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Effect of tied riding and mulch ripping on water conservation in Maize production on sandveld soils

Auswirkungen des Kammerfurchensystems und des Hakenpflügens in Mulch auf den Wassergehalt von Sandböden im Maisanbau

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1 Introduction

The results of three (1988-89 to 1990-91) rainfall/growing seasons (October to April) of tillage research on granitic soils in Zimbabwe had shown that the low topsoil water-holding capacity (9% by volume) of these coarse-grained soils minimises the benefits of rainwater harvesting or even nullifies them (VOGEL, 1993a). Average soil water data by treatment had revealed little or no differences between tillage treatments for a particular rainfall season except for (a) the pre-planting period and (b) waterlogged conditions occuring in above-average rainfall years. It was, therefore, decided to continue soil water recording throughout the dry season (that is, for the entire calendar year) to complement data previously applying to the rainfall seasons only.

A parallel lysimeter study carried out during the 1991-92 and 1992-93 rainfall seasons was aimed at quantifying percolation water and nutrient leaching in tied ridged *versus* ploughed fields.

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2 Method and materials

The study site is located in Natural Region IIa (750-1000 mm of seasonal rainfall) at Domboshawa Training Centre (1735'S, 3110'E), approximately 30 km north of the capital Harare. Soils are derived from granite and their particle size distribution generally features loamy sands in the topsoil to sandy loams in the subsoil (FAO, 1988). They also feature little inherent fertility and are prone to waterlogging in times of high rainfall and to hard-setting in the absence of rain (VOGEL, 1992).

For this study, two conservation tillage systems, namely ripping into maize residues and no-till tied ridging (ELWELL and NORTON, 1988) were compared to the conventional system of mouldboard ploughing. The field plots for the conventional tillage and mulch ripping treatments were planed to a 4,5 % slope while the ridges for the tied ridging treatment were laid out at 1 % gradient across the slope. All three techniques were animal powered. With the conventional system, ploughing was done immediately after harvesting (winter ploughing). With mulch ripping, planting lines were ripped open between the previous season's crop rows during mid to late winter. Ploughing and ripping was to 200-250 mm depth. In the case of tied ridging, ridges were permanent and only re-ridging and re-tying (at 1 to 1.5-m intervals) was practised: once after harvesting the previous season's crop and again four to six weeks after sowing the new season's crop. The crop was planted into the crest of the ridges using a digging hoe (badza).

Soil water content was estimated with a CPN 503DR Hydroprobe on field plots measuring 20 x 35 m. Each plot had four access tubes installed to a depth of 1.5 m. In the case of tied ridging, however, the plots measured 9 m in width and 160 m in length and, because of the larger area, had six tubes each installed through the ridges. Weekly observations were made at six depth levels (0.15, 0.3, 0.45, 0.75, 1.1, and 1.4 m). These depth readings were taken as count ratios and were converted into volumetric soil horizon water contents using field calibrations. Soil water content over the top 0-0.1 m was determined gravimetrically and converted to volumetric basis by field-determined bulk densities. The experiment was laid out in a completely randomized block design with the blocks separated from each other by contour bunds. All treatments were applied in triplicate.

Percolate volume and nutrient leaching (NO_3-N, K) from the root zone of tied ridged and ploughed field plots was evaluated with simple non-weighing lysimeters located on a reasonably well-drained Areni-Gleyic Luvisol (FAO, 1988). One lysimeter tank was installed for one ridged, one ploughed plot, and one bare plot. They measured 0.9 x 1.5 m in surface area and 0.5 m in height and were buried at 0.25 m depth below the ploughed soil surface (which corresponds to the maximum depth of cultivation) and furrow bottom respectively. A hose pipe connected to an outlet pipe at the bottom of each tank collected the leachates into buckets sited in pits, so that the flow out of the lysimeter tanks was simply by gravity. The leachate was collected on a daily basis, the volume assessed and a small sample of 300 ml was taken for nutrient analysis whenever the leachate volume exceeded one litre. Nutrient analyses were carried out using a HACH spectrophotometer after calibration with standard solutions.

