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Effects of Chiselling and Sulfur Fertilization on Infiltration, Soil Water Content, Peak Season Biomass Production, and Botanical Composition in the Ait Rbaa Perimeter

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EFFECTS OF CHISELLING AND SULFUR FERTILIZATION ON INFILTRATION, SOIL WATER CONTENT, PEAK SEASON BIOMASS PRODUCTION, AND BOTANICAL COMPOSITION IN THE AIT RBAA PERIMETER

by

Mohammed Tigma

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Mohammed Tigma

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ABSTRACT

Effects of Chiselling and Sulfur Fertilization on Infiltration, Soil Water Content, Peak Season Biomass Production, and Botanical Composition in the Ait Rbaa Perimeter

by

Mohammed Tigma, Master of Science

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Major Professor: Charles W. Gay
Department: Range Science

This study evaluated the effectiveness of chiselling and elemental sulfur fertilization in improving an upland and a swale range site with fine loamy, carbonatic, typic calcixeroll soils in the Ait Rbaa Perimeter of central Morocco. Ponding infiltration, soil water content on a mass basis of the 0- to 10-cm and 10- to 20-cm soil layers, peak season biomass production, and botanical composition were monitored during the two growing seasons following the treatments (1984/85 and 1985/86). Chiselling significantly improved infiltration on both sites, although the improvement was greater on the finer and less stony swale site, where chiselling resulted in more stable ridges. The land treatment also increased the average water content by weight of the 0- to 20-cm soil layer. The increase was more frequent on the upland site and most pronounced on its 0- to 10-cm surface soil layer. In the chiselled treatments, average soil water content decreased with soil depth on the upland site while it increased on the swale site because of differential furrow stability and soil texture. Both the average infiltration rates of 5 cm of water and the average water content varied with sampling time, although generally in opposite directions. The application of elemental sulfur at the rates of 0, 30, and 60 kg ha^{-1} did not significantly affect any of the measured variables. Average peak season biomass production was 11% greater with chiselling. Chiselling also positively affected botanical composition on the upland site by depressing average forb proportion and increasing legume ratio in the first growing season. The gain in biomass does not seem to be high enough to strongly recommend chiselling in the Ait Rbaa Perimeter before performing an economic analysis of the operation.

(73 pages)

INTRODUCTION

The communally grazed Ait Rbaa Perimeter in the Beni Mellal Province of Morocco has been subjected to livestock overutilization for more than two decades. Stocking rates over twice the carrying capacity (Goebel and Kouriri 1982, Harkousse et al. 1985) resulted in the degradation of soil and vegetation (El Mzouri and Gay 1987, Gay et al. 1987). Overgrazing is known to negatively affect water infiltration into the soil directly by compacting the soil and indirectly by reducing soil cover (Rhoades et al. 1964, Rauzi and Hansen 1966, McGinty et al. 1979).

Increasing awareness of the degrading situation of the Ait Rbaa range led to a series of studies (Goebel and Kouriri 1982, Harkousse et al. 1985, Gay et al. 1987, El Mzouri and Gay 1987) designed to improve understanding of the ecosystem and to find ways for its rehabilitation. The present study was directed towards the same goals, through addressing the possibility for improving soil hydrological properties by chiselling and plant cover and production attributes by sulfur fertilization.

The objectives of the study were (1) to evaluate the effect of chiselling on infiltration and (2) to assess the effects of chiselling and elemental S application on soil moisture, peak season biomass, and botanical composition of the range.

DESCRIPTION OF THE STUDY SITES AND METHODOLOGY

Study Sites

The Ait Rbaa Perimeter is located Northwest of Kasbah Tadla in the Beni Mellal Province of Morocco. The climate is Mediterranean, lower semiarid, with temperate winters (El Mzouri 1985). The dry and mostly hot season extends from May to October. Rainfall, averaging 420 mm annually in the neighboring village of Kasbah Tadla, is highly variable in amount and distribution. The long-range average annual temperature is 19.4 °C (El Mzouri 1985), with January as the coldest month (4.1 °C average of minima) and July the hottest (39.5 °C average of maxima).

Because of the rolling topography, the study was conducted on two different sites: the upland and the swale. Both sites had been protected by fenced exclosures since December 1983. They are located on the eastern part of the Perimeter, 12 km to the northwest of Kasbah Tadla, at an elevation of 560 m above sea level. The soils are fine loamy, carbonatic, thermic, typic calcixeroll developed on Cretaceous Marl.

The gently slopping (5%) upland site's soil surface is covered by gravel and by stones (to 30 and 10% respectively) and has a loamy surface layer (Table 1). In the Ap and A horizons 15-30% of volume is occupied by coarse material. This proportion decreases to 10-15% in

Table 1
Some Physical and Chemical Characteristics of the Soils of Two Sites in the Ait Rbaa Perimeter

Horizon	Depth (cm)	Organ. matter (%)	pH[a]	$CaCO_3$ (%)	Coarse sand[b] (%)	Fine sand[c] (%)	Total sand (%)	Silt[d] (%)	Clay[e] (%)
Upland site									
Ap	0-8	3.07	8.3	39.5	8.5	29.8	38.3	41.6	20.1
A	8-30	1.99	8.6	43.7	6.4	29.8	36.2	39.2	24.6
Bca	30-44	1.26	8.6	52.7	8.4	28.2	36.6	34.0	29.4
Cca	44-70	0.45	8.7	66.1	9.0	31.2	40.7	32.6	26.6
Swale site									
Ap	0-10	2.34	8.3	47.1	4.4	32.7	37.1	39.7	23.2
A	10-30	1.29	8.5	47.2	2.8	29.5	32.4	39.0	28.7
Bca	30-67	0.85	8.6	56.8	3.5	22.9	26.4	37.0	36.6
Cca	67-90	0.37	8.8	54.1	10.6	42.5	53.1	29.7	17.2

[a]pH H_2O 1:5

[b]Coarse sand: 0.2-2 mm

[c]Fine sand: 0.05-0.2 mm

[d]Silt: 0.002-0.05 mm

[e]Clay: < 0.002 mm

Soil analyses were performed by the Institut National Agronomique et Vétérinaire Hassan II, Rabat, Morocco.

the Bca horizon. The Cca horizon is affected by a discontinuous calcareous crust.

The nearly level (< 2%) swale site also has a loamy surface soil but is not much affected by stoniness nor by calcareous crust. The swale soil is deeper than the upland and has more calcium carbonate, more clay, and less organic matter.

Soil pH is relatively high on both sites (8.3). This level is expected to have negative influences on the availability of phosphorus and a number of micronutrients: cobalt, copper, iron, boron, manganese, and zinc (Pritchett and Fisher 1979). It is outside the optimum range of most plants (Christensen 1982).

The vegetation, belonging to the *Satureia peltieri* and *Ferula communis* association (Nègre 1956), is dominated by annuals, with some scattered stands of the shrub *Zyziphus lotus* L. Grasses (*Stipa retorta* Cav. , *Cynodon dactylon* (L.) Pers.) and legumes (*Medicago laciniata* (L.) Miller essentially) produce only 15 to 30% of the biomass. Forbs constitute the bulk of the production, with *Malva parviflora* L. prevailing on the upland site and *Asphodellus tenuifolius* Cav. on the swale.

Methods

The experimental design used in this study was a split plot (dictated by the land treatment) with two locations (upland site and swale site), three replications (blocks) in each location, two land treatments (chiselling and no chiselling) as main plots, and three S fertilization levels as subplots, 4 m by 6 m in size. Three types of measurements were monitored throughout the growing seasons of 1984/85 and 1985/86: infiltration, soil moisture, and peak season biomass production.

The land treatments, consisting of chiselling and control, were randomly distributed within repetitions. Chiselling, with a standard chisel-plow pulled by a tractor, was applied on September 25, 1984, perpendicularly to the greatest slope, to counter runoff. The timing coincided with the end of the annual long dry season, minimizing the compaction effect by the tractor and maximizing the efficiency of the operation. Chisels, set 15 cm apart, reached between 15- and 30-cm depth depending on the stoniness of the soil.

Sulfur treatments were randomly distributed within land treatments. Three levels (0, 30, and 60 kg ha^{-1}) of 93% pure elemental sulfur powder were applied with a hand-pushed spreader, in mixture with sand to facilitate the operation prior to chiselling. Elemental sulfur was chosen for its low cost and high acidifying power (Stroehlein and Pennington 1986). It was used in the powder form to speed up the oxidation of elemental S, which is mediated by soil microorganisms (Konopta <u>et al.</u> 1986).

Water infiltration was measured by a double-ring infiltrometer, with the position of the center of the rings randomly selected in each nonfertilized plot and each infiltration run. The open steel cylinders were 20-cm high with a 25-cm radius for the smaller ring and a 50-cm radius for the larger one. Both cylinders were concentrically placed and vertically driven into the soil to a depth of 10 cm, carefully to minimize soil disturbance. Well water was poured into the cylinders up to a height of 5 cm, over the palm of the hand to reduce soil disruption by the impact of water. As soon as the 5-cm level was reached, a chronometer was started (initial time), and five readings of time to the nearest second were made, one at each cm decrease of the water level in the inner cylinder. Water was added to the outer cylinder to keep it at the same level as the inner one. This action intended to reduce the lateral flow component in the inner ring (Swartzendruber and Olson 1961). Fourteen infiltration runs were carried out at monthly intervals during the two growing seasons. The measurements were used to calculate average infiltration rates and were fitted to Kostiakov's equation (1932) to derive instantaneous infiltration rates.

Soil water content, on weight basis, was monitored in all plots twice a month during the two growing seasons. For logistical reasons, measurements could not begin before March 1985 but were carried out regularly thereafter. In each plot and each run, a random soil sample was taken with a Belgian auger from 0- to 10-cm depth, and another from 10- to 20-cm depth. Soil samples were weighed, oven dried at 100 °C (Brady 1984), and weighed again to determine soil dry-mass water percentage. Peak season biomass production was determined at the end of each of the two growing seasons. The timings of the harvests were set according to the findings of a previous study by Gay et al. (1987), in the same site/exclosures, showing that maximum biomass production coincided with the fruit development of the dominant species (*Malva parviflora* L. and *Asphodellus tenuifolius* Cav. for the upland site and the swale site respectively). In each plot, two randomly selected 1 m^2 samples were clipped to the ground level. Plant material was then separated into three categories - grasses, legumes, and other forbs (referred to as forbs in this paper) - oven dried at 70 °C, and weighed to the nearest tenth of a gram to determine dry-matter yield.

The analysis of variance, developed from Cochran and Cox (1966), Ott (1988), and Gomez and Gomez (1984), was run for all data, and the least significant differences (LSDs) were calculated in case of significant differences between means. Analysis of variance tables are presented in Table 2.

Table 2
Analysis of Variance Tables for the
Statistical Analysis

Infiltration

Source of variation	DF[a]
Location (L)	1
Blocs within L	4
Chiselling (C)	1
L/[b]C	1
Error (1)	4
Time (T)	13
L/T	13
Error (2)	52
C/T	13
L/C/T	13
Error (3)	52
Total	167

Biomass production

Source of variation	DF
L	1
Blocs/L	4
C	1
L/C	1
Error (1)	4
Sulfur (S)	2
L/S	2
C/S	2
L/C/S	2
Error (2)	16
Year (Y)	1
L/Y	1
Error (3)	4
C/Y	1
S/Y	2
C/S/Y	2
L/C/Y	1
L/S/Y	2
L/C/S/Y	2
Error (4)	19
Sampling	72
Total	143

Soil water content

Source of variation	DF
L	1
Blocs/L	4
C	1
L/C	1
Error (1)	4
S	2
L/S	2
C/S	2
L/C/S	2
Error (2)	16
Depth (D)	1
L/D	1
C/D	1
S/D	2
C/S/D	2
L/C/D	1
L/S/D	2
L/C/S/D	2
Error (3)	24
Time (T)	23
L/T	23
Error (4)	92
C/T	23
S/T	46
C/S/T	46
D/T	23
C/D/T	23
S/D/T	46
C/D/S/T	46
L/C/T	23
L/S/T	46
L/C/S/T	46
L/D/T	23
L/C/D/T	23
L/S/D/T	46
L/C/D/S/T	46
Error(5)	1012
Total	1727

[a]Degrees of freedom
[b]The slash (/) refers to interaction

REVIEW OF RELATED LITERATURE

Effects of Chiselling

Mechanical treatments are important tools of range improvement (Vallentine 1980, Stoddart *et al.* 1975). Chiselling is one of the techniques that received special attention because of its reduced disruptive action on surface horizons. The benefits, increased forage production, beneficial shifts in plant composition, and erosion control (Vallentine 1980), are expected to result from an improvement of infiltration and water storage and from a facilitation of root growth by increasing soil surface macroporosity and fracturing a less permeable soil layer.

In Arizona, Brown and Everson (1952) reported 2.5-times higher forage production in ripped furrows ten years after ripping. They also noted earlier growth and a shift in botanical composition in addition to higher seed production of grasses. In New Mexico, deep chiselling was efficient in reducing runoff and increasing forage production (Aldon and Garcia 1972), although the effects weakened with time. In a four-year study on Wyoming short grass prairie, Griffith *et al.* (1984) also found that chiselling increased total production with a positive shift in botanical composition. The main beneficiary from the disturbance, the rhizomatous western wheatgrass, brought a substantial increase in the carrying capacity (1.3 to 4.8 times). Five years after the treatment, the ridges were still 50% intact. In their conclusion, Griffith et al. (1984) recommended chiselling over contour furrowing for the studied area.

Increased forage production and favorable shifts in species composition in response to chiselling have also been found by Shuman and Rauzi (1985). Western wheatgrass increased by 2 to 3.6 times in the treated plots. Forbs, benefiting from the improvement of moisture conditions and the void created by the disturbance, increased their forage production five fold before falling back with time.

Langdale et al. (1983) reported higher infiltration rates in in-raw chiselled treatments versus conventional tillage. In-raw chisel-planted soybeans in rye residues controlled runoff when soil water content was less than 8.7%. Runoff was also reported to be influenced by slope and cover.

