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Bare Fallowing on Sandy Fields of Niger, West Africa

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ABSTRACT

An experiment was conducted in three rainfall zones of Niger, West Africa, to evaluate the potential of mulched and nonmulched bare fallow to conserve water in deep, sandy soils. Water content of adjacent bare and cropped experimental plots was monitored with a neutron probe at three sites during the 1985 growing season and the subsequent dry season. Experimental sites, with soil type and 1985 rainfall, were near the villages of Chikal (Ustic Torripsamment; 233 mm) N'Dounga (Psammentic Paleustalf; 344 mm), and Kala Paté (Alfic Ustipsamment; 428 mm). Cropped plots were managed using traditional low-input practices. Bare plots were weeded using a traditional, shallow cultivating hoe. At the end of the growing season, portions of the bare and cropped plots were mulched with millet stalks at a rate of 25 Mg ha^{-1}. At the end of the dry season, no significant increases in profile water storage were detected in mulched treatments. Increased soil water storage in the upper 1.65 m of bare fallowed plots toward the end of the dry season was 16.5 ± 10.5 mm at Chikal, and 40.6 ± 17.9 mm at N'Dounga. No increase in storage was observed in bare fallowed plots at Kala Paté. Mean increases in storage efficiency at Chikal and N'Dounga were 7.1% and 11.8%, respectively. Position of the zero-flux boundary during the dry season and profile water distribution toward the end of the dry season indicate that drainage was substantial at all sites. However, large losses due to evaporation are also possible, due to high evaporative demand during the dry season. Data obtained in this study suggest that bare fallowing, with and without dry-season mulching, is an inefficient means of water conservation for these soil systems. A possible application of bare fallow is in sandy soils underlaid by laterite in high-risk, low-rainfall zones of the Sahel if accompanied by adequate erosion prevention.

BARE OR SUMMER FALLOW is defined as the practice of preventing plant growth during one growing season to store soil water for the subsequent season. Greb et al. (1974) considered the practice of fallow as mandatory for small-grain crop production where annual precipitation is 275 to 550 mm. Annual rainfall in much of the Sahelian region of Africa falls within this range.

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Advantages of bare fallow when compared to continuous grain cropping include decreased risk of crop failure (Greb et al., 1974), increase in the land area that can be handled with limited labor or equipment, and increased control of insects, disease, and weeds (Johnson et al., 1974; Brengle, 1982). Disadvantages include increased water and wind erosion, and a decrease in total N and organic C (Haas et al., 1974a).

Storage efficiency, the percentage of precipitation received during fallow that remains in the soil profile at the beginning of the subsequent cropping season is known to be affected by length of fallow, climatic conditions, amount and management of mulch, quality of weed control, soil texture, soil reflectance, depth to inhibiting layers, and tillage (Greb et al., 1974). The effective depth and total quantity of soil water extraction of the previous crop are also a factor (Haas et al., 1974b). Haas et al. (1974a) reported an average storage efficiency of about 19% in the U.S. Great Plains. Crop residue may increase storage efficiency by decreasing evaporation (Unger and Stewart, 1983). Efficiency is increased with thicker mulch layers and lower density materials (Unger and Parker, 1976).

Nearly all bare fallowing in the USA is practiced in 17 western states (Haas et al., 1974c), mostly on Mollisols. On sandy soils, bare fallowing generally increases wind erosion and is therefore considered impractical in the USA, particularly in semiarid areas. Chepil et al. (1963) stated that for grain production in the northern semiarid USA, continuous cropping and crop–forage rotations are preferred to bare fallow on loamy sands and sandy loams, due to better erosion protection. Nonetheless, there are some reports of increased yield and water conservation from bare fallowing on U.S. sandy soils. Johnson et al. (1974) found that wheat (*Triticum aestivum* L.) yield on a Pratt fine sandy loam (sandy, mixed, thermic Psammentic Haplustalf) increased 28% in a fallowed field compared with a continuously cropped field in the Rolling Red Plains of Oklahoma. Rainfall during fallow was ~850 mm. Luebs and Laag (1971) examined the effects of bare fallowing on barley (*Hordeum vulgare* L.) production during a 4-yr period on a Hanford sandy loam (coarse-loamy, mixed, nonacid, thermic Typic Xerorthent) at Riverside, CA. Average rainfall and storage