The ponding capacity for the micro-catchments created by the cross-ties in the ridge-furrow system was also determined weekly from four adjacent ties in each tied ridged field plot. A sheet of plastic was placed into each tie and a measured amount of water poured in until overflow occurred.

Maize (*Zea mays* L.) was grown at a density of 44000 plants (i.e. at a spacing of 0.9 m x 0.25 m). Planting was to approximately 50 mm depth for all treatments. Fertilizers applied were 300 kg ha^{-1} of Compound D (containing 8% N, 14% P_2O_5, and 7% K_2O) as a basal application and 200 kg ha^{-1} of ammonium nitrate (containing 34.5% N), top dressed in two split applications.

Maize growth was recorded weekly on a total of 16 crop research field plots. Twenty plants were selected randomly on each plot after complete emergence. Plant height was measured as the distance from the ground surface to the top emerging leaf. Yields were determined from sample plots of 4 crop rows by 6 m long from all field plots of both experiments. For final analysis, grain yields were corrected to a uniform moisture content of 12.5%.

3 Results and discussion

Results reported in this study are for the severe drought season of 1991-92 (Fig. 1a) and the average rainfall season of 1992-93 (Fig. 2a). Soil water analyses are for the same periods but include the two dry seasons following the 1991-92 and 1992-93 rainfall seasons.

Maize production

During the 1991-92 drought season (which was the worst drought on record in Zimbabwe), grain yields were poor for all three tillage treatments (Table 1). Conventional tillage had the highest yields in absolute terms, although the difference was statistically insignificant. The poorer performance of tied ridging during this severe drought season suggested that this treatment has climatic limits on sandveld soils because of increased soil temperature and dryness on the ridges (VOGEL, 1993a, 1994a). The poor performance of mulch ripping was attributed to an unknown pathogen which reduced grain yields to nil on two research field plots (VOGEL, 1993b).

In stark contrast to the previous 1991-92 season, grain yields for 1992-93 were excellent with tied ridging yielding significantly highest (Tab. 1). Similarly, the tied ridging technique had resulted in significantly highest grain yields at the Domboshawa site in earlier trial years (VOGEL, 1993a). Parallel root excavations at the beginning of tasseling in January 1993 revealed that maize plants grown on ridges featured not only deepest root proliferation (to approximately 750 mm depth) but also twice the root length density than maize plants grown in ploughed plots (VOGEL, 1994b).

Tab. 1: Effect of tillage treatment on maize grain yields (t ha^{-1}) during the 1991-92 and 1992-93 seasons at Domboshawa, Zimbabwe. Means within a column followed by the same superscript do not differ significantly at $P < 0.05$.

Tillage systems	Grain yield (t/ha)	
	1991-92	1992-93
Conv. tillage	1.2	5.1^b
Mulch ripping	0.3	4.3^b
Tied ridging	0.8	6.6^a

Surface runoff

Tied ridging proved a highly effective rainwater-harvesting technique due to its treatment-specific retention of rainwater. Measured ponding capacities for individual pairs of cross-ties ranged from 55 l at the beginning of the growing season to 5.5 l at the season's end. As a result, surface runoff from tied ridged field plots was always significantly lower than from the ploughed field plots (Table 2). While ploughed field plots lost between 2% (1991-92) to 13% (1992-93) of the total seasonal rainfall due to surface runoff, only 0.02% (1991-92) to 1.6% (1992-93) of the total seasonal rainfall ran off the tied ridged field plots. Surface water retention in mulch ripped plots was nearly as good as in tied ridged plots.

Tab. 2: Effect of tillage treatment on seasonal surface runoff during the 1991-92 and 1992-93 rainfall/growing seasons at Domboshawa, Zimbabwe. Means within a column followed by the same superscript do not differ significantly at $P < 0.05$.