Sulfur fertilization

The use of high synthesis fertilizers, the trend toward less pollutant industry, and the increase of crop productivity in the last decades have been reducing incidental S fertilization and atmospheric S depositions, while increasing S export from soil. This has resulted in S deficiencies worldwide, and in the revival of the importance of S as major plant nutrient (Duke and Reisenauer 1986). Component of three essential amino acids (cysteine, methionine, and sulfoquinovosyldiglyceride) as well as of a number of other important compounds such as enzymes and vitamins (Thompson et al. 1986), sulfur must be provided for plants to adequately grow and produce.

A number of S fertilization studies reported increases of yield and/or quality of a number of plant species (Stevens and Watson 1986, Buttrey et al. 1987, Rahman et al. 1988, Aulakh et al. 1989, Nichols et al. 1990). Positive responses are, however, bound to S deficient soils with low atmospheric S depositions, and are more likely where other nutrients are not more limiting than S. Coarse soil texture, low organic matter content, and prolonged periods of leaching appear to be associated with S deficiency (Islam et al. 1986, Arora and Takar 1988). The problem of S fertilization is complicated by the facts that sulfate uptake was reported to be high at low S concentrations in soil, and that species and cultivars have differential S needs that vary during the growing season (Duke and Reisenauer 1986). Legumes are particularly sensitive to S deficiency resulting in poor nitrogen fixation (Munson 1982). Sulfur response may also be influenced by the method of S application, with S broadcast more efficient than deep placement (Blair 1987).

In a pasture fertilized with P and K and seeded one part to subclover and the other to ryegrass, Jones et al. (1982) found that forage yield, S concentration in forages, and average daily weight gain of lambs responded positively to S fertilization. The efficiency of feed increased from 48 to 18 kg of forage kg^{-1} of gain for ryegrass, but only from 11 to 9 kg for subclover, showing substantial qualitative improvement of the grass. Weight gain increases were also reported earlier in steers by Green et al. (1958), who related the gain to an increase in crude protein, phosphorus, and calcium contents in forage, resulting from a favorable shift in species composition. In a two year study, Shock et al. (1983) showed a significant yield increase in response to 74 kg S ha^{-1} with a shift in species composition favoring the legume subclover in its mixture with filaree and soft chess. Positive legume and grass (Cenchrus ciliaris) responses were also reported by Gill et al. (1986).

Other workers failed to show yield responses to S fertilization. In a study involving five different sites on brown forest soils with ryegrass pastures in Southern Scotland, Keer et al. (1986) found no significant dry matter increase with 50 to 160 kg ha^{-1} S fertilization and suggested that atmospheric deposition supplied enough S. Sulfur concentration in grasses did, however, respond positively. On fine sand in Florida, Mitchell and Blue (1989) found that bahiagrass dry matter yield did not respond to S applications up to 40 kg ha^{-1} before the fourth year at a 200 kg ha^{-1} N fertilization level, but did respond earlier at an N level of 400 kg ha^{-1}. The delay in response was not observed in the average S concentration in the plant, though S concentration decreased with the growing season, like N concentration.

In California annual grasses, striking results have been reported. Bentley et al. (1958) reported an increase in total biomass in response to 67 and 45 kg ha^{-1} of elemental S application after the first year for legumes and after the second for grasses, while forbs were depressed. They related the lack of response of legumes in the first year to insufficient rain and the increase of grasses from the third year on to N fixation by legumes. Sulfur fertilization, however, had to be continued in order to maintain the increase in production. The latter was more pronounced on the better site. Caldwell et al. (1985) failed to show any significant yield responses, but found significant shifts in botanical composition, with an increase of grasses and legumes (in the wet year) mostly in the seventh and eighth year of the experiment. Response was more likely on the coarse and nutrient limiting upland sites than on the wetter swale.

In calcareous soils, S has been successfully used to reduce the pH and increase the availability of a number of nutrients (P, Fe, Zn, Mn). Sahu and Singh (1987) showed an increase in chlorophyll a and b and of N, K, and S concentrations in the plant following application of 250 kg ha^{-1} of elemental S, and suggested that S fertilization balanced the nutritional conditions. Using 500 and 1500 ppm S application, Yousry et al. (1984), decreased the pH from 8.4 to 8.1 and showed an increase in soluble P, Fe, Mn, and Zn. Similar results concerning Fe, Mn, and Zn were found by Dawood et al. (1986) after eight weeks incubation, but the increase was only temporary. Dawood (1990) found that soil sulfate content increased while $CaCO_3$ content decreased with increasing S application levels and incubation time. The decrease of $CaCO_3$ content and pH were also noted by Abo-Radi and Nabulsi (1989), who found an increase of P solubility in the soil and of N, S, and P in plant tissue in a green house experiment with barley. Plant growth was improved at 200, 400, and 600 ppm application rates, but was retarded at higher levels.

One of the problems with calcareous soil amendments is the need for high inputs of S. Badr El-Din et al. (1981) found a significant increase of broad bean (Vicia faba) dry weight with 776 kg S ha^{-1}, but no increase with half of that dose. P uptake, however, was improved in both cases. There was no carry-over on the succeeding corn crop, except for dry matter at the higher S application. To reduce the application level and still receive some benefits, some workers used band application. Clement (1978) found an increased P uptake in lettuce and a decreased soil pH in response to 168 kg and 336 kg elemental S ha^{-1} applied in simulated bands. The soil with the highest pH gave the least increase in biomass. The usefulness of band application was also reported by DeLuca et al. (1989) who obtained an improvement of phosphorus nutrition, and by Kidder et al. (1990), who found no spreading of the acidifying effect.

Infiltration Measurements with Double-Ring Infiltrometers

Infiltration measurements involve tracing the quantity of water that enters the soil with time. Initial infiltration rates are usually high, and decrease with time to reach more or less constant values, the steady state infiltration rates (Johnson 1963). Most infiltration studies use steady state infiltration rates, particularly for irrigation purposes. In arid climates, however, steady state infiltration rates may not occur naturally very frequently because of the limited rainfall, and because rain events are often separated by periods of drought (Ben-Hur and Shainberg 1989).

Because of their simplicity and low sampling errors (Julander and Jackson 1983), ponding infiltrometers are widely used in characterizing water infiltration of soils. One of the strongest criticisms of ponding devices is the poor simulation of infiltration under rain due to the lack of rain drop impact, which has been shown to affect infiltration by disintegrating soil surface aggregates, leading to seal formation (Ben-Hur and Shainberg 1989, Helalia et al. 1988). Rain drop impact, however, is affected by soil texture and can be reduced by residue and vegetation (Zuzel 1990). For comparison purposes there seems to be a wide acceptance for the use of ponding infiltrometers (Amerman 1983, Matula and Dirksen 1989).

With no rain drop effect and with a permanent head of water over the whole infiltrating surface, ponding devices usually give much higher infiltration rates than rain simulators (Sidiras and Roth 1987, Freebairn et al. 1989). There are, however, counter examples where no significant differences between the two techniques could be proven (Julander and Jackson 1983, Amerman 1983). This is more likely under stable soil surface conditions.

RESULTS AND DISCUSSION

Rainfall conditions

Rainfall conditions were very different during the two studied growing seasons (Fig. 1), reflecting the high variability in the area. Rainfall started earlier in 1984/85, which is a big advantage under Mediterranean climate, allowing germination and growth before less favorable temperatures arrive. The first growing season had a very moist early winter followed by a pronounced drought in late winter/early spring, a critical period for plant growth. Rainfall in the second growing season was more evenly distributed and higher in amount, although a large portion of it (around 100 mm) came too late to benefit plant growth.

Infiltration

The time required for the infiltration of 5 cm of water averaged 24 min, 07 s, with 9 min, 32 s and 31 min, 38 s as lower and upper quartiles respectively, and 2 min, 00 s and 1 h, 44 min, 37 s as extremes. As consequence, infiltration values were generally far from the steady state, and could only characterize the early stages of the infiltration event. Kostiakov's equation (1932) fitted the data relatively well (correlation coefficient values above 0.97), except for some very short cumulative infiltration times, where infiltration rates sometimes increased with

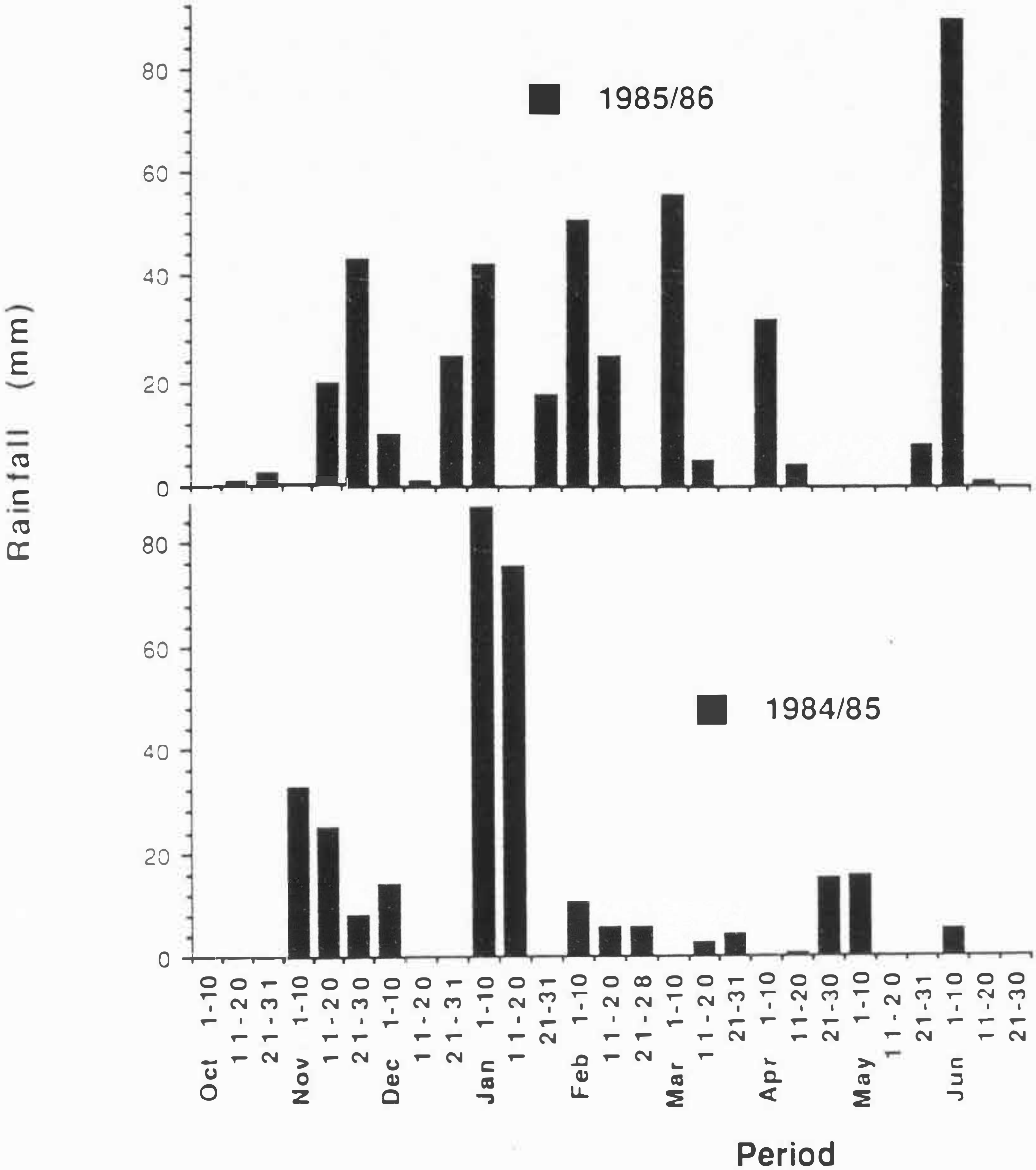

Figure 1. Rainfall data by 10 day periods in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

The data for April to June 1986 were not available on the study sites. For this period, averages from the weather stations of Beni Mellal, Kasbah Tadla, and Boujaad (Meteorologie Nationale, Morocco) were presented.

increasing time, probably because of preferential flow through cracks. Two solutions have been presented for this problem: (1) use instantaneous infiltration rates at an early phase of the infiltration events (15 min) in order to keep the predictions inside or as close as possible to the range of measurements and (2) concurrently use other variables, namely average infiltration rates for 5 cm of water and average infiltration rates between the two time readings before the last. The last variable was preferred to the average infiltration rate between the two last readings because it was less affected by the reading error.

The analysis of variance showed significant effects of location (0.01 level), chiselling (0.001 level), and their interactions (0.01 level), and no significant interactions involving time for all the three types of infiltration rates (Tables 3-5). The simple effect of time was significant (0.01 level) for average infiltration rates of 5 cm water depth and not for the other variables.