efficiency were 353 mm and 16.7%, respectively. Substantial deep drainage occurred during fallowing, and an average of only 56 mm was stored to 2 m before the subsequent season. In Texas, Fryrear and Koshi (1974) reported that mulching a bare sandy soil with 11.2 Mg ha^{-1} of cotton-gin trash improved soil water storage in the upper 2 m and increased cotton yield by 10 to 67%. Beneficial effects on soil physical properties were also noted.

In semiarid East Africa, Pereira et al. (1958) compared the effects of rotating peanuts (*Arachis hypogaea* L.) with volunteer cover, maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], and bare and protected fallow on a "sandy red loam of high fertility." Protected fallow consisted of densely seeded tef [*Eragrostis tef* (Zucagni) Trott.], a shallow-rooted grass that provided complete protection from wind and water erosion. Rainfall for the 1st and 2nd yr was 560 and 216 mm, respectively. At the advent of the second growing season, bare-fallowed and tef-protected plots held ~75 mm more water in 2 m than cropped or unweeded plots, and produced twice the yield. Rainfall in the third and fourth years was respectively 340 and 334 mm. Average yield on bare-fallowed plots was 24, 62, 93, and 47% higher than on plots previously treated with tef, volunteer cover, sorghum, and maize, respectively. The average amount of water held in the top 1 m of soil at the beginning of the fourth season was 351, 295, 260, 267, and 292 mm for bare fallow, protected fallow, volunteer cover, sorghum, and maize, respectively. Despite these positive results, Pereira et al. (1958) stated that the difficulties of protecting tilled bare soil from erosion rendered the technique dangerous and inappropriate, and therefore recommended using fallow protected with a short-season, shallow-rooted annual grass.

In Botswana, Whiteman (1975) compared sorghum–bare fallow and sorghum–vegetated cover rotations on a loamy sand with a "ferruginous concretionary deposit" at a depth of 0.70 to 1.00 m. Sorghum grain yield following bare fallow was 41% higher than in vegetated treatments for the first year (671 mm rainfall) and 27% higher for the second (614 mm rainfall). Soil water storage in the top 1 m of bare-fallowed plots was respectively 74 and 54 mm more for the first and second year than in the vegetated treatments. In the third year, rainfall was only 289 mm and bare fallowed plots showed an average yield increase of 549% and held 84 mm more water in the top 1 m than did the vegetated plots. Whiteman (1975) concluded the method was appropriate for high risk areas in Botswana and had implications for similar latitudes of semiarid Sahelian Africa.

No reports on the effects of bare fallow on water storage of the deep, sandy soils of Sahelian West Africa were located. However, Hall and Dancette (1978) used a model to predict water conservation during fallow on a deep, sandy Dior soil (Ustipsamment) of Senegal. The Dior soil has been described in detail by Charreau and Nicou (1971). The model predicted that storage efficiency, calculated assuming no surface runoff and no drainage below potential root zones, was positively correlated with annual rainfall, and that the amount of water stored after 1 yr fallow would be substantial when annual rainfall is >200 mm. The model also predicted that substantial quantities of water would be conserved in the soil during wetter years (rainfall ≥ 470 mm) if a short-season millet (75 d) was used. However, for this partial-year fallow, their simulations suggested that much of the conserved water would be stored below 1.5 m. Hall and Dancette (1978) state that a major deficiency of the model is the inability to predict water losses from bare fallow during the dry season.

