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Full Length Research Paper

Drainage beyond maize root zone in an Alfisol subjected to three land management systems at Minna, Nigeria

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The objective of this experiment was to estimate drainage beyond maize rooting depth of 80 cm in relation to tillage and mulch by using Darcy Buckingham's equation for unsaturated, one-dimensional, vertical flow. Three land management systems were investigated, namely; untilled-mulched, tilled-mulched and tilled-unmulched. The three treatments were replicated three times in a randomized complete block design (RCBD). Individual plots had dimensions of 10 m × 10 m and were planted to maize. The mulch material was rice straw and the application rate was 5 t ha^{-1}. Triplicate tensiometers were installed at 70 and 90 cm depth in the three plots that made up the middle replication for the determination of hydraulic gradient across that depth interval on a daily basis for a 97-day evaluation period. The unsaturated hydraulic conductivity of the same depth interval was determined near the experimental site by the instantaneous profile method. The application of 5 t ha^{-1} of rice straw mulch increased drainage approximately five times and altered the drainage fraction of rainfall from 4 to 22% compared with unmulched soil. Mulch effect on drainage overshadowed tillage effect.

Key words: Drainage, unsaturated hydraulic conductivity, tillage, mulch.

INTRODUCTION

Quantitative water balance information is required for the development of efficient methods of soil water management. Drainage or deep percolation, as a water budget component, has received little attention in Nigeria because its measurement is difficult and reliable data sets, though extremely valuable, are very challenging to obtain. In order to measure drainage, the hydraulic properties that govern water transport in the soil must be quantified. Of these hydraulic properties, the unsaturated hydraulic conductivity is, if not the most important, certainly the most difficult to measure accurately. Field methods for measuring it include the instantaneous profile method, steady-flux methods (with sprinkler irrigation or artificial crusts), sorptivity measurements, use of tension infiltrometers, and unconfined infiltration measurements (Ankeny et al., 1991; Dirksen, 1991). The instantaneous profile method was adopted in this study.

Changes in land management systems alter water budget components with implications for soil and environmental quality, hence, the need to compare water budget components among old and new land management systems. Conservation agriculture is a rapidly spreading trend in land management globally but it is not being actively promoted among Nigerian farmers. The two core principles of conservation agriculture are (i) disturbing the soil as little as possible, and (ii) keeping the soil covered. Conservation agriculture is being promoted as the ultimate in land management systems for optimizing crop yields and farm profits, for improving environmental quality and for protecting the soil for future use (IIRR and ACT, 2005; Dumanski et al., 2006; Sanginga and

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Table 1. Physical properties of the soil profile.

Physical properties	Soil depth intervals (cm)				
	0-20	20-40	40-60	60-80	80-100
Sand (g kg^{-1})	760	700	660	600	520
Silt (g kg^{-1})	140	140	140	140	160
Clay (g kg^{-1})	100	160	200	260	320
Textural class	SL	SL	SL	SCL	SC
Bulk density (g cm^{-3})	1.52	1.54	1.59	1.65	1.65
Organic matter (g kg^{-1})	8.3	3.5	2.8	0.9	1.5

SL = sandy loam, SCL = sandy clay loam, SC = sandy clay.

Woomer, 2009).

Although, the influence of conservation agriculture in increasing water infiltration and consequently drainage is known qualitatively, there is very little quantitative information in Nigeria. In this study therefore, we investigated the effect of untilled-mulched land management system on drainage in comparison with the effects of tilled-mulched and tilled-unmulched systems. The untilled-mulched and tilled-unmulched systems represent conservation agriculture and conventional agriculture respectively while the tilled-mulched system represents mulched conventional agriculture.