Chiselling significantly improved infiltration. The high density of furrows was probably one of the keys for this result. The two sites did not respond to chiselling in the same way. The increase of infiltration on the swale was much superior to that on the upland (Fig. 2). There are at least two plausible explanations for this difference, both of them related to soil texture: (1) The depth of chiselling was higher in the less stony swale

Table 3
Effect of Chiselling on 15 min Infiltration Rates ($cm\ min^{-1}$) as Affected by Location and Time

Sampling date	Upland			Swale			Average		
	Chiselling								
	yes	no	Avg.	yes	no	Avg.	yes	no	Avg.
Growing season 1984/85									
17 Dec	.21	.12	.17	2.48	.09	1.28	1.35	.10	.72
21 Jan	.22	.09	.15	.43	.08	.26	.32	.09	.20
15 Feb	.43	.22	.33	1.73	.23	.98	1.08	.22	.65
15 Mar	.24	.12	.18	.70	.17	.43	.47	.14	.31
15 Apr	.37	.17	.27	.63	.19	.41	.50	.18	.34
15 May	.52	.20	.36	1.35	.18	.77	.93	.19	.56
Growing season 1985/86									
25 Oct	.74	.22	.48	.83	.23	.54	.79	.23	.51
14 Nov	.23	.15	.19	.96	.16	.56	.59	.16	.38
16 Dec	.23	.13	.18	.82	.12	.47	.53	.12	.33
15 Jan	.26	.09	.17	.26	.16	.21	.26	.12	.19
21 Feb	.21	.09	.15	.53	.07	.30	.37	.79	.22
14 Mar	.15	.14	.14	.99	.09	.54	.57	.11	.34
17 Apr	.30	.17	.24	.72	.16	.44	.51	.17	.34
15 May	.24	.22	.23	.53	.24	.39	.39	.23	.31
Average	.31	.15	.23	.93	.15	.54	.62	.15	.39

Location significant ($\underline{p}^a = 0.0033$)
Chiselling significant ($\underline{p} < 0.001$)
$LSD_{0.05}$: 0.08
Location/Chiseling/significant ($\underline{p} < 0.001$)
$LSD_{0.05}$ Chiselling within Location: 0.12
Location within Chiselling: 0.12

[a]Probability value

Table 4
Effect of Chiselling on Average Infiltration Rates (cm min^{-1}) Between the Two Readings Before the Last as Affected by Location and Time

Sampling date	Upland			Swale			Average		
	Chiselling								
	yes	no	Avg.	yes	no	Avg.	yes	no	Avg.
17 Dec 84	.29	.11	.20	.15	.08	.80	.90	.09	.50
21 Jan 85	.22	.09	.15	.73	.07	.40	.47	.08	.28
15 Feb	.49	.31	.40	1.50	.27	.88	.99	.29	.64
15 Mar	.31	.13	.22	2.41	.19	.13	1.36	.16	.76
15 Apr	.56	.15	.36	.65	.24	.45	.61	.19	.40
15 May	.45	.21	.33	1.39	.21	.80	.92	.21	.56
5 Oct	.96	.26	.61	.74	.23	.49	.85	.24	.55
14 Nov	.24	.20	.22	.16	.22	.90	.90	.21	.56
16 Dec	.24	.14	.19	.69	.16	.43	.47	.15	.31
15 Jan 86	.34	.08	.21	.28	.15	.21	.31	.11	.21
21 Feb	.20	.08	.14	.67	.06	.37	.43	.07	.25
14 Mar	.15	.13	.14	.37	.09	.23	.26	.11	.18
17 Apr	.43	.22	.32	.55	.23	.39	.49	.23	.36
15 May	.62	.31	.46	.60	.36	.48	.61	.33	.47
Average	.39	.17	.28	.98	.18	.58	.68	.18	.43

Location significant ($\underline{p} < 0.001$)
Chiselling significant ($\underline{p} < 0.001$)
$LSD_{0.05}$: 0.06
Location/Chiselling significant ($\underline{p} < 0.001$)
$LSD_{0.05}$ Chiselling within Location: 0.09
Location within Chiselling: 0.10

Table 5
Effect of Chiselling on Average Infiltration Rates (cm min^{-1}) of 5 cm of Water as Affected by Location and Time

Sampling date	Upland			Swale			Average		
	Chiselling								
	yes	no	Avg.	yes	no	Avg.	yes	no	Avg.
Growing season 1984/85									
17 Dec	.32	.16	.24	1.08	.09	.59	.70	.12	.41
21 Jan	.29	.10	.20	.73	.08	.41	.51	.09	.30
15 Feb	.51	.37	.44	.75	.22	.49	.63	.30	.47
15 Mar	.41	.14	.27	.16	.22	.92	1.02	.18	.60
15 Apr	.42	.19	.30	.73	.21	.47	.58	.20	.39
15 May	.49	.24	.37	1.29	.21	.75	.89	.22	.56
Growing season 1985/86									
25 Oct	.51	.28	.40	.79	.26	.53	.65	.27	.46
14 Nov	.33	.17	.25	1.03	.18	.60	.68	.17	.43
16 Dec	.28	.16	.22	.42	.13	.28	.35	.15	.25
15 Jan	.34	.09	.22	.29	.17	.23	.31	.13	.22
21 Feb	.27	.09	.18	.74	.07	.41	.51	.08	.29
14 Mar	.21	.16	.18	.38	.09	.24	.29	.13	.21
17 Apr	.58	.24	.41	.77	.21	.49	.67	.22	.45
15 May	.82	.29	.55	.70	.29	.50	.76	.29	.52
Average	.41	.19	.30	.81	.17	.49	.61	.18	.40

Location significant ($\underline{p}$ = 0.0061)
Chiselling significant ($\underline{p}$ < 0.001)
    $LSD_{0.05}$: 0.10
Location/Chiselling significant ($\underline{p}$ = 0.0045)
    $LSD_{0.05}$ Chiselling within Location: 0.14
        Location within Chiselling: 0.12
Time significant ($\underline{p}$ < 0.01)
    $LSD_{0.05}$: 0.22

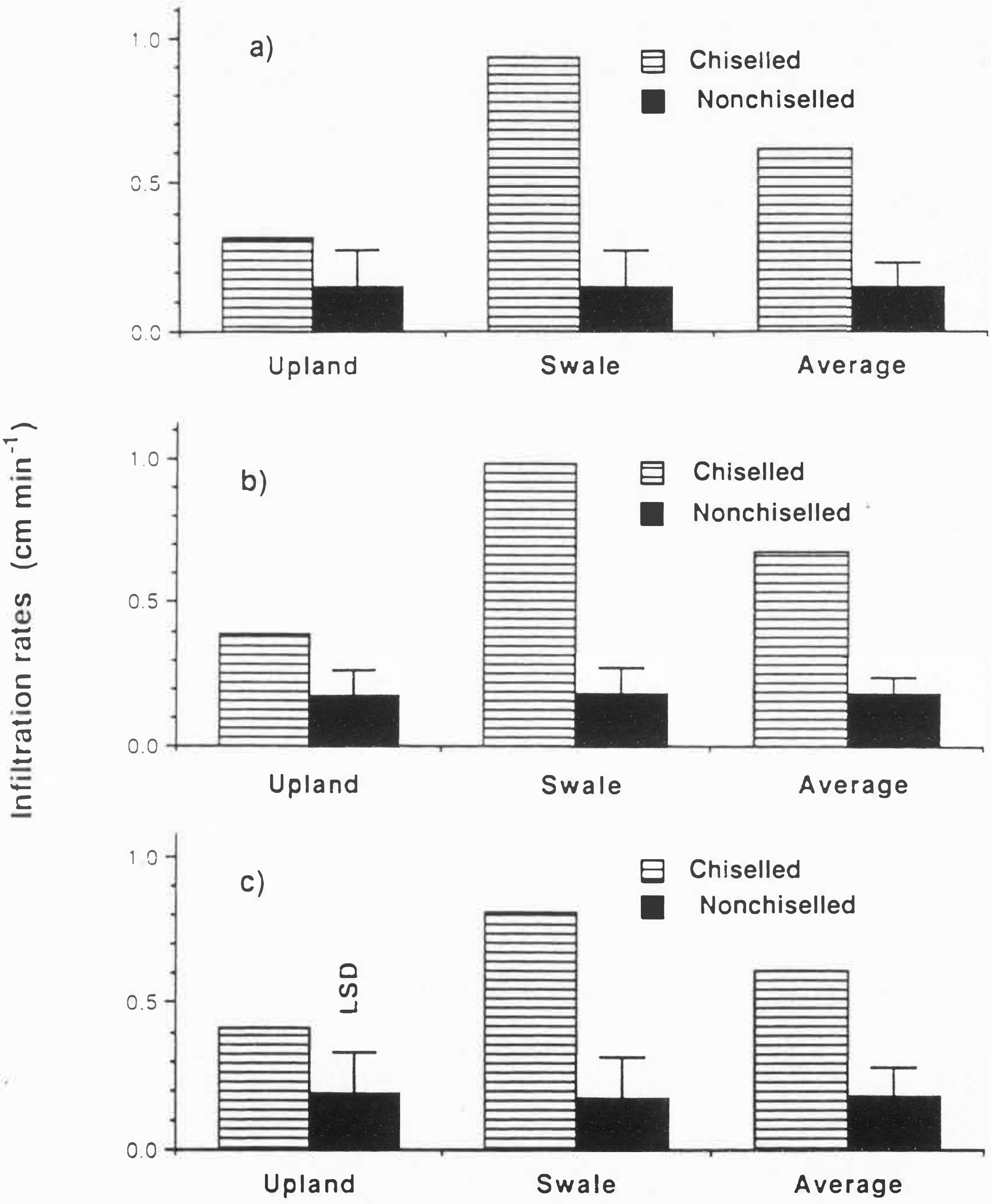

Figure 2. Effect of chiselling on infiltration in the Ait Rbaa Perimeter: (a) 15 min infiltration rates, (b) average infiltration rates between the two readings before the last, and (c) average infiltration rates of 5 cm of water.

site. Depth of tillage was found to be positively correlated with infiltration (Rahman and Islam 1989). And (2) the higher clay content on the swale gave the ridges more stability, as could be noticed by visual observations, even after the end of the second year. Ridges are known to capture runoff water and to increase infiltration surface as well as water storage (White 1986). The high variability (coefficient of variation up to 179%) prevented getting enough evidence to reject the equality of infiltration means involving time. The only exception was the significant effect of time on the average infiltration rates of 5 cm of water, which had the least coefficient of variation of the three analyzed variables (66%). The average infiltration rates of 5 cm water depth was more likely to show differences because of the effects of initial infiltration rates (Rahman and Islam 1989). Average infiltration rates increased in periods of prolonged droughts, and decreased under moist conditions (Fig. 3).

The variation of infiltration with sampling time is mainly due to differences in initial moisture content (Hino et al. 1987, Hino et al. 1988). Other reasons may account for the variation of infiltration rates with time: the speed of organic matter decomposition as affected by temperature and moisture (Meek et al. 1989), soil structure improvement by wetting and drying cycles (Blackwell et al.

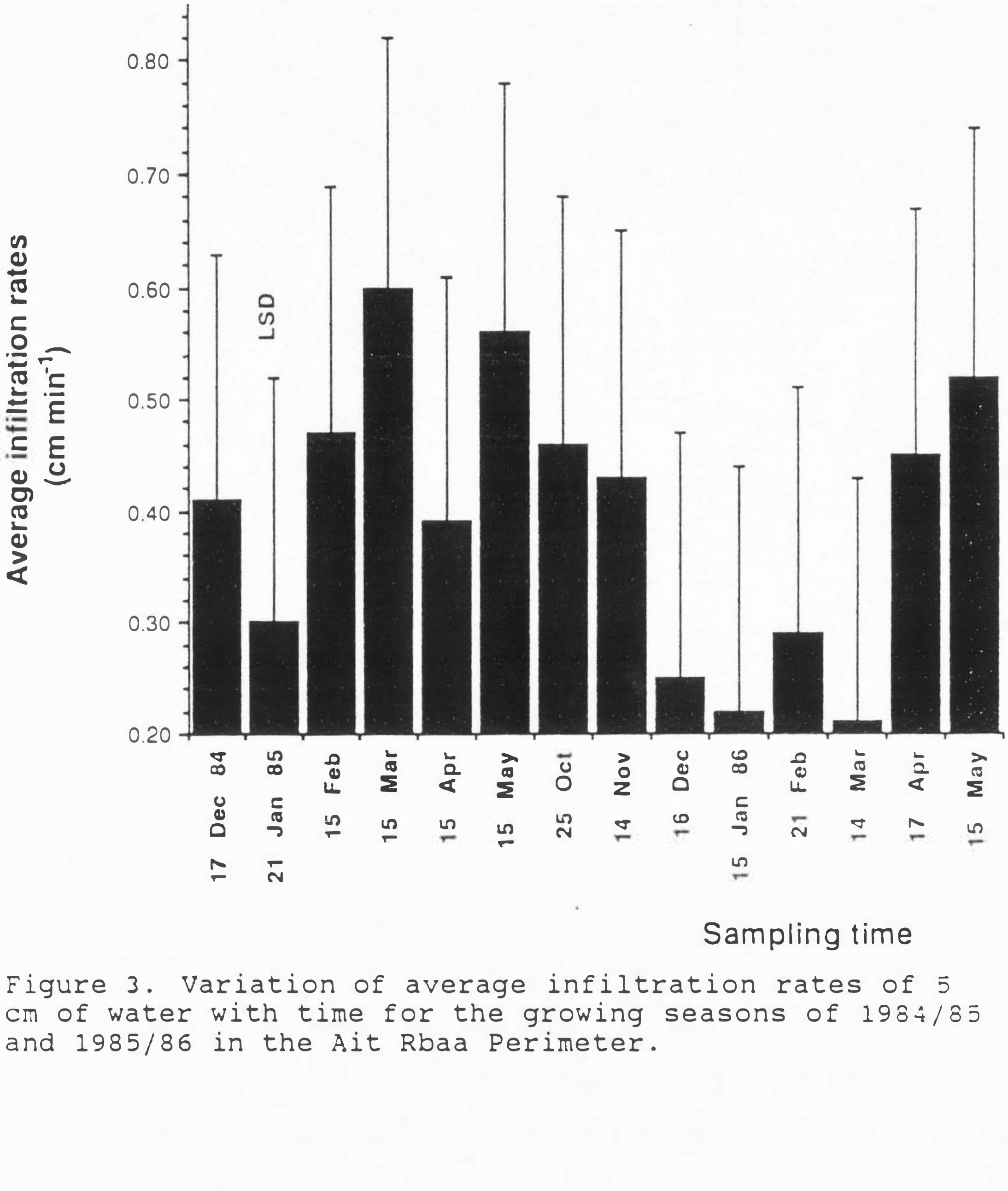

Figure 3. Variation of average infiltration rates of 5 cm of water with time for the growing seasons of 1984/85 and 1985/86 in the Ait Rbaa Perimeter.

