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Hydrological processes and water resources management in a dryland environment II: Surface redistribution of rainfall within fields

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Abstract

Soil water movement was studied within fields on two different soil types, a red clay soil and a duplex soil of sand over clay, at the Romwe Catchment in southern Zimbabwe. Each study site comprised two fields and formed a surface water sub-catchment (1.0–2.4 ha) from which runoff was gauged. Soil moisture was measured *in-situ* at up to 20 locations within each sub-catchment over an entire cropping season and the following dry season. Maize was cultivated at both sites according to the farmers' normal cropping practice and crop yields were recorded.

Surface redistribution of rainfall through localised runon and runoff was shown to be an important process in both sub-catchments with rainfall concentration factors between 0.2 and 2.7 for major rainfall events. This process was a key factor controlling deep drainage to groundwater. Results indicate that surface water redistribution is of particular importance for groundwater recharge in years with low or evenly distributed rainfall, when it would not otherwise have occurred. The soil water conditions created by surface redistribution of rainfall are also actively exploited by farmers who vary cropping practices within fields to maximise crop yields and reduce the risks of crop failure.

Introduction

Surface redistribution of rainfall has been shown by several recent authors to be a particularly important hydrological process in dryland environments (e.g. Harris *et al.*, 1994; Gaze *et al.*, 1997). This is partially attributed to the rainfall characteristics in semi-arid regions, where a large proportion of rainfall often falls in a relatively small number of high intensity storms. In cropped areas the surface redistribution of rainfall is encouraged by such features as sloping fields, contour bunds, paths and roads, termite mounds, surface crusts, sparse crop cover and microtopography created by cultivation practices. In areas of natural vegetation, variable infiltration rates have also been observed, particularly where there is a lack of near surface vegetative cover (Bromley *et al.*, 1997).

Surface water redistribution processes within fields can be observed at a range of scales. Contour ridges are a particularly widespread feature in communal areas of Zimbabwe, owing to colonial agricultural policies introduced in the 1930s (Hagmann and Murwira, 1996). Many fields are on noticeable slopes or have been partially eroded since clearance, resulting in considerable height differences within fields. Rills and gullies commonly form in fields where an up-slope contour bund has been over-topped and damaged. In a survey of 115 fields in a smallholder farming area in southern Zimbabwe, Hagmann (1995) found that 16% of all contour ridges were broken and 50% overflowed, and that on average each field was cut across by 4.2 rills. At a smaller scale, microtopography occurs because of disturbance of the soil surface by ploughing, ridging, hoeing and other types of cultivation technique.

Understanding the effects of surface redistribution of rainfall is important for several reasons. Firstly, the outputs of soil water balance models may be significantly improved by representation of this process, particularly in the simulation of groundwater recharge. Secondly, the use of a uniform infiltration rate tends to result in underestimation of recharge in low rainfall years when accurate prediction of groundwater resources is most important (Butterworth *et al.*, 1999). And thirdly, the importance of surface redistribution of rainfall also needs to be recognised when planning on-farm experiments in dryland regions and in the extension of agronomic advice (Miller *et al.*, 1994).

In this paper, the variability of infiltration within farmers' fields on two soil types is investigated to assess the effects of surface redistribution on deep drainage/groundwater recharge.

Materials and Methods

STUDY SITE

The Romwe Catchment is located in southern Zimbabwe, 86 km south of Masvingo (20° 45′ S, 30° 46′ E). A detailed description of the catchment characteristics and background to the Romwe Catchment Study is given by Bromley *et. al.* (1999). The two most important soil types for rainfed cultivation are well-structured and relatively freely draining sandy clay soils with a strong red colour (Chromic Lixisols or red clay soils), and grey-coloured sandy loams over sandy clays (Ferric Lixisols or grey duplex soils) which are prone to waterlogging and interflow in wet years.

Two surface water sub-catchments, one with red clay soils, the other with grey duplex soils, were identified; these are subsequently referred to as the Red and Grey sub-catchments. Each sub-catchment contained two fields managed by an individual farmer, and in both cases the contour bund between the fields had been breached in one place (Fig. 1). Management of the sub-catchments was carried out by the farmers, and detailed records were kept of all crop management practices. During the season studied here (1994/95), maize was grown in both sub-catchments.

The Red sub-catchment had a total area of 2.4 ha and a cropped area of 1.7 ha. The remaining area was scrub and woodland vegetation on the flanks of the fields. The upper field was relatively flat (mean slope 2%). A 2 m wide bund covered with grass and shrub vegetation separated the two fields but had been breached. The lower field was more steeply sloping (mean slope 3.1%) and incised by an erosion gulley which had deposited a fan of red sediment, eroded from the upper parts of the field, over the more vertic soils towards the base of slope. There were limited areas with locally steeper slopes, up to 14.5% at the southern edge of the lower field.

The Grey sub-catchment on the southern side of the stream had an area of 1.1 ha and the area of cropped land, excluding the contour bund and grassed waterways was 1.0 ha. A low bund separated the two fields but was bro-