Our objective was to evaluate the potential of bare fallow, with and without dry season mulching, to conserve soil water in three deep, sandy millet fields in different rainfall zones of Niger, West Africa. Rainfall distribution in Niger is monomodal, normally beginning in May or June and ending in September, with peak intensity in August. Millet, the primary cereal crop in Niger, is typically sown when the soil's wetting front is at ~20 cm. After cessation of rains in September, there is no further precipitation until the advent of the following growing season. The dry season is characterized by high temperatures, low humidity and, beginning in February or March, the hot, dry wind known as the Harmattan.

MATERIALS AND METHODS

During the 1985 growing season and the subsequent dry season, the water balance of bare and cropped fields near Chikal (Ustic Torripsamment), N'Dounga (Psammentic Paleustalf), and Kala Paté (Alfic Ustipsamment) was monitored. Mean annual rainfall is ~450 mm at Chikal, 590 mm at N'Dounga, and 700 mm at Kala Paté; however, actual rainfall varies greatly from year to year in Niger, and had been considerably lower than average for several years previous to 1985. Sites were chosen due to their proximity to Class A meteorological stations, textural homogeneity, level slope, and different rainfall zones. Detailed physical and pedologic descriptions of experimental sites have been given by Payne (1987); soil-geomorphic relationships have been described by Wilding and Daniels (1989). Particle-size distribution as a function of depth is shown in Fig. 1. At all three sites, depth to impermeable (lateritic) contact is several meters. In 1985, 233 mm of total rainfall was received at Chikal, 344 mm at N'Dounga, and 428 mm at Kala Paté. Details of the water balance during the growing season, plot layout, and instrumentation have been elsewhere described (Payne et al., 1990). Briefly, two 20.0 by 20.0 m adjacent experimental plots were established at each site in a large field traditionally sown in millet. One was kept bare of weeds using the *hilaire*, a local hoe that cultivates to a depth of about 0.05 m. The other plot was cropped in millet, using traditional, low-input management practices. Within the cropped plots, five neutron-probe access tubes were installed at random locations to a depth of 2.0 m, and enclosed in 2.0 by 2.0 m barriers to prevent runon and runoff during torrential storms, following the example of Dancette (1971). The barriers were constructed of galvanized sheet metal, and were positioned ~0.15 m above to 0.10 m below the soil surface. Bare plots were similarly treated, but two of the access tubes at each site were replaced at harvest with tubes that were 2.60 m in length. At N'Dounga, one additional access tube was installed at harvest in an unweeded plot adjacent to experimental plots. At N'Dounga and Kala Paté, tensiometers were installed in both treatments around two of the access tubes. At Chikal, tensiometers were installed around only one access tube in each treatment. Tensiometers were installed at depths of 0.10, 0.25, 0.40, 0.55, 0.70, 0.85, 1.00, 1.20, 1.40, 1.60, 1.80, and 2.00 m, and were read using a pressure transducer (Marthaler et al., 1983) (Soil Moisture

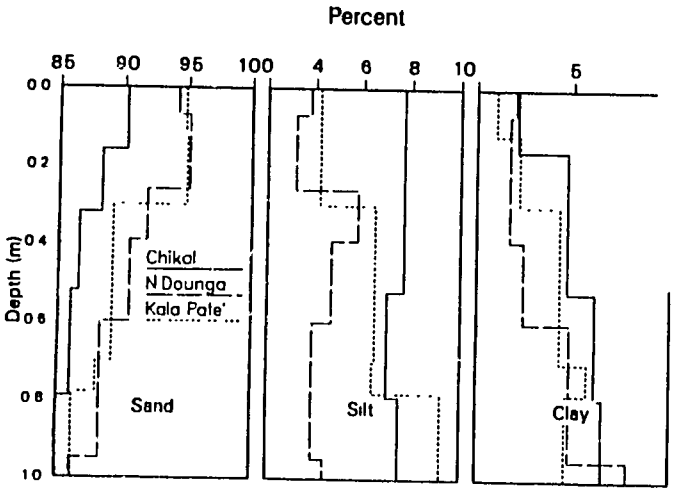

Fig. 1. Particle-size distribution with depth at three experimental sites.

