Impact of land clearance on the thorn scrub water balance (North Senegal)

J.NIZINSKI, D.MORAND, C.FOURNIER

Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM), Paris, France

Abstract The actual evapotranspiration (E_a) was followed from 1989 to 1992 in a thorn scrub stand in the northern Ferlo region (North Senegal, West Africa) for an *Acacia tortilis* grove, a *Balanites aegyptiaca* grove (every grove possessed its characteristic herbaceous layer) and a herbaceous zone outside the tree crown shade (annuals). E_a was derived from the water balance equation method (neutron probe measurements). The mean seasonal E_a of the thorn scrub was 1.92 mm.d^{-1} during the rainy season (period 1), 1.62 mm.d^{-1} during the "deferred" season (period 2), 0.62 mm.d^{-1} during the cool dry season (period 3) and 0.09 mm.d^{-1} during the hot dry season (period 4). The daily maximal E_a of the groves was higher than that of the herbaceous zone and the *A. tortilis* grove's maximal daily E_a was higher than that of the *B. aegyptiaca* grove: 5.04-4.15 and 3.98 mm.d^{-1} (period 1), 4.28-3.76 and 2.89 mm.d^{-1} (period 2), 1.73-1.79 and 1.34 mm.d^{-1} (period 3), 0.93-0.46 and 0.36 mm.d^{-1} (period 4) for the *A. tortilis* and *B. aegyptiaca* groves and the herbaceous zone respectively. For soil depth to 3.5 m taken into account in the water balance equation, by the end of the growing year, soil moisture differed by 20.8 mm between tree and grassland zones in favour of grassland. Knowing the rain-use efficiency of woody production in the sahelian ecoclimatic zone, 0.3 m3.ha-1.y-1.mm-1 or 0.66 to 1 kg DM ha-1.y-1.mm-1, this thorn scrub ought to have produced 6.25 m3.ha-1.y-1 more wood or 14 to 21 kg DM ha-1.y-1.mm-1, as well as 7.4 % of the mean annual primary production (186 to 282 kg DM ha-1.y-1.mm-1 with Pi=282.4 mm, annual mean). In the energy budget of the thorn scrub, the E_a increase promotes a decrease in sensible heat flux and according to General Circulation Models, the increase of the E_a of 20.8 mm per year in this Sahel-Sahelian subzone would result in a mean annual air temperature decrease of 1.5 °C and a rainfall increase of 0.5 mm.d-1 or 0.9 mm.d-1.

INTRODUCTION

The sahelian thorn scrub is composed of a continuous graminoid layer and a discontinuous shrub-tree layer (30 to 80 % tree canopy cover according to Cole (1986)). Evapotranspiration studies of sparse plant canopy cover ought to take into account 1) the spatial structure of plant community units *i.e.* groves, herbaceous zones and bare soil areas; and 2) the relative contributions of these units, which vary throughout the day and season, to produce the total E_a (Massman, 1992). The total E_a should be carefully considered in view the complexity of this ecosystem (Sivakumar and Wallace, 1991) which comprises sand dune formation with four main topographic units: top of the dune, slope, low slope, hollow, and for each topographic unit, a sparse vegetation.

This paper deals with 1) E_a of the thorn scrub stand in the northern Ferlo region (North Senegal, West Africa) (E_a was derived from the water balance equation method (neutron probe measurements)). We chose a slope zone representative of a large part of the thorn scrub surface (according to Cornet (1981), 40 % of the total area), this slope zone contains purely herbaceous surfaces, herbaceous surfaces having isolated shrubs or trees, and shrub and tree groves surfaces); and 2) impact of land clearance on this thorn scrub water balance.

SITE DESCRIPTION AND MEASUREMENTS

Study site

The study area is a Sahelian zone in the northern Ferlo region (North Senegal, West Africa). The climate of the region is dry tropical with mean annual precipitation (1918-1990, Dagana) of 282.4 $mm.y^{-1}$. The rainy season which lasts about 80 days, starts in July and ends in September; the mean annual temperature is 28.7 °C, the potential evapotranspiration is 2031 $mm.y^{-1}$ (Anon., 1988). According to Le Houérou (1989) the Ferlo belongs to the ecoclimatic Sahel-Sahelian subzone *sensu stricto*: this *Mimosaceae* thorn scrub has three main vegetation layers: a herbaceous layer (mainly composed of annual grasses) dominated by shrub and small trees layers (Poupon, 1980). The landscape is typically a gently undulating surface composed of low magnitude non-oriented dunes that end in small hollows. Field work was carried out on a 1 ha plot situated on a dune's rise (including the dune's crest and hollow with 1.6 % slope). The plot was located near Souilène, about 400 km from Dakar and 20 km from Dagana (16°20'39"N, 15°25'40"W). The overstorey canopy is mainly 20-year-old *Acacia tortilis* (Forsk) Hayne ssp. *raddiana* (Savi) Brenan and 25-year-old *Balanites aegyptiaca* (L) Del; stand density is 151 trees.ha-1 and the total basal area is 3.87 $m^2.ha^{-1}$. On the 1 ha plot we selected a grove with *A. tortilis*, a grove with *B. aegyptiaca* and a herbaceous zone outside the tree crown shade (without trees). Mean height of *A. tortilis* and *B. aegyptiaca* trees was 6.6 m and 6.4 m respectively, and mean stem diameter at soil level was 0.56 m and 0.61 m. The age of selected trees, (20 (Mariaux, 1975) and 25 years (Poupon, 1980) respectively) correspond to the most important populations in the pyramid-shaped diagrams representing the populations of *A. tortilis* and *B. aegyptiaca* by age-groups. Every grove possessed its characteristic herbaceous layers (annuals). The plot's soils belong to the brown subarid sandy soils (French taxonomy) which are slightly acid (pH 6-6.5), poor in clay, organic matter, nitrogen and phosphorus. The study zone is a rangeland with average annual primary production of the herbaceous layer (2895 kg DM $ha^{-1}.y^{-1}$) being 10 % lower than the actual demand of the grazing livestock (livestock of Dagana Department is 35791 TLU, Tropical Livestock Unit)(Akpo, 1992). The continuous livestock presence destroys the crust at the soil surface and promotes infiltration of rainfall. The study plot was fenced off in May 1989 (livestock exclusion); towards the end of the rainy season a crust formed on the soil's surface under rain drop impact (Lamarchère, 1991). In this case there was little opportunity to recover the germination of annuals the following year (Cornet, 1981); so, the study plot was weeded before the rainy seasons of 1990 and 1991.