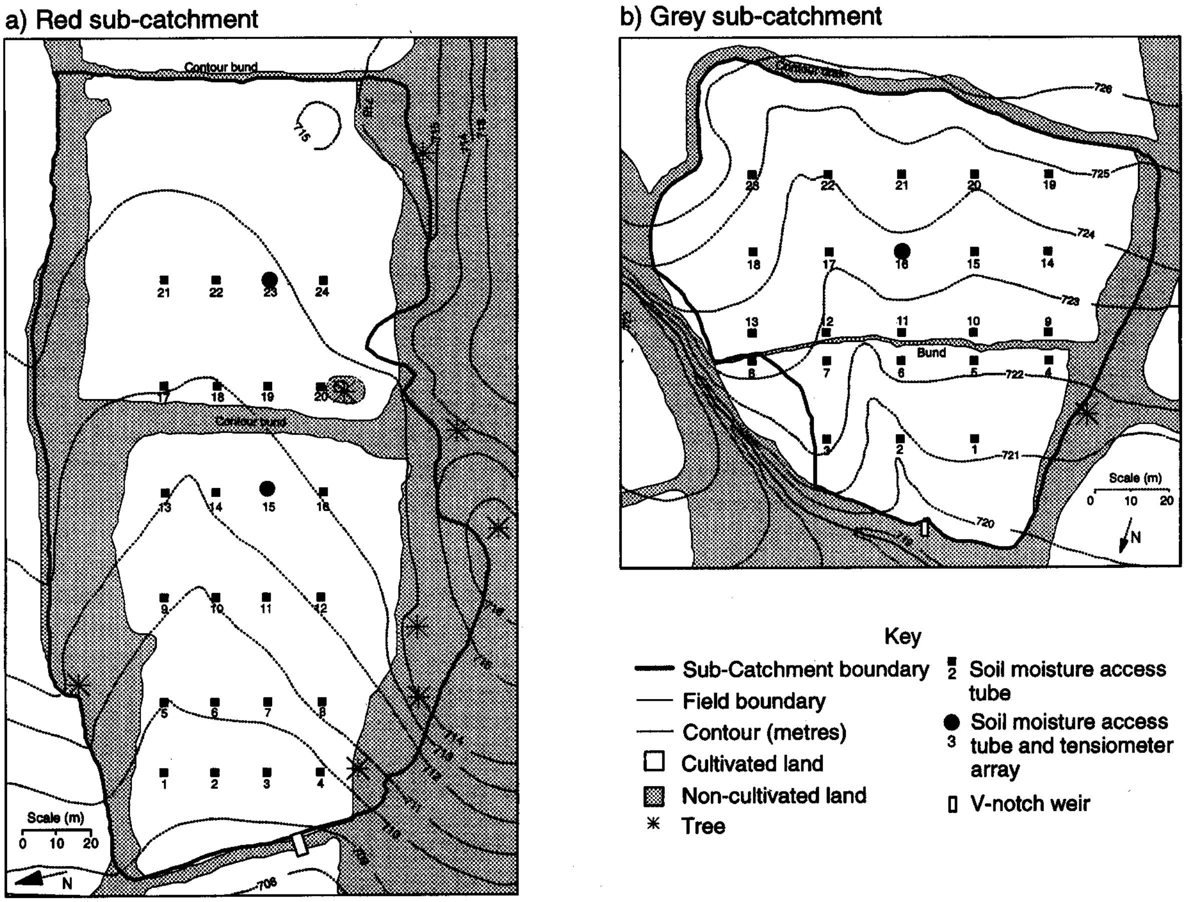

Fig. 1. *Red and Grey sub-catchment study sites.*

ken near the centre where runoff channels in the upper field converged. The lower field was divided by the channel running from this break in the bund. The fields sloped more steeply than the Red sub-catchment, having a mean slope of 5.5 and 5.8% in the upper and lower fields respectively. Along the sides of the channel in the lower field and at the top of the upper field, slopes were up to 16.3 %.

METEOROLOGICAL MEASUREMENTS

Rainfall was measured using a tipping-bucket raingauge located within 700 m of both sub-catchments. Over this distance across the valley floor, spatial variation in annual rainfall has been shown to be within 2.5% (Butterworth, 1997). Reference potential evaporation was calculated after Penman (1948). Further details of meteorological measurements are given by Bromley *et al.* (1999).

RUNOFF

Runoff losses from the sub-catchments were gauged using 90° V-notch weirs with a maximum rating of 0.14 m^3s^{-1} (Bureau of Reclamation, 1984). Stage measurements were made continuously using a chart recorder, and also by observers present at each site during flow events.

INFILTRATION

Average sub-catchment infiltration was determined for major rainfall events by subtracting any runoff at the catchment outlet from rainfall. To determine point-scale infiltration, *in-situ* soil water measurements were made using a neutron probe (Didcot Instruments, UK) as described by Bromley *et al.* (1999). A grid of 24 aluminium access tubes was installed in the Red sub-catchment, and 23 tubes in the Grey sub-catchment, to a maximum depth of 3 m (Fig. 1). Continuous records were restricted to 17 sites in the Red sub-catchment and 20 sites in the Grey sub-catchment because of damage to tubes after installation and the limited depth of some tubes.

Infiltration during major rainstorms was calculated as the difference in profile soil water storage before and after the event. To determine soil water storage just before a rainstorm, evaporative losses between the time of the last neutron probe measurement and the rainstorm were modelled using the ACRU soil water balance model (Schulze, 1995; Smithers and Schulze, 1995). Drainage losses were negligible in the periods just before major rainfall events in 1994/95 because of the long dry spells between rainstorms. Soil water storage after a rainstorm was determined from the measurement taken soon after rainfall. This was normally on the same day as rainstorms, but always within 48 hours. To allow for evaporative losses between the rainstorm and the time of soil water measurement, the measured profile storage was increased, assuming that evaporation had occurred at the potential rate determined using the Penman equation (1948). Rainfall concentration factors (RCF) at each neutron probe site were calculated for major rainstorms, following Gaze *et al.* (1997), where:

$$RCF = I/P$$

and I is the measured infiltration and P is the recorded rainfall. Infiltration values include water subsequently assigned to drainage.

DRAINAGE

Soil hydraulic potential profiles were measured daily at two sites in the Red sub-catchment and one site in the Grey sub-catchment using mercury manometer tensiometers installed to a maximum depth of 2 m (Bromley *et al.*, 1999). A clearly defined zero flux plane (ZFP) could be identified from soil hydraulic potential profiles in the Red sub-catchment and was used to calculate evaporation and drainage from soil water content changes (Butterworth, 1997) using the ZFP method (Cooper, 1979). This method could not be applied to the soil profiles in the Grey sub-catchment where a ZFP did not form.