1985, Reid and Parkinson 1984), differential mulch and standing vegetation (Rauzi 1960, Meeuwig 1970).

Soil water content

The overall effect of chiselling on soil moisture was highly significant (0.001 level). Chiselling improved average dry mass water percentage in the 0- to 20-cm surface layer by 10% (Table 6). This finding is consistent with the average effect of chiselling on infiltration. The consistency, however, did not hold for the interaction location/chiselling which was also significant (0.05 level). Although infiltration was improved more on the swale site than on the upland site, the latter had higher gain in soil moisture: 14% on the upland against only 7% on the swale (Fig. 4a). Three possible causes may account for this apparent discrepancy: (1) the greater slope of the upland site was more conducive to runoff, so that there was more water available for improved infiltration to be effective, everything kept equal; (2) because of the deeper and more efficient ridges, there may have been more dilution effect on the swale site with more water reaching the non-sampled deeper soil layers; and (3) the swale site may have lost more water by evapo-transpiration in the case of higher biomass (McKell et al. 1959) or less water use efficient species. For water holding capacity, the finer texture of the swale site could have been partially

Table 6
Effect of Chiselling and Sulfur Application (kg ha^{-1}) on Soil Water Content (%) on a Mass Basis as Affected by Location and Soil Depth (cm)

Sulfur	Nonchiselled			Chiselled			Averages		
/Depth	0-10	10-20	0-20	0-10	10-20	0-20	0-10	10-20	0-20
Upland site									
0	10.2	10.2	10.2	11.8	11.3	11.5	11.0	10.7	10.9
30	10.1	10.3	10.2	12.2	10.9	11.6	11.2	10.6	10.9
60	10.6	10.0	10.3	12.0	11.4	11.7	11.3	10.7	11.0
Avg.	10.3	10.2	10.2	12.0	11.2	11.6	11.2	10.7	10.9
Swale site									
0	10.5	10.5	10.5	11.1	11.6	11.3	10.8	11.0	10.9
30	11.0	10.8	10.9	10.9	11.4	11.2	10.9	11.1	11.0
60	10.5	10.4	10.4	11.2	11.5	11.3	10.9	10.9	10.9
Avg.	10.6	10.6	10.6	11.1	11.5	11.3	10.9	11.0	10.9
Average of the two sites									
0	10.3	10.4	10.3	11.4	11.4	11.4	10.9	10.9	10.9
30	10.5	10.6	10.5	11.6	11.2	11.4	11.1	10.9	11.0
60	10.6	10.2	10.4	11.6	11.4	11.5	11.1	10.8	10.9
Avg.	10.5	10.4	10.4	11.5	11.3	11.4	11.0	10.8	10.9

Chiselling significant ($p < 0.001$)
$LSD_{0.05}$: 0.3
Location/Chiselling significant ($p = 0.045$)
$LSD_{0.05}$ Chiselling within Location: 0.5
Location/depth significant ($p < 0.001$)
$LSD_{0.05}$ Depth within Location: 0.2
Location/Chiselling/Depth significant ($p = 0.0016$)
$LSD_{0.05}$ Chiselling within Depth and Location: 1.0
Depth within Chiselling and Location: 0.3

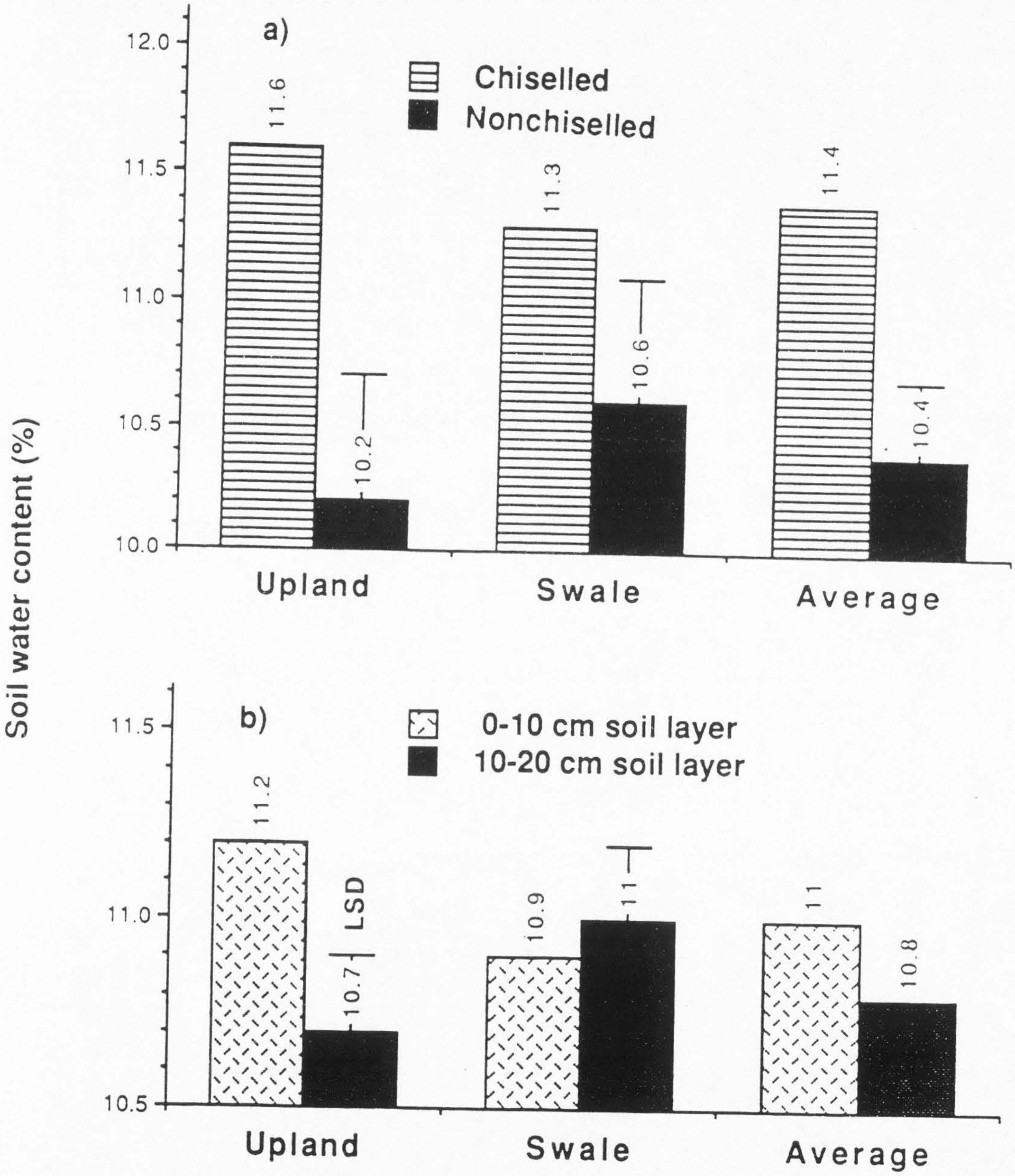

Figure 4. Effects of chiselling and soil depth on average soil water content on a mass basis in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86: (a) effect of chiselling and (b) effect of soil depth.

balanced by the higher organic matter content on the upland (Martinez Cortizas 1988).

Average water contents significantly (0.05 level) varied with depth and location. Soil water content decreased with depth on the upland site, but not on the swale site (Fig. 4b). The three way interaction location/chiselling/depth was highly significant (0.001 level). Chiselling substantially improved soil water content in the 0- to 10-cm soil layer of the upland site (Fig. 5a). Average water contents of the 0- to 10-cm and 10- to 20-cm layers were similar in both locations under no chiselling, while different in the chiselled treatments, with a decrease of water content with depth on the shallower upland site and an increase with depth on the swale site (Fig. 5b). This could be related once more to the differences in texture and chiselling depth. The 10- to 20-cm layer of the upland site, having 5% less clay, and 4% more coarse sand (0.2- to 2.0-mm diameter), offered less water holding capacity than that of the swale. Moreover, the more stable and deeper ridges of the swale site allowed water to reach deeper layers more quickly and more efficiently.

High significance (0.001) was also found for the simple effect time as well as for the interactions chiselling/time and location/chiselling/time (Table 7). Soil moisture varied with time (Fig. 6) as a function of

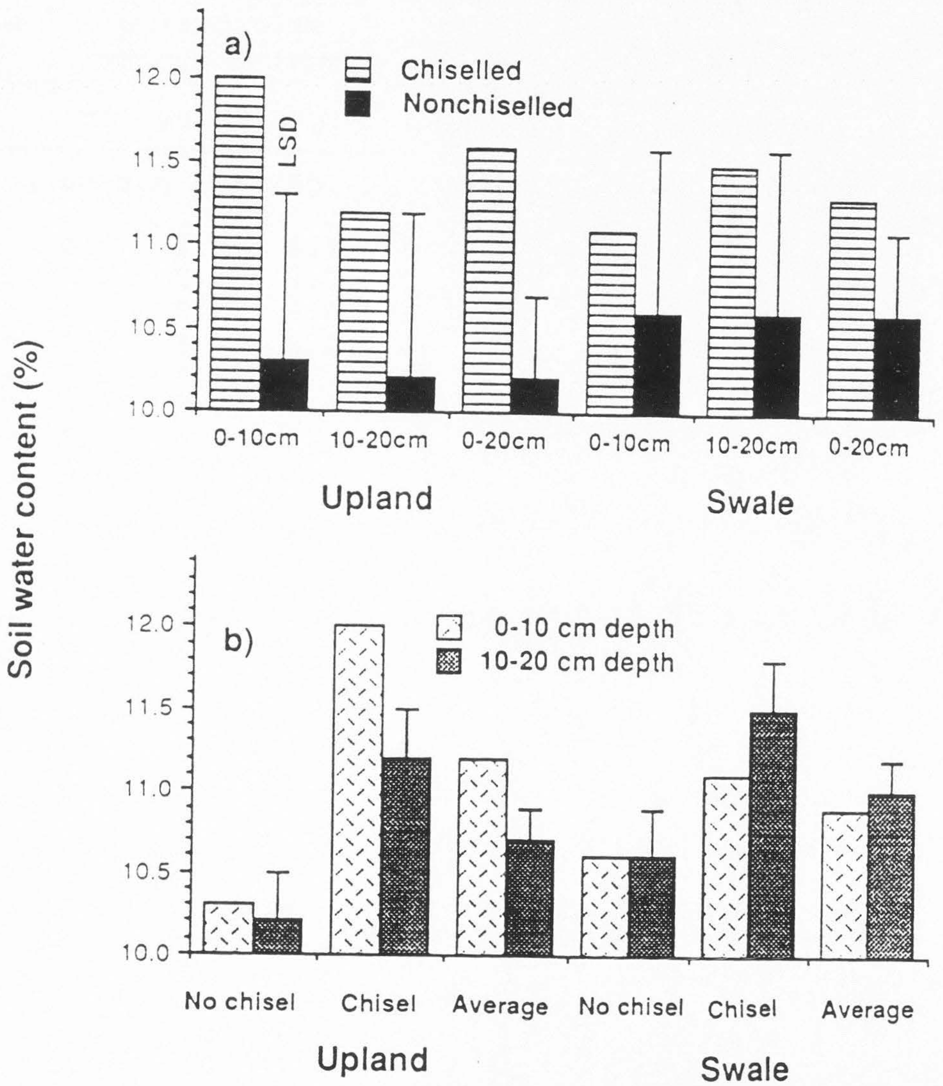

Figure 5. Effects of chiselling and soil depth on soil water content on a mass basis in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86: (a) chiselling within the same depth and location and (b) depth within the same land treatment and location.

Table 7
Effect of Chiselling on Soil Water Content (%) on a Mass Basis as Affected by Location and Time

Date of Sampling	Upland site			Swale site			Average		
	Chiselling								
	no	yes	Avg.	no	yes	Avg.	no	yes	Avg.
Growing season 1984/85									
8 Mar	8.5	9.7	9.1	8.7	9.6	9.2	8.6	9.7	9.1
23 Mar	7.1	8.4	7.7	7.3	8.5	7.9	7.2	8.4	7.8
5 Apr	6.1	6.7	6.4	6.0	7.3	6.6	6.0	7.0	6.5
19 Apr	1.6	2.4	2.0	2.0	3.1	2.5	1.8	2.7	2.3
3 May	7.6	7.6	7.6	8.1	7.9	8.0	7.9	7.8	7.8
17 May	7.9	7.0	7.4	8.6	7.9	8.2	8.2	7.4	7.8
31 May	4.8	6.3	5.5	5.1	6.8	6.0	5.0	6.6	5.8
14 Jun	1.9	2.9	2.4	3.0	4.5	3.7	2.5	3.7	3.1
Growing season 1985/85									
25 Oct	3.8	4.0	3.9	4.0	4.6	4.3	3.9	4.3	4.1
15 Nov	4.5	4.1	4.3	4.7	5.6	5.1	4.6	4.8	4.7
29 Nov	17.9	20.7	19.3	18.0	18.3	18.2	18.0	19.5	18.7
13 Dec	14.5	17.7	16.1	15.5	15.9	15.7	15.0	16.8	15.9
28 Dec	9.9	11.6	10.7	9.7	10.1	9.9	9.8	10.8	10.3
9 Jan	18.7	20.6	19.6	18.8	20.2	19.5	18.8	20.4	19.6
24 Jan	11.9	14.1	13.0	11.9	11.3	11.6	11.9	12.7	12.3
7 Feb	20.8	21.1	20.9	22.0	22.8	22.4	21.4	22.0	21.7
21 Feb	19.4	20.2	19.8	20.1	20.9	20.5	19.8	20.6	20.2
7 Mar	18.0	19.9	19.0	19.0	19.4	19.2	18.5	19.7	19.1
21 Mar	14.0	15.9	14.9	12.9	13.4	13.2	13.4	14.6	14.0
4 Apr	14.5	15.7	15.1	14.3	14.6	14.4	14.4	15.1	14.8
18 Apr	11.3	14.5	12.9	12.4	13.4	12.9	11.8	13.9	12.9
2 May	4.7	6.5	5.6	6.7	8.1	7.4	5.7	7.3	6.5
16 May	5.6	6.8	6.2	5.7	5.9	5.8	5.7	6.4	6.0
30 May	10.8	13.9	12.4	9.9	10.4	10.1	10.3	12.2	11.3