Tillage systems	Surface runoff (mm)	
	1991-92	1992-93
Conv. tillage	9.4^b	105.0^b
Mulch ripping	1.0^a	15.2^a
Tied ridging	0.1^a	13.0^a

Soil water

The analysis of variance of the soil water data recorded over the 26-months period between October 1991 to November 1993 revealed that, generally, the effect of tillage treatment was statistically insignificant during the rainfall/growing season (October-April) once the planting rains had fallen in mid to late November. The treatment effect on soil water content became significant ($P < 0.05$) during the dry seasons (May-September), and as a result entered the following rainfall season at significantly different soil water levels (Figs. 1b, c). It was interesting to note that after the severe drought season of 1991-92, the effect of treatment on soil water content became significant in early July 1992, but a month later in August 1993 after the average rainfall season of 1992-93. The significant treatment effect for both periods extended down to the 750 mm depth level, which coincides with the observed maximum root penetration depth (VOGEL 1993a,1994b). In the 1991-92 drought, the treatment effect remained significant at the 750 mm depth level for the whole drought plus dry-season period between February 1992 to late November 1992. Soil water content at this depth level remained at approximately 14% by volume ($0.14\ m^3\ m^{-3}$) under conventional tillage while the soil water content at 750 mm depth below the ridge tops dropped to a significantly ($P < 0.05$) lower level of only approximately 8.5% by volume ($0.085\ m^3\ m^{-3}$). However, soil water contents monitored in the two lower depth levels, that is 1.1 and 1.4 m respectively, showed no significant treatment effect at any time over the entire 26-month period.

In spite of the significantly better rainwater harvesting by tied ridging, topsoil water levels in the ridges generally were between 5 to 25% lower than those recorded in ploughed soil throughout the rainfall/growing seasons. On the other hand, surface mulching with maize residues raised topsoil water levels 5 to 10% above those measured in ploughed field plots. During the severe drought period in February and March 1992 water levels in the top 0-150 mm of the soil under maize residues were 20% higher than in ploughed soil (Fig. 1b) while, in the ridged treatment, they dropped to less than 60% of the ploughed soil at 300 mm depth (major root concentration) (Fig. 1c).

Deep percolation and associated nutrient leaching

Due to the severe drought conditions (Fig. 1a) no leaching occurred during the 1991-92 season. During the following 1992-93 season (Fig. 2a), the lysimeter tanks yielded drainage only after receiving a total weekly rainfall of 60 mm (Fig. 2b), of which 43 mm fell in one heavy rainstorm on 16 December 1992. In the two weeks thereafter, more heavy rainfall was received resulting in continued drainage from the lysimeter tanks, in particular from the tied ridged field plots. That higher percolation occurred on the tied ridged plots during this time period is confirmed by weekly water budgets.

The soil water balance for the week (23-30 December 1992) with the highest weekly rainfall total (109.9 mm) in 1992-93 (Fig. 2a), and with a weekly pan evaporation of 16.3 mm (assumed to be the same for all treatments because of prevailing wet soil surfaces during this period of time), showed conventional tillage to produce 39.4 mm of surface runoff, to store an additional 34.4 mm in the soil profile, and to lose 19.8 mm through deep percolation. During the same period of time, tied ridging produced only 7.3 mm of runoff, stored an extra 46.6 mm in the profile, but lost 39.7 mm through deep percolation. This supports earlier findings (VOGEL, 1992, 1993a) which indicated that, in the presence of crops demanding little water, the ponding capacity of tied ridging (which was approx. 17 l m^{-2} between 23-30 December 1992) encourages deep percolation and thus groundwater recharge. As a result, virtually all seasonal NO_3-N deep-percolation losses of 50.5 kg ha^{-1} from tied ridged plots had occurred by 30 December 1992. Even from conventionally tilled plots, however, virtually all of the total seasonal NO_3-N losses were recorded by 30 December 1993, albeit at a much lower absolute level of only 30.7 kg ha^{-1}. In both cases it is assumed that the loss mainly affected the ammonium nitrate fertilizer top dressed on 26 December 1992 when maize stands were still low (Figs. 2b,c), yet rainfall frequent and heavy (72 mm on 29 December 1992, followed by 15 mm the day after). Unlike at Makoholi (HAGMANN, 1994), nitrate losses from the unfertilized bare plot were lower than for the fertilized cropped plots by 30 December 1993.