Systems, Las Cruces, NM).[1] Hydraulic gradients determined from tensiometric data were used to detect the presence and approximate position of the zero-flux boundary, as described by Arya et al. (1975). Theoretically, water moves in response to the hydraulic gradient in an upward direction above this boundary, which may be assumed planar, and downward below it.

Details of neutron-probe calibration are given by Payne et al. (1990) During the dry season, surface soil layers become extremely dry. To include these points in the probe calibration curve, water content was determined gravimetrically, then converted to volumetric units using independently determined bulk-density values. Although data from such dry soil samples were used in the field calibration curves, probe count ratios substituted into regression equations occasionally gave slightly negative volumetric water contents. In these cases, a volumetric water content of 0.002 $m^3\ m^{-3}$, the lowest water content determined in the field, was used.

At harvest (see Fig. 2 for dates), grain and aboveground dry matter were harvested from the cropped plots. Two of the 2.0 by 2.0 m squares in the cropped and bare fallow treatment were covered with ~10 kg of millet straw, corresponding to a rate of 25 Mg ha^{-1} and a thickness of 0.10 to 0.15 m. The purpose of the mulch was to reduce dry-season evaporative loss. The remaining three squares in each treatment were left bare. Water content was monitored at all sites until nearly the end of the dry season; dates of measurements are indicated in terms of days after 22 June 1985, the first day of measurement at Kala Palé (Fig. 2). Volumetric water content was summed to a depth of 1.65 m, the maximum depth of probe readings, to determine treatment effects on soil water storage. Thus, treatments consisted of mulched and nonmulched squares on previously bare-fallowed and cropped plots in each rainfall zone.

Volumetric water content at −1.5 MPa was measured on samples from each pedologic horizon at each site using a pressure plate apparatus (Richards, 1965). Water content at −1.5 MPa was integrated to a depth of 1.65 m, to give an estimate of available water in the soil profile for each date of measurement.