CROP MANAGEMENT AND MEASUREMENTS

Details of the farmers' crop management activities are summarised in Table 1. Ploughing and other cultivations were always across the main slope of the fields but, owing to the variation in topography, in some areas this was directly up- or down-slope particularly in the vicinity of the incised channel in the lower fields. In the Red sub-catchment, the farmer adopted different secondary cultivation and sowing practices between fields because of delays in hiring a tractor to finish ploughing the lower field. In the upper field, emergence was consequently delayed due to the drier soil conditions at the time of sowing, and micro-topography was more pronounced owing to the method of planting in furrows. Where germination was poor in both sub-catchments, gaps were infilled about 2 weeks after the main sowing.

Grain yield was measured at the end of the growing season for 5 × 5 m plots around each neutron probe access tube. Maize grain was harvested, stripped from the cobs, air-dried and weighed. A sample was oven-dried to determine the grain yield at 12.5% moisture content.

Results

RAINFALL

The total rainfall in 1994/95 (the period 1 July 1994 to 30 June 1995) was above average, with 737.5 mm recorded (Table 2). The cropping season was confined by rainfall between 9 December 1994 and 29 March 1995 when a total of 502 mm rainfall was received. Of this amount

Table 1. Summary of crop management activities

Activity	Red sub-catchment	Grey sub-catchment
Primary cultivation	Tractor-drawn disc plough (0.15-0.20 m depth)	Oxen-drawn mouldboard plough (0.12–0.15 m depth)
Secondary cultivation	Upper field: 1 m wide ridges and furrows Lower field: none	Harrowing
Crop (variety)	Maize (hybrid R201)	Maize (hybrid R201)
Method of planting	Upper field: In furrows, seeds covered by hand-hoeing Lower field: Oxen-drawn single-row planter	Oxen-drawn single-row planter
Plant spacing	1 m rows, avg. 0.23 m between plants	1 m rows, avg. 0.23 m between plants
Sowing date	15 Dec 1994	12 Dec 1994
Harvest date	15–30 May 1995	9-13 Apr 1995
No. of weedings	Upper field: 1 Lower field: 2	Upper field: 4 Lower field: 3

Table 2. Rainfall, runoff, and infiltration at sub-catchment and point scales, during major rainfall events, 1994/95

	Rainfall event data				Total
	24–28 Dec 1994	16–20 Jan 1995	16–18 Feb 1995	26–29 Mar 1995	1994/95
Rainfall					
Total rainfall (mm)	75.5	75.5 (Red)[1] 90.5 (Grey)	141.0	75.5 (Red)[2] 81.0 (Grey)	737.5
Peak rainfall intensity (mm hr^{-1})	60	135	90	90	
Rainfall at intensities > 15 mm hr^{-1} (mm)	35.0	49.0	111.5	30	
Sub-catchment runoff					
Red sub-catchment runoff (mm)	0.0	2.1	5.8	0.0	7.9
Grey sub-catchment runoff (mm)	0.0	0.9	42.6	0.0	43.6
Sub-catchment scale infiltration					
Red sub-catchment (mm)	75.5	73.4	135.2	75.5	730
Grey sub-catchment (mm)	75.5	89.6	98.4	81.0	694
Point-scale infiltration—Red sub-catchment					
No. of observations	8	17	17	17	17
Minimum	46	15	97	41	658
Maximum	144	202	227	85	891
CV %	53	64	23	22	8
Mean	83	66	136	57	719
Point-scale infiltration—Grey sub-catchment					
No. of observations	20	20	20	10	20
Minimum	57	37	33	51	548
Maximum	100	180	254	210	1087
CV %	15	43	51	63	17
Mean	70	68	102	76	664

[1] Rainfall for period 16–19 Jan 1995.

[2] Rainfall for period 26-28 March 1995.

444.5 mm was received in 5 single or closely-spaced groups of rainfall events. A large proportion of rainfall during these rainstorms (56%) was at intensities above 15 mm hr^{-1}. There were dry spells of two to five weeks duration between these events. The year studied was unusual because of frequent light rainfall outside the normal rainy season, in April, May and June. This resulted in considerable weed growth after crops were harvested.

RUNOFF AT A SUB-CATCHMENT SCALE

Runoff from both sub-catchments is shown in Table 2. Three discrete runoff events occurred at the Red sub-catchment in 1994/95. Two minor runoff events during the period 16–18 January 1995 resulted in 2.1 mm runoff. Most of the runoff (5.8 mm) occurred as a result of a single event, on 17/18 February 1995 when the rainfall total was 141 mm. Total runoff from the Red sub-catchment during the 1994/95 season amounted to only 1.0% of the rainfall.

Only two rainstorms resulted in runoff from the Grey sub-catchment. The first storm of 44.5 mm on 16 January 1995 produced runoff amounting to 0.9 mm. The second runoff event was caused by the 141 mm rainstorm on 17/18 February 1995 which resulted in 42.6 mm runoff. Total runoff from this sub-catchment during 1994/95 was 43.6 mm or 5.9% rainfall, a much larger component of the water balance than for the Red sub-catchment in this year.

Sub-catchment scale infiltration values are included in Fig. 2, and in the following section are compared with point measurements of infiltration at the neutron probe access tube sites.

WITHIN-FIELD VARIATION IN INFILTRATION

Point-scale infiltration data for rainstorms in 1994/95 which resulted in significant redistribution of surface water are shown in Table 2 and Fig. 2. Total infiltration in 1994/95 varied between 658 and 891 mm (89–121% of total rainfall) for a sample of 16 sites in the Red sub-catchment with a coefficient of variation (CV) of 8%. The mean total infiltration of 719 mm for these sites was close to the sub-catchment scale measure of 730 mm.