After the second top dressing (11 January 1993) virtually no deep percolation of water, and hence no leaching of NO_3-N, was recorded for both tied ridging and conventional tillage (Fig. 2b) while continuous leaching occurred from the bare plot. Due to less frequent and less intense rainfall, maize growth was very vigorous between mid January and late February thus utilizing most of the amonium nitrate fertilizer applied on 11 January 1993. Only towards the end of February 1993, when rainfall was plentiful again (Fig. 2a), with single events delivering 38 mm (23 February) and 45 mm (26 February), did percolation of water and some leaching of nutrients occur again. This coincided with the crop commencing to senesce (Fig. 2c), which is a time when uptake of water and nutrients through maize plants is close to nil (GEUS, 1973). At the end of the season, tied ridged field plots had lost 54% (50.5 kg ha^{-1}) of the applied NO_3-N (93 kg ha^{-1}) while only 33% (30.7 kg ha^{-1}) was leached down the soil profile from ploughed plots. Similar proportions of the applied K (17 kg ha^{-1}) were leached, namely 36% (6.2 kg ha^{-1}) from mouldboard ploughing and 58% (10 kg ha^{-1}) from tied ridged plots. It should be noted, however, that lysimeters have limitations in accurately mimicing field conditions (WEBSTER et al., 1993). Thus, the accuracy of the absolute values may be treated with care.

Results conflicting with these findings from Domboshawa were obtained at Makoholi Experiment Station where similar studies are being conducted since 1991-92 in a low-rainfall area. The results for 1992-93 indicate substantially lower nutrient losses from tied ridged field plots than from conventionally tilled plots at Makoholi. Recor-