Material and methods

Water balance equation method

The water balance of an element of the soil (direct or surface run off and water table can be neglected in the present context) can be expressed as:

$$P_i = E_a + D + \Delta S/t \quad (mm.d^{-1}) \qquad (1)$$

$$\text{where } E_a = E_t + I_n + E_s \quad (mm.d^{-1}) \qquad (2)$$

$$\text{and } I_n = P_i - (P_n + P_s) \quad (mm.d^{-1}) \qquad (3)$$

where P_i=rainfall ($mm.d^{-1}$); E_a=actual evapotranspiration ($mm.d^{-1}$); D=drainage ($mm.d^{-1}$); ΔS=change in soil water content (mm); t=time resolution (day=24 hours); E_t=transpiration ($mm.d^{-1}$); I_n=net interception ($mm.d^{-1}$); E_s=evaporation from soil ($mm.d^{-1}$); P_n=throughfall ($mm.d^{-1}$); P_s=stemflow ($mm.d^{-1}$). The soil-water content, rainfall, throughfall and stemflow were measured; drainage and actual evapotranspiration were derived: when the actual soil-water content exceeds its field capacity (S_{FC}), drainage occurs and the E_a equals the E_p; when the soil-water content is lower than S_{FC} it is assumed that no drainage occurs; thus, drainage and S_{FC} can be quantitatively expressed as follows:

$$\text{if } S >= S_{FC} \text{ then } E_a=E_p$$

$$\text{and } D=P_i-E_p-\Delta S/t \quad (mm.d^{-1}) \qquad (4)$$

$$\text{if } S < S_{FC} \text{ then } D=0$$

$$\text{and } E_a=P_i-\Delta S/t \quad (mm.d^{-1}) \qquad (5)$$

The assumption that no drainage occurs when the soil-water content is lower than field capacity ($S<S_{FC}$) is valid for sandy soils; the sandy texture promotes a rapid decline of the

hydraulic conductivity with decreasing soil-water content (Marshall and Holmes, 1988). A soil depth of 4.75 m was taken into account in the water balance equation.

***In situ* water balance measurements**

Soil-water content (S). The neutron probe("Solo") was made at the Centre d'Etudes Nucléaires in Cadarache. The neutron probe calibration was established using the gravimetric technique. The sampling system (Fig.1) comprised 15 permanent access tubes: 3 access tubes in the *A. tortilis* grove (tubes 1, 2 and 3), 3 access tubes in the *B. aegyptiaca* (tubes 4, 5 and 6), 5 access tubes in the herbaceous zone outwith the tree crown shade (tubes 7, 8, 9, 12 and 13) and 4 access tubes in edge zones (tubes 10, 11, 14 and 15); all 15 permanent access tubes were situated at similar contour lines. Measurements were made in each tube every 0.1 m from the soil surface until a depth of 1 m was reached then every 0.2 m until 2 m and subsequently every 0.5 m until 5 m depth was achieved. The soil-water sum (expressed in mm) summed for each layer of the tube amounts to the tube (profile) soil-water content. The field capacity (S_{FC}, matric potential equal to -0.01 MPa) and permanent wilting point (SWP, matric potential equal to -1.6 MPa) were measured *in situ*. 6 access tubes were combined with 19 psychrometer thermocouples (ceramic chambers set up every 0.1 m from the soil surface to 1 m depth, then every 0.5 m until 4 m depth) in an area 1 m in diameter which was delimited by a metal infiltrometer ring (Marshall and Holmes, 1988). The ring infiltrometer (1 m in diameter, 0.2 m height), was pressed 0.1 m into the soil, to help limit the lateral spread of water thus maintaining infiltration under a constant hydraulic head and ensuring approximate homogeneity of water contents in the soil profile throughout the whole range of water contents and potentials between S_{FC} and S_{WP} (dry season). The difference between S_{FC} and S_{WP} is the « available water content » (S_{AW}) amount in each soil layer and the sum of each layer's S_{AW} made up the S_{AW} of the soil profile (tube). The soil-water content of each grove, of the herbaceous zone and of the thorn scrub are the arithmetic means of the water contents of the access tubes combined within them (as for S_{AW}).

Rainfall (Pi). The rainfall data came from a meteorological station situated at the center of the study plot (ARG100 Campbell raingauge; collecting area 510.7 cm^2).