MATERIALS AND METHODS

Site location and characteristics

The experimental site lies on latitude 9°41′ North and longitude 6°31′ East and is approximately 2 km from the Bosso campus of the Federal University of Technology, Minna in the Nnrth-east direction. Minna falls within the southern Guinea savanna vegetation zone with a sub-humid tropical climate. The soil of the experimental site is an Alfisol classified as Typic Plinthustalf (USDA) or Plinthic Lixisol (FAO/UNESCO). The texture of the soil varies from sandy loam in upper horizons to sandy clay in deeper horizons (Table 1). The 0 to 20 cm soil layer contains 760 g kg^{-1} sand, 140 g kg^{-1} silt and 100 g kg^{-1} clay while the 20 to 40 cm soil layer contains 700 g kg^{-1} sand, 140 g kg^{-1} silt and 160 g kg^{-1} clay and is hence, argillic. Alfisols are characterized by poor structure and proneness to surface sealing with resultant reduced infiltration (Wuddivira et al., 2000). The presence in Alfisols of argillic subsoil is thought to have some considerable effect on water infiltration (Rao et al., 1998).

Treatments and plot instrumentation

Three land management systems were investigated, namely; untilled-mulched, tilled-mulched and tilled-unmulched. The three treatments were replicated three times in a randomized complete block design (RCBD). Individual plots had dimensions of 10 m × 10 m and were separated by 5 m-wide interval to permit a tractor to turn without entering into an adjacent plot. Growing weeds and surviving litter of previous crops and weeds on the nine plots were cleared manually. No primary tillage was carried out on the untilled-mulched plots. The tilled-mulched and tilled-unmulched plots, on the other hand, were disc-ploughed to a depth of approximately 20 cm, followed by one disc-harrowing. Rice straw was subsequently spread evenly on the untilled-mulched and tilled-mulched plots at the rate of 5 t ha^{-1}, followed by planting of maize. Bunds were constructed along the upper and lateral sides of each plot to prevent run-on while permitting run-off.

For the measurement of drainage, only the three plots which made up the middle replication were used, with one plot representing each treatment. Triplicate vacuum gauge tensiometers were installed close to the centre of the three plots at 70 and 90 cm soil depths. Tensiometer readings were taken daily between 8.00 and 10.00 am from the first day after planting (25th June, 2009) to the day of harvesting (30th September, 2009) of the maize crop planted on the three plots. A rain gauge was installed for on-site measurement of rainfall events. Water table depth was monitored weekly with three piezometers installed close to the three plots. The depth of each piezometer below the soil surface was 200 cm.

Drainage flux

Drainage through a depth of 80 cm, above which 99.7% of maize root biomass was found by Odofin (2005) was estimated by using Darcy-Buckingham's equation for unsaturated, one-dimensional, vertical flow with depth (z) taken positive upward, expressed in the form:

$$Jw = - K(h)\ \delta H/\delta z \qquad (1)$$

where Jw (cm d^{-1}) is the drainage flux through a soil layer, K (h) (cm d^{-1}) is the hydraulic conductivity (K) of the soil layer as a function of matric potential head (h), and δH/δz (cm cm^{-1}) is the hydraulic gradient across the boundaries of the soil layer (Reichardt et al., 1998; Da Silva et al., 2009; Kang et al., 2012).

The average daily readings of triplicate tensiometers installed at 70 and 90 cm soil depths were used for calculating δH/δz across that depth interval. The K (h) function of the same depth interval was determined *in situ* by the instantaneous profile method, otherwise referred to as unsteady drainage flux method (Dirksen, 1991; Da Silva et al., 2009) as subsequently described.

Having determined δH/δz and K (h) for the 70 to 90 cm depth interval, drainage flux (Jw) through 80 cm depth was then calculated for each day, using Darcy-Buckingham's equation (Equation 1). The signs of calculated Jw values were used to partition downward flux (drainage) and upward flux (capillary rise).

Instantaneous profile method for the determination of unsaturated hydraulic conductivity, K (h)

This method entails the simultaneous measurement of volumetric water content (θ) and matric potential head (h) as functions of time and soil depth during redistribution of water in an initially saturated,

Table 2. Scheme for calculating hydraulic conductivity {K(h,θ)} with Equation 3, using matric potential head (h) and volumetric water content (θ) data obtained at 0 and 8 h of drainage* from the instantaneous profile method.