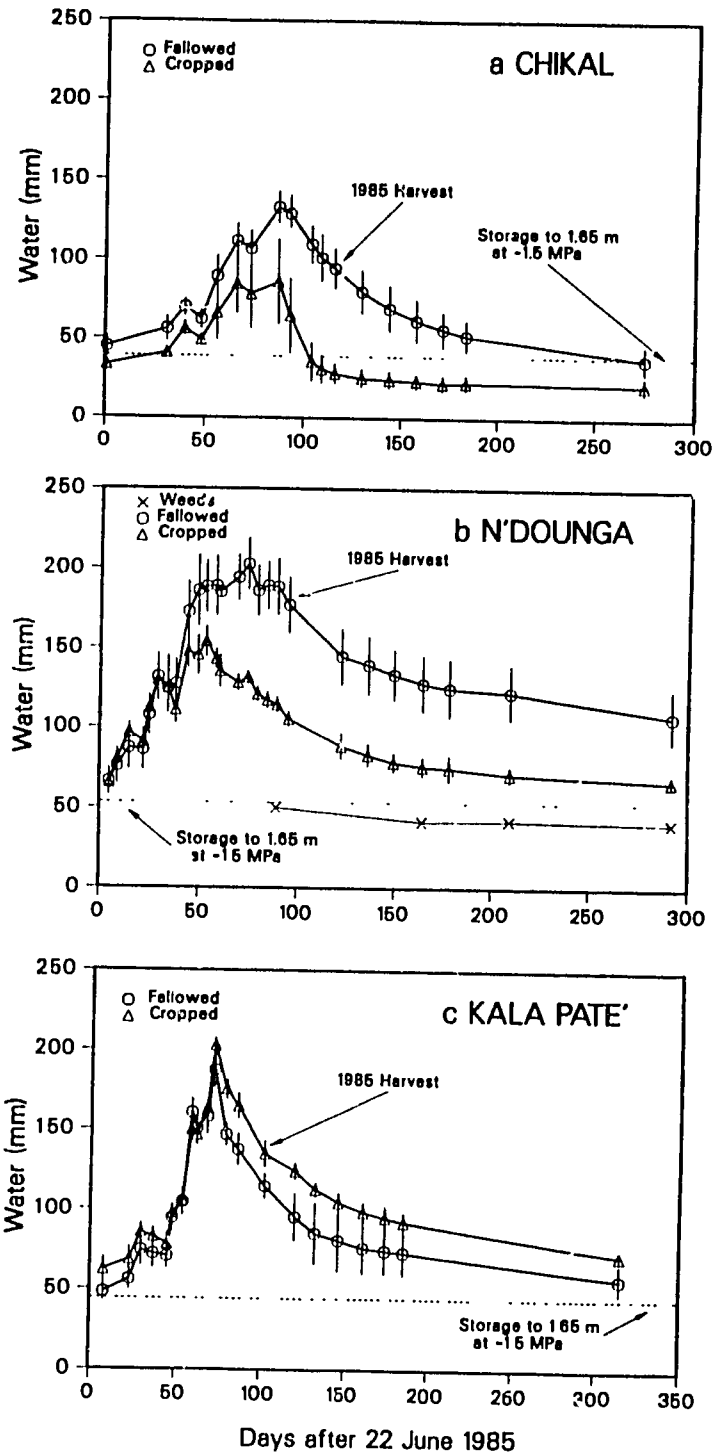

Fig. 2. Stored water in upper 1.65 m of bare and cropped plots at (a) Chikal, (b) N'Dounga, and (c) Kala Paté after 22 June 1985. Points represent the mean of five measurements; bars represent one standard deviation. Dashed line represents storage at −1.5 MPa. For N'Dounga, stored water of adjacent, unweeded fallow plot, (× weeds) for which there was only one access tube, is also indicated.

RESULTS

Water content measurements of mulched and nonmulched squares at each site indicated no significant difference in soil water conservation during the dry season: therefore, water contents of mulched and nonmulched squares within each treatment were pooled to evaluate the effectiveness of bare fallow. The amount of water stored to a soil depth of 1.65 m in the cropped and bare fallowed treatments is shown in Fig. 2. At Chikal (Fig. 2a), a mean gain of 66 mm in stored water was measured in the top 1.65 m following harvest (Day 116), but the difference had diminished

[1] Mention of trade names does not constitute an endorsement.