Potential evapotranspiration (Ep). The potential evapotranspiration was calculated by Penman's (1948) formula, modified by Van Bavel (1966):

$$ETP = \frac{\Delta R_n + \rho c_p \frac{\delta e}{r_a}}{L\Delta + \gamma} \quad (\mathrm{mm.d^{-1}}) \tag{6}$$

where Δ=slope of the saturation vapour pressure *vs.* temperature curve ($\mathrm{bar.K^{-1}}$); R_n=net radiation ($\mathrm{W.m^{-2}}$); ρc_p=heat capacity of air at constant pressure ($\mathrm{J.m^{-3}.°C^{-1}}$); δe=saturation pressure deficit of air (mb); γ= psychrometric constant (mb.°C^{-1}); L=latent heat of vapourization of water (J.kg^{-1}; 2,46 10^6); aerodynamic resistance, r_a (s.m^{-1}), was calculated from the formula given by Monteith (1965) as:

$$r_a = \frac{1}{k^2 u} \ln \frac{z-d^2}{z_o} \quad (\text{s.m}^{-1}) \qquad (7)$$

where k=von Karman's constant (0.39); u=wind speed (m.s^{-1}); z=height above ground (m); z_o=roughness height (m) and d=zero plane displacement height (m). In the absence of wind profile data, d and z_o, the surface roughness parameters, were estimated according to an empirical formula which relates both parameters to mean vegetation height (Thom, 1971):

$$d=0.75h \quad (\text{m}) \qquad (8)$$

$$z_o=0.1h \quad (\text{m}) \qquad (9)$$

where h=mean vegetation height (m).

Data collection. Measurements of soil-water content, soil-water potential and rainfall were made (from 10 August 1989 to 2 July 1992) weekly during the rainy season and every 20-30 days during the dry season; rainfall, mean air temperature, dew point temperature, air humidity, soil temperature (at 0.5, 1.0 and 1.5 m depth), total air pressure, solar radiation, net radiation and wind speed were recorded hourly from May 1990 on a 21X Datalogger (Campbell Scientific, Inc.).

RESULTS AND DISCUSSION

Actual evapotranspiration

Our results concern the period from 8 August 1989 to 2 July 1992. According to Le Houérou (1989), there are 4 main seasons in the annual cycle in the ecoclimatic Sahael-Sahelian subzone: period 1, from mid-June to mid-September (rainy season); period 2, from September to November (« deferred » season: it has stopped raining, annuals still alive); period 3, from November to February (cool dry season); period 4, from March to May (hot dry season). The annual rainfall for the 3 years was in 1989, 226.5 mm, 1990, 172 mm and in 1991, 148.3 mm (each year had annual rainfall less then the long-term mean of 282.4 mm). The annual Ep was 2233.2 mm.y^{-1}, 2352.4 mm.$^{y-1}$ and 2183 mm.$^{y-1}$ respectively. *A. tortilis* and *B. aegyptiaca* maintained live leaves throughout the year (with variations in the leaf area index; Fournier, 1993), so there is water uptake/transpirent by the tree throut year. The herbaceous layer's water uptake/transpiration, outside and inside of the tree crown shade (*A. tortilis* and *B. aegyptiaca* groves) occurred during the rainy and « deferred » seasons only (periods 1 and 2).

The E_a was calculated using eqn (5) (no drainage). In 1989, 1990, 1991, during the rainy seasons (period 1) which lasted about 86 days (90, 79, 90 days respectively), the mean seasonal E_a of the thorn scrub was 165.1 mm of water with range 120.1 to 203.3 mm, and mean daily E_a was 1.92 mm.d^{-1}. During periods 2, 3 and 4, the thorn scrub's main E_a was 1.62, 0.62 and 0.09 mm.d-1. The measured E_a values were compared with those determined by Cornet (1981) who assessed the water balance equation (soil depth of 3 metres was taken into account). Cornet's plot too was situated on a dune's rise with similar thorn scrub vegetation in the same ecoclimatic zone (Fété Olé, 15°06'W, 16°14'N) during 2 years, 1975 (Pi=311.2 mm) and 1977 (Pi=130.3 mm).Cornet reported that seasonal Ea for period 1 and 2 were 206.4 mm and 126.2 mm (1.4, 1.88 and 1.09-1.25 mm.d^{-1}). The period from mid-June 1990 to mid-June 1991 was chosen to illustrated the daily maximal E_a of the 2 groves, herbaceous zone and thorn scrub during the 4 seasons. The soil depth of 4.75 m was divided into 2 parts: 0 to 1 m depth and 1 to 4.75 m. According to the soil-water potential profiles, herbage roots outside and inside the tree crown are concentrated in the upper (also rooted by trees), the 1-4.75 m depth was rooted by trees only (Nizinski *et al.* 1994). From 0 to 4.75 m, from period 1 to period 4, for the whole soil profile, all daily maximal E_a decreased in concert with the pluviometric régime (Fig.2a). The daily maximal Ea of the tree groves were higher than that of the herbaceous zone, and maximal daily E_a was higher from the *A. tortilis* grove than from the *B. aegyptiaca* grove. Daily E_a estimates were 5.04, 4.15, 3.98 mm.d^{-1} (period 1), 4.28, 3.76, 2.89 mm.d^{-1} (period 2), 1.73, 1.79, 1.34 mm.d^{-1} (period 3), 0.93, 0.46, 0.36 mm.d^{-1} (period 4) for *A. tortilis* grove, *B. aegyptiaca* grove and herbaceous zone respectively. During the rainy season (period 1, there was no water stress, soil-water content was equal to or grater than 60% S_{FC}), the groves and the herbage preferentially take up water from the upper 0 to 1 m of soil rather than from the layer 1 to 4.75 m depth (Fig. 2b, a ratio of about 2 to 1 for *A. tortilis*, and 4 to 1 for *B. aegyptiaca* and the herbaceous zone), even although water was not a limiting factor at depths in excess of 1 m. In period 2, the situation inverts, and stays constant for the remainder of the year; *i.e.* water uptake from the soil layer 1-4.75 m deep contributes more than towards the daily maximal E_a water uptake from the upper 0-1 m of soil. The herbaceous zone is an individual case - it can be reasonably assumed that water withdrawal from the soil layer 1-4.75 m deep is due to *A. tortilis* water uptake. 2 pieces of evidence suggest this, 1) it can be inferred from the matric potential profiles; and also from continuous water uptake during periods 1, 2, and 3 (0.73, 0.88 and 0.90 mm.d^{-1}) despite the fact that toward the end of period 2 the life-cycle of the herbs is completed and they die. During the rainy season, the daily maximal E_a

