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Full Length Research Paper

Soil moisture and its consequences under different management in a six year old hedged agroforestry demonstration plot in semi-arid Kenya, for two successive contrasting seasons

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Hedged agroforestry (AF) demonstration plots with maize/bean intercrops were studied at Matanya in Laikipia district, Kenya, between 1991 and 1995 inclusive, to understand crop yield behaviour due to selected soil moisture conservation methods applicable in semi-arid areas. The treatments were: Grevillea robusta trees root pruned, compared to unpruned, both in combination with (1) minimum tillage and mulching with 3t/ha maize stalks harvested from the plots with additional stalks collected from the nearby farms, and (2) the locally applied method of deep tillage practiced by the immigrants from wetter regions, acting as the control. Results showed that: (i) plots with root pruned Grevillea robusta trees that were mulched and minimum tilled had most soil moisture available in the shallower layers, during the wettest and the driest season on which this paper is based; (ii) the variation of soil moisture with distance from the Grevillea robusta trees showed patterns that were quite similar for plots with root pruned trees in the dry and the wet season; (iii) beans had greater seed yields and maize had more (stover) biomass and (only in the wettest season) grain in plots with pruned trees, minimum tilled and mulched, than in other AF plots. In the wettest season this resulted in identical maize yields but lower bean seed yields compared to those in the mulched and sometimes also the local control plots without trees. In the driest season bean yields remained the same but maize biomass yields improved above the control yields for the most successful agroforestry intervention applied; (iv) competition between the six year old Grevillea robusta trees and the crops was indirectly confirmed to be stronger than in earlier experiments in the same plots. This way the agroforestry demonstration plots were very successful in showing the consequences of the ageing agroforestry system, where the soil moisture conservation measures of pruning and mulching kept their effects. Statistical analysis only weakly confirmed the positive effect of root pruning on reducing competition for soil moisture between crops and trees that were very clearly shown to exist by the physical error analysis.

Key words: Agroforestry, demonstrations, hedges, intercropping, Kenya, semi-arid land, soil moisture management, wind problems

INTRODUCTION

Many farmers in Kenya have been forced to migrate from

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Acronyms

AF: Agroforestry; AFL1 and AFL2 : Unmulched deep tilled agro-forestry plots 1 & 2 at Matanya; AFM1 & AFM2:Mulched minimum tilled agrofo-restry plots 1 and 2 at Matanya; ANOVA :Analysis of Variance; BD : Bulk density of the soil; CTA :Technical Centre for Agricultural and Rural Cooperation; DAP : Days after planting DGIS/DST/SO : Directorate General of International Cooperation Research Focus Programme of the

Netherlands Government; DOYs: Days of the year; FAO : Food and Agriculture Organisation; J-STEM: Journal of Science, Tecnology ,Education and Management; WUCST KARI: Kenya Agricultural Research Institute; L1…L5; Unmulched control plots; LR & SR: Long Rains & Short Rains growing seasons LR91…LR95 : Long Rains for years 1991 to 1995; LRP : Laikipia Research Programme; M1…M5 : Mulched control plots; NAF : Non-agroforestry control plots; PQRS : Upper portion of experimental agroforestry plot; PT1…PT5 : Root-Pruned *Grevillea robusta* trees 1 to 5; SR91…SR95 : Short Rains for years 1991 to 1995; t/ha : Tones per hectare; TTMI :Traditional Techniques of Microclimate Investigations USA : United States of America; UT1…UT5 : Root-Unpruned *Grevillea robusta* trees 1 to 5; VSMC : Volumetric soil moisture content (%); WMO : World Meteorological Organisation; WUCST : Western University College of Science and Technology ; MMUST : Masinde Muliro University of Science and Technology

high and medium potential areas, where land availability has increasingly reduced, to semi-arid areas such as Laikipia district. The immigrants now comprise the bulk of the small-scale farming community, who produce most of the food on farm sizes of between 0.8 and 2.0 ha. Strong winds during part of the growing season (Oteng'i et al. 2000) have caused havoc by blowing away mulch and lodging maize (*Zea mays*) plants. Agroforestry (AF) skills acquired by the farmers from their areas of origin are used to protect the crops against strong winds. This applies for instance to the intercrops of maize and beans (*Phaseolus vulgaris*) in a mixture with perennial trees (Liniger, 1991; Liniger et al., 1998).

The current price ratios of fertilisers to crop production are not conducive to fertiliser utilisation (e.g. Savadogo, 2000). Soil nutrient contents and soil moisture conditions are improved when mulch is kept on the soil. High winds make traditionally used hedges (Ess and Stuber, 1992) imperative, if mulch is applied. This mixture of intercropped maize and beans with trees was not developed for the ecologically fragile soils and, because of competition for water, must be considered risky in semi-arid conditions. However, farmers use agroforestry as part of their risk management strategy and the combination of trees and mixed crops may have a high preference even when perceived as moderately risky (Senkondo, 2000). This was particularly so in the Matanya area, where the farmers were experimenting with trees and live fences most abundantly because of their need for fire wood, poles, wind protection, shade and building material, in that order (Ess and Stuber, 1992).

As a result of the associated risks, demonstration plots that involved district level authorities were initially developed at Matanya in the Laikipia Research Programme (LRP). In terms of crop performance and yield, the system was successful in demonstration plots when the trees were small (Liniger, 1991). This is not a guarantee for success under semi-arid conditions with the same trees when mature (Lott et al., 2000a; 200b; Kinama et al., submitted). When the TTMI-Project entered cooperation with LRP, the aim of this study became to assess performance of the system with ma-ture trees and fully grown hedges in these demonstration experiments. A physical approach through multipoint environmental measurements of soil moisture, shade, wind and soiltemperature was used, as first advocated and defended by Van Wijk (1966). Such an undertaking is particularly suitable for understanding already existing complex and inhomo-geneous agroforestry systems (e.g. Leyton, 1983; Kainkwa and Stigter, 1994; Baldy and Stigter, 1997; Onyewotu et al., 1998; Oteng'i et al. 2000; Stigter et al., 2000). Analysis of variance (ANOVA; Moore and McCabe 1999) was used to assess whether the observed differences among the means of soil moisture at different distances from pruned and unpru-ned trees and different depths are statistically significant, at 95% level. The differences in moisture competition between trees and crops in mulched plots with pruned and unpruned trees, and their relationships were established. The ANOVA F-test normally gives a general answer to a general question, 'Are the differences among the observed means significant?' If, however, there are no differences among the group means, F statistically approximates unity. The F statistics tend to be larger when differences are larger. The F tests were confirmed using Student's t-test (Moore and McCabe 1999). This showed the statistical significance of pruning effects in the mulched plots, in addition to a thorough overall physical error analysis that was also possible from the data.

Trees stabilise the soil by settling/anchoring it against erosive forces of wind and water (e.g. CTA 1994, Ong et al., 1996; Mohammed et al., 1996). When sufficiently grown they provide wind reduction/protection to the intercrops and prevent mulch material from being redistributed or blown away (Oteng'i et al., 2000). The roots of growing tall plants and trees also loosen the deeper soil and enhance infiltration during rainfall periods (e.g. Nair, 1984; Nicoullaud et al., 1994). However, they may also compete with intercrops for soil water and nutrients during the growing season. The tree canopies shade the soil and intercrops, thereby reducing evapotranspiration of crop land (crops and soil) but also photosynthesis when radiation falls below saturation values (e.g. Baldy and Stigter, 1997).

Rainfall in semi-arid areas is highly variable in time and space. Mulching, minimum tillage and tree root-pruning have frequently been used to conserve soil moisture in situations of limiting soil water (e.g. Davies, 1975; Liniger 1991; Moges, 1991, Liniger and Thomas, 1998). It has, however, been ob-served that management of AF systems is labour intensive and in the tropics is only feasible on small-scale farms (e.g. Rachie, 1983; Reifsnyder, 1989) and with the use of organic or inorganic fertilizers (e.g.

Mathuva et al., 1996).

Deep tillage has been observed to conserve deeper soil moisture by providing diffusion resistance to water vapour and obstruction to liquid water flow by breaking the capillary connection to the surface. Tillage this way reduces evapora-tion from deeper layers, thus acting as a mulch (e.g. Tyler and Overton, 1982; Stigter, 1984; Unger, 1987; Nicoullaud et al., 1994). On the other hand, deep tillage exposes the bulk of the tilled top soil - the home of the crop roots - to high evaporation, especially in the semi-arid areas (Van Wijk, 1965). Under such conditions, minimum (or zero) tillage is recommended (e.g. Liniger, 1991; Nicoullaud et al., 1994; Oteng'I, 1996; Hoogmoed, 1999). Minimum tillage can incr-ease water use efficiency by minimizing direct evaporation from the soil in a semi-arid environment. Liniger (1991) observed in two such environments, Matanya and Kalalu, no runoff but enhanced infiltration and enhanced water recharge. This resulted in higher yields of hybrid maize varieties 511 and 614, popular with local farmers, and beans, rosecoco variety, in AF plots mulched with 60% coverage maize stalk residue, when the trees were still young.