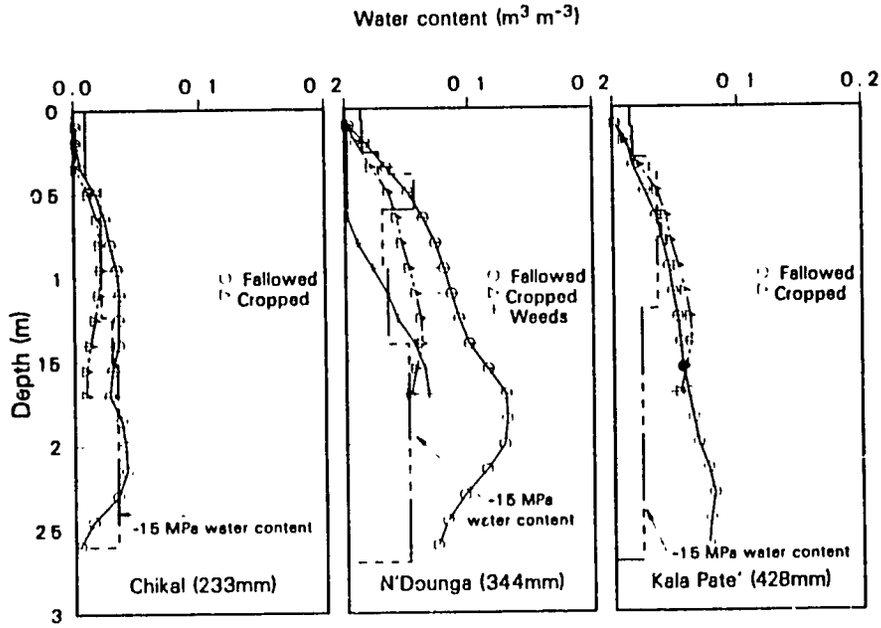

Fig. 3. Profile water distribution at experimental sites on last day of measurement, with total rainfall for 1985. Unweeded fallow data (Weeds) at N'Dounga is from only one access tube; otherwise, points above 1.65 m represent the mean of five measurements and points below 1.65 m represent the mean of two measurements. Stepped curves represent water content at −1.5 MPa.

to 16.5 ± 10.5 mm (using the *t*-test at the 95% confidence level) by the last day of measurement, 24 Mar. 1986 (Day 275). Storage to 1.65 m in both cropped and bare fallowed treatments was at or below the amount stored at −1.5 MPa. Profile water distribution on the last day of measurement (Fig. 3) suggests that, although water content in the bare-fallow treatment was slightly higher than in the cropped, very little water would be available for plant uptake. Mean bare-fallow water storage at N'Dounga (Fig. 2b) was 72 mm more at harvest (Day 97) than mean cropped water storage, but by 10 Apr. 1986 (Day 292), the difference was only 40.6 ± 17.9 mm. As the model of Hall and Dancette (1978) predicted for partial-year fallow for the Dior soil of Senegal, much of this water had drained to below 1.5 m (Fig. 3). Virtually all available water in the top 1.5 m had been used in the unweeded fallow plot (Figs. 2b and 3). At Kala Paté (Fig. 2c), the bare-fallow treatment appears to have held less water than the cropped treatment throughout the experiment; however, the difference is not significant at the 99% confidence level. Using 1985 total rainfall data, mean increases in storage efficiency of bare-fallowed plots compared to cropped plots were 7.1% at Chikal and 11.8% at N'Dounga, with no measurable increase at Kala Paté.

DISCUSSION

Our data show that bare fallow and dry-season mulching were inefficient methods of water conservation at the experimental sites during the time of measurement. Field capacity was estimated from in situ measurements by Payne (1987) to be 0.10 to 0.14 $m^3\ m^{-3}$; thus, a 1.65 m profile at field capacity may be expected to hold 165 to 231 mm of water. At Kala Paté and N'Dounga, then, profiles water storage approached field capacity during the first week of September (Fig. 2, Day 72 to Day 79), which usually is the end of the rainy season. It is doubtful, therefore, that bare fallow would better conserve water for the following year if rainfall were heavier, unless perhaps rains ceased at an unusually late date.

The failure of bare fallow to effectively conserve water in the soil profile is due to a combination of evaporation and drainage. Drainage below potential root zones during the dry season cannot be reasonably assumed as null in these soils, as Hall and Dancette (1978) assumed for the Dior soil. As in situ moisture retention data for the upper 0.25 m at N'Dounga (Fig. 4) suggest, most soil water is lost as pressure potential becomes more negative than −5 kPa. Retention curves for all pedologic horizons at all sites were similar to Fig. 4. The zero flux boundary in bare plots (Fig. 5) was located between 0.0 and 0.25 m for most of the 1985 growing season, indicating downward flow below these depths. After the growing season, the boundary gradually moved to about 1.0 m at Kala Paté and N'Dounga. The boundary appears somewhat higher at Chikal, but these results may be considered as suspect, since there was only one replicate, and water pressure potential may have been out of the range of tensiometers. The data indicate continued downward unsaturated flow in fallowed plots throughout the dry season. Calculations of hydraulic conductivity as a function of water content using the method of Jackson (1972) indicate that drainage may contribute to water loss on a monthly basis at water contents as low as 0.05 $m^3\ m^{-3}$ (Payne, 1987; Payne et al., 1990). On the other hand, 60, 41, and 65% of the July 1985 rainfall was lost to evaporation from bare plots at Chikal, N'Dounga, and Kala Paté, respectively, (Payne, 1987). Similar evaporative loss has been measured during the growing season from bare plots at N'Dounga by Gandah (1982) and in the Tarna region of Niger by Charoy (1974). Although the rate of evaporative loss during the dry season generally diminishes due to drying of the soil surface layers, it may still be substantial, since atmospheric evaporative demand is generally much higher than during the growing season.