1	2	3	4	5	6	7	8	9	10	11	12
Z[a] (cm)	$h(t_1)$[b](cm)	$h(t_2)$[b] (cm)	$\theta(t_1)$[c] (cm^3/cm^3)	$\theta(t_2)$[c] (cm^3/cm^3)	$h(t_a)$[d] (cm)	$\theta(t_a)$[d] (cm^3/cm^3)	dW/dt[e] (cm/d)	dH/dZ[f] (cm/cm)	$h(t_ad_a)$[g] (cm)	$\theta(t_ad_a)$[g](cm^3/cm^3)	K(h,θ)[h] (cm/d)
0											
-10	0	-45	0.30	0.21	-22.5	0.255	-5.41				
-20								+0.750	-20.0	0.24	7.21
-30	0	-35	0.26	0.20	-17.5	0.230	-3.60				
-40								+0.750	-15.0	0.24	12.01
-50	0	-25	0.27	0.22	-12.5	0.245	-3.00				
-60								+0.850	-11.0	0.25	14.13
-70	0	-19	0.27	0.25	-9.5	0.260	-1.20				
-80								+0.975	-9.3	0.27	13.55
-90	0	-18	0.29	0.25	-9.0	0.270	-2.40				
-100											

*Other time segments were 8 to 48 h, 2 to 19 days and 19 to 56 days; [a]Z = soil depth, positive upward, from soil surface (Z = 0 cm) to 100 cm depth (Z = -100 cm); [b]h (t_1, t_2) = matric potential head (h) at the initial time (t_1) and final time (t_2) of a specified time interval; [c]θ (t_1, t_2) = volumetric water content (θ) at t_1 and t_2; [d]h(t_a) and θ(t_a) = the time averages of h and θ; [e]dW/dt = the water storage change between t_1 and t_2; [f]dH/dZ = the hydraulic gradient across two adjacent depths of tensiometer installation (Z_1 and Z_2); [g]h(t_ad_a) and θ(t_ad_a) = depth averages of h(t_a) and θ(t_a); [h]K(h,θ) = the hydraulic conductivity K as a function of h and θ.

bare soil profile. The values of θ and h are the basic data required for determining K (h) for the bottom layer of the soil profile in particular and for the overlying soil layers as well. Unsaturated hydraulic conductivity is strongly dependent on θ and h. Consequently, all methods used for determining it require the measurement of θ and/or h (Jury et al., 1991; IAEA, 2003).

Procedure for the instantaneous profile method

In December 2009, when there were no more rains, a 5 m × 5 m plot was marked out near the main experiment. A trench, 30 cm deep was excavated along the perimeter of the plot. The vertical faces of the trench were lined with plastic sheets and back-filled with the excavated soil to form a dike 15 cm above the soil surface. The buried plastic sheets minimized lateral water flow across the perimeter of the plot while the earth dike facilitated ponding. Quadruplicate tensiometers of the vacuum gauge type were installed at 10, 30, 50, 70 and 90 cm depths. The plot was thoroughly wetted by repeated ponding for two days until all the tensiometers indicated saturation (zero suction). After all the ponded water had infiltrated, the plot was covered up with plastic sheets and rice straw mulch used to prevent evaporation such that water flow was only downward. A condition of zero flux was thus created at the soil surface.

Volumetric water content (θ) was determined with the gravimetric method, using triplicate soil samples taken with an auger within 20 cm incremental depths from the surface layer (0 to 20 cm) to the bottom layer (80 to 100 cm). In order to determine matric potential head (h) corresponding to θ, tensiometer readings were taken immediately after sampling for θ determination. Measurements of both θ and h were taken twice on Day 0, twice also on Day 1, daily from Day 2 to Day 9, once in two days from Day 10 to 21, once in three days from Day 22 to 48, and once in four days from Day 49 to 60.