Grevillea robusta (Silky Oak) trees were considered deep rooted and therefore good companions to shallow-rooted annuals like maize and beans (Harwood 1992), but this may not apply to older trees. In limiting soil moisture conditions, root pruning of the trees anyway helps to reduce competition for soil resources between the trees and the crops. The latter develop larger leaf area index (LAI) which increases plant water use efficiency due to earlier and better ground shading (e.g. Jama et al., 1991; Ibrahim et al., 1999).

It was the objective of that part of the study reported on here, to quantify effects of the above mentioned soil water conservation methods of pruning and minimum tillage with mulching on soil moisture. Results are reported for the work in (i) a very dry season, long rains (LR92), with 173 mm of rainfall, 38% below the long term average of 1942 - 1994, and (ii) a very wet season, short rains (SR92), with 538 mm, 55% above such a long term average. These successive contrasting seasons were the driest and the wettest among seven seasons of experiments (Oteng'i 1996).

MATERIALS AND METHODS

Experimental sites

Experiments were conducted for seven growing seasons between 1991 and 1995 at Matanya (0° 04' S, 36° 57' E; altitude 1840 m), Laikipia, Kenya. The soil type in the study area is Mt. Kenya volcanics (Phonolites) dark clay (Vertoluvic phaeozem). The natural vegetation is open grassland with evergreen and semi-deciduous bush-land with scattered *Acacia drepanolobium* trees. The annual rainfall received in Matanya area lies between 650 and 750 mm, most of which is distributed in two rainy seasons: Long Rains (LR, March to June) and Short Rains (SR, October to January). These rains are locally and orographically influenced by Mt. Kenya and the Aberdare Ranges (Griffiths 1972).

The Matanya site was planted with intercrop of maize (*Zea mays;* var. hybrid H511) in spacing of 0.94 m by 0.60 m and beans (*Phaseolus vulgaris*; var. rosecoco) in spacing of 0.94 m by 0.20 m. The entire AF plot at Matanya measured 50 m by 30 m and had a westward slope of 4-5% (Figure 1). 1n 1986, half of this plot whose area was 30 by 25 m had been planted with *Grevillea robusta* (Silky Oak) trees at spacings of 7.5 m (between five parallel rows in staggered planting) by 5.0 m (within the rows). This area was divided into four treatment plots, namely: AFM1, AFL1, AFM2 and AFL2 measuring 30 by 5 m each (Figure 1). (In the acronyms, M stands for mulched/minimum tilled and L for local/deep tilled.) The intercrop was planted in rows running parallel to the tree rows, and used to study the effect of competition for soil moisture between the perennial trees and annual crops under a semi-arid environment. Five *Grevillea robusta* trees, namely; PT1, PT2, PT3, PT4 & PT5 (Table 1, Figure 1) in plots AFM1 and AFL1, were treated to root-pruning by digging a 0.3 m deep trench of 0.2 m wide at a distance of 0.5 m around the tree trunks. The trenches were covered by returning the soil dug from them. Also pruned were all trees bordering the live fence. Five others were, namely; UT1, UT2, UT3, UT4 & UT5 PT5 (Table 1, Figure 1) in AFL2 and AFM2, were left unpruned. Trees PT3 and UT3 were at the borders of the plots. A one metre deep trench was dug between AFL1 and AFM2 to exclude invasion of tree roots into the pruned tree area. These treatments were carried out two weeks before the onset of the main rains (LR92 and SR92) when also sowing, tilling and mulching were done. The mulched plots AFM1 & AFM2 plots were minimum tilled to a depth of 0.05 m or less. The unmulched plots AFL1& AFL2 were deep tilled to a depth of 0.2 to 0.25 m at the same time.

Table 2 shows that the heights of the pruned trees varied from 6.2 m in the Long rains season of 1992 (LR92) to 8.9 m in the short rains season of 1992 (SR92); whereas those of the unpruned trees varied from 8.25 m in LR92 to 9.25 m in SR92. The average canopy diameter of the pruned trees varied from 1.6 m in LR92 to 3.5 m in SR92. The unpruned trees measured up to 3.4 m in both seasons. The stem circumference of pruned trees measured at 0.2 m above the ground varied from 0.34 m in LR92 to 0.52 m in SR92; whereas that for unpruned trees varied from 0.47 m in LR92 to 0.57 m in SR92. The pruned trees were therefore relatively smaller than the unpruned trees; a factor that made competition for soil factors between the intercrop and the AF trees less severe.

Fertilisation of Matanya plots with farmyard manure was done by the Laikipia Research Programme (the hosts), at the rate of 10 t/ha, prior to the long rains of 1991, before we started our study, to offset differences in the experimental plots. Subsequently, all plots received 5t/ha farmyard manure prior to each long rains season up to 1994. Three (3) tonnes per hectare (t/ha) of crop residue mulch, in the form of maize stalks from the previous season, were applied after tillage on mulched plots, once in a growing season.

Mulched plus minimum tilled plots and five unmulched plus deep tilled plots were located at 60 to 70 m north of the AF plot. The entire AF plot was surrounded with a pruned *Coleus barbatus* live-fence to reduce competition for soil factors between plants and trees.

Data taken

Liniger (1991) found that the soil moisture differences in Matanya AF plots were perpendicular to the contours. Given the prevailing age of the individual trees, soil moisture measurements near the trees there-

Table 1. Locations of access tubes in relation to *Grevillea robusta* trees in AF experimental plot at Matanya.

Plot with AF root-pruned trees				**Plot with AF root-unpruned trees**			
Pruned Trees				Unpruned Trees			
Tree 1: PT1				Tree 1: UT1			
Tree 2: PT2				Tree 2: UT2			
Tree 3: PT3				Tree 3: UT3			
Tree 4: PT4				Tree 4: UT4			
Tree 5: PT5				Tree 5: UT5			
Access tubes from pruned trees				**Access tubes from unpruned trees**			
Distance (m) from trees				**Distance (m) from trees**			
Tree	0.94	1.88	3.76	Tree	0.94	1.88	3.76
Tree 1: PT1	A1	B1	C1	Tree 1: UT1	D1	E1	F1
Tree 2: PT2	A2	B2	C2 = O2	Tree 2: UT2	D2	E2	F2
Tree 3: PT3	A3	B3	C3	Tree 3: UT3	D3	E3	F3 = R2
Tree 4: PT4	M1	N1	O1	Tree 4: UT4	P1	Q1	R1
Tree 5: PT5	M2	N2	O2 = C3	Tree 5: UT5	P2	Q2	R2 = F3

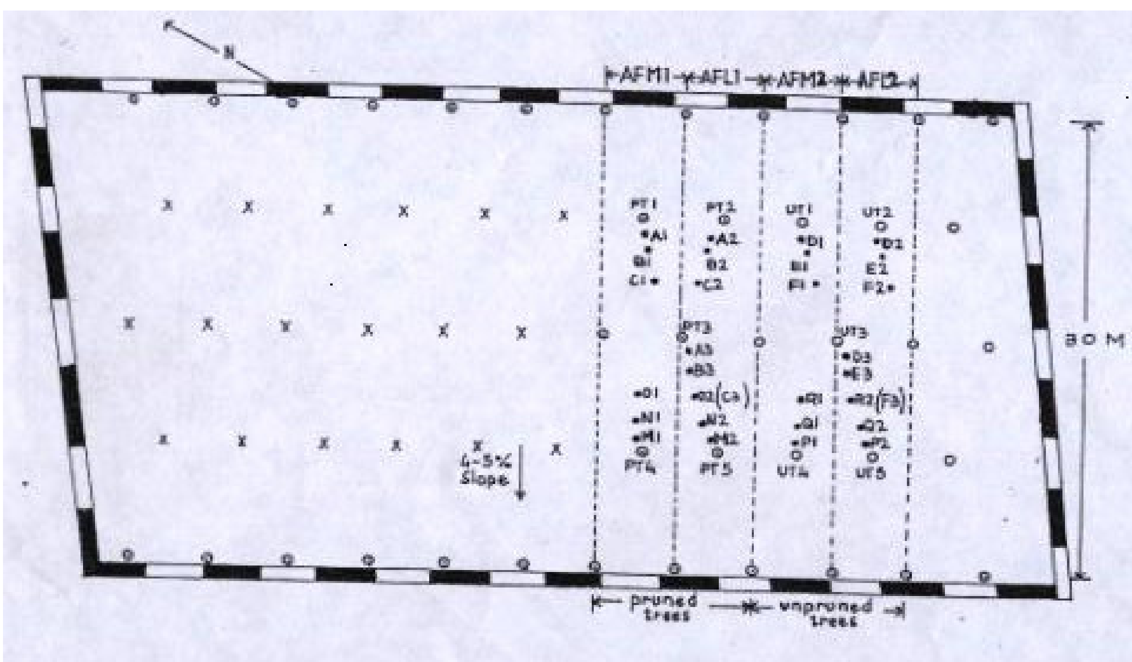


Figure 1. Layout of access tubes installed at distances of 0.94, 1.88 and 3.76 m from Grevillea robusta trees in AF plots at Matanya. Dotted circles are pruned trees (PT), open circles are unpruned trees (UT), crosses are fruit trees. The black and white boundaries are Coleus barbatus live hedges. AFM=Mulched AF; AFL=Local AF. Other letters label access tubes mentioned in the text.

fore represented different situations in the field, particularly in pruned (AFM1 & AFL1) and non-pruned (AFM2 & AL2) plots. The plots were not replicates, but had individual characteristics. Neutron probe (CPN 501, Pacheco, California, USA) measurements in 28 pre-installed access tubes at distances of 0.94, 1.88 and 3.76 m from the tree trunk were used to measure soil moisture radially from the trees and at seven depths: 0.18, 0.3, 0.6, 0.9, 1.2, 1.5 and 1.7 m (Figure 1). Soil moisture measurements were done following calibration exercises that lasted 1½ months. The data were then analysed for different demonstration plots in order to understand the feasibility soil moisture variation with distance from AF trees. This approach was a generally accepted for agroforestry conditions (Onyewotu et al., 1994; Onyewotu et al., 2004). The variability in wind protection that created differences in water consumption of the trees strengthened this

Table 2. Dimensions of pruned and unpruned *Grevillea robusta* trees during Long rains and Short rains seasons in 1992 (LR92 & SR92).