Time significant ($p < 0.001$)
$LSD_{0.05}$: 0.7
Location/Time significant ($p < 0.001$)
Chiselling/Time significant ($p < 0.001$)
$LSD_{0.05}$ Chiselling within Time: 1.2
Location/Chiselling/Time significant ($p < 0.001$)
$LSD_{0.05}$ Chiselling within Time and Location: 1.6

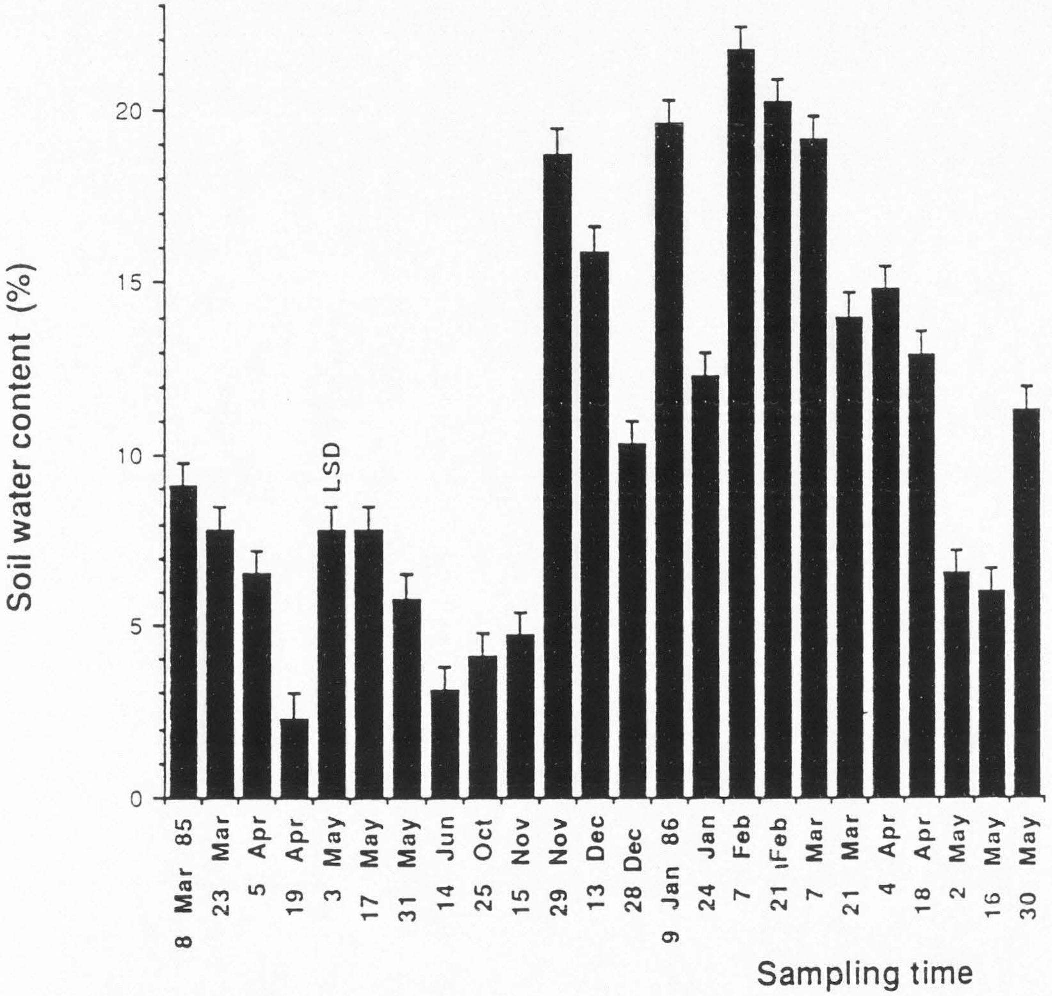

Figure 6. Variation of soil water content on a mass basis with time in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

the inputs by rain and the outputs by evapo-transpiration and drainage. The effect of chiselling on soil water content varied with sampling time. Chiselled treatments had higher water content in 13 out of 24 sampling dates. The increase of soil water content due to chiselling was much more frequent on the upland site than on the swale (Fig. 7). This was consistent with the differential average gain in moisture in the sampled depths.

Another highly significant (0.001) three way interaction was location/depth/time. Soil water content varied with depth and sampling date (Table 8 and Fig. 8). The general tendency was an increase with depth when there was little or no rain in the two weeks before measurement and a decrease in the opposite case. The surface layer is the first to receive water from rainfall, and the one that loses water first because of direct exposure to evaporation and higher rooting density. The increase of soil moisture with depth occurred more frequently on the swale site than on the upland, due to higher infiltration rates.

Interactions involving soil water content are complicated by the characteristics of rainfall events and are confounded by vegetation effects. On the one hand, the benefits from improved infiltration can be fruitful only if rainfall intensity exceeds the infiltration rate of the control and the soil water content is less than the water holding capacity of the treatment. On the other hand, a

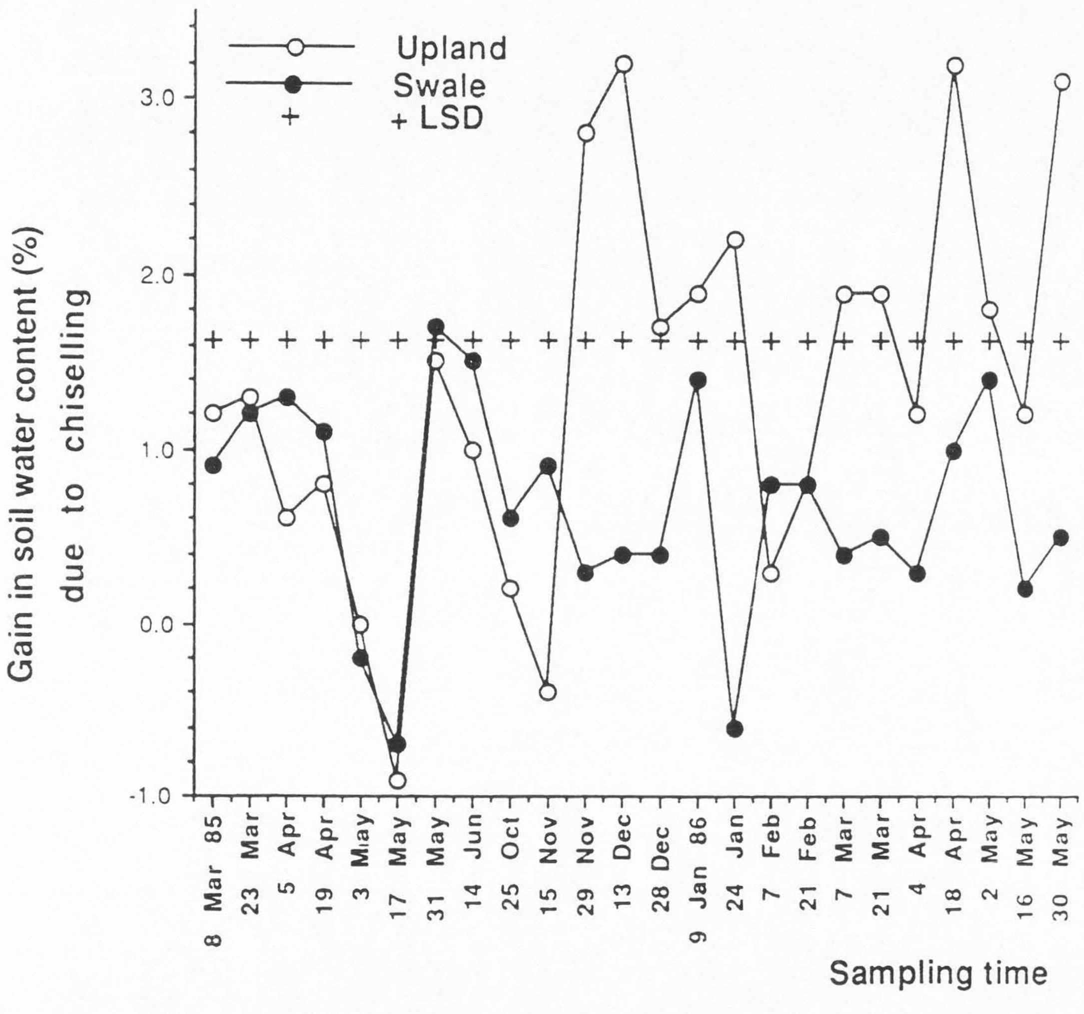

Figure 7. Effect of chiselling on soil water content on a mass basis as affected by time and location in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

Table 8
Variation of Soil Water Content (%) on a Mass Basis with Location, Soil Depth (cm), and Time

Date of	Upland site		Swale site		Average	
sampling	0-10	10-20	0-10	10-20	0-10	10-20
Growing season 1984/85						
8 Mar	8.4	9.8	8.5	9.9	8.4	9.8
23 Mar	6.9	8.5	6.7	9.1	6.8	8.8
5 Apr	5.6	7.2	7.4	5.8	6.5	6.5
19 Apr	1.8	2.3	1.1	3.9	1.5	3.1
3 May	8.1	7.1	8.7	7.3	8.4	7.2
17 May	6.2	8.6	6.5	10.0	6.4	9.3
31 May	5.4	5.7	4.3	7.7	4.8	6.7
14 Jun	1.9	3.0	2.7	4.7	2.3	3.8
Growing season 1985/85						
25 Oct	4.4	3.4	5.0	3.6	4.7	3.5
15 Nov	5.1	3.4	6.4	3.8	5.7	3.6
29 Nov	20.4	18.2	19.0	17.4	19.7	17.8
13 Dec	17.3	14.9	16.9	14.5	17.1	14.7
28 Dec	10.8	10.6	8.8	11.0	9.8	10.8
9 Jan	20.5	18.7	20.4	18.6	20.5	18.7
24 Jan	12.3	13.6	10.7	12.7	11.4	13.1
7 Feb	23.0	18.9	23.2	21.6	23.1	20.3
21 Feb	19.8	19.8	21.4	19.7	20.6	19.8
7 Mar	20.3	17.6	20.2	18.2	20.3	17.9
21 Mar	14.7	15.1	12.3	14.0	13.5	14.6
4 Apr	17.6	12.6	17.7	11.1	17.7	11.9
18 Apr	13.8	12.1	12.8	13.0	13.3	12.5
2 May	5.5	5.7	6.0	8.8	5.7	7.3
16 May	5.5	7.0	5.0	6.7	5.2	6.8
30 May	12.2	12.5	9.2	11.1	10.7	11.8

Depth/time significant ($\underline{p} < 0.001$)
$LSD_{0.05}$ Depth within Time: 0.9
Location/Depth/Time significant ($\underline{p} < 0.001$)
$LSD_{0.05}$ Depth within Time and Location: 1.2

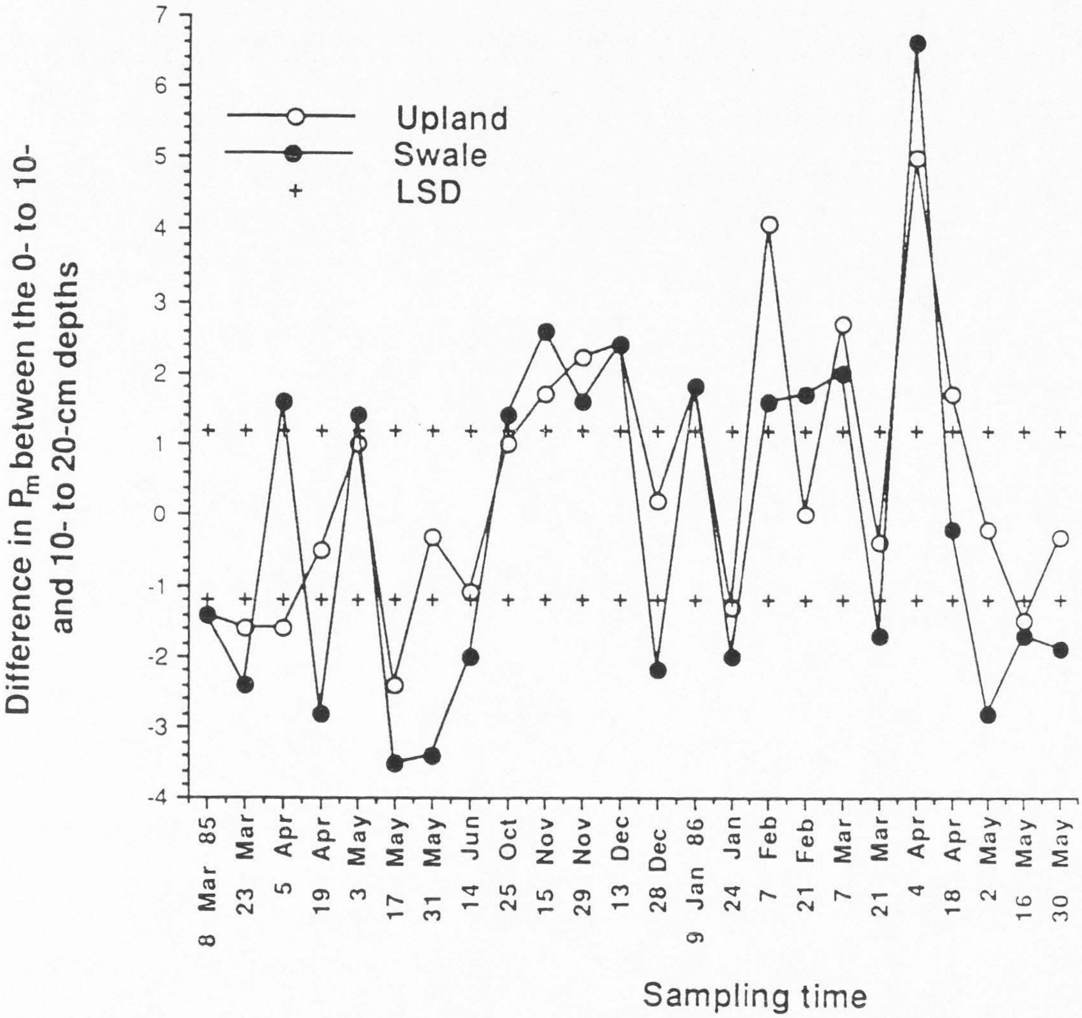

Figure 8. Effect of soil depth on average soil water content (%) on a mass basis (P_m) as affected by location and time in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

treatment with improved soil water content would probably support more vegetation, which in turn would lose more water by transpiration. Moreover, different species affect soil moisture differently. Mackie-Dawson et al. (1989) found that perennial grasses depleted soil moisture to deeper soil layers than the annual barley, resulting in the development of cracks only under the former.