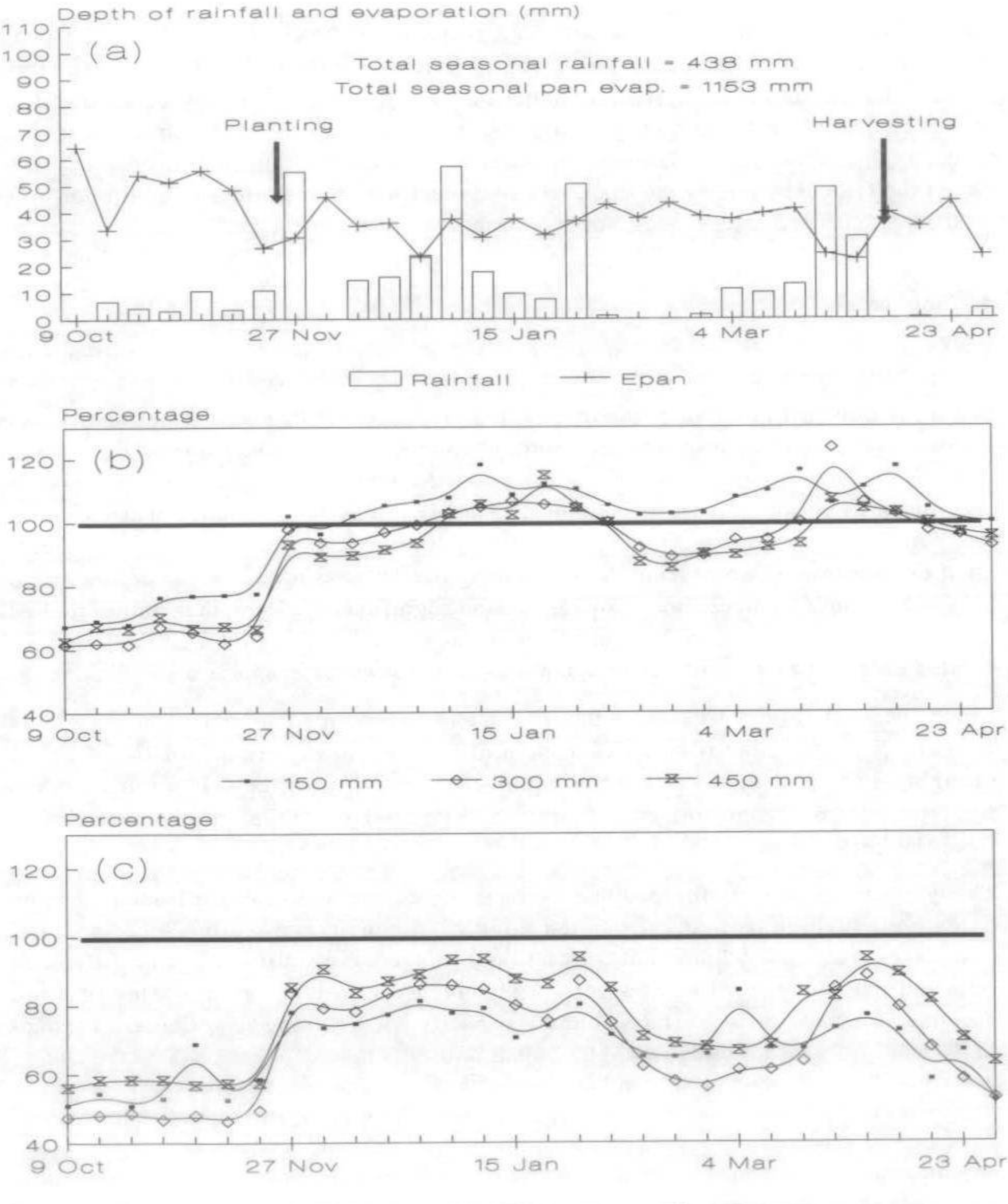

Fig. 1: (a) Total weekly rainfall and open pan evaporation; (b) weekly relative topsoil water content under mulch ripping and (c) under tied ridging compared to conventional tillage (= 100%) during the 1991-92 drought at Domboshawa, Zimbabwe.

sses of NO_3-N and K were 40% and 56% respectively lower from tied ridged than from ploughed plots (Hagmann, 1994), yet the percolate volume for the two treatments was similar as had been the case at Domboshawa. This difference may be attributable to less frequent rainstorms and, possibly, more upward movement of nutrient salts due to the higher atmospheric demand for water at Makoholi. From this discrepancy between the two sites, one in the semi-arid south and the other in the subhumid north, it is apparent that the results must not be extrapolated prematurely.

4 Conclusion

Tied ridging and mulch ripping proved very efficient rainwater-harvesting techniques. Yet, in spite of losing significantly less rainwater due to surface runoff than conventional mouldboard ploughing, the effect of tillage treatment on soil water levels was statistically insignificant during the rainfall/growing seasons. Only during the second half of the dry seasons (and the mid-season drought in 1992) did tillage have a significant effect on soil water content. From this it may be concluded that the minimal soil disturbance caused by the two conservation tillage techniques allowed continued evaporation of water from the soil during the dry season. Thus, the conservation tillage techniques entered the growing season significantly dryer than the ploughed treatment. In contrast, conventional tillage, through winter ploughing, is likely to have created an effective topsoil buffer against further soil water evaporation.

Since the tied ridged treatment has consistently produced higher biomass yields over the 5 years of the tillage experiment at Domboshawa (except for the 1991-92 drought season), it appears that the equally consistently lower soil water contents are, apart from higher soil evaporation, a reflection of higher transpiration rates from the better crop.

The lysimeter results highlighted that nitrogen losses due to downward leaching can be excessively high, in particular from tied ridging. Although total seasonal deep percolation losses from tied ridging and conventional tillage were similar, a major difference occurred early in the 1992-93 season when intense rains fell shortly after first top dressing. Because of its surface ponding capacity, tied ridging experienced substantially more internal leaching of applied plant nutrients than conventional tillage during that time. It must be borne in mind, however, that conventional tillage is likely to have lost overall possibly even higher proportions of applied fertilizer nutrients in the observed significantly higher surface runoff. In any case, the lysimeter results emphasise that nitrogen applications have to be timed carefully and split as much as is practically possible to minimise loss of this crucial plant nutrient.