Treatments and tree specifications		Seasons of 1992	
Treatment	**Tree dimensions (m)**	**Long rains (LR92)**	**Short rains (SR92)**
Root- Pruned	Height(m)	6.2	8.9
	Canopy(m)	1.6	3.5
	Stem circumference (m)	0.34	0.52
Root Unpruned	1.Height (m)	8.25	9.25
	2. Canopy (m)	3.4	3.4
	3. stem circumference (m)	0.47	0.57

argument (Oteng'i et al., 2000). This was essential to understand the physical approach in comparison with the statistical investigation in the "Results and Discussion" section below.

In the NAF control plots located 60 – 70 m from AF plot, 14 access tubes were used in mulched plus minimum (M1…M5) and unmulched plus deep tilled (L1…L5) replications. The soil moisture measurements carried out at Matanya, were done at the seven depths mentioned above. Neutron probe (CPN 503) was used at irregular intervals to further check the accuracy of the data and the consistency of the probe CPN 501 readings. The CPN 501 had advantage over the CPN 503 because the former could also be used to measure soil bulk density after initial calibrations. Greacen (1981)'s and Ibrahim et al. (1999)'s methods were used to calibrate the two neutron probes (CPN 501 & CPN 503) in the Matanya *vertoluvic phaeozem* (dark-grey clay) soils. This was done to: (1) establish a calibration equation for calculating volumetric soil moisture content (VSMC %) from count rates, and (2) determine the bulk density (BD) of these soils. Two calibration exercises were done, within a pre-installed access tube, to establish a calibration curve for soil moisture from count ratios (ratio of individual counts to standard count). Gravimetric soil moisture was regressed on the count ratios to convert to volumetric soil moisture (Oteng'i 1996). The dry calibration was done on 19 February 1992 to establish the lowest point of the soil moisture scale leading to the determination of the permanent wilting point (PWP), that is, water at suction of about -15 bar. The grass was visibly drying as the soil had attained its wilting point (about 30% by volume). The wet calibration was done on 18 June 1992 to establish the highest points that would lead to the deter-mination of the field capacity (FC). The wet conditions were attained by flooding soil of an enclosed area around the pre-installed tube and covering it with polythene paper for about one and half months to allow for gravitational draining (by percolation into the deeper layers) of the flood water and to eliminate direct evaporation of the water from the soil. The soil had reached field capacity (FC) at about 50% by volume (suction of -0.1 to -0.33 bar). These values of FC and WP were within the range obtained earlier on by the Kenya Soil Survey Department, Kenya Agricultural Research Institute (KARI; Liniger, 1991).

Five ring samples were taken from each depth around the pre-installed access tube and weighed before oven drying at a temperature of 105°C for 12 h. The sphere of importance, that is, the sphere of a cloud of neutrons that radiates from the neutron probe source, was determined for every depth (e.g. Kristensen, 1973; Ibrahim et al., 1999). This showed, for cracking clay and other very inhomogeneous soils, that the average soil collected outside the sphere of importance was different from that within that sphere (Greacen, 1981). Loss of accuracy estimations due to soil inhomogeneity was already therefore incorporated.

Ten standard counts were taken at the beginning and at the end of each calibration exercise. Four counts were taken at each of the seven depths mentioned above. Volumetric soil moisture from oven dried samples was regressed on count ratios (e.g. Ibrahim et al., 1999) and regression constants obtained with a correlation coefficient (r) of 0.98 for CPN 501. Similarly, the constants obtained for CPN 503 had a correlation coefficient (r) of 0.96. The results showed that the calibration equation derived slightly underestimated VSMC during dry condi-tions at depths of 0.3 m and below.

During calibration it was found that the layers 0-0.75 m had more than 50% of the available water in 1.8 m of soil profile for the crop of water requirement of 275 mm. The VSMC values obtained with the two probes in the same access tubes always differed systematically by less than 5%. The accuracy of the moisture measurements lay between $\pm$ 1% and $\pm$ 5%. This amount is small because of the integration that takes place over the sphere of importance. The magnitudes of VSMC data were therefore different and agronomically important for values more than $\pm$2%. Measurements of VSMC were done once a week for the crop growing seasons of 1991-1995. This paper reports results for the successive worst (very dry) and best (rather wet) cases obtained for the demonstration experiments during long rains (LR92) and short rains (SR92) seasons in 1992.

Average weekly VSMC were determined in the upper and lower parts of the Matanya AF plot in agronomically important depths of 0.18, 0.3, 0.6 and 0.9 m (see Figure 1). Access tubes A1 and M1 pre-installed at 0.94 m, and C1 and O1 at 3.76 m from pruned trees PT1 and PT4 in mulched plot AFM1 were used. Others used were tubes A2 and M2 installed at 0.94 m and C2 and O2 at 3.76 m from pruned trees PT2 and PT5 in the "local" plot AFL1. Access tubes in the unpruned plots which were used included D1 and P1 at 0.94 m and F1 and R1 at 3.76 m from unpruned trees UT1 and UT4 in mulched plot AFM2. Others used were D2 and P2 at 0.94 m and F2 and R2 at 3.76 m from unpruned trees UT2 and UT5 in "local" plot AFL2.

Weekly VSMC data averages for plots AFM1, AFM2, AFL1 and AFL2 were subjected to statistical analysis and the means and stan-dard deviations (as measure of fluctuations) obtained. The differences of means of VSMC between tree rows (spatial variations) and also with time (temporal variations) in weeks (in year 1992) for pruned/unpruned treatments were obtained using one-way analysis of variance (ANOVA) in the depths of the soil: 0.18, 0.30, 0.60 and 0.90 m, and distances from the trees of 0.94 and 3.76 m. Two degrees of freedom (d.f.) of the distances from the tree, that is, 0.94, 1.88 and 3.76 m read from F- tables at 95% level, is 3.09. At 50 d.f. for 51 weeks (time) the critical value from the table, at 95% level, is 1.48. Values larger than 1.98 implies statistical significance.

Table 3. Distribution of seasonally averaged weekly volu-metric soil moisture content, VSMC, with depth at two distan-ces from pruned Grevillea robusta trees in AFM1 (A1, A2, C1, C2) and AFL1 (M1, M2, O1, O2) during LR92 (see also Fig. 1). Note: Xm is the mean VSMC, STD is standard deviation and X-Xm is deviation from the VSMC

(a) 0.94 m from trees								
		Depth						
Tube		0.18	0.3	0.6	0.9	1.2	1.5	1.7
A1	Xm	32.1	32.7	30.2	29.8	32.1	30.9	31.2
	STD	±2.0	±0.9	±0.5	±0.4	±0.4	±0.3	±0.4
	X-Xm	8	4.2	2.8	-0.08	0.09	1.2	-
A2	Xm	31.1	31.9	29.1	29.8	31.1	31.2	30.5
	STD	±1.2	±0.4	±0.4	±0.3	±0.5	±0.3	±0.6
	X-Xm	5.2	2.1	-1.2	-0.9	-2.5	2.3	-
M1	Xm	30	31.9	30.1	30.2	32.5	30.4	27.7
	STD	±2.6	±0.5	±0.3	±0.4	±0.3	±0.5	±0.6
	X-Xm	2	1.8	2	1.7	1.8	-0.9	-
M2	Xm	24.8	27.6	28.7	29.6	32.5	29.2	31.2
	STD	±1.4	±1.4	±0.9	±0.6	±0.7	±0.7	±0.6
	X-Xm	-18	-12	-3.5	-1.5	1.6	-4.5	-
(a) 3.76 m from trees								
Tube		0.18	0.3	0.6	0.9	1.2	1.5	1.7
C1	Xm	33.3	32.7	30	29.9	30.6	30.3	30.9
	STD	±2.1	±0.6	±0.2	±0.5	±0.5	±0.5	±0.4
	X-Xm	6.5	0.5	0.9	2.2	-4.9	-2.3	-
C2	Xm	29.4	32.1	30.6	29.6	31.3	32.4	33.3
	STD	±2.2	±1.0	±0.8	±0.8	±0.4	±1.6	±2.1
	X-Xm	-6	-1.8	3.1	1.8	-2.7	4.1	-
O1	Xm	32	32.1	30.5	28.6	33.6	30.4	30.8
	STD	±2.2	±0.5	±0.4	±0.4	±0.4	±0.3	±0.6
	X-Xm	2.7	-1.8	2.6	-1.8	4.5	-2.4	-
O2	Xm	30.7	33.1	28.8	28.6	32.7	31.2	30.2
	STD	±2.4	±0.9	±0.6	±0.4	±0.6	±0.5	±0.6
	X-Xm	-1.7	1.3	-3.2	-1.7	1.5	0.6	-