Sulfur fertilization did not have any effect on soil moisture (Fig. 9). No interaction involving S was significant except the four way interaction location/chiselling/sulfur/time (Table 9). Even there, the F value was rather small (1.54) and the significance was mainly due to the huge degree of freedom for error (1012). The differences among treatments did not appear to show any clear pattern. Four way interactions are difficult to interpret, and in the case of split-plot designs, statistics literature does not go further than the three way interactions, as far as I know.

Possible effects of S application on soil moisture may result from its impact on biomass production and thus evapo-transpiration through the improvement of plant nutrition, from the amelioration of soil water infiltration (Ryan and Tabbara 1989) and from a temporary increase in water holding capacity of the soil (Mostafa and Abd-Elfattah 1987).

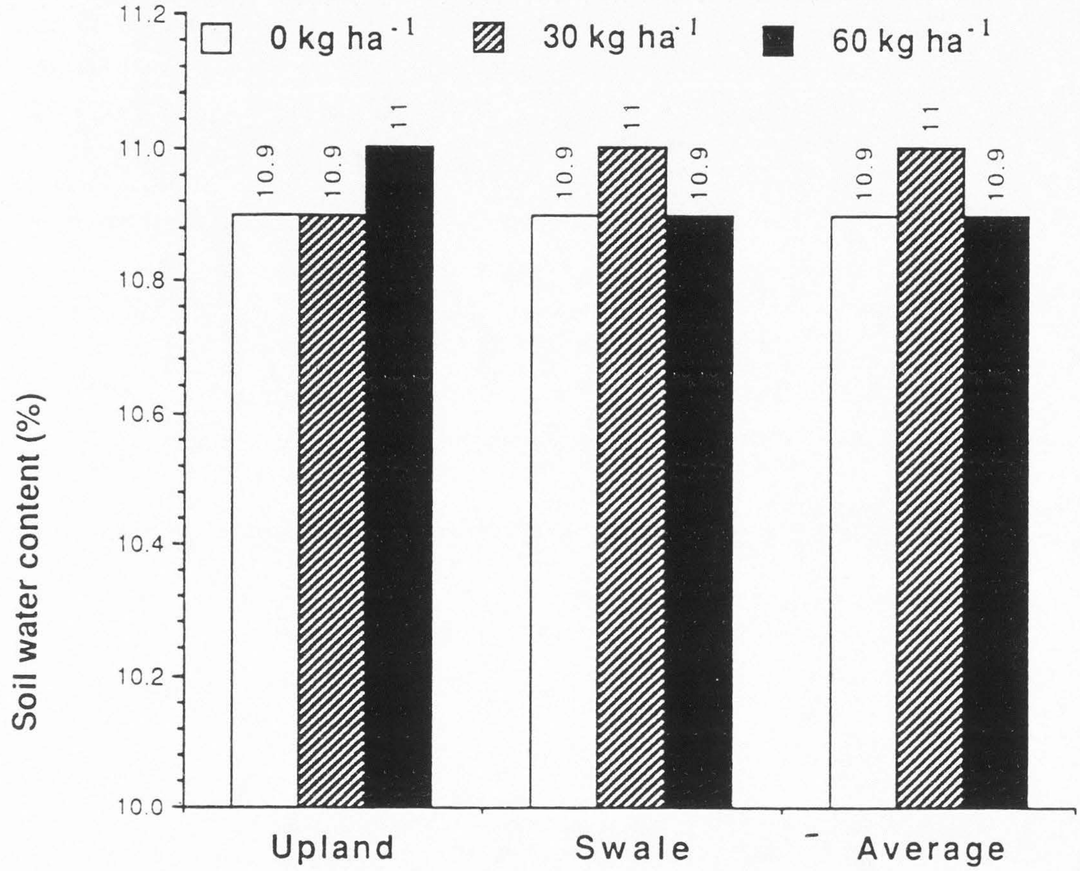

Figure 9. Effect of sulfur application on soil water content on a mass basis in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

Table 9

Effect of Chiselling and Sulfur Application (kg ha^{-1}) on Soil Water Content (%) on a Mass Basis as Affected by Location and Time

Date of Sampling	Upland site						Swale site					
	No chiselling			Chiselling			No chiselling			Chiselling		
/S level	0	30	60	0	30	60	0	30	60	0	30	60
8 Mar 85	9.4	7.4	8.6	9.4	9.4	10.4	8.5	9.5	8.3	9.8	9.6	9.4
23 Mar	7.1	6.7	7.4	8.3	8.0	8.8	7.1	7.8	7.0	8.7	7.7	9.1
5 Apr	6.3	6.2	5.9	7.2	6.2	6.6	5.9	6.0	6.0	7.5	6.9	7.4
19 Apr	1.6	1.5	1.8	2.5	2.0	2.6	2.0	2.4	1.5	2.9	3.2	3.2
3 May	8.0	7.4	7.5	7.6	7.3	8.0	8.1	8.2	7.9	8.0	7.9	7.9
17 May	7.9	8.2	7.5	5.9	8.2	6.9	8.3	8.5	8.9	8.3	8.4	7.0
31 May	4.6	4.5	5.2	5.2	8.8	4.9	5.1	5.0	5.3	7.5	6.6	6.4
14 Jun	2.2	2.1	1.5	3.1	2.7	2.9	2.5	3.4	3.2	5.1	4.0	4.3
25 Oct	4.2	3.4	3.9	3.8	4.3	4.2	4.2	3.9	3.9	4.4	4.6	4.9
15 Nov	5.1	3.8	4.5	4.2	3.9	4.2	4.4	5.1	4.5	5.5	5.3	5.8
29 Nov	16.4	17.8	19.5	21.4	20.9	19.9	18.3	18.4	17.4	18.6	17.9	18.4
13 Dec	14.2	15.3	14.0	17.8	16.2	19.0	15.7	14.5	16.3	16.0	16.6	15.2
28 Dec	11.8	8.5	9.2	11.7	11.0	11.9	9.5	10.2	9.3	10.0	9.7	10.7
9 Jan 86	17.9	19.7	18.6	20.0	20.5	21.2	18.5	19.6	18.2	20.1	19.6	21.0
24 Jan	11.0	12.3	12.3	14.5	13.6	14.1	11.9	12.0	11.8	10.5	11.7	11.8
7 Feb	20.1	20.6	21.6	21.2	21.2	20.9	21.8	22.2	22.0	23.0	22.9	22.5
21 Feb	18.9	19.2	20.2	20.1	20.0	20.6	20.1	20.0	20.2	21.9	20.1	20.8
7 Mar	17.6	18.3	18.1	20.1	19.6	20.2	19.1	20.0	18.0	19.7	19.1	19.4
21 Mar	13.7	15.4	12.9	15.7	16.2	15.6	12.7	13.4	12.6	13.1	14.0	13.2
4 Apr	15.3	13.8	14.4	15.7	16.5	15.0	13.5	15.1	14.3	15.0	14.2	14.4
18 Apr	10.9	11.7	11.3	15.7	15.1	12.7	13.2	13.0	10.9	12.7	12.5	15.0
2 May	5.3	4.2	4.6	6.7	5.9	7.0	6.4	7.0	6.8	8.0	7.3	8.8
16 May	5.8	5.7	5.4	7.1	5.9	7.5	5.5	6.1	5.6	5.9	6.1	5.8
30 May	9.1	11.6	11.7	12.2	14.8	14.8	9.6	9.5	10.4	9.3	11.9	10.2

Location/Chiselling/Sulfur/Time significant ($p = 0.013$)

Peak season biomass production

Peak season dry-matter production responded positively to chiselling, but not to S fertilization. Similar to S application, location and year simple effects were not significant at 0.05 level (Table 10). There were no significant interactions between any combination of factors, be they location, chiselling, S fertilization, or year.

The previously shown improvement in infiltration and ultimately in soil moisture was reflected on peak season biomass production. Increased water availability improves yield by its benefic action on photosynthesis (Turner 1988) and on nutrient availability (Mouat and Nes 1986). Average biomass production was significantly improved ($p = 0.053$) by chiselling from 2414 to 2684 kg ha^{-1}. The gain in biomass production was numerically higher on the swale site than on the upland (Fig. 10a) although no interaction was significant. This is surprising in view of the gain in soil moisture in the 20-cm deep surface layer which was found to be significantly higher on the upland site. This suggests that the swale site had higher transpiration losses due to greater biomass quantities, and possibly higher moisture gain in the non-sampled deeper soil layers of the swale.

A further break down of the effect of chiselling shows that numerically, biomass increases appeared on the upland

Table 10
Response of Peak Season Biomass Production ($g\ m^{-2}$) to Chiselling and Sulfur Application ($kg\ ha^{-1}$) as Affected by Location and Year

Sulfur	No Chiselling			Chiselling			Averages		
appl.	84/85	85/86	Avg.	84/85	85/86	Avg.	84/85	85/86	Avg.
Upland site									
0	215.9	232.0	223.9	295.8	263.6	279.7	255.8	247.8	251.8
30	305.5	256.5	281.0	356.0	204.6	280.3	330.7	230.5	280.6
60	278.4	215.1	246.7	273.2	228.4	250.8	275.8	221.7	248.7
Avg.	266.6	234.5	250.5	308.3	232.2	270.2	287.4	233.3	260.4
Swale site									
0	248.5	216.8	232.6	234.0	274.6	254.3	241.3	245.7	243.5
30	217.4	199.5	208.4	242.8	298.8	270.8	230.1	249.1	239.6
60	273.4	238.1	255.7	291.2	258.0	274.6	282.3	248.0	265.2
Avg.	246.4	218.1	232.3	256.0	277.1	266.6	251.2	247.6	249.4
Average of the two sites									
0	232.2	224.4	228.3	264.9	269.1	267.0	248.5	246.7	247.6
30	261.4	228.0	244.7	299.4	251.7	275.6	280.4	239.8	260.1
60	275.9	226.6	251.2	282.2	243.2	262.7	279.0	234.9	256.9
Avg.	256.5	226.3	241.4	282.2	254.7	268.4	269.3	240.5	254.9

Only chiselling simple effect was significant ($p = 0.053$).

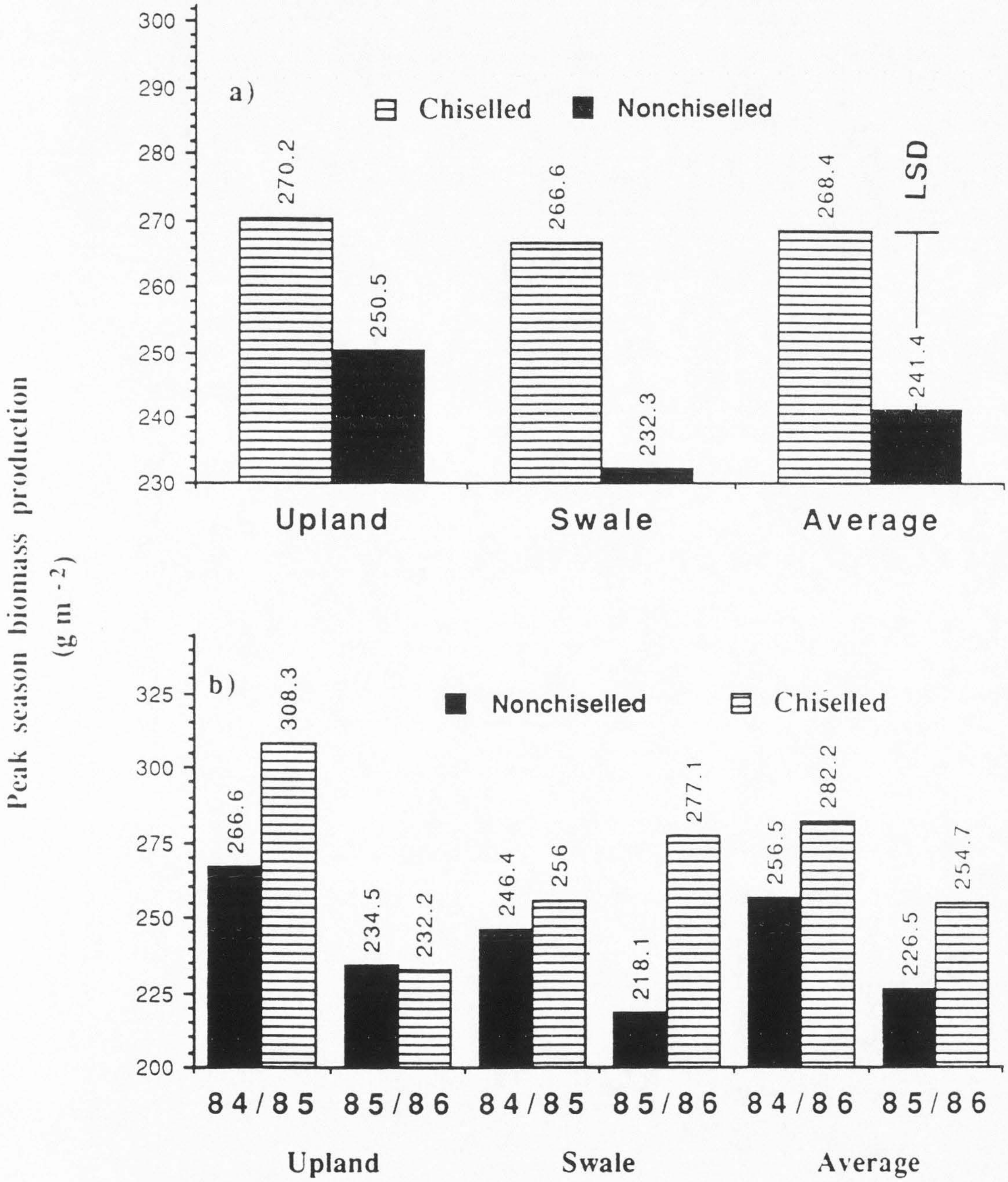

Figure 10. Effect of chiselling on peak season biomass production in the Ait Rbaa Perimeter as affected: (a) by location and (b) by location and year.

site only during the first growing season and on the swale site only during the second one (Fig. 10b). As noted above, soil surface was much more disrupted on the swale site, diminishing the chances for plant establishment and delaying the response. Other possible reasons could be a temporary excessive wetness of the swale site during January of the first growing season because of poorer drainage, in addition to differential species response to water stress in the early spring drought of the same year.