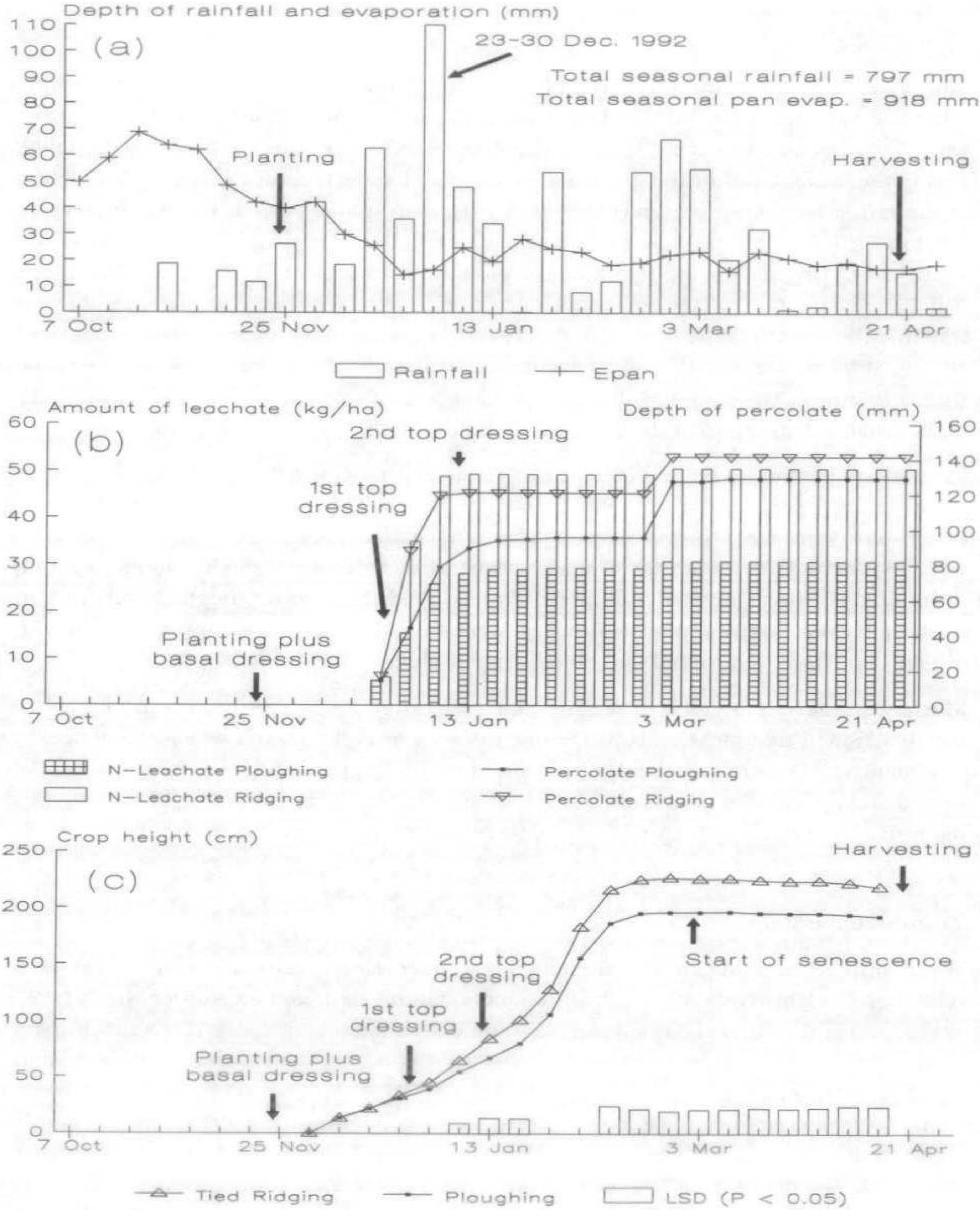

Fig. 2: (a) Total weekly rainfall and open pan evaporation, (b) weekly leachate of NO_3-N and percolate cumulatively from an Areni-Gleyic Luvisol and, (c) maize growth as affected by ridging and ploughing during the 1992-93 rainfall season at Domboshawa, Zimbabwe.