Correlation coefficients were obtained between 0.18 depth and the depths 0.30, 0.60 and 0.90 m for distances of 0.94 and 3.76 m from the trees. This measured the closeness of the surface soil moisture at 0.18 m depth (hence influence of surface) to the rest of the depths in the depths: 0.30, 0.6 and 0.9m. The Student's t-test for paired samples was used to determine level of statistical significant difference between the average soil moisture at 0.18 m and other depths. A test of null hypothesis in was done. The critical values (t_{crit}) for one-tailed (larger or smaller than) t-test was found to be 1.68, at 95% level, for the d.f. of 50 from a sample size of 51. Thus values exceeding 1.68 implied that soil moisture at 0.18 m was significantly larger than at any other depth.

Over the many seasons of measurements only the wettest season (SR92) gave maize grain yields. Other seasons gave only biomass yields (compare also Liniger et al., 1998). Other measurements carried out in all seasons in addition to VSMC included weekly maize plant heights, and maize and beans phenological phases. In LR92 maize and bean biomass were measured row by row in the entire Matanya AF plot. In the Matanya non-AF control plots areas of 9 x 2 m were harvested by row in all seasons. In SR92, grain, cob and stover maize biomass were collected plant by plant in the AF plots, while the other yield takings remained the same. (Oteng'i et al., 2007).

Maize biomass yields were harvested from each plot (AFM1, FM2, AFL1 and AFL2) in the two seasons (LR92 and SR92). The seasonally averaged VSMC in the agronomically important depths (0.18, 0.30, 0.60 & 0.90 m) and distance from trees (0.94 and 3.76 m) were used (Tables 2 and 3). Effective VSMC that produced maize bio-mass yields was obtained by utilizing the differences between each pair of plots (AFM1-AFL1, AFM1-AFM2, AFM1-AFL2, AFL1-AFM2, AFL1-AFL2 & AFM2-AFL2) according to treatments; mulching and minimum tillage (AFM1 &AFM2), no-mulching and deep tillage (AFL1 & AFL2), Pruning (AFM1 & AFL1) and no-pruning (AFM2 & AFL2). Effective VSMC that produced maize biomass yields was obtained by correlating the VSMC differences between each pair of plots and the corresponding yields differences for the treatments in the agronomically important layers (0.18 - 0.90 m).

RESULTS AND DISCUSSIONS

Across mulched plots comparison of pruned and unpruned areas

In Figures 2a to 2d variations of average weekly VSMC, as a function of depth, 0.18-0.90 m, are given for the distances 0.94 (Figure 2a and 2c) and 3.76 m (Figure 2b and 2d) from the tree trunks of pruned (average of PT1 & PT4 in AFM1) and unpruned (average of UT1 & UT4 in AFM2) trees respectively for the year 1992 (DOYs 3-363). Also plotted are weekly rainfall and two horizontal lines of field capacity (FC, 50%, upper limit) and wilting point (WP, 30%, lower limit). The VSMC series were smoothed with 5-weeks moving ave-rage trends for the shallowest agronomically important depths 0.18 and 0.30 m.

The results indicate values below FC (Figs. 2a, 2b, 2c and 2d) throughout 1992. Short rains (SR92, about DOYS 275-365) was the wettest season of the experimental period of seven seasons, with the highest rainfall amount of 115.8 mm obtained on DOY 276. Long rains season (LR92, about DOYs 80-150), was the driest (Oteng'i et al., 2005). The VMSC at 0.94 m from trees PT1 & PT4 in the depth of 0.3 m remained above WP. The VMSC nearest the surface (at 0.18 m) exceeded WP early in the year (between DOYs 115 and 165) and during the SR92. The pattern of VSMC at 3.76 m distance was such that 0.18 m depth experienced very dry conditions in DOYs 35-80, particularly in unpruned plots, and remained above WP

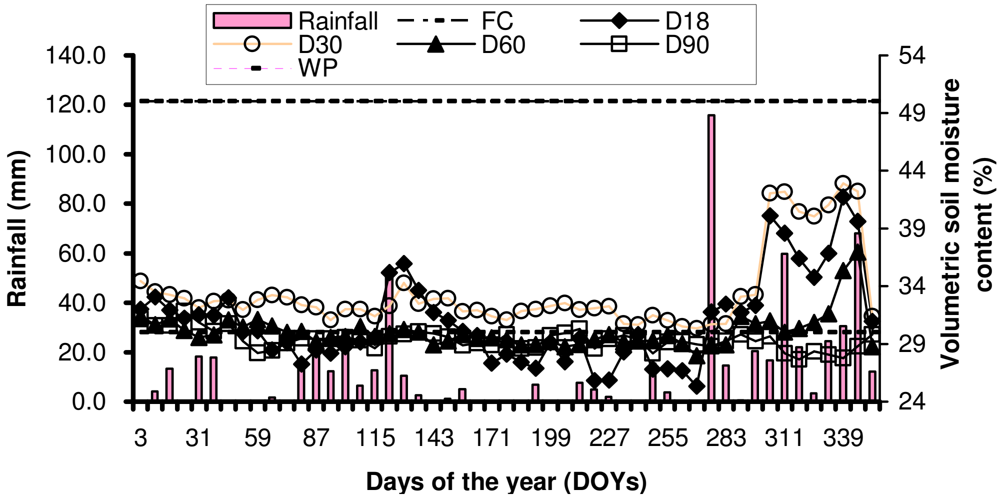


Figure 2a.

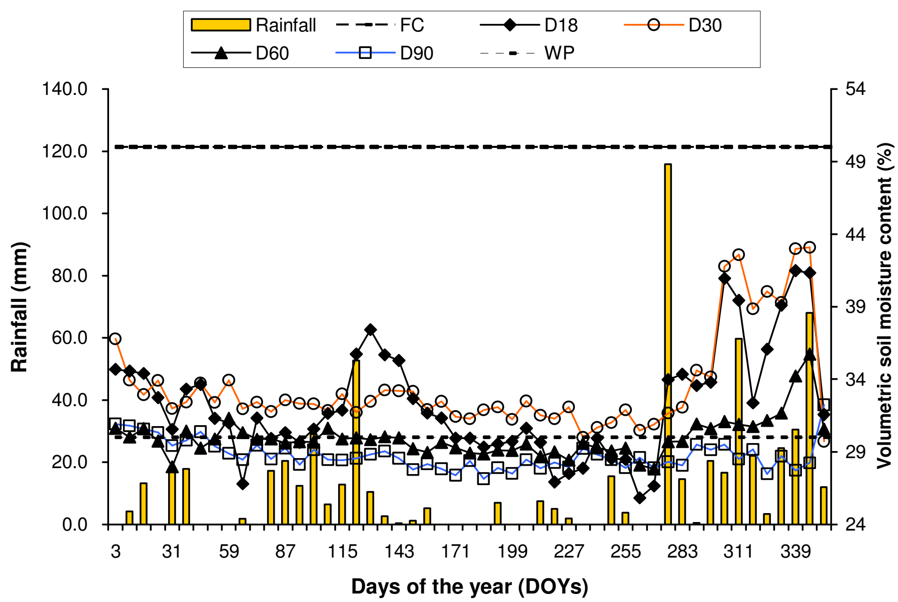


Figure 2b

during LR92 (Figs. 2b & 2d). In the surface layer, VSMC was higher between DOYs 105 to 150. Relatively little rainfall received during this period penetrated into the deeper layers, especially for the depleted ones arou-nd the unpruned trees. High rainfall received in the short rains season cancelled the effect of pruning when comparing VSMC in AFM2 with that in AFM1 between DOYs 275 and 355. Generally, VSMC for the pruned trees deviated little from its mean values in the lowest layers. For the unpruned trees increases were visibly delayed after rainy periods. The soil moisture was usually highest at 0.3 m depth, in the layer that had the highest clay content. Volumetric soil moisture content (VSMC) at 0.60 m depth was somewhat higher in SR92 but lowest during the intervening June-September dry period before the short rains, particularly for unpruned trees. VSMC was lowest at 0.9 m depth in the pruned plots because of a less favourable structure to store water, less clay content and lime and manganese concretion observed there (Liniger, 1991).