In the Grey sub-catchment, total infiltration ranged from 548 to 1087 mm (74–147% rainfall) for a sample of 20 sites with a CV of 17% which was considerably greater than in the Red sub-catchment. Mean total infiltration determined from the neutron probe sites was 664 mm, which was 30 mm less than the estimate derived at a sub-catchment scale. Point-scale infiltration values for the largest rainstorm, which occurred on the night of 17/18 February 1995 are shown on Fig. 3. In the Red sub-catchment a range of infiltration values between 97 and 227 mm (69–161% rainfall) was observed with a CV of 23%. Mean infiltration at 16 sites was 136 mm for this rainstorm, very close to the 135 mm determined at the sub-catchment scale by subtracting runoff from rainfall. In the Grey sub-catchment average infiltration for this event was 102 mm, with a CV of 51% and a range between 33 and 254 mm (23–180% rainfall). The mean of 102 mm is again very close to the sub-catchment scale value of 98 mm.

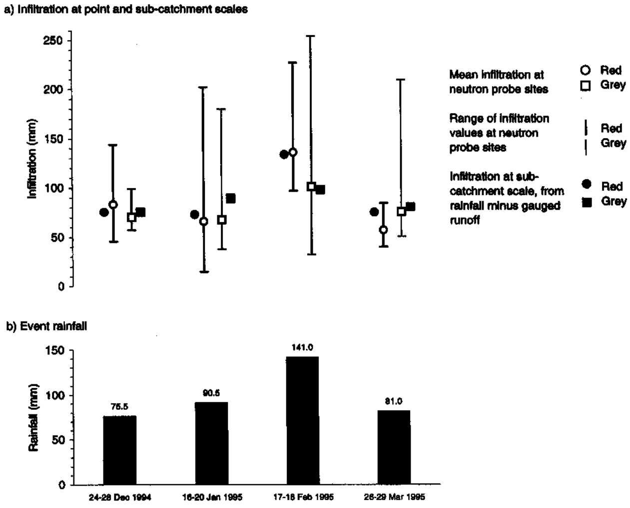

Fig. 2. *Infiltration at point and sub-catchment scales, 1994/95.*

Significant surface redistribution of water was also observed for rainfall events between 24–28 December 1994, 16–20 January 1995 and 26–28 March. With the exception of the mid-January event in the Grey sub-catchment and the late March event in the Red sub-catchment, measures of infiltration at the point and sub-catchment scales corroborated each other (Fig. 2). In these two cases, there was a discrepancy of 23 mm and 18.5 mm respectively.

The degree of surface redistribution varied considerably between the two sub-catchments and over time during the season. For the first two rainfall events, the range and CV of infiltration values was greater in the Red sub-catchment than the Grey sub-catchment. The degree of redistribution increased during the season in the Grey sub-catchment and, in the latter two events, the range and CV of infiltration values were greater in the Grey sub-catchment.

DRAINAGE

In both sub-catchments, drainage from the soil profile was almost entirely associated with the 17/18 February 1995 event. The pattern of drainage was spatially variable within both catchments and drainage did not occur at all sites. In the Red sub-catchment, soil hydraulic potential profiles measured at two sites indicated almost identical movement of the ZFP during the season. These two sites were both locations at which drainage was observed, and the ZFP depths were used to estimate drainage at the nine sites where drainage was indicated by soil water content changes (Butterworth, 1997). Total drainage for the year is shown in Fig. 4. The maximum drainage was 75 mm and occurred at the site where the highest infiltration was observed (RSC18). This site was located up-slope of the contour bund close to where it was breached. The average drainage for 16 sites was 24 mm. Where drainage was observed, it commenced soon after the 17/18 February 1995 event and had generally ceased within 70 days.

In the Grey sub-catchment, a ZFP was not observed and drainage could not be calculated using this method. However, significant changes in soil water content occurred throughout the profile at four sites to at least 1.8 m depth, indicating that drainage had occurred (Fig. 4). At all of the other sites, there was no seasonal change in soil water contents in the sandy clay layer. Long-term soil water content records implied that drainage through the soil matrix did not occur at these sites (Butterworth, 1997).

CROP YIELDS

Maize grain yields at the sites of each access tube in both sub-catchments are shown in Fig. 5. In the Red sub-catchment yields varied between 0.87 and 4.24 t ha^{-1} with an average yield of 1.77 t ha^{-1} (excluding site RSC20 which is located at the edge of a termite mound and was only partially cropped). In the Grey sub-catchment, the mean yield was 11% greater than in the Red Sub-catchment although a similar range in yields was observed. Maize grain yields averaged 1.96 t ha^{-1} and varied between 0.50 and 4.29 t ha^{-1} (excluding site GSC2 which is located in the gulley in the lower field and was not cropped but left under grass to reduce soil erosion).

Discussion

RAINFALL CONCENTRATION FACTORS (RCF)

Observed point-scale infiltration during storms was equivalent to RCFs of 0.20–2.68 on the red clay soils, and 0.23–2.59 on the grey duplex soils. The frequency distribution of RCFs for all events which resulted in surface distribution of rainfall are shown in Fig. 6. On both soil types there were a greater number of runoff sites, with the largest observed RCF class being 0.5–0.75 in the Red sub-catchment and 0.75–1.0 in the Grey sub-catchment. A smaller number of runon sites was distributed over a wider range. A similarly shaped frequency distribution was observed by Gaze *et al.* (1997) on cropped sandy soils in Niger where RCFs were between 0.3 and 3.4 times the recorded rainfall. In Botswana, similar levels of concentration have been observed in cropped areas; infiltration was found to be 2.5 times greater in the low areas of fields than the high areas, with a range between 1.6 to 3.8 (Harris *et. al.*, 1994; Miller *et al.* 1994). In this study, elevated areas