5 Summary

Soil water measurements taken weekly at 6 depth levels over a period of 26 months (October 1991 to November 1993) in a sandveld soil in the subhumid north of Zimbabwe revealed tillage treatment to have a significant effect ($P < 0.05$) on soil water levels during the second half of the dry season (May-September) and for the first two months of the rainfall-growing season (October-April). During this period, soil water levels in the top 750 mm of the soil profile, the rooting depth for maize in this soil, was significantly higher on the mouldboard ploughing treatment. Thereafter (December-April), the effect of tillage treatment on water content within the same zone was not statistically significant, except for the severe drought in February and March 1992. During this mid-season drought period, soil water levels in the top 450 mm of the ridged treatment were 30-40% lower than those recorded in ploughed soil; and slightly higher than the ploughed soil in the top 150 mm on the mulched treatment.

Parallel studies involving non-weighing lysimeters indicated that tied ridges experience more deep percolation of water than ploughed soil, in particular if heavy rainfall occurs early in the growing season when the maize plants are still small and the water-collecting cross-ties are of adequate height. In 1992-93, more internal leaching of applied fertilizer nutrients occurred from ridged than from ploughed soil. In contrast, however, surface runoff from ploughed field plots was always significantly higher than from tied ridged and mulch ripped plots.

Maize (*Zea mays* L.) yields at the site under investigation were significantly higher on the tied ridged treatment; except for the 1991-92 drought season when differences in treatment yields were statistically insignificant. The higher biomass production on tied ridged field plots was mainly due to increased root depth and root length density, and the prevention of waterlogging in above-average rainfall years.

Zusammenfassung

Wöchentliche Messungen der Bodenfeuchte über einen Zeitraum von 26 Monaten (Oktober 1991 bis November 1993) in Sandböden im subhumiden Norden Simbabwe's ergaben, daß die Bodenbearbeitung während der zweiten Hälfte der Trockenzeit (Mai-September) und der beiden ersten Monate der Regenzeit (Oktober-April) einen statistisch signifikanten Einfluß auf den Bodenwasserhaushalt ausübte. Während dieses Zeitraumes verzeichneten die Bodenprofile unter konventioneller Pflugbearbeitung die signifikant höchsten Bodenwassergehalte bis in eine Tiefe von 750 mm. Diese Tiefe entspricht der maximalen Wurzeltiefe von Mais auf diesen Standorten. Danach (Dezember-April) war der Einfluß der Bodenbearbeitung auf den Wasserhaushalt nicht mehr statistisch bedeutsam, mit Ausnahme der Jahrhundertdürre im Februar und März 1992. Während dieser beiden extremen Dürremonate sanken die Bodenwassergehalte in den Dämmen des Kammerfurchensystems um 30-40 % unter die Werte in gepflüg-

ten Versuchsparzellen. Lediglich in den obersten 150 mm des Bodens in den gemulchten Versuchsparzellen des Hakenpflugsystems konnten etwas höhere Bodenwassergehalte als in konventionell gepflügten Parzellen ermittelt werden.

Gleichzeitig durchgeführte Untersuchungen mit nicht wägbaren Lysimetern legten den Schluß nahe, daß das Kammerfurchensystem dem Grundwasserbereich mehr Sickerwassser zuführt als konventionelles Pflügen, insbesondere wenn die Starkregen zu Beginn der Wachstumsperiode fallen wenn die Kulturpflanzen noch klein und die wassersammelnden Querdämme in den Kammerfurchen noch in gutem Zustand sind. Mit Hilfe der Lysimeter konnnte während der Regenzeit 1992-93 auch eine gegenüber gepflügten Parzellen erhöhte Verlagerung und Auswaschung gelöster Stoffe aus dem Kammerfurchensystem beobachted werden. Im Gegensatz hierzu verzeichneten gepflügte Parzellen jedoch immmer einen signifikant höheren Oberflächenabfluß als die Parzellen mit Kammerfurchen oder Mulch.

Das Kammerfurchensystem produzierte generell die signifikant höchsten Maiserträge am untersuchten Standort, außer während der Dürre in 1991-92 als die Ertragsunterschiede zwischen den Bodenbearbeitungsmethoden unbedeutend waren. Die höhere Biomassenproduktion des Kammerfuchensystems war eine Folge der durch die Dämme geschaffenen größeren Wurzeltiefe und Wurzeldichte. In überdurchschnittlich niederschlagsreichen Jahren trugen die Dämme durch weitgehende Verhinderung von Staunässe zur besseren Maisproduktion bei.

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