derived from the soil layer 0 to 1 deep was constant irrespective of vegetation cover (Fig.2b, herbage zone 3.25 $mm.d^{-1}$, *A. tortilis* 3.44 $mm.d^{-1}$, *B. aegyptiaca* 3.29 $mm.d^{-1}$), with 3.31 $mm.d^{-1}$ being average for the thorn scrub vegetation complet. Cornet (1981) calculated 3.5 $mm.d^{-1}$ for the same soil depth and period. As progress the seasons from wet to dry the daily maximal E_a of the herbaceous zone becomes larger than that of the groves. Values for the herbaceous zone, *A. tortilis* grove and *B. aegyptiaca* grove were 2.01, 1.72 and 1.5 $mm.d^{-1}$ (period 2); 0.44, 0.26 and 0.23 $mm.d^{-1}$ (period 3); 0.21, 0.13 and 0.1 $mm.d^{-1}$ (period 4) respectively. During periods 3 and 4, the herbaceous zones withern and outwith the open covered by tree crowns remain more or less denuded of vegetation, (dead herbs and litter remain). Whereas outwith tree crowns only evaporation occurs, in the grove's soil both evaporation and the uptake of water by tree's roots takes place however (shade from tree crown's limit evaporation from soil). Assessed from the development of the matric potential profiles in the herbaceous zone during the course of the dry season, there was progressive drying from soil surface where mulch was absent. Similar drying was also observed in the grove's soil and leads to the conclusion that the water taken up by tree roots (in the first 1 m of soil) decreases in relation to soil evaporation during the course of the dry season. For instance, in the *A. tortilis* grove, the depth from which water uptake by tree roots can occur, (matric potential equal or higher than -1.6 MPa), changes from 0.6 m (from 0.4 to 1 m) at the beginning of the dry season to 0.1 m (from 0.9 to 1 m) at the end of the dry season. Water uptake at depth from 1 to 4.75 m by *A. tortilis* roots which exploited the herbaceous zone was not insignificant, especially during period 3. In total, 25-30% (periods 1 and 2), 40% (period 3) and 15% (period 4) of water taken up by *A. tortilis*. come from the herbaceous zone. At the 1-4.75 m depth, *A. tortilis* water uptake was greater than that of *B. aegyptiaca* over the year (excluding period 3 where both water uptakes were similar) and distincely larger if water uptake in colonized zones was added (Fig.2b). Respectively *A. tortilis* and *B. aegyptiaca* removed 2.33 and 0.86 $mm.d^{-1}$ (period 1), 3.44 and 2.26 $mm.d^{-1}$ (period 2), 2.37 and 1.56 $mm.d^{-1}$ (period 3), 0.95 and 0.36 $mm.d^{-1}$ (period 4). *A. tortilis* and *B. aegytiaca* water uptake during period 1 when available water was not a limiting factor, was less than that during period 2 (the « deferred » season). Roots growth begins during period 1, so it is reasonable to assume that period 2 is the time of year with the maximum amounts of absorptive roots. Moreover, water uptake by *A. tortilis* and *B. aegyptiaca* during period 3 (Fig.2b) was still significant even although rainfall had stopped at least 5 months previously. Water uptake estimates were similar in periods 1 and 3 for *A. tortilis*, and greater in period 3 than in period 1 for *B. aegyptiaca*.

