled and described (Hiernaux et al., 1984). Some of the sites were selected at the locations where Boudet and his colleagues had made their observations in order to capitalise on the dynamics already described. Other sites were added to sample the North–South bioclimatic gradient, the three main soil types and the range of grazing intensity. The monitoring of these 25 sites was carried out over ten years (1984–1993) and progressively intensified in 2000 onwards under the AMMA project (Redelsperger et al., 2006; Mougin et al., 2009).

Located at the northern edge of the area reached by the West African monsoon, Gourma has recorded extremes in inter-annual variation of rainfall and resulting variations in vegetation growth (de Leeuw et al., 1992). This paper aims at presenting, first, the methods used to monitor range vegetation, climate and environment, second, the resulting data base, and third, the analyses of the herbage yield dynamics over years. Yield trends are discussed and related to rainfall, grazing status and species composition. The interpretation of yield trends also rely on previous surveys on soil seed stocks and germinations (Hiernaux and Diarra, 1993), root masses and grass tillering (Hiernaux et al., 1994), and on the results of controlled burning and grazing experiments conducted at the same sites (Hiernaux and Turner, 1996).

The first hypothesis tested in these analyses, is that Sahel vegetation, dominated by annual herbaceous, would linearly respond to rainfall (Le Houérou et al., 1988; Prince, 1991; Olsson et al., 2005). And because variation in rainfall are larger, at least in relative term, toward the north of the gradient, variation in vegetation production would also be greater toward the drier end of the bioclimatic transect (Le Houérou et al., 1988). Moreover, the impact of rainfall being mediated by the redistribution of rain water at the soil surface, a corollary is that vegetation on shallow soil or poorly permeable soil should vary more than in deep permeable soils. A complementary hypothesis is that the herbaceous layer would suffer more and recover less from drought when subjected to heavy grazing by livestock (Boudet, 1972; Breman and de Wit, 1983; Bille, 1992; Hein and de Ridder, 2006). Because the herbaceous layer is dominated by annuals, it is also hypothesised that the duration of the wet and dry periods that succeeded in the second half of the 20th century are long enough to trigger a shift in species composition toward species more adapted to dryer climate, including some perennial grasses (Breman and Cissé, 1977; Hiernaux and Le Houérou, 2006).

Material and methods

Monitoring sites are sampled along the South–North bioclimatic gradient in four groups (Fig. 1, Table 1). In each or these four sets of sites, three main edaphic situations were sampled: deep sandy soils, deep loamy-clay soils, shallow soils on rock or hard pans. On the sandy soils that extend over about half the landscape (Kammerud, 1996), three levels of grazing pressure where systematically sampled: low, medium and high, in relation to the proximity, size and seasonal duration of neighbouring water points and associated villages and encampments.

Climate

Unfortunately, the web of rain gauges and meteorological stations managed by the National Meteorological Service (DNM) is quite lax over Gourma. A few manual rain gauges were set by research or development projects following 1984, but it is only since AMMA research project developed, starting in 2000, that automatic meteorological stations were set in a few field sites (Fig. 1) and the web of manual gauges densified especially within the targeted 2500 km^2 'AMMA super-site' area close to Hombori (Frappart et al., 2009).

Soils

The elevation profile is recorded along site transects, together with the line intersection of the soil surface features visually identified following Casenave and Valentin (1989). Soil profiles have been described systematically in each vegetation facies with texture and chemical analysis (organic C, total N and total P concentrations) of soil samples at depth of 0–6, 6–12, 12–25, 25–50, 50–100 and 100–150 cm (Hiernaux et al., 1984).

Herbaceous vegetation

Plant species are named according to the Flora of West Tropical African second edition (Hutchinson and Dalziel, 1954–1972). In Sahel, vegetation is composed of an herbaceous layer dominated by annual plants, and a scattered population of shrubs and low trees (Hiernaux and Le Houérou, 2006). At landscape scale, vegetation is organised in large units following main topography, soil types and land uses (Breman and de Ridder, 1991). Locally, woody and herbaceous plant density and species composition are organised in facieses following finer topography and soils nuances or differences in land use practices and histories. The pattern of these facieses is often repetitive such as in the succession of dunes and interdunes in ergs, or thicket and impluvium in 'tiger bush', or else crop-fallow fields in croplands. In order to reduce both the variance associated to field sampling and field labour, the herbaceous layer is monitored using a two-level stratified random sampling design. Facieses are the first level of stratification and are sampled separately. When there are at least two facieses, the site is considered a mosaic of facieses described by the relative area and the distribution pattern of the component facieses (Fig. 2). Within each facies the herbaceous layer is variable enough at the scale of measure plots (1 × 1 m) to maintain the standard deviation of the mean attributes high when the number of samples is increased, even to large numbers (Grouzis, 1988). This local heterogeneity justifies the second level of stratification systematically applied. All facieses are stratified into four strata based on the apparent bulk of the herbaceous layer: either nil in bare soil patches, low, medium or high in vegetated patches. The three vegetated strata are empirically defined relative to the status of the herbaceous layer within facies at the date of observation starting by identifying what could be considered a 'modal state' based on the apparent bulk of the herbaceous layer, from which 'low' ('high') states are derived when bulk is 'obviously' (at least by 25%) inferior (superior) to the mode. The three vegetated strata are sampled separately. The facies is described by the frequency of the component strata, and by the weighted mean of the strata mean attributes such as plant cover, mass, species composition. In turn the site is described by the frequency of the component facieses, and the weighed mean of the facieses mean attributes. To match with the spatial scale of facies distribution, the stratification in facieses and strata in the Gourma sites is performed along one (or two) 1000 m long transect, with readings every meter within the 1 m wide band (Fig. 2). Total and green vegetation cover (visual estimates in %), standing and litter mass (destructive measure, with harvest, air drying and weighing) and species composition (list with visual estimates of contribution to bulk) are assessed in 1 × 1 m plots randomly