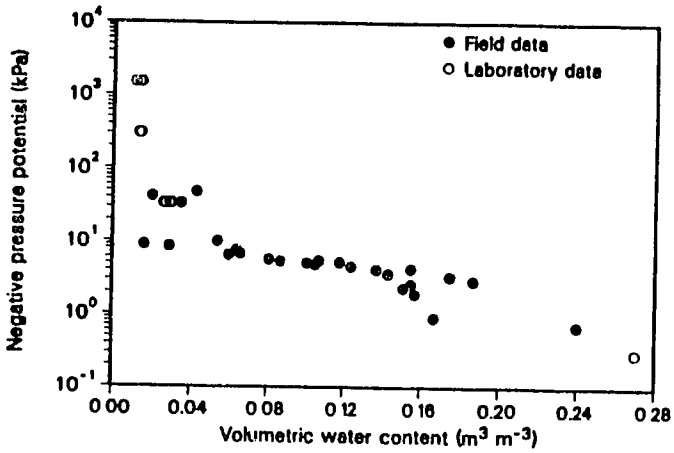

Fig. 4. Moisture-retention curve for surface 0.25 m at N'Dounga. Curves for all horizons were similar at the other sites. Laboratory data were determined from a pressure plate apparatus (dry end) (Richards, 1965) and undisturbed, covered cores allowed to freely drain for 24 h (wet end). Field data are from tensiometer and neutron probe measurements.

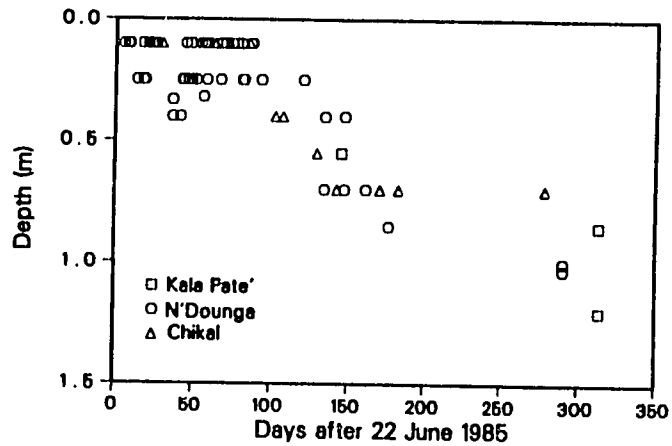

Fig. 5. Approximate position of zero-flux boundary during 1985–1986. Points were determined from reading one set of tensiometers. Not included are readings that showed no evidence of a zero flux boundary.

Although our data suggest that bare fallow is inefficient for water storage in these soils, data from Whiteman's (1975) study in Botswana demonstrate that bare fallow can make the difference between harvest and crop failure during an extremely dry year. However, the sandy soils in Whiteman's (1975) study were underlaid by an impermeable contact. Water-retention of sandy soils can be greatly improved by the presence of an impermeable barrier (e.g., Erickson, 1972). There are large areas of the Sahel which have lateritic contacts within 2 m. Where such areas are characterized by high risk agriculture due to low and erratic rainfall, bare fallow may be a viable technique of stabilizing yield and reducing crop failure, so long as erosion prevention is practiced. Possible modifications of the method include the use of a densely sown, shallow rooting grass as suggested by Pereira et al. (1958), or the use of double-row grass barriers as described by Chepil et al. (1963).

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