The 5-week moving average trendlines in the time series analysis of VSMC at 0.18 m and 0.3 m depths showed gentle rise in SR92 (see Figures 3a - 3d). The increase in soil moisture following the short rains in both 0.18 and 0.3 depths for the unpruned trees was more gradual due to

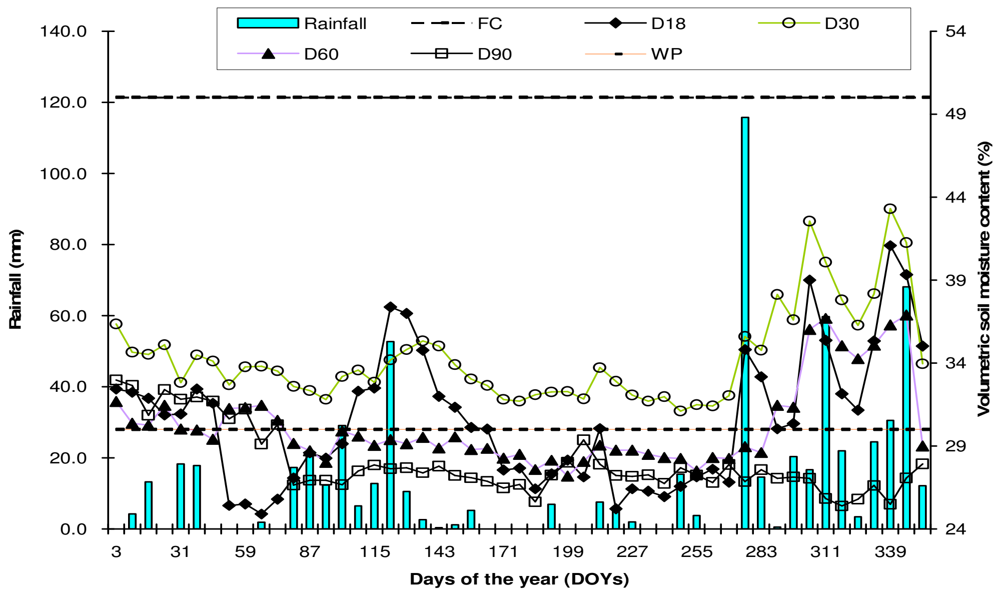
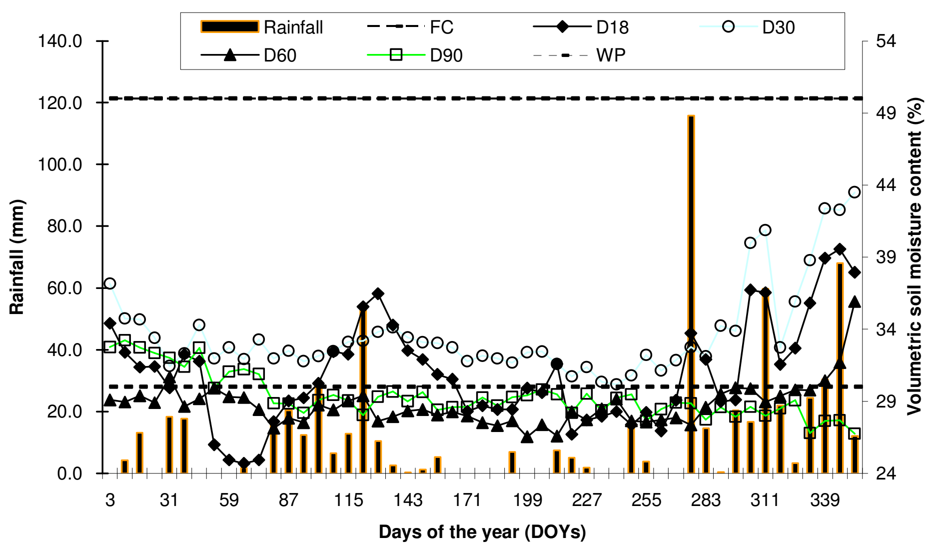


Figure 2c



Figures 2a-2d. Averages of weekly volumetric soil moisture content, VSMC (%), at agronomically important soil depths (0.18, 0.3, 0.6 & 0.9 m) in Matanya in 1992, in access tubes A1 cum M1, D1 cum P1, C1 cum O1, F1 cum R1 installed as in Figure 1 near root pruned and unpruned *Grevillea robusta* tree trunks. In 2a and 2b for plot AFM1, respectively at 0.94 m and 3.76 m from trees PT1 and PT2. In 2c and 2d for plot AFM2, respectively at 0.94 m and 3.76 m from trees UT1 and UT2. Also weekly rainfall totals are given and two horizontal lines representing field capacity (FC, upper line) and wilting point (WP, lower line).

vigorous uptake by both trees and the intercrop.

Across surface treatment comparison of pruned and unpruned plots

A comparison seasonal average VSMC data for the full pruned and unpruned plots were made (Figure 2 and 3). The patterns of VSMC for mulched plots were found to differ mainly for pruned and unpruned trees. Differentiating bet-ween upper and lower parts of the Matanya AF plot, which has a slope of 4 - 5% indicated that soil moisture around the trees and that along the slope could not be replicated. The measurements represent actual trends over

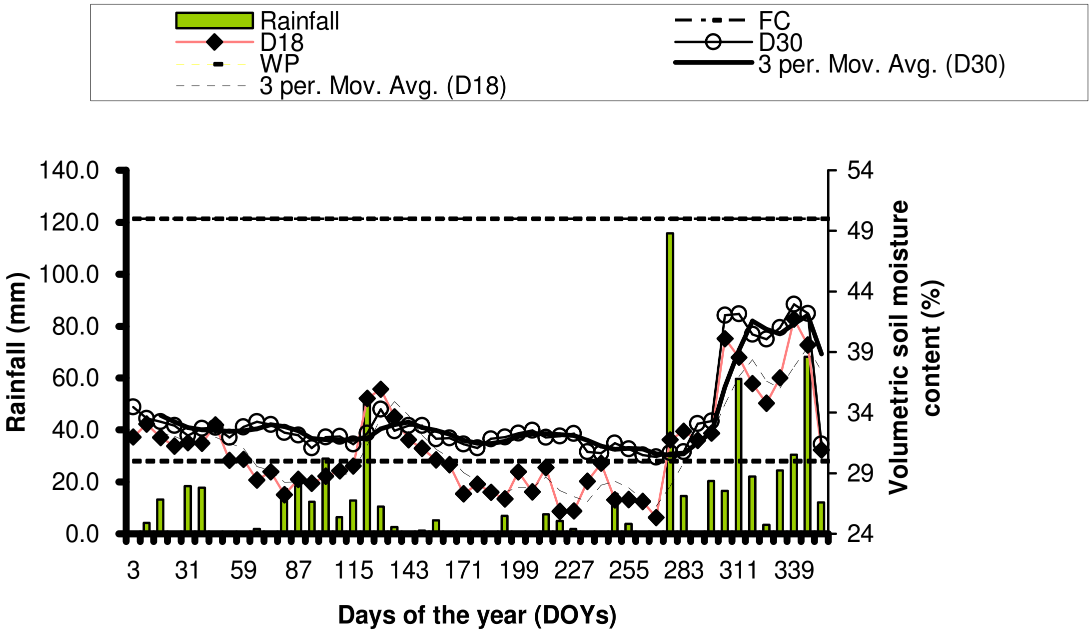


Figure. 3a.

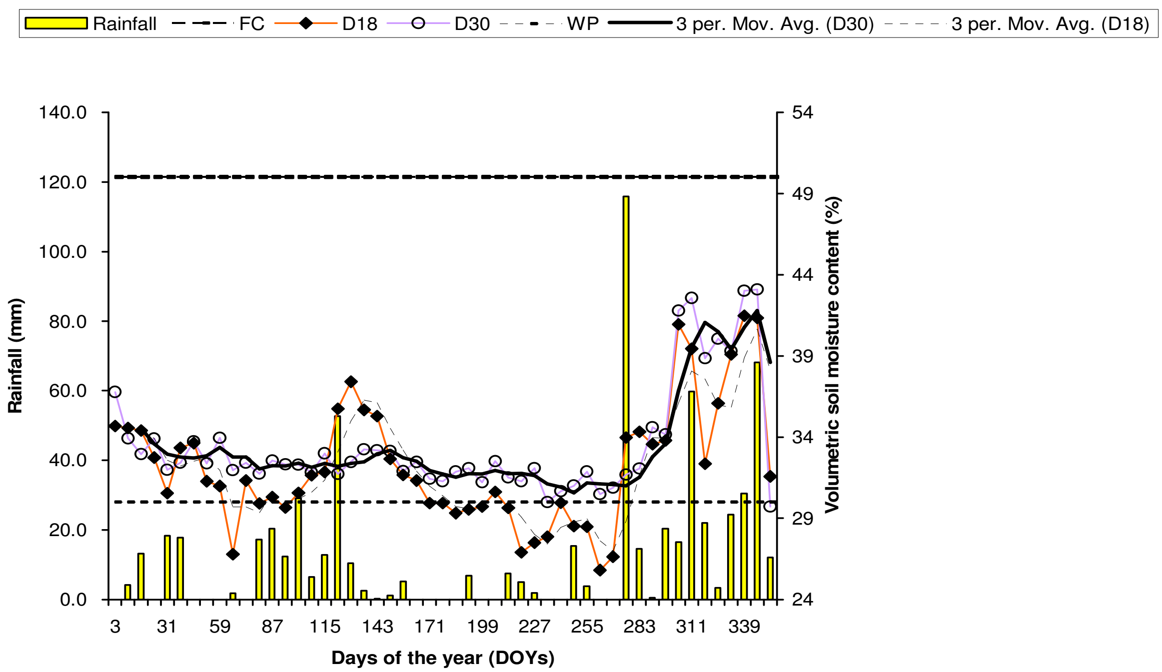


Figure 3b.

the fields.