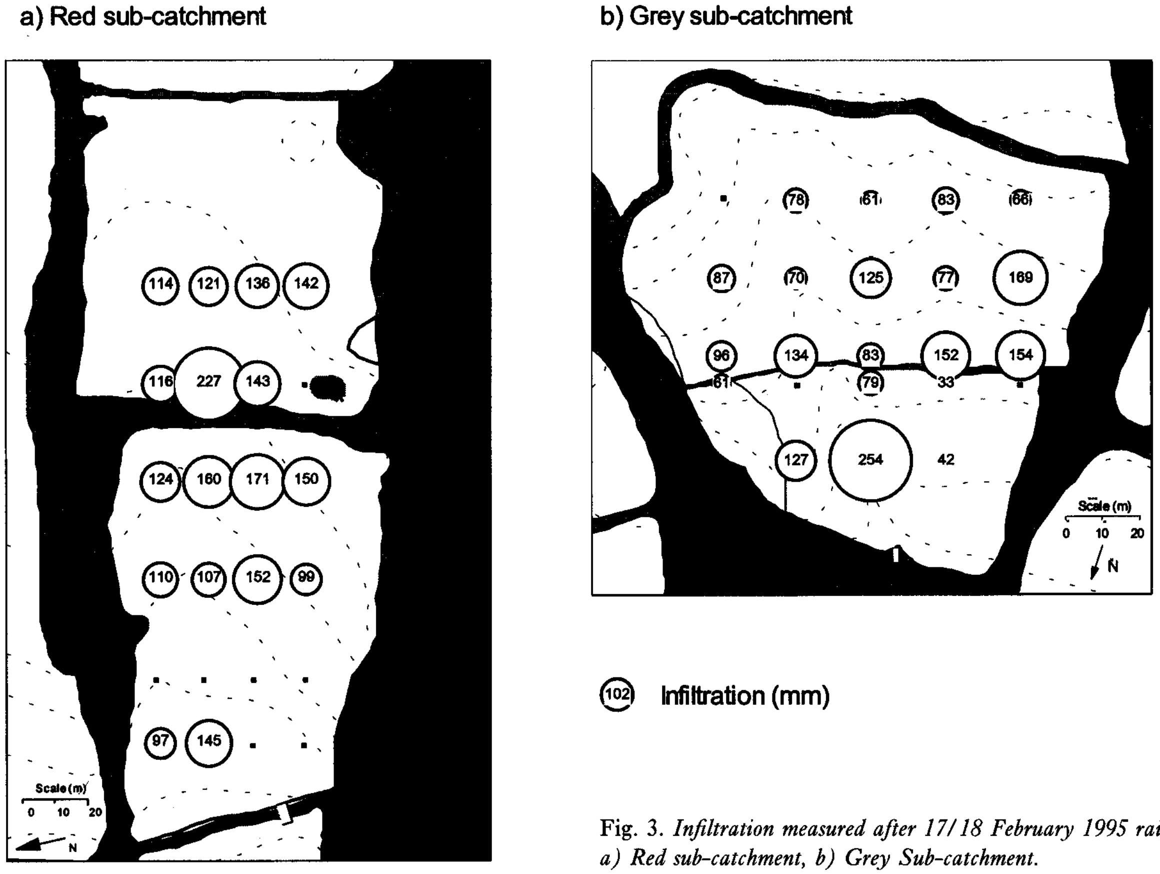

Fig. 3. *Infiltration measured after 17/18 February 1995 rainstorm, a) Red sub-catchment, b) Grey Sub-catchment.*