Impact of land clearance on the thorn scrub water balance

Annually, and for soil depth to 4.75 m taken into account in the water balance equation, daily maximal E_a of the *A. tortilis* grove was bigger than that of the *B. aegyptiaca* grove which in turn was grater than that of the herbaceous zone (Fig.2a). The difference in daily maximal E_a demonstrates the extravagent water use by *A. tortilis* which it achieves by its roots colonising and exploiting the herbaceous zones (Fig.3). *A. tortilis* roots do not colonize all herbaceous zones in the thorn scrub: Instead an intermediate situation prevails between the 2 situation shown in Fig.2a and Fig.3. According to the terms of the water balance, on an annual average, the herbaceous zone water content was larger that that of the *B. aegyptiaca* grove, which was greater that that of the *A. tortilis* grove. If we set the *A. tortilis* grove's water content against that of the *B. aegyptiaca* grove or herbaceous zone, we must conclude that « surplus water content » exists in the thorn scrub. *B. aegyptiaca* uses less water than *A. tortilis,* consequently *B. aegyptiaca* will have access to available water during rainless years. In the herbaceous zones, we can assume that this « surplus water content » could be of use to trees if they were present. In this respect, the « unused water content » is the difference between the water content of the herbaceous zone and that of the *A. tortilis* grove, and the situation in the dry season provides an estimate of « unused water content » remaining after the vegetative cycle. Thus, the « unused water content » was 26.7 mm at the end of dry season of 1990-1991 (18 July 1991; Pi_{1990}: 172 mm) and 28 mm at the end of the dry season of 1991-1992 (2 Jyly 1992; Pi_{1991}: 148.3 mm). This amounts to 12.1 and 14 % of the annual rainfall each year respectively. The depth in the soil where this « surplus water content » was located has been defined by comparing the moisture profiles of the 2 groves with the herbaceous zone moisture profile (Fig. 4a, 4b, 4c, end of dry season 1990-1991). The surplus water was located: 1) in the herbaceous zone at 1-2 m and close to 2.5-3 m depth (Fig.4b), and 2) in the *B. aegyptiaca* grove at 0.6-1.2 m and at 2-3.5 m depth (Fig.4c), these locations of surplus water being unchanged over the 3 years. Fig.4a clearly illustrates: a) that *B. aegyptiaca* had few if any, absorptive roots located deeper than 2 m (the most important depth for water content) and b) that *A. tortilis* roots colonized the herbaceous zones at 2 m (water content intermediate between the water content of *B. aegyptiaca* grove and *A. tortilis* grove). the thorn scrub water balance concerned 1989, 1990, 1991, 3 years with annual rainfall less than the long-term mean, and which included a noticable decline in the numbers of trees in this thorn scrub. The *A. tortilis* population is subjected to heavy cutting and thus the herbaceous and bare soil areas increase. The studies population basal area, representative of the plant community structure in the region in 1989 (date of fencing off of the study plot) was 3.87 $m^2.ha^{-1}$. However the *A. tortilis* structure analysis demonstrates that the basal area ought to have been larger without woodcutting (missing circumferences of 1.1, 1.2, 1.6, 1.7 m in the pyramid-shaped diagrams representing circumferences of the *A. tortilis* population; deficient numbers of the circumferences 0.7, 0.9 m). From the herbaceous zone « unused water content » it is possible to calculate the mean « unused water content » of the whole thorn scrub and evaluates this in terms of corresponding *A. tortilis* population. The study plot (1 ha) was divided into 100 units, each unit of 10 m^2 possessing its characteristic tree basal areas. The « unused water content » of the herbaceous zone was 26.7-28 mm with basal area of 0 m^2 per 10 m^2, and the *A. tortilis* grove's « unused water content » was 0 mm with basal area of 0.14789 m^2. The mean « unused water content » of the thorn scrub was assessed using a linear regression [« unused water content »=f(basal area)](using the *A. tortilis* population only): 20.82 mm (208.13 $m^3.ha^{-1}$). Knowing the rain-use efficiency of woody production (woody biomass produced per mm of rainfall) in the sahelian ecoclimatic zone, 0.3 $m^3.ha^{-1}.y^{-1}.mm^{-1}$ (Bailly *et al.* 1982; Menault, 1983) or 0.66 to 1 kg DM $ha^{-1}.y^{-1}.mm^{-1}$ (Bille, 1977; Poupon, 1980), this thorn scrub ought to have produced 6.25 $m^3.ha^{-1}.y^{-1}$ more wood or 14 à 21 kg DM $ha^{-1}.y^{-1}$, as well as 7.4 % of the mean annual primary production (186 to 282 kg DM $ha^{-1}.y^{-1}$ with Pi=282.4 mm, annual mean). On the other hand, knowing 1) the 3-year mean E_a of the groves was 165.1 $mm.y^{-1}$, 2) the actual thorn scrub tree canopy cover (vertical tree's canopy projection onto the 1 ha soil surfac) was 3755 $m^2.ha^{-1}$ (37.6 %)(Akpo, 1992), one can assess the tree canopy cover of *A. tortilis* which would have E_a equal to the « unused water content » of the thorn scrub (455 $m^2.ha^{-1}$), and transform this tree canopy cover based on E_a to tree number, with given height and stem circumference according to published *A. tortilis* allometric relationships, 1) aerial woody biomass ploted against stem diameter at soil level Poupon (1980), 2) circumference plotted against tree canopy cover Akpo (1992). Using the above relationships, the « unused water content » corresponds to the annual E_a of 10 trees in the grove (6.5 m height, 0.84 m stem circumference). In the radian energy budget, an increase in tree canopy cover decreased thorn scrub albedo (the evergreen crown albedo is smaller than the grassland albedo, which in turn is smaller that that of dry sand) and promotes an increase of the net amount of radiant energy (that is transformed into other forms of energy, basically into sensible and latent head). In the energy budget of thorn scrub, the E_a increase promotes a decrease in sensible heat flux and according to General Circulation Models (GCMs), the increase of the E_a of 20.82 mm per year in this Sahel-Sahelian subzone would result in 1) a mean annual air temperature decrease of

1,5 °C (Mylne and Rowntree, 1992)(a decrease in sensible heat flux and surface temperature despite the decrease in albedo; evaporation of 20.82 mm, at 30 °C, 505.75 $MJ.m^{-2}$ which is equal to 16.04 $W.m^{-2}$ of sensible heat over the year), and 2) a rainfall increase of 0.52 $mm.d^{-1}$ (Sud and Fennessy, 1982, 1984) or 0.91 $mm.d^{-1}$ (Charney *et al.* 1977).