Table 3 gives seasonally averaged VSMC, standard deviation values, as measure of fluctuations, and deviations from the average of pruning treatment, for the depths 0.18 to 1.7 m and first two months of long rains season (LR92; DOYs 80 - 150). Also given in Table 2 are the distances of 0.94 and 3.76 m from the pruned *Grevillea robusta* trees PT1, PT2, PT4 and PT5 (Table 3). The soil moisture distribution at 0.94 in the 0.18 m depth had slightly lower values than at 0.3 m depth. Non-systematic errors in the VSMC averages were conservative at single measurements of $\pm$ 1% in the access tubes A1, A2, M1 and M2 and

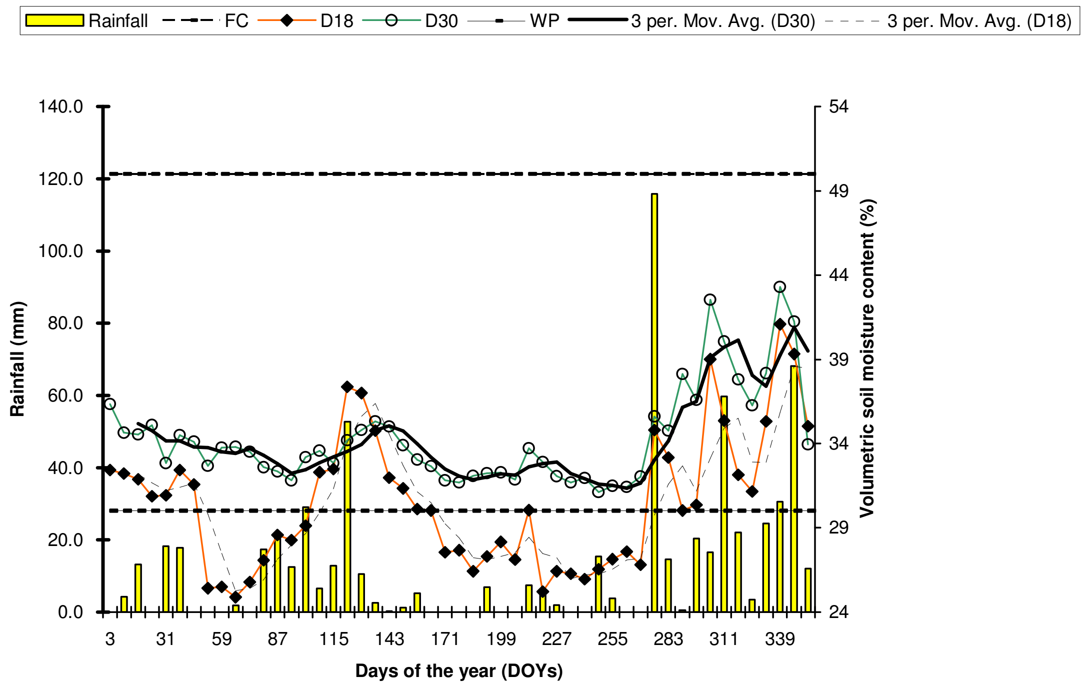
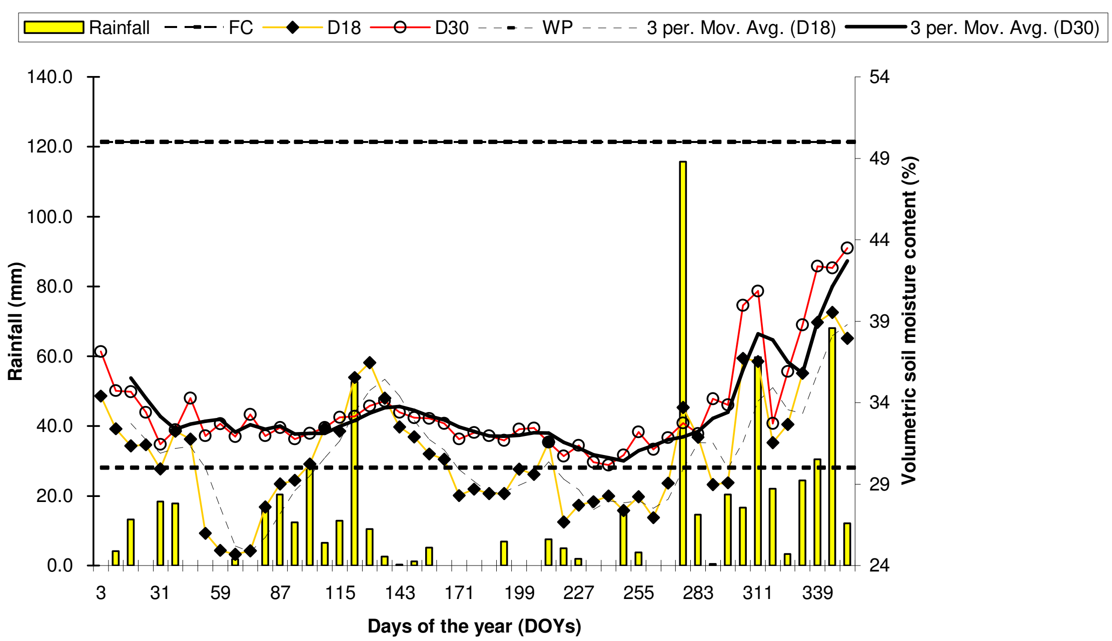


Figure. 3c



Figures 3a - 3d. Five weeks moving average volumetric soil moisture content, (%), at the two shallowest agronomically important soil depths (0.18 and 0.3 m) for the locations of Figures 2a - 2d

larger than +2% for depths 0.3 and 0.9 m. The combination of pruning with mulching must be the cause of the differences of M2 near the surface closes the tree. At 0.94 m distance there was more moisture in upper than lower parts of AF treatment plots. At 3.76 m the above was no longer the case. This dissimilarity for the two distances is in line with what was expected from pruning of the surface roots. Fluctuations near the surface roots. Fluctuations near the surface were typically larger, also influenced by soil water uptake by the intercrop (cf. Figure 2 and 3).

In Table 3, three out of the four tubes nearest pruned trees (A1, A2, M1) recorded above average VSMC at a

Table 4. Distribution of seasonally averaged weekly volumetric soil moisture content, VSMC, with depth at two distances from pruned Grevillea robusta trees in AFM1 (A1, A2, C1, C2) and AFL1 (M1, M2, O1, O2) during SR92 (see also Figure. 1). Note: Xm is the mean VSMC, STD is standard deviation and X-Xm is deviation from the VSMC.

(a) 0.94 m from trees								
		Depth						
Tube		0.18	0.3	0.6	0.9	1.2	1.5	1.7
	Xm	39.4	40.3	34.5	29.8	32.3	29.3	30.3
	STD	±4.1	±4.4	±4.4	±2.6	±1.2	±0.9	±0.8
A1	X-Xm	11.1	9.2	7.5	0.5	1.8	-1.7	-
	Xm	36.6	36.4	31	29.7	31.4	30.5	30
	STD	±6.0	±5.1	±3.3	±2.4	±1.0	±1.4	±1.2
A2	X-Xm	3.1	-1.8	-4.2	0.4	-3.2	2.9	-
	Xm	36	39	33.3	30.2	31.8	30.3	29.4
	STD	±4.0	±4.8	±2.3	±2.9	±2.3	±1.4	±0.7
M1	X-Xm	1.8	5.7	4.5	1.9	-0.7	2	-
	Xm	30.1	31.5	29.6	29.3	32	28.3	29.9
	STD	±6.6	±5.4	±4.2	±2.7	±1.2	±1.0	±1.0
M2	X-Xm	-15.2	-14.7	-7.5	-1.8	0.7	-4.9	-
(b) 3.76 m from trees								
Tube		0.18	0.3	0.6	0.9	1.2	1.5	1.7
	Xm	40.8	41.2	33.6	30.7	32.3	29.4	29.9
	STD	±3.6	±4.0	±4.4	±3.2	±3.4	±1.6	±0.8
C1	X-Xm	11	5.8	-1.9	5.2	-1.8	-2	-
	Xm	34	36.7	34.4	29.7	32.1	30.1	31.6
	STD	±6.8	±5.8	±5.2	±3.4	±2.1	±0.7	±1.2
C2	X-Xm	-2.4	-5.5	1.1	-0.5	-1	0.4	-
	Xm	37.1	38.7	34.7	30.2	32.9	30.5	29.8
	STD	±5.1	±4.9	±4.9	±4.1	±2.5	±2.1	±1.1
O1	X-Xm	1	-0.5	1.8	1	0.4	1.1	-
	Xm	34.7	39	33.1	28.9	33.6	30.1	29.6
	STD	±6.1	±4.6	±4.7	±3.6	±2.5	±1.6	±1.0
O2	X-Xm	-5.3	0.4	-2.5	-2.8	2.6	-0.4	-