Unsaturated hydraulic conductivity for the different soil layers was calculated with the θ and h data generated, using the equation:

$$K(h) = \int_{z_0}^{z_b} (\delta\theta/\delta t)/(\delta H/\delta z)_{z_b} \qquad (2)$$

where K(h) is hydraulic conductivity (cm d^{-1}), θ is volumetric water content (cm^3 cm^{-3}), t is time (d), δH/δz is hydraulic gradient across the boundaries of the soil layer (cm cm^{-1}), z is soil depth (cm) with z taken positive upward, z_o is depth of zero flux plane which is at the soil surface (z_o = 0 cm), and z_b is depth (cm) below zero flux plane (Dirksen, 1991; Minhas et al., 1994).

Data analysis

The scheme for calculating K (h) with Equation 2, using experimental h and θ data at 0 and 8 h of drainage obtained from the instantaneous profile method is presented in Table 2 as an illustration. The same scheme was used for other time segments, namely 8 to 48 h, 2 to 19 days and 19 to 56 days. Table 3 contains h, θ and K data for the 70 to 90 cm depth interval and the overlying

Table 3. Matric potential head (h), volumetric water content (θ) and hydraulic conductivity (K) at various soil depths determined with the instantaneous profile method.

Soil depth (cm)	h (cm)	θ (cm^3 cm^{-3})	K (cm d^{-1})
20	-20.0	0.24	7.21
	-47.0	0.20	0.267
	-65.8	0.17	0.182
	-88.3	0.14	0.012
40	-15.0	0.24	12.01
	-37.0	0.20	0.436
	-53.5	0.18	0.236
	-74.8	0.15	0.071
60	-11.0	0.25	14.13
	-29.8	0.23	0.662
	-44.0	0.21	0.217
	-59.8	0.18	0.116
80	-9.3	0.27	13.55
	-24.3	0.24	0.993
	-35.5	0.22	0.280
	-46.0	0.21	0.123

layers emanating from the aforementioned scheme. The K (h) function has been established to be exponential while log K (h) function is linear (Adeoye, 1983; Minhas et al., 1994). With respect to the 70 to 90 cm depth interval, the simple linear regression equation between log K and h was computed to be:

$$\text{Log } K = 1.52 + 0.056h \ (R^2 = 0.95, P \leq 0.05) \qquad (3)$$

Equation 3 was used to obtain K corresponding to the daily h data at 80 cm depth in the main experiment. Next, the K (h) data and the daily hydraulic head gradients ($\delta H/\delta z$) across 70 and 90 cm depth interval for the main experiment were substituted into Darcy-Buckingham's equation (Equation 1) to obtain daily drainage fluxes from the beginning to the end of the evaluation period, a total of 97 daily fluxes. The scheme for the computation of drainage fluxes is presented in Table 4.

RESULTS

Daily drainage fluxes beyond 80 cm depth for a period of 97 days calculated using Darcy-Buckingham's equation is presented in Table 5. There was no drainage from the tilled-unmulched treatment from Day 1 to Day 26 whereas there was drainage from the untilled-mulched and tilled-mulched treatments on each day during the same period. The sign of daily fluxes indicated that there was no upward flux across the 80 cm soil depth throughout the 97-day evaluation period. Cumulative drainage values were 147 mm from the untilled-mulched treatment, 148 mm from the tilled-mulched treatment and 25 mm from the tilled-unmulched treatment. Drainage from the two mulched treatments (untilled-mulched and tilled-mulched) were statistically comparable ($P > 0.05$) while drainage from the two tilled treatments (tilled-mulched and tilled-unmulched) were significantly different ($P < 0.01$). Thus, the application of 5 t ha^{-1} of rice straw mulch increased drainage approximately five times and altered the drainage fraction of rainfall from 4 to 22% as compared with unmulched soil. During the first 49 days of the evaluation period, the water table was deeper than 200 cm from the soil surface (Table 6). Between Day 49 and Day 56, the water table rose above 200 cm depth and continued to rise until it reached an average depth of 131 cm from the soil surface.