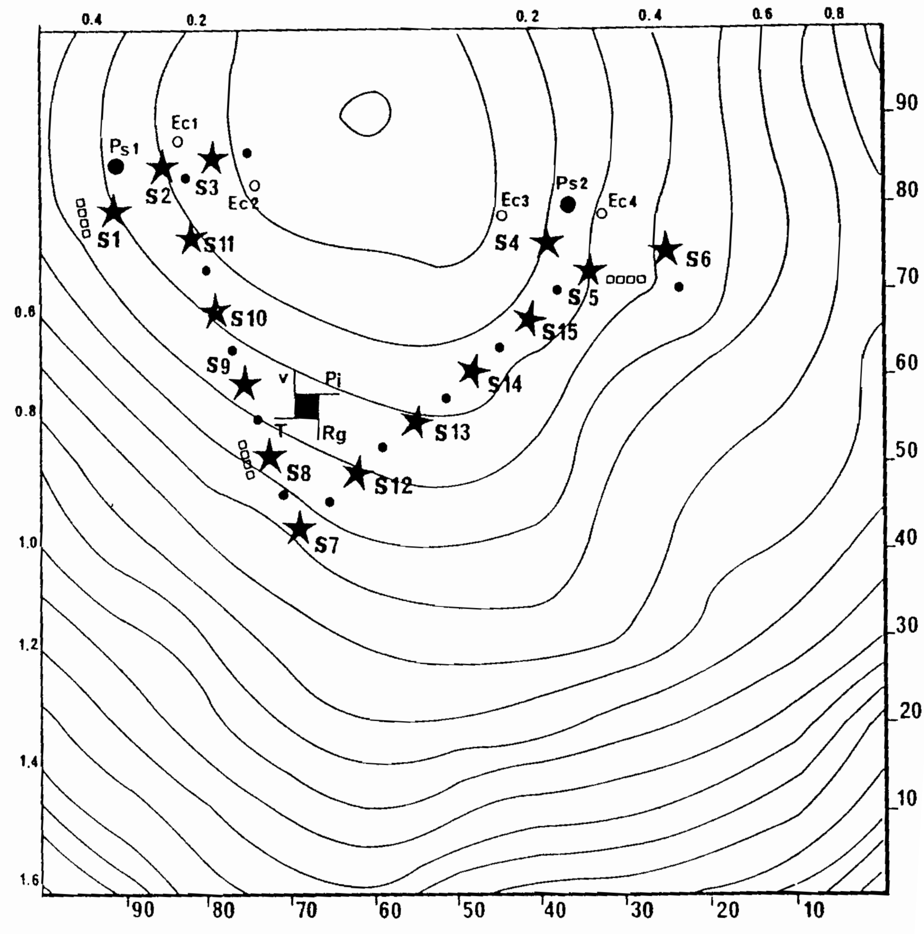

Fig. 1. Map of study plot

LIST OF FIGURES

Fig.1. Map of study plot (area: 10000 m^2, slope: 1,6 %, elevation: 5 m above see level); ■ meteorological station (rainfall, mean air temperature, dew point temperature, soil temperatures (at 0.5, 1.0 and 1.5 m depth), air humidity, solar radiation, net radiation, wind speed); ★ neutron probe access tube; ● raingauge; ○ stemflow collar; □□ psychrometer thermocouple.

Fig.2. Mean daily maximal actual evapotranspiration ($mm.day^{-1}$) *Acacia tortilis* grove (——), *Balanites aegyptiaca* grove (----) and herbaceous zone (•••••) (a) from 0.00 to 4.75 m depth (●); (b) from 0.00 to 1.00 m depth (▲) and from 1.00 to 4.75 m depth (■); *Acacia tortilis* grove and herbaceous zone from 1.00 to 4.75 m depth (◆□◆).

Fig.3. Mean daily maximal actual evapotranspiration ($mm.day^{-1}$) of an *Acacia tortilis* grove from 0.00 to 4.75 m soil depth with herbaceous zone from 1.00 to 4.75 m depth (——), of a *Balanites aegyptiaca* grove from 0.00 to 4.75 m depth (----) and of a herbaceous zone from 0.00 to 1.00 m depth (•••••).

Fig.4. Soil-water content profiles ($cm^3.cm^{-3}$), on 18 July 1991 (a) *Acacia tortilis* grove (——), *Balanites aegyptiaca* grove (----) and the herbaceous zone (•••••); (b) *Acacia tortilis* grove (——) and *Balanites aegyptiaca* grove (----) with "surplus water content" zones; (c) *Acacia tortilis* grove (——) and the herbaceous zone (•••••) with "surplus water content" zones.