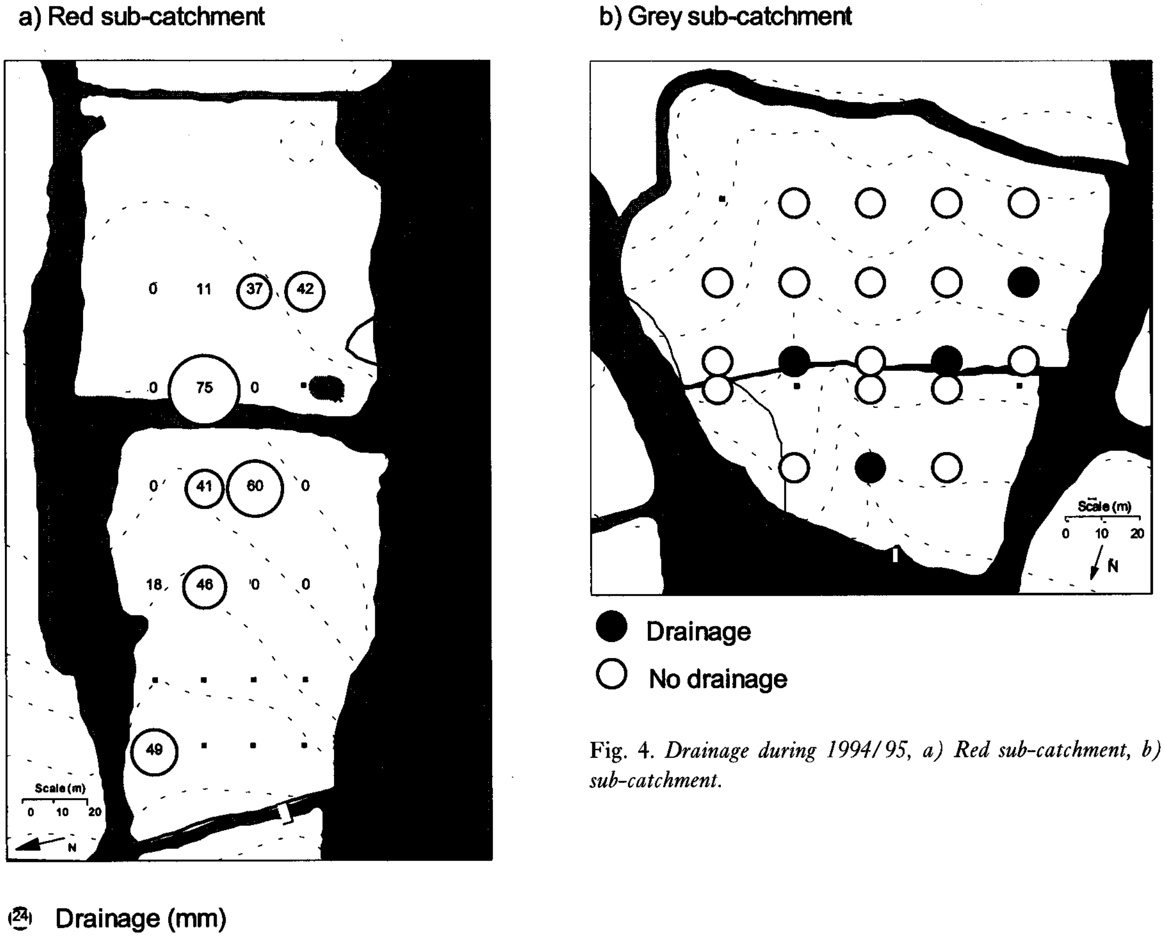

Fig. 4. *Drainage during 1994/95, a) Red sub-catchment, b) Grey sub-catchment.*

were associated with termite activity which resulted in increased clay contents, greater water-holding capacities and better nutrient status than in the low areas with sandier, less fertile and more leached soils attributed to the greater infiltration rates.

SITE BEHAVIOUR AS LOCATIONS OF RUNON OR RUNOFF

The generally close comparison between point and sub-catchment scale measurements of infiltration, suggests that the sample of monitoring sites was not significantly biased between sites of runon or runoff. The discrepancies observed for one event in both the Red and Grey sub-catchments may have arisen due to spatial variability in rainfall or error in the measurement of rainfall, errors associated with near-surface soil water measurement, and the possibility that the sample of sites was not representative of redistribution patterns in these storms.

In both sub-catchments, many of the neutron probe sites were not characterised as being locations of consistent runon (infiltration > rainfall) or runoff (infiltration < rainfall) during the season, allowing for the maximum error due to random counting as calculated after Hodnett (1986). Of the 17 sites in the Red sub-catchment, 10 were locations where both runon and runoff were observed during the year. Similarly, in the Grey sub-catchment 6 out of 20 sites behaved inconsistently over the year. The most likely explanation for this behaviour is that infiltration at these locations was significantly affected by local redistribution of water, caused by micro-topography which varied during the season with repeated weeding and the gradual flattening of ridges created by initial cultivations. In both sub-catchments, the soil surface was disturbed by cultivations between each runoff event.

Only one of the sites in the Red sub-catchment (RSC14) responded consistently as a runon site. This site was located below the bund between the two fields, close to the position of the breach. The high infiltration typical at site RSC14, due to channelling and ponding of water behind the contour bund, is illustrated by the 17/18 February 1995 rainstorm (Fig. 3). At this site infiltration was affected not only by the micro-topography created by cultivation but by redistribution of water over a larger scale, over distances of perhaps tens of metres, because of the general slope of the fields and the location of the bund and breach. There were six sites from which runoff occurred during all events, of which four were located on the field margins.

Table 3. Comparison of infiltration above and below contour bunds for 17/18 February 1995 rainstorm.

Site	Infiltration above bund			Infiltration below bund		
	Mean (mm)	Std. dev. (mm)	No. of sites	Mean (mm)	Std. dev. (mm)	No. of sites
Red sub-catchment	161	125	3	154	99	4
Grey sub-catchment	104	57	5	42	36	3

In the Grey sub-catchment, again only one site was consistently a site of runon. Site GSC2 was located in the lower field near to the centre of the gulley which drained the whole sub-catchment. By far the greatest infiltration for the 17/18 February 1995 event was recorded at this site (Fig. 3), and the four next highest values were all observed in relatively low areas (GSC14 and GSC9, 10 and 12 just up-slope of the contour bund). No significant relationship was found between the depth to clay and the amount of infiltration in large rainfall events. It was expected that infiltration might be limited where the less permeable sandy clay layer was close to the surface, resulting in saturation-excess runoff. However, even during this event, infiltration was not sufficient to lead to the formation of perched water tables above the sandy clay layer except at site GSC2. Instead, infiltration-excess runoff was the dominant process of runoff generation in the Grey sub-catchment because of the distribution, size and intensity of rainfall events and the low hydraulic conductivity of the soil surface. There were 13 sites from which runoff occurred consistently. These were located in the more steeply sloping parts of the field, particularly down-slope of the contour bund and at the field edges.

The changing behaviour over time may reflect the differently varying surface detention and infiltration capacities of the soils. The grey duplex soils in particular tend to lose surface roughness more rapidly and are prone to development of surface crusts, facilitating infiltration-