Biomass production was not significantly affected by year nor by location. Against all expectations, the 40% higher and more evenly distributed rainfall in the second year did not significantly improve yield. It could have been balanced by the earlier rain in the first season and the higher water storage from the heavy rain of January 1985. A good part of the second year's rain came too late in the season (June) and did not benefit plant growth at all. The lack of differences in mean production of the two locations confirms the results of Gay et al. (1987) who found differences between the two sites during mid stages of plant development, but these tended to equalize towards the end of the growing season. Although not significant, the upland production was numerically higher in the first growing season than in the second one (Fig. 10b), suggesting that the upland site benefited more from the earlier rain and wetter winter.

There was no evidence of any beneficial effect of sulfur application on biomass production (Fig. 11), confirming the absence of effect on soil moisture. The lack of evidence could be interpreted as a sign of non-critical S contents in the studied soils for the given levels of production. This could be supported by the moderate organic matter content in the soil that supplies S by mineralization of organic S, by the aridity that limits sulfate leaching, and by the relatively fine soil texture (Table 1), in addition to the high $CaCO_3$ to clay ratio (Mostafa and Abd-Elfattah 1987). The acidifying effect of elemental S was apparently buffered by the relatively high soil pH (8.3) and high $CaCO_3$ content. The applied S quantities were probably too low to affect such soils. Moreover, an ongoing study in the same area (El Mzouri and Gay 1987) found high P contents in the forage, suggesting no P nutrition problems, which should lower the potential benefits from increased P solubility. Wild species in infertile environments, on the other hand, possess adaptations to nutrient stress, mechanisms that may limit their response to fertilization (Chapin 1980).

Botanical composition

Unlike total biomass, botanical composition, expressed as weight ratios of grasses, legumes, and forbs, was strongly affected by the different treatments, except S

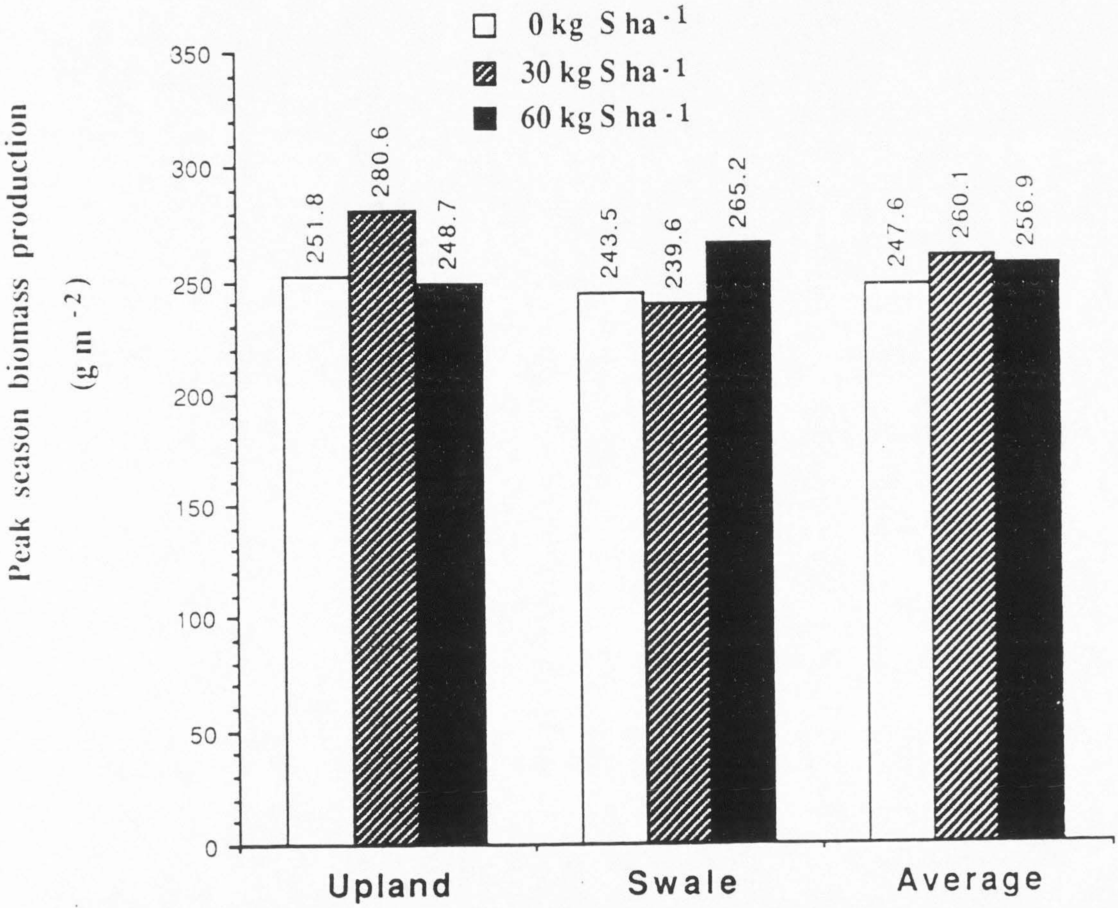

Figure 11. Effect of elemental sulfur application on peak season biomass production in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

application (Tables 11-13). Chiselling was the key factor, since all combinations with significant effects except one (effect of year on legume ratio) involved chiselling.

The simple effect of chiselling was significant (0.01 level) only on the proportion of forbs. On the average, chiselling depressed the percentage of forbs from 74 to 62.7% (Fig. 12). The significant (0.05 level) chiselling/ location interaction indicated that the decrease occurred on the more forb rich upland site and not on the swale.

The average botanical composition significantly (0.01 level) varied with year only for the ratio of legumes (Table 12), which was much higher in the first growing season (29.7 against 12.6%). This variability of legume ratio with years was also noted by Gay et al. (1987), who found that legume production was lower in 1983/84 than in 1984/85. This may suggest some cyclicity of legume production, perhaps related to the hardness of annual medic seeds. The highly significant (0.01 level) three way interaction location/chiselling/year showed that the ratio of legumes was significantly improved by chiselling only on the upland site in the first growing season (Fig. 13), although the average legume ratios were numerically increased in most cases. The first year, with heavy rain in January, offered the opportunity for the chiselling effect to bring about the gain in water availability that boosted legume growth, but not on the swale site where

Table 11
Response of the Proportion (%) of Forbs in Peak Season Biomass to Chiselling and Sulfur Application (kg ha^{-1}) as Affected by Location and Year

Sulfur	No chiselling			Chiselling			Averages		
appl.	84/85	85/86	Avg.	84/85	85/86	Avg.	84/85	85/86	Avg.
Upland site									
0	81.7	87.1	84.4	40.5	72.7	56.6	61.1	79.9	70.5
30	75.5	76.1	75.8	49.7	68.5	59.1	62.6	72.3	67.4
60	70.6	91.9	81.2	60.3	59.9	60.1	65.5	75.9	70.7
Avg.	75.9	85.0	80.5	50.2	67.0	58.6	63.1	76.0	69.5
Swale site									
0	60.8	79.2	70.0	66.6	77.1	71.8	63.7	78.1	70.9
30	56.6	83.2	69.9	67.2	54.6	60.9	61.9	68.9	65.4
60	66.9	58.5	62.7	66.0	69.6	67.8	66.5	64.0	65.2
Avg.	61.4	73.6	67.5	66.6	67.1	66.8	64.0	70.4	67.2
Average of the two sites									
0	71.2	83.1	77.2	53.6	74.9	64.2	62.4	79.0	70.7
30	66.0	79.6	72.8	58.5	61.5	60.0	62.2	70.6	66.4
60	68.8	75.2	72.0	63.2	64.7	63.9	66.0	69.9	68.0
Avg.	68.7	79.3	74.0	58.4	67.0	62.7	63.5	73.2	68.4

Chiselling significant ($\underline{p}$ = 0.014)
$LSD_{0.05}$: 7.5
Location/Chiselling significant ($\underline{p}$ = 0.017)
$LSD_{0.05}$ Chiselling within location: 10.6
Location within chiselling: 15.9

Table 12
Response of the Proportion (%) of Legumes in Peak Season Biomass to Chiselling and Sulfur Application (kg ha^{-1}) as Affected by Location and Year

Sulfur	No chiselling			Chiselling			Averages		
appl.	84/85	85/86	Avg.	84/85	85/86	Avg.	84/85	85/86	Avg.
Upland site									
0	13.2	7.7	10.4	51.3	8.8	30.1	32.2	8.3	20.3
30	18.6	3.9	11.3	45.9	16.3	31.1	32.3	10.1	21.2
60	23.6	4.5	14.0	34.1	4.2	19.1	28.9	4.3	16.6
Avg.	18.5	5.4	11.9	43.8	9.7	26.8	31.1	7.6	19.3
Swale site									
0	32.1	11.1	21.6	27.6	20.3	23.9	29.8	15.7	22.8
30	32.6	12.8	22.7	25.2	20.4	22.8	28.9	16.6	22.7
60	24.1	19.7	21.9	28.4	21.1	24.8	26.3	20.4	23.3
Avg.	29.6	14.5	22.1	27.0	20.6	23.8	28.3	17.6	22.9
Average of the two sites									
0	22.6	9.4	16.0	39.4	14.6	27.0	31.0	12.0	21.5
30	25.6	8.3	17.0	35.5	18.3	26.9	30.6	13.3	22.0
60	23.9	12.1	18.0	31.3	12.6	22.0	27.6	12.4	20.0
Avg.	24.0	10.0	17.0	35.4	15.2	25.3	29.7	12.6	21.1

Year effect highly significant ($\underline{p}$ = 0.0074)
$LSD_{0.05}$: 9.5
Location/Chiselling/Year significant ($\underline{p}$ = 0.014)
$LSD_{0.05}$ Chiselling within Location and Year: 11.5

Table 13
Response of the Proportion (%) of Grasses in Peak Season Biomass to Chiselling and Sulfur Application (kg ha^{-1}) as Affected by Location and Year

Sulfur	No chiselling			Chiselling			Averages		
appl.	84/85	85/86	Avg.	84/85	85/86	Avg.	84/85	85/86	Avg.
Upland site									
0	5.2	5.2	5.2	8.2	18.5	13.3	6.7	11.8	9.3
30	5.8	20.1	12.9	4.4	15.3	9.9	5.1	17.7	11.4
60	5.8	3.6	4.7	5.5	35.9	20.7	5.7	19.8	12.7
Avg.	5.6	9.6	7.6	6.0	23.3	14.6	5.8	16.4	11.1
Swale site									
0	7.1	9.6	8.4	5.8	2.6	4.2	6.5	6.1	6.3
30	10.8	4.0	7.4	7.6	24.9	16.3	9.2	14.5	11.9
60	8.9	21.8	15.4	5.6	9.3	7.5	7.3	15.6	11.4
Avg.	9.0	11.8	10.4	6.4	12.3	9.3	7.7	12.1	9.9
Average of the two sites									
0	6.1	7.4	6.8	7.0	10.6	8.8	6.6	9.0	7.8
30	8.3	12.0	10.2	6.0	20.1	13.1	7.2	16.1	11.6
60	7.4	12.7	10.1	5.6	22.6	14.1	6.5	17.7	12.1
Avg.	7.3	10.7	9.0	6.2	17.7	12.0	6.7	14.3	10.5

Location/Chiselling/Sulfur/Year significant (p = 0.051)