The increase in drainage from 25 mm (4% of rainfall) in tilled-unmulched treatment to 147 mm (22% of rainfall) in untilled-mulched treatment and 148 mm (22% of rainfall) in tilled-mulched treatment has clearly shown the tremendous effect of surface residue cover on the drainage component of field hydrologic cycle in southern Guinea savanna agro-ecological zone of Nigeria. The result of this research work may be compared with those of Grema and Hess (1994) and Oluwasemire et al. (2002). Grema and Hess (1994) using the method of Klaij and Vachaud (1992), estimated drainage to be 8 to 20% of seasonal rainfall from plots that were bunded at the edges to prevent run-on and run-off in North-east Nigeria. Oluwasemire et al. (2002) reported that drainage losses measured with lysimeters accounted for 15 to >20% of annual rainfall from ridged sole and intercropped millet ecosystems near Kano in the Sudan savanna.

The insignificant difference ($P > 0.05$) between untilled-mulched and tilled-mulched treatments and the highly

Table 4. Scheme for the computation of the first 7 out of the 97 daily drainage fluxes measured, using Darcy-Buckingham's equation.

Day	Treatment	h (cm)	log K(h)	K (cm/d)	H_1 (cm)	H_2 (cm)	dH/dZ	Jw	
								(cm/d)	(mm/d)
1	Untilled-mulched	-40.5	-0.74395	0.1803	-23	-38	0.75	-0.1352	-1.35
	Tilled-mulched	-38.5	-0.63215	0.2332	-20	-37	0.85	-0.19822	-1.98
	Tilled-unmulched	-355	-18.3245	0	0	0	0	0	0.00
2	Untilled-mulched	-39.5	-0.68805	0.2051	-21	-38	0.85	-0.17434	-1.74
	Tilled-mulched	-41.5	-0.79985	0.1585	-23	-40	0.85	-0.13473	-1.35
	Tilled-unmulched	-169	-7.9271	0	0	0	0	0	0.00
3	Untilled-mulched	-37.5	-0.57625	0.2653	-18	-37	0.95	-0.25204	-2.52
	Tilled-mulched	-40.5	-0.74395	01803	-23	-38	0.75	-0.13523	-1.35
	Tilled-unmulched	-190	-9.101	0	0	0	0	0	0.00
4	Untilled-mulched	-41.5	-0.79985	0.1585	-25	-38	0.65	-0.10303	-1.03
	Tilled-mulched	-41.5	-0.79985	0.1585	-23	-40	0.85	-0.13473	-1.35
	Tilled-unmulched	-189	-9.0451	0	0	0	0	0	0.00
5	Untilled-mulched	-36.5	-0.52035	0.3018	-16	-37	1.05	-0.31689	-3.17
	Tilled-mulched	-41.5	-0.79985	0.1585	-23	-40	0.85	-0.13473	-1.35
	Tilled-unmulched	-161	-7.4799	0	0	0	0	0	0.00
6	Untilled-mulched	-36.5	-0.52035	0.3018	-16	-37	1.05	-0.31689	-3.17
	Tilled-mulched	-41.5	-0.79985	0.1585	-23	-40	0.85	-0.13473	-1.35
	Tilled-unmulched	-161	-7.4799	0	0	0	0	0	0.00
7	Untilled-mulched	-43.0	-0.8837	0.1307	-26	-40	0.70	-0.09149	-0.91
	Tilled-mulched	-40.5	-0.74395	0.1803	-23	-38	0.75	-0.13523	-1.35
	Tilled-unmulched	-155	-7.1445	0	0	0	0	0	0.00

h = matric potential head at 80 cm depth, log K (h) is logarithm of K as a function of h, K = hydraulic conductivity, H_1 = hydraulic head at 70 cm depth, H_2 = hydraulic head at 90 cm depth, dH/dZ = hydraulic gradient, Jw = drainage flux.

significant difference ($P < 0.01$) between tilled-mulched and tilled-unmulched treatments in the amounts of deep percolation pointed to mulch factor as dominant over tillage factor. In other words, the presence or otherwise of mulch influenced deep percolation much more than tillage or no-tillage.