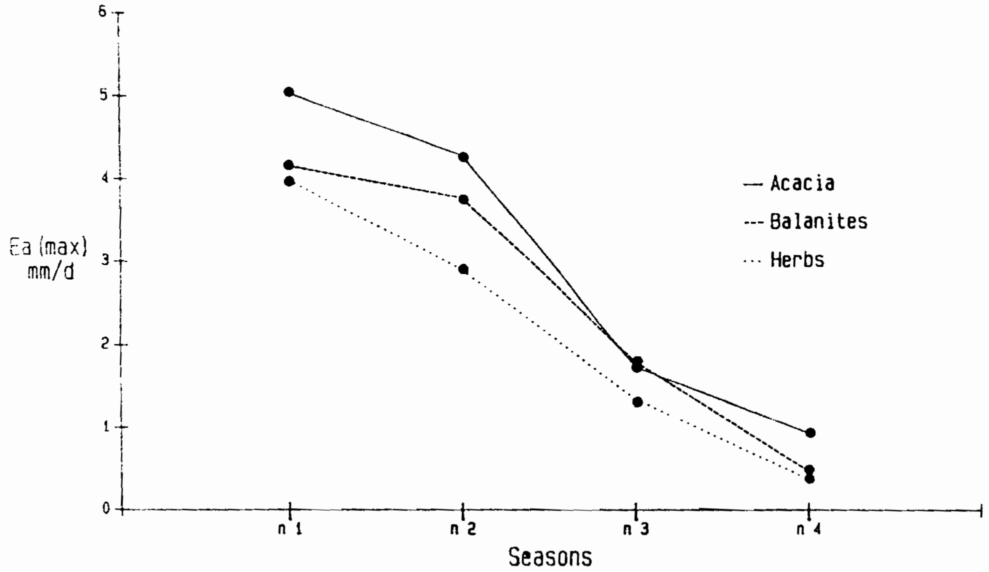

Fig. 2a. Mean daily maximal actual evapotranspiration

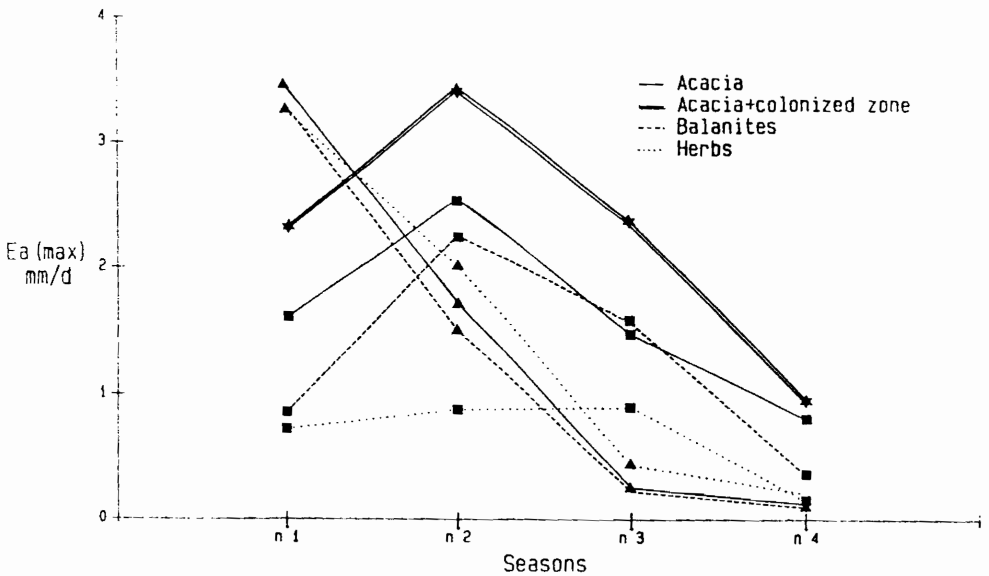

Fig. 2b. Mean daily maximal actual evapotranspiration

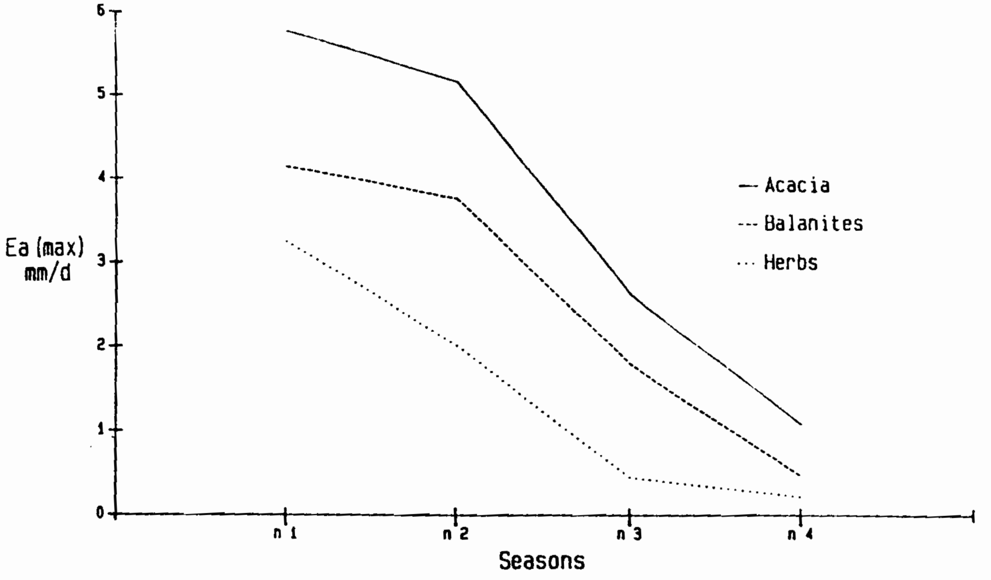

Fig. 3. Mean daily maximal actual evapotranspiration