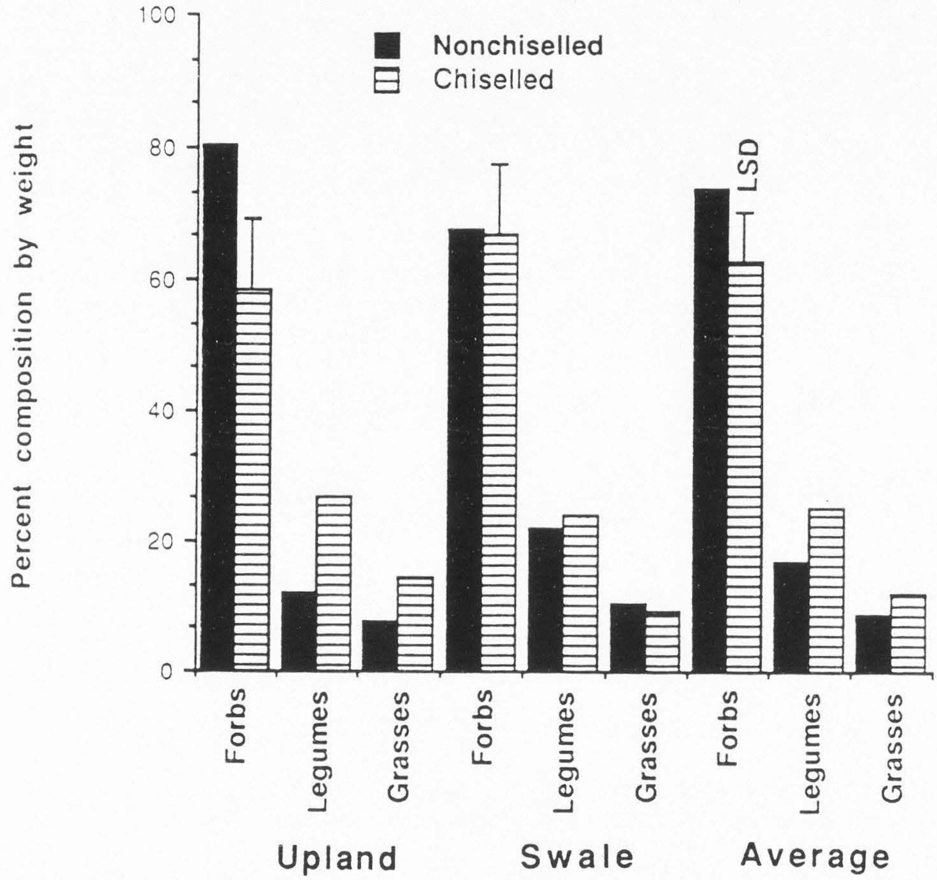

Figure 12. Effect of chiselling on the botanical composition of two locations in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

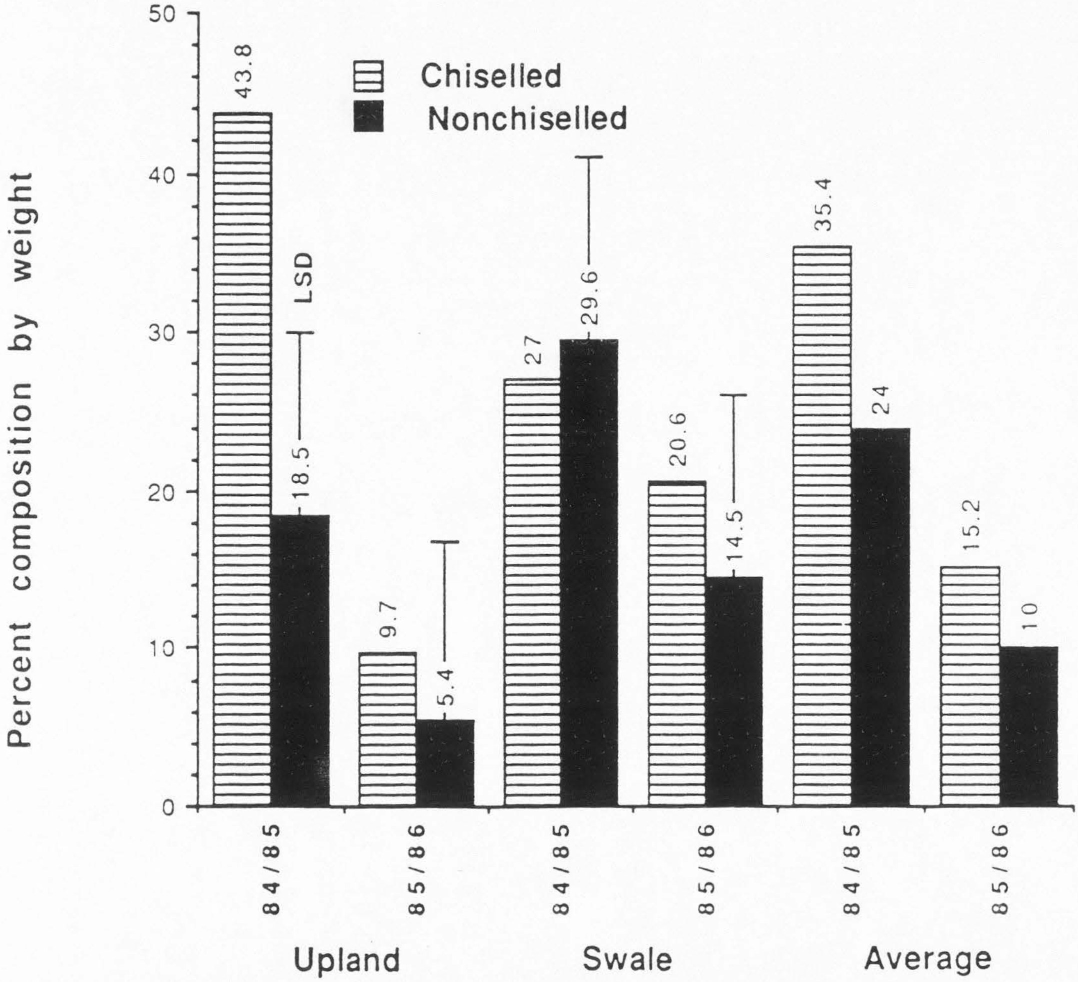

Figure 13. Effect of chiselling on the proportion of legumes as affected by location and year in the Ait Rbaa Perimeter.

surface soil was more disrupted by the treatment and soil moisture was probably excessive in January. Water stress was reported to affect nitrogen fixation by legumes (Dawson and McGuire 1972, Rao and Venkateswarlu 1987).

Similar to biomass production, sulfur fertilization did not significantly affect botanical composition (Fig. 14). The unique, and still not strongly, significant (p = 0.051) interaction involving S was the four way location/chiselling/sulfur/year for grasses ratios, but practical implications of this high level interaction with low level of significance could be questionable. There is however, one noteworthy trend: the high proportion of grasses in the chiselled treatment of the upland site in the second growing season suggests some benefits from nitrogen fixation by legumes during the previous year (Fig. 15). At least for this combination, the high S application level seems to have been effective.

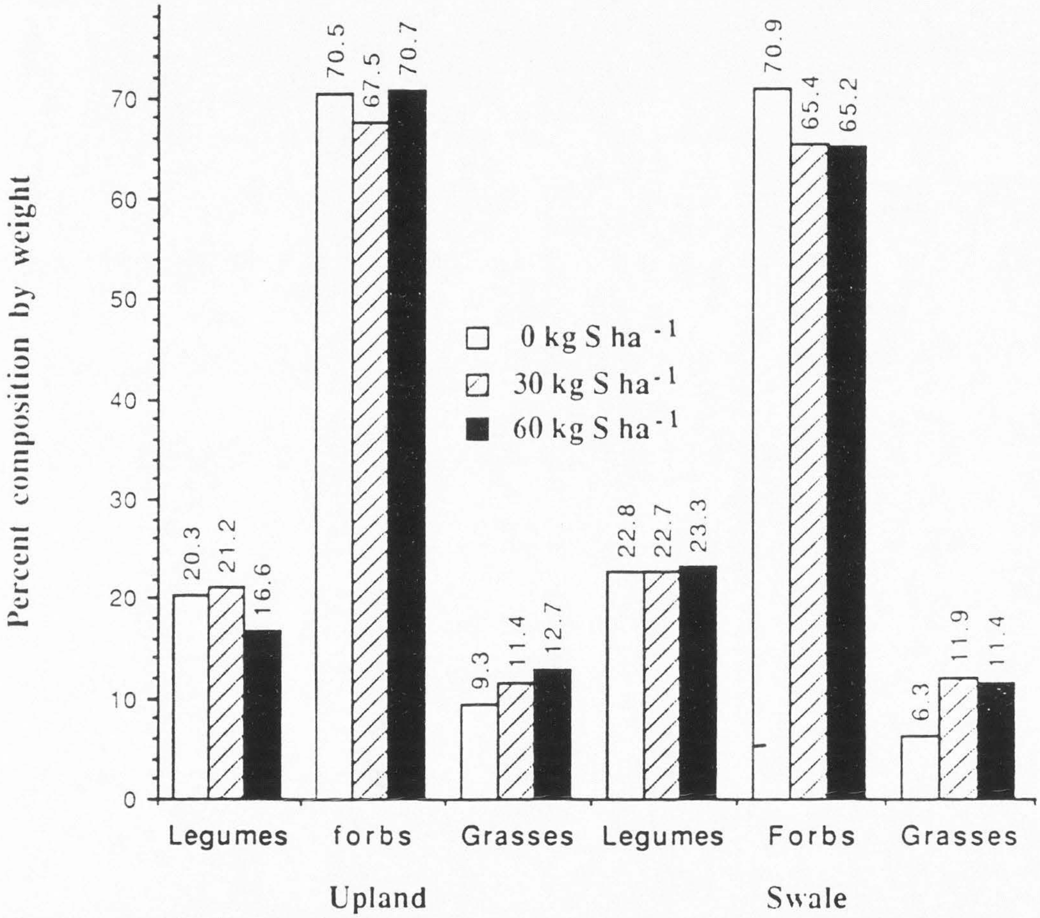

Figure 14. Effect of sulfur application on botanical composition in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

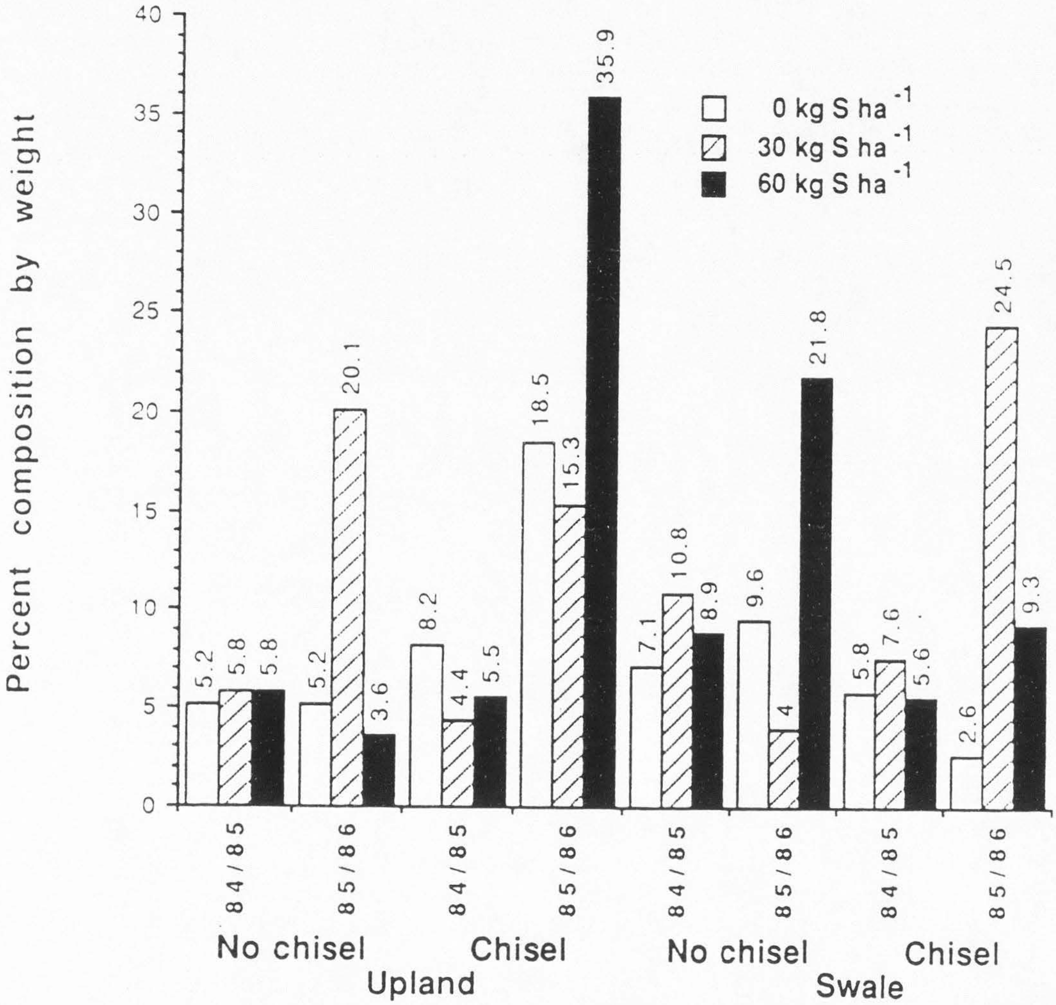

Figure 15. Proportion of grasses as affected by location, chiselling, elemental sulfur application, and year in the Ait Rbaa Perimeter for the growing seasons of 1984/85 and 1985/86.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The study showed that chiselling could be successfully used to improve water infiltration in the soils of the Ait Rbaa Perimeter, while it failed to clearly show any substantial response to S application. Infiltration amelioration brought about a gain in the use efficiency of rainfall water, as it was demonstrated by the gain in the average soil water content in the 0- to 20-cm soil layer. Chiselling significantly improved herbage production by 11%, and caused a beneficial shift in botanical composition. The proportion of forbs in the total biomass was significantly depressed in the upland site. In response to chiselling, legume proportion substantially increased on the upland site during the first growing season, even though the increase was not maintained in the following year. Broadcast elemental S did not have any tangible effect on yield, nor on botanical composition. The application levels were apparently too low to be effective in these soils with high pH and $CaCO_3$ contents. Band-applied elemental S could probably be more promising.

Although the present study showed the potential of chiselling for range improvement in the Ait Rbaa Perimeter, herbage production gain was only 11%, which may question the economic soundness of the operation unless its effectiveness is long-lived. The economic analysis should take into consideration the increase in carrying capacity resulting from the qualitative improvement of forage. The fact that the study was conducted in an exclosure that was undergoing recovery from overgrazing may have reduced the gains from the land treatment. It should be noted that the variability of the climatic conditions, and the shift in botanical composition that is still unsettled, make it necessary to study the effects over more years before giving strong recommendations. Any recommendation of chiselling for the improvement of the Ait Rbaa rangelands could be conceivable only if associated with management measures to prevent overgrazing.

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