The components of field water budget are strongly interdependent because they occur sequentially or simultaneously (Sivakumar and Wallace, 1991). Water infiltration controls surface run-off, soil water storage and deep percolation. The low deep percolation observed in the tilled-unmulched treatment was due to low water infiltration caused by a surface seal (Rao et al., 1998). Surface seal is formed by physical disintegration of soil aggregates and subsequent dispersion and compaction by the beating action of raindrops and is enhanced by low organic matter content, poor aggregation, and low soil strength under saturated condition leading to slumping, high bulk density, and loss of surface roughness. Water infiltration can also be reduced by the presence of argillic subsoil with low permeability. Low water infiltration caused by either surface sealing or argillic subsoil in Alfisols decreases deep percolation.

As this and other researchers have shown, neither tillage (ploughing and harrowing) nor no-tillage can be expected to increase water infiltration and consequently deep percolation in the absence of surface residues (Lopez et al., 1996; Duiker, 2011). The presence of mulch is required to prevent the formation of surface seal, thereby, increasing water infiltration. Mulch also retards surface water flow, thereby, providing more time for water infiltration. Ridging, like mulching, can increase rainfall infiltration. Ridges trap rainwater in the furrows and increase soil-water interface during rain events, thereby, increasing water infiltration. Cross-slope ridges were reported to have induced 7 to 13-fold increase in water infiltration as compared with flat cultivation in parts of West Africa (Aina, 1993).

Concerning the partitioning of downward flux (drainage) and upward flux (capillary rise), Darcy-Buckingham's

Table 5. Daily drainage fluxes (mm) beyond 80 cm soil depth for a period of 97 days.

Day	UM	TM	TU	Day	UM	TM	TU	Day	UM	TM	TU	Day	UM	TM	TU
0[a]	-	-	-	25	-1.75	-1.92	0	50	-0.47	-0.70	-0.29	75	-2.49	-1.66	-0.18
1	-1.35	-1.98	0	26	-2.52	-2.79	0	51	-3.17	-3.06	-0.29	76	-2.49	-1.66	-0.18
2	-1.74	1.35	0	27	-1.31	-4.29	-0.04	52	-2.52	-2.49	-0.54	77	-0.69	-1.35	-0.55
3	-2.52	-1.35	0	28	-2.52	-1.97	-0.14	53	-0.91	-1.46	-0.55	78	-0.43	-0.98	-0.28
4	-1.03	-1.35	0	29	-0.91	-1.97	-0.51	54	-0.47	-0.98	-0.28	79	-0.43	-0.96	-0.17
5	-3.17	-1.35	0	30	-0.69	-1.35	-0.53	55	-0.48	-1.21	-0.36	80	-0.37	-0.54	-0.19
6	-3.17	-1.35	0	31	-0.71	-0.98	-0.37	56	-0.20	-0.70	-0.29	81	-0.34	-0.53	-0.20
7	-0.91	-1.35	0	32	-0.36	-0.77	-0.29	57	-0.37	-0.42	-0.20	82	-0.34	-0.53	-0.20
8	-0.71	-1.35	0	33	-0.25	-0.69	-0.20	58	-2.49	-1.74	-0.15	83	-0.20	-0.35	-0.08
9	-4.39	-2.25	0	34	-0.37	-0.69	-0.15	59	-1.35	-1.35	-0.27	84	-0.20	-0.80	-0.15
10	-1.74	-2.79	0	35	-0.71	-1.31	-0.28	60	-0.92	-1.26	-0.29	85	-2.57	-3.47	-0.18
11	-1.74	-1.35	0	36	-0.71	-1.21	-0.28	61	-0.92	-1.26	-0.29	86	-0.81	-1.35	-0.27
12	-1.03	-1.97	0	37	-0.47	-0.77	-0.19	62	-0.34	-0.70	-0.18	87	-3.26	-1.31	-0.34
13	-1.03	-1.97	0	38	-0.47	-0.78	-0.20	63	-0.92	-0.98	-0.28	88	-0.55	-0.80	-0.36
14	-0.71	-1.82	0	39	-0.48	-0.77	-0.20	-64	-0.46	-0.78	-0.29	89	-0.55	-0.80	-0.36
15	-1.31	-2.49	0	40	-0.34	-0.77	-0.12	65	-0.47	-0.78	-0.55	90	-1.06	-1.26	-0.34
16	-1.35	-1.97	0	41	-0.71	-1.21	-0.15	66	-2.49	-1.82	-0.54	91	-0.72	-1.41	-0.37
17	-4.58	-1.98	0	42	-4.39	-1.92	-0.37	67	-1.35	-1.82	-0.98	92	-4.95	3-.77	-0.17
18	-1.74	-1.97	0	43	-4.39	-2.79	-0.69	68	-1.35	-1.82	-0.98	93	-3.11	-1.99	-0.86
19	-0.65	-1.86	0	44	-3.17	-1.97	-1.35	69	-0.65	-1.35	-0.36	94	-3.83	-1.54	-0.22
20	-0.71	-1.31	0	45	-1.74	-1.86	-0.69	70	-0.92	-1.74	-0.27	95	-4.32	-1.04	-0.43
21	-4.58	-4.29	0	46	-0.92	-1.01	-0.55	71	-0.69	-1.66	-0.36	96	-2.60	-1.04	-0.35
22	-2.57	-2.52	0	47	-0.91	-2.31	-0.54	72	-1.46	-1.21	-0.29	97	-0.95	-0.81	-0.20
23	-1.74	-1.92	0	48	-0.92	-1.03	-0.55	73	-0.34	-0.96	-0.18	98[b]	-	-	-
24	-3.26	-1.92	0	49	-1.64	-1.01	-0.27	74	-2.49	-1.66	-0.18				
												Mean	-1.51	-1.52[ns]	-0.25**
												Total	-146.55	-147.81	-24.53
												% of rainfall	22.00	22.19	3.68