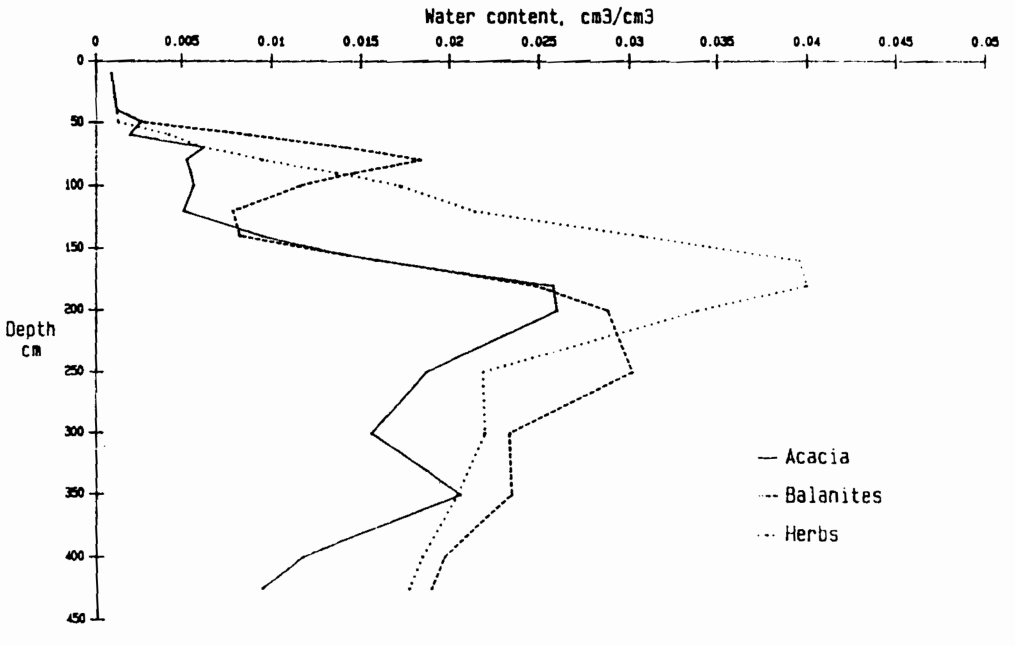

Fig. 4. Soil-water content profiles

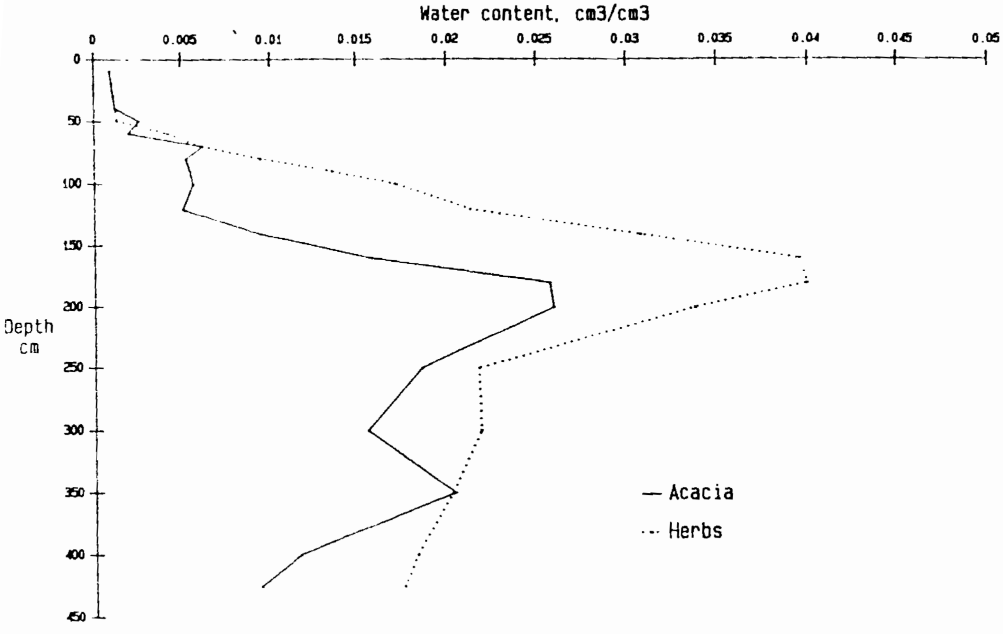

Fig. 4b. Soil-water content profiles

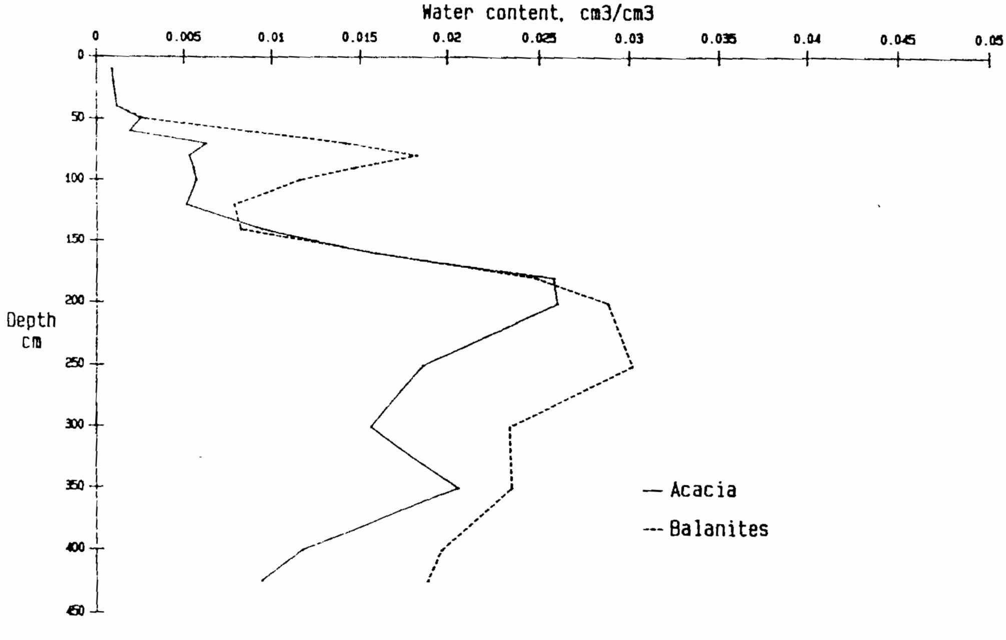

Fig. 4c. Soil-water content profiles

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