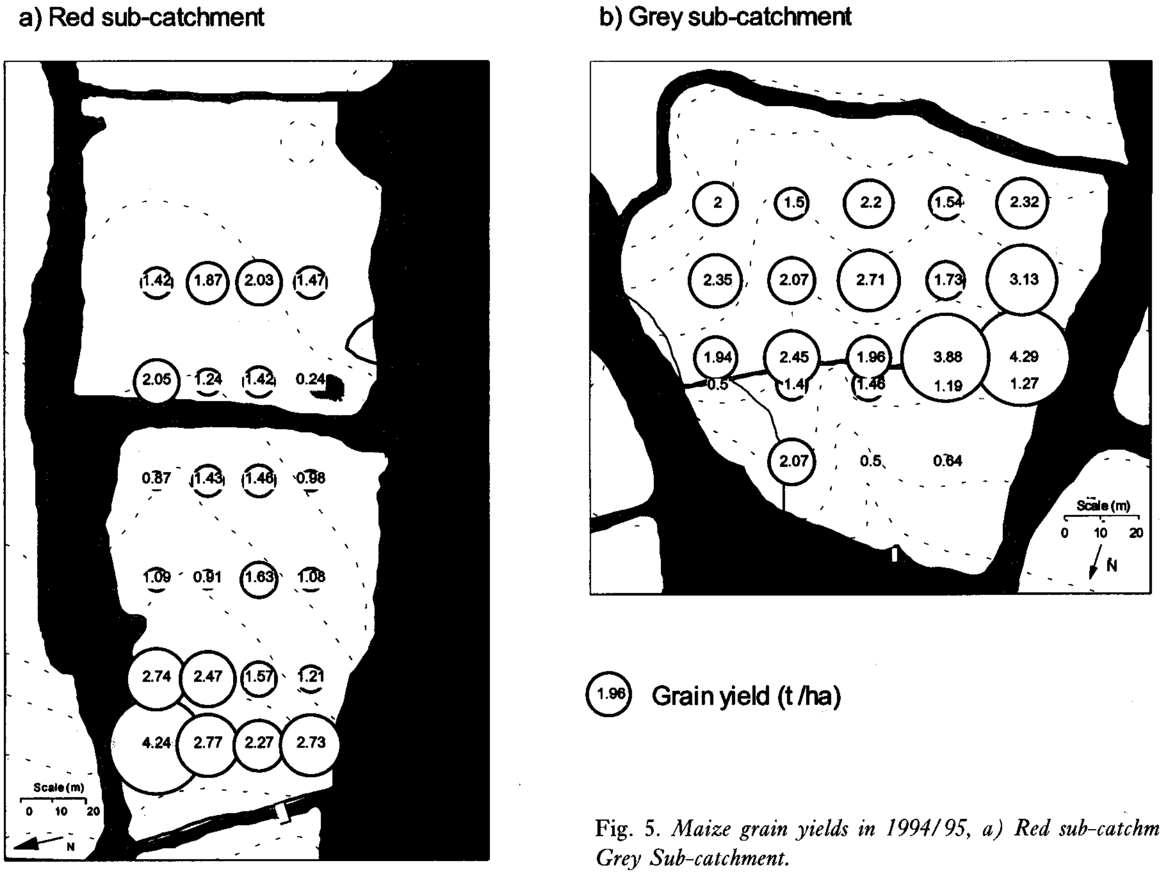

Fig. 5. *Maize grain yields in 1994/95, a) Red sub-catchment, b) Grey Sub-catchment.*

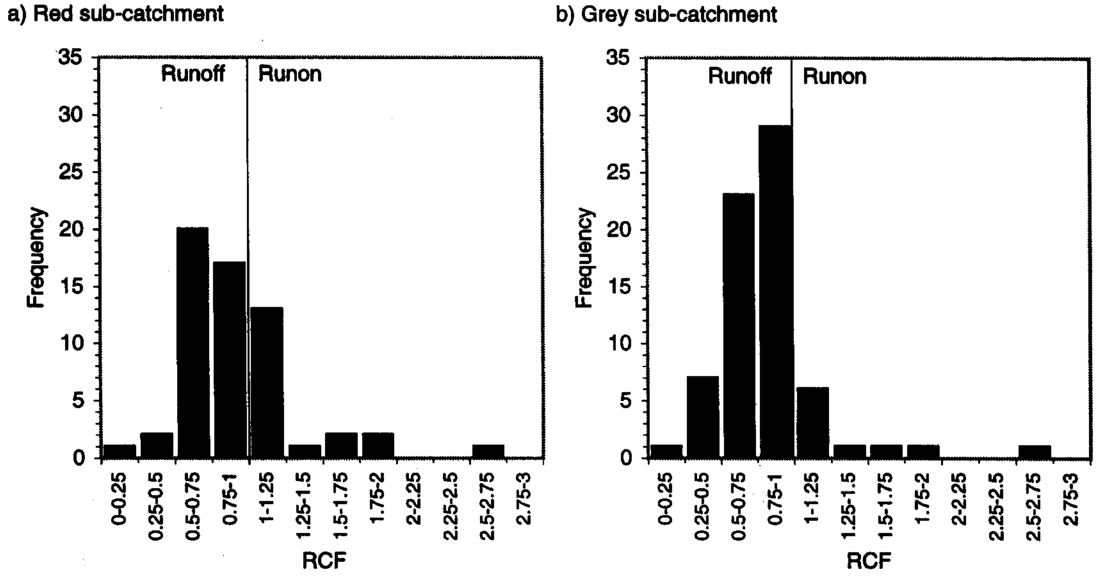

Fig. 6. *Frequency plots of rainfall concentration factors (RCF) for rainstorms in 1994/95 which resulted in surface redistribution of rainfall.*

excess overland flow. This is believed to be the cause of the greater runoff from these soils in this year compared to the red clay soils, rather than saturation overland flow and interflow which can, however, be very considerable in wetter years (McCartney *et al.*, 1998).

EFFECT OF CONTOUR BUNDS ON INFILTRATION WITHIN FIELDS

A summary of the infiltration up-slope and down-slope of contour bunds during the 17/18 February 1995 rainstorm is given in Table 3. In the Grey sub-catchment considerably greater infiltration was observed at sites located immediately up-slope of bunds. In the Grey sub-catchment, the infiltration up-slope of the bund was 104 mm compared to 42 mm down-slope of the bund. In the Red sub-catchment, there was little difference between the mean infiltration above and below the bund between the two fields. This may reflect the smaller amount of runoff and surface redistribution of water which was observed at the Red sub-catchment during this event (only 5.8 mm runoff from the Red sub-catchment compared to 42.6 mm from the Grey sub-catchment).

SURFACE WATER REDISTRIBUTION AND DEEP DRAINAGE/RECHARGE

For the nine sites where drainage was observed, there was a significant linear relationship between the amount of infiltration and drainage (R = 0.79). At these sites, enhanced infiltration, due to runon exceeding runoff, resulted in greater drainage. However, the remaining sites where drainage did not occur were not sites of particularly low infiltration. This suggests that other factors, in addition to surface redistribution of rainfall, were important in controlling the amount of drainage from the profile. Spatial variability in soil properties between the sites may account for this behaviour, but was not quantified in detail in this study. In the Grey sub-catchment, the four sites where drainage was indicated by soil water content measurements were all sites of relatively high infiltration during the 17/18 February 1995 event. Mean infiltration at these sites was 178 mm, compared to the sub-catchment average of 102 mm.