UM = untilled-mulched treatment, TM = tilled-mulched treatment, TU = tilled-unmulched treatment, [a] = day of planting, [b] = day of harvesting, ** = significantly different from UM and TM at 1% (t test), [ns] = not significantly different from UM (t test).

Table 6. Depth of water (cm) below ground surface measured with triplicate piezometers.

Day	1st tube	2nd tube	3rd tube	Mean
0	> 200	> 200	> 200	> 200
7	> 200	> 200	> 200	> 200
14	> 200	> 200	> 200	> 200
21	> 200	> 200	> 200	> 200
28	> 200	> 200	> 200	> 200
35	> 200	> 200	> 200	> 200
42	> 200	> 200	> 200	> 200
49	> 200	> 200	> 200	> 200
56	192	187	189	189
63	188	184	187	186
70	178	172	178	176
77	167	167	160	165
84	162	158	152	157
91	157	152	147	152
98	132	130	132	131

equation computes flux as a vector quantity with magnitude and direction. Positive flux stands for capillary rise and negative flux for drainage (Jury et al., 1991). The negative sign of daily fluxes during the first half of the cropping season indicated that there was no upward flux across the 80 cm depth. The piezometer readings supported this observation as the water table was deeper than 200 cm from the soil surface and upward flux into the root zone was most unlikely. During the second half of the cropping season, when the water table rose above 200 cm depth and reached an average depth of 131 cm from the soil surface, the sign of daily fluxes remained negative, indicating that there was no upward flux. It could therefore be inferred that the height of capillary rise was less than the height difference (51 cm) between the minimum depth of water table (131 cm) and the depth of the root zone (80 cm) from the soil surface. The experimental soil is coarse-textured. One of the characteristics of coarse-textured soils is that they possess pores which are largely non-capillary and capillary rise is consequently little (Jury *et al.*, 1991).

Conclusion

In the experiment, 5 t ha of rice^{-1} straw mulch increased drainage through an Alfisol at Minna in the southern Guinea savanna of Nigeria from 25 mm (4% of rainfall) in tilled-unmulched treatment to 147 mm (22% of rainfall) in untilled-mulched treatment and 148 mm (22% of rainfall) in tilled-mulched treatment. Thus, it is inferred that drainage loss in this agro-ecological zone ranges from 4 to 22% of rainfall, depending on the degree of soil cover and regardless of tillage (ploughing and harrowing) or no-tillage.

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