instance of 0.94 m in the 0.18 and 0.3 m depths. Large negative deviations were observed in tube M2 for the same depths and negative ones at larger depths for A2 and M2, this may be due to the deep tillage treatment. The VSMC values app-eared to have been influenced mostly by root pruning. Similar trends were partly observed at the distance of 3.76 m (Table 3). Large negative deviations occurred around tube C2 at shallow depths. VSMC in tube O2 was generally lower than in tube O1, with the exception of the 30 cm depth. In the pruned plots, mulched areas (AFM1 with A1, M1, C1 & O1 in Figure 1) had generally more moisture nearest the soil surface. The picture of more moisture in the upper parts of AF was con-firmed at 0.94 cm for the unpruned plots; but not at 3.76 m, where the tubes are closer to each other (Oteng'I, 1996).

Table 4 gives seasonally averaged VSMC values for DOY 283-029 during short rains season, SR92. In the shallower layers, the SR92 (Table 4) had considerably more soil moisture than LR92 (Table 3) at the same dis-tances from the trees. There are larger fluctuations for SR92 than for LR92 at the two distances. Generally larger differences are observed for the wettest season, SR92, than for the driest season, LR92. The same is true for the layers till 0.6 m; at 3.76 till 0.3 m at 0.94 m distance (Tables 2 and 3). Tubes A1 and A2 as well as M1 and M2 differ at the three shallowest depths in the way expected from minimum tilling cum mulching. At 3.76 m with less effect of pruning than close to the trees. At the depths of 0.18 and 0.30 m the mulch influence is still visible in the upper plot.

Higher moisture in the upper plots are confirmed by larger positive differences. There is relatively low soil cover from the maize stalks. Hence, maize stalk mulch was more effective as a barrier against run off water that subse-quently infiltrates into the soil than as a barrier against vapour flow (Liniger 1991). In general, the differences were small near the surface, in unpruned tree areas at both distances (0.94 & 3.76 m). This confirms the role played by the tree canopies and roots of unpruned trees. During the short rains season (SR92) in the unpruned plots at 0.94 m a residual mulch effect was detectable near the surface in the lower parts of the plot; whereas 3.76 m a mulch effect was still seen (Oteng'i 1996). At 0.94 m, gradients in tree shading and mulching caused no soil moisture differences in the unpruned plots during the long rains season (LR92; Oteng'i 1996). This showed the importance of water uptake by *Grevillea robusta* trees in the unpruned plots (also Van Roode 1992).

Table 4 shows that tubes A1 and M1 installed at 0.94 m from pruned trees recorded surplus VSMC in most layers during SR92. Tube A2 had much lower surpluses and mostly deficits at 0.18 m while tube M2 had large deficits in the shallowest depths till 0.6 m. Similar but generally somewhat reduced effects were observed for tubes C1 and O1. The effects for tubes C2 and O2 were less pronoun-ced. These tubes were closer to each other at 3.76 m (Table 4); thus confirming the mulch effects in soil moisture conservation. In the unpruned tree area at both distances from the trees, the differences were small near the surface. This again confirmed the role played by the canopies and

Table 5. Gradients of VSMC with distance from the trees for LR92 & SR92 in pruned and unpruned treatments. Here (-+) means Θ decreasing from 0.94 m to 1.88 m then increasing to 3.76 m, (+-) means Θ increasing then decreasing, (++) or (--) means Θ increasing or decreasing all the way

Tube	0.18	0.3	0.6	0.9	1.2	1.5	1.7
(a) Pruned trees							
PT1:LR92	(- +)	(+ -)	(- +)	(- +)	(+ -)	(- -)	(- -)
SR92	(- +)	(+ +)	(- +)	(- +)	(+ -)	(+ -)	(- +)
PT2:LR92	(+ -)	(+ -)	(+ +)	(+ -)	(- +)	(- +)	(- +)
SR92	(+ -)	(+ -)	(+ -)	(+ -)	(- +)	(- +)	(+ +)
PT4:LR92	(- +)	(+ -)	(+ -)	(- -)	(- +)	(- +)	(+ +)
SR92	(+ +)	(+ -)	(+ -)	(+ -)	(- +)	(+ -)	(+ +)
PT5:LR92	(+ +)	(+ +)	(+ -)	(--)	(- +)	(+ +)	(+ -)
SR92	(+ +)	(+ +)	(+ -)	(--)	(+ +)	(+ +)	(+ -)
(b) Unpruned trees							
PT1:LR92	(- -)	(- -)	(- -)	(- +)	(- -)	(- -)	(+ +)
SR92	(- +)	(+ -)	(- -)	(+ +)	(+ -)	(- +)	(+ +)
PT2:LR92	(- +)	(- +)	(- +)	(+ -)	(- +)	(- +)	(- +)
SR92	(- +)	(- +)	(- +)	(- -)	(- -)	(+ +)	(+ +)
PT4:LR92	(- +)	(+ -)	(+ -)	(+ +)	(+ -)	(+ +)	(+ +)
SR92	(- +)	(- -)	(- -)	(+ +)	(+ +)	(+ +)	(+ +)
PT5:LR92	(- +)	(- -)	(+ -)	(+ +)	(- +)	(+ +)	(+ +)
SR92	(+ +)	(+ +)	(+ +)	(+ +)	(- +)	(+ -)	(- +)

roots of unpruned trees in soil water retention. At 0.94 m a remaining mulch effect near the surface was detectable in the lower parts of the plot, while at 3.76 m the effect was seen throughout the experimental period (Oteng'i 1996).

Comparing the radial gradients of soil moisture from the trees as shown in Table 5 indicates that SR92 behaved quite similar to LR92 at the depths of 0.18, 0.30 and 0.90 m for pruned trees. At each of these depths there was one exception, in which SR92 had increasing trends outwards, thus pointing at more water availability in this season. The similar behaviour in the two seasons (LR92 & SR92) suggests that the tree rooting system, the rainfall interception, the shade, the wind reduction and the pruning and mulching treatments had combined effects on soil moisture gradients. For the unpruned trees the similarities in trends were everywhere less, particularly closer to the trees, mainly due to the smaller differences in VSMC values.

Statistical comparison

The analysis of variance (ANOVA) on the soil moisture

Table 6. Analysis of Variance (ANOVA) with F-test for soil moisture data in agronomically important depths which is 0.1.8, 0.30, 0.60 and 0.90 m for the year 1992. Note the critical values of F-test (italics) and at 95% level of significance are given below. Degree of freedom (d.f.) for weekly soil moisture readings is 50

Plot No	**space variation between tree rows**	**time variation with days of year 1992 (3-363 DOYs)**
Distance from trees (0.94 and 3.76 m)	(F-values)	(F-values)
Critical values	3.09	1.48
AFM1		
0.94 m	58.4	1.57
3.76 m	87.7	2.02
AFM2		
0.94 m	119.8	2.22
3.76 m	88.4	1.44
AFL1		
0.94 m	22.2	1.3
3.76 m	83.4	1.57
AFL2		
0.94 m	140.6	1.61
3.76 m	120.4	1.33

means (VSMC) at distances 0.94 and 3.76 m from the trees and in the depths; 0.18 m, 0.30 m, 0.60 m and 0.90 m in plots AFM1, AFM2, AFL1 and AFL2 showed statistical significance. The VSMC differences were confirmed by the F-test at 95% level (Table 6), all the F-values were much larger than the table value of 3.09, thus confirming the benefit of conservation measures on soil moisture. Time variations within the year 1992 also showed statistical significance in the differences of means at all distances, except at 3.76 m in plots AFM2 and AFL2 and 0.94 m in plot AFL1. Here the F-values at 95% level were less than the table of 1.48 (Table 6). These significant differences were because of less competition for soil moisture of pruned trees compared to unpruned trees.