On both soil types therefore, surface redistribution was important in determining whether drainage occurred at a particular point and, in the Red sub-catchment where this could be quantified, the magnitude of the drainage flux. Although rainfall was above average in this year, the rainfall characteristics were typical of a relatively poor rainfall year in terms of generating groundwater recharge, due in particular to the widely-spaced distribution of rainstorms. It is most important that in such rainfall years the redistribution of rainfall at the soil surface is considered in recharge studies, because without this process recharge would often not occur at all. In wetter years or on more freely draining soils, where drainage is more likely to occur at all locations, the effect of surface redistribution on drainage may be less important, since increased drainage at runon sites would tend to be compensated for by reduced drainage at runoff sites (Gaze *et al.*, 1997).

SURFACE WATER REDISTRIBUTION AND CROP PRODUCTION

The primary objective of this paper is to illustrate the importance of surface redistribution of rainfall to groundwater recharge. However, the importance of this process to

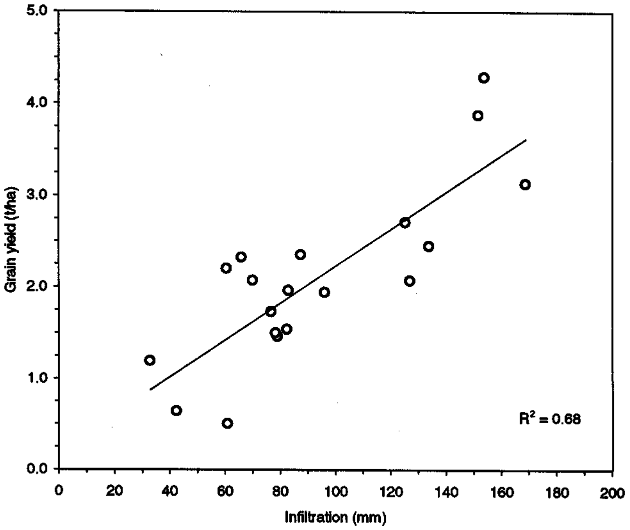

Fig. 7. *Relationship between infiltration measured after 17/18 February 1995 rainstorm and maize grain yield, Grey sub-catchment.*

crop production in dryland environments was also highlighted during the study.

The grey duplex soils, although of poor nutrient status, are valued by farmers because of the reduced tillage requirements in cultivating the sandy loam topsoil. This enables farmers to plant quickly after rainfall and get crops established in the narrow window when soil moisture conditions are favourable for germination. However, because of the limited potential storage of available moisture, crops cultivated on these soils are often prone to moisture stress during the dry spells which are common during the rainy season in this region. By 17 February 1995 the sandy loam horizons contained very little available moisture following a 4 week dry spell, and the mature maize plants showed signs of moisture stress, particularly leaf rolling. Grain yields were highly variable across the Grey sub-catchment (0.5 to 4.29 t ha^{-1}), and were strongly correlated with the amount of infiltration due to the 17/18 February 1995 event (Fig. 7) which was the only significant rainfall during the latter period of crop growth (correlation coefficient of 0.82 significant at the 0.1% level of the F-distribution). There was no significant relationship between crop yield and the amount of infiltration earlier in the season or the depth to the clay layer. Although it is possible that other factors contributed to the relation between single event infiltration and yield (e.g. variations in soil fertility at sites of greater infiltration), it seems likely from field observations that the amount of infiltration during the 17/18 February 1995 event was the single most important factor. In the Red sub-catchment, yields were not obviously related to the effects of variable infiltration, and field observations suggest the most important factors were catenary variation in soil properties and differences in crop management.

The relationship between infiltration and yield illustrate how significant improvements in crop yield can be achieved in difficult years by management practices designed to enhance infiltration and reduce runoff. Such practices include tied-ridging and mulch ripping (Chuma and Hagmann, 1995), and adaptation and maintenance of bunds to retain moisture within fields. Farmers are well aware of spatial variation in soil water conditions within fields, and alter their cropping strategies accordingly. For example on the grey duplex soils they often grow rice in the wetter areas of their fields.

Conclusions

1) Surface redistribution of rainfall at a field scale was an important hydrological process on two different soil types in 1994/95. Rainfall concentration factors for four events in this year ranged between 0.20–2.68 for red clay soils, and between 0.23–2.59 for grey duplex soils. Over the whole season, variable infiltration and runoff resulted in a range of total infiltration between 658–891 mm on the red clay soils and 548–1087 mm on the grey duplex soils in a year with 737.5 mm rainfall.

2) In a year with four rainfall events that resulted in significant surface redistribution of rainfall, only a few sites located behind a contour bund or on the field margins were consistently locations of either runon or runoff. Average slope and location within the field were not the dominant control at many other sites where the varying microtopography created by cultivation was more important.

3) Soil and water conservation structures can have a strong influence on the amount of infiltration within fields, especially when runoff volumes are large. On grey duplex soils, infiltration above a bund was 2.5 times greater on average.

4) Drainage from the unsaturated zone in the 1994/95 season on both red clay and grey duplex soil types was associated with a single rainstorm, and the location and magnitude of drainage was strongly influenced by the amount of infiltration during this event. If surface redistribution of rainfall had not occurred during this year, there would have been no deep drainage to groundwater through the soil matrix below fields with either soil type.

5) Although many factors affect crop yields, surface redistribution of rainfall can in certain circumstances be one of the most important. In 1994/95, maize grain yields in a field with grey duplex soils were strongly correlated with the amount of infiltration that occurred during a single rainstorm when the crop was reaching maturity.

6) The process of surface redistribution of rainfall presents a challenge in applications of water balance models to semi-arid regions, particularly where accurate prediction of groundwater levels is important. Simulations that neglect this process are likely to be most in error in years when groundwater recharge is low, when the accurate assessment of resource availability is most crucial.

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