Table 7 gives the results of correlation coefficients between 0.18 m and other depths in the depths 0.30, 0.60 and 0.90 m and distances from the trees 0.94 m and 3.76 m for the four plots; AFM1, AFM2, AFL1, and AFL2. The soil moisture at 0.18 m depth was highly correlated with that at 0.30 m depth, but became less with increase in depth. Correlation values at 0.30 m depth were higher in AFM1, AFL1 and AFL2 and became progressively less with depth till 0.9 m in AFM1 and AFL2; perhaps due to lime concretion at that depth. The 0.90 m depth was found by Liniger (1991) to contain a lot of lime and manganese concretions. These might have reduced soil mois-

Table 7. T-test paired two sample for means, for correlation between surface (0.18 m depth) and other agronomically important depths, that is 0.30, 0.60 and 0.90 m and distances 0.94 and 3.76 m from trees and at 95% level of significance. Note the critical values (t_{crit}) of one-tailed and two tailed -tests (italics) are respectively 1.68 and 2.01

				correlation	t-statistic
with 0.18 depth		**correlation**	**t-statistic**		
plot	**other depths**	**Coefficients (%)**	**(tcrit:1.68;2.01)**	**Coefficients (%)**	**(tcrit:1.68;2.01)**
AFM2: 0.94 m				**AFM2: 3.76 m**	
0.3		84	-8.38	80.3	-3.85
0.6		67.6	2.06	75.1	5.65
0.9		-9.25	2.83	16.8	66.6
AFM2: 0.94 m				**AFM2: 3.76 m**	
0.3		78.5	-10.72	79.4	-8.86
0.6		56.8	0.78	45.3	4.92
0.9		-9.96	3.86	-22.3	2.68
AFL1: 0.94 m				**AFL1: 3.76 m**	
0.3		91.3	-8.67	85.8	-15.33
0.6		39.5	2.62	36.7	-2.38
0.9		12.3	-1.73	-10.4	0.004
AFL1: 0.94 m				**AFL1: 3.76 m**	
0.3		86.7	-9.97	83.4	-7.54
0.6		48.4	5.42	41.5	7.48
0.9		-26.5	3.4	-35.9	3.29

sture retention capacity of the Matanya soil, thus resulting in poor correlation with the surface layers. Similar results were obtained for the distance of 3.76 m from the trees. For plot AFM2, correlation coefficients, though displaying similar trends, are weaker, possibly as a result of competition between AF trees and the intercrop since in this plot the trees were not pruned. The test of significance with t-test revealed that the correlations for AFM1 at 0.94 and 3.76 m distance were significant in both the one-tailed and 2-tailed tests, since all t-values exceeded table value 1.68 for the one-tailed and 2.01 for the two-tailed test. All the t-test results for soil moisture data in plot AFL2 were significant, since their values exceeded these critical values (see Table 7). These results confirmed that plots with minimum tillage, mulching and pruned treatments had more soil moisture than those with deep tillage, unmulched and unpruned treatments.

Yield effects

The conservation effort that resulted in more soil moisture in mulched-pruned than unmulched-unpruned plots at Matanya was reflected in the rate of maize growth, which is an indicator of dry matter accumulation and final yield. In LR92, maize plants were about 1 m in height and only biomass was obtained at harvest. Plants in mulched pruned plots were 10 - 30 cm higher than those in local (or unmulched) unpruned plots within the AF. For example, in SR92, seven days after planting (DOY 294: at emergence). Although AF gave low bean seed yields of about 0.10 to 0.16 t/ha in LR92, mulched pruned plots had the highest (Table 8) which were obtained in the lower parts 0.16 t/ha in LR92, mulched pruned plots had the highest (Table 8) which were obtained in the lower parts of the four AF plots (AFM1, AFM2, AFL1 & AFL2). Maize biomass yields were similarly low of about 0.3 to 0.6 t/ha in LR92 in AF(Table8). Again lower parts of AF plots had somewhat higher yields than the upper parts. Yield in pruned mulched plots were highest and those in unmulched unpruned were lowest. The importance of pruning in combination with minimum tillage and stalk mulching is indeed supported by these data. For the high bean seed yields, of between 0.6 and 0.7 t/ha in SR92 in AF (Table 8), again mulched pruned plots were highest whereas unmulched unpruned plots were lowest. Mulching and pruning separately therefore gave about 10% yield advantage over unmulched plots within mulched- pruned and unmulched-unpruned plots. In SR92, mulching alone appeared to have little effect for maize grain yields of less than 1.2 and more than 1.5 t/ha in AF.

Table 8. Maize and beans yields for LR92 and SR92 in t/ha. The maize yields in are grain yields.

(a) Maize biomass/grain yields (t/ha)						
	Pruned		Unpruned		Control	
Season	AFM1	AFL1	AFM2	AFL2	M	L
LR92	0.56±0.13	0.35±0.06	0.33±0.08	0.42±0.16	0.37±0.08	0.50±0.11
SR92	2.93±0.75	2.64±0.60	2.45±0.52	3.03±0.63	2.42±0.40	2.38±0.46
SR92	1.54±0.39	1.42±0.40	1.18±0.26	1.30±0.33	1.60±0.37	1.30±0.34
(b) Beans biomass yields (t/ha)						
LR92	0.24±0.04	0.25±0.03	0.18±0.04	0.23±0.03	0.33±0.07	0.19±0.02
SR92	0.68±0.20	0.46±0.09	0.50±0.26	0.38±0.16	0.98±0.26	0.96±0.30
(c) Beans seed yields (t/ha)						
LR92	0.16±0.03	0.12±0.02	0.10±0.02	0.11±0.04	0.14±0.04	0.03±0.03
SR92	0.71±0.10	0.63±0.12	0.63±0.18	0.57±0.26	1.18±0.21	1.02±0.24

Pruning in combination with minimum tillage and mulching was most successful, having between about 10 and 30% more grain yield than the other plots. That picture was repeated for maize stover (between 10% and 30%) and maize cob (between 10 and 20%) yields. In the wettest year, mulching lost its effect on maize yields unless combined with the strong pruning effect. This confirms the consequences of tree ageing. Comparison of yields of maize grain and cob in control mulched plots with mulched pruned in the AF in SR92 showed the same magnitude (Table 8). The yields from the mulched control plots were more than 20% higher than those from the local control plots. The stover yields in the mulched and local control plots were as low as those in the AF unpruned local plots. Such differences between cob/grain and stover yield pictures are normally due to rainfall distributions over the growing season. Bean seed yields in control plots for wet season (SR92), ranged between 1.0 (local) and 1.2 (mulched) t/ha higher than those of the AF plots (0.6 - 0.7 t/ha; Table 8). In dry LR92, bean seed yields in the local control plots were negligible, while they were as high as the highest in the AF plots, but only 0.14 t/ha. In the same season (LR92), mulched control plots received 0.4 t/ha maize yields and local control plots had 0.5 t/ha. These values were lower than the best AF plots but higher than the worst AF plots.

The correlation coefficient of 23.5% was obtained between the VSMC differences in the four treatment plots (AFM1, AFL1, AFM2 & AFL2) and the corresponding maize biomass yield data. This indicated positive combined effects of the treatments on the maize biomass yields. Hence, the biomass yields responded more to differences in treatments (mulching, root pruning, minimum tilling) as this affected soil moisture availability in various ways. Expressing the yields with physical error limits from repeated sampling in Tables 2 and 3 has the same value as using statistics with significance levels.

The outcome from these two contrasting seasons can now be summarised as: (i) beans suffered from competetion in the AF plots in the wet SR92 season; (ii) combination of pruning, minimum tillage plus mulching higher seed yields in the AF plots in the dry season (LR92); (iii) combined application of pruning, minimum tillage plus mulching resulted in higher maize grain, cob and stover biomass during the wet season (SR92); (iv) the control plots had higher yields than AF plots in LR92 as result of less competition for soil moisture since there were no trees here.

Any advantages of the AF plots obtained from the woody components were therefore only gains for the farmers in the seasons considered here. However, relative losses in bean yields had to be taken into account in the wettest season, which was climatologically not representative for the seven seasons studied. In general, the use and economics of the additional AF plot products will then influence the choice of the farmers (e.g. Ong et al., 1996; Leakey, 1999). Negative yield influences may be more than compensated for by revenues derived from major tree products (Boffa, 1999; Ong et al., 2000).

Conclusion

The following conclusions could be drawn from the results. Neutron probe measurements indicated that SR92 had at the shallower agronomically most important depths more soil moisture than LR92 at all distances from *Grevillea robusta* trees, with minimum tilled and mulched AF plots (using 3t/ha maize stalks) with pruning generally being outstanding. This combination of treatments yielded in both contrasting seasons in Matanya within AF (i) more bean seed as well as (ii) more maize biomass (in LR92, with low crop yields) and grain, cob and stover (in SR92, with high crop yields). The positive moisture effects were stronger closer to the pruned trees while unpruned trees typically used more moisture and therefore exhibited stronger competition, negatively influencing yields. These and other effects or their absence appeared indeed similar for the two seasons concerned as to spatial moisture behaviour, so the same is likely to apply to yields in general. The agroforestry intervention with pruned older trees and maize stalk mulching did not negatively influence maize yields in the wettest season and showed a positive effect on maize biomass yields in the driest season. Compared to the controls, the latter season kept the bean seed yields the same, but in the wetter season bean seed yields were negatively influenced by the intervention, due to competition. The statistical tests (F- and t-Tests) on the soil moisture data at Matanya showed which differences were statically significant in both space and time.

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