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Full Length Research

Effect of Acacia tortilis trees on the nutritive quality of understorey species in truncated ecosystems in Kenya

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The primary objective of the current study was to investigate the effect of cutting isolated *Acacia tortilis* on soil fertility and herbaceous understorey nutrient quality in a truncated ecosystem in south central Kenya. The hypotheses tested revolved around the premise that microenvironmental gradients in nutrients within and without *Acacia tortilis are* central to explanations of differences in nutrient quality of shade adapted and sun adapted C4 grasses. Standard scientific methods were used to evaluate changes in soil fertility and nutrient quality of *Panicum maximum* (shade adapted), *Chloris roxburghiana* and *Themeda triandra* (sun adapted). A randomized complete block design was used to measure the treatment effects created by cutting *Acacia tortilis* trees on soil mineral content and nutrient quality of the C4 grasses. Descriptive statistical parameters were used to determine the presence or absence of *Acacia tortilis* effects on nutrient relations. Mean soil mineral content for the canopy microsites were, nitrogen (0.2%), carbon (2.0%), phosphorous (22.0%), potassium (1.76me/100g), magnesium (3.15me/100g), calcium (6.0me/100g), manganese (0.30me/100g), compared to nitrogen (0.33%), carbon (2.1%), phosphorous (35.5ppm), potassium (1.95me/100), magnesium (4.20me/100g), calcium (6.8me/100g) and manganese (0.42me/100g) in the non-canopy microsites. Higher levels of mineral elements were reflected in the higher levels of nitrogen (2.23+_0.5262), phosphorous (0.17+_0.0239), potassium (2.83+_0.6052) in plant tissues of *Panicum maximum* compared to nitrogen (1.4 +_0.243), phosphorous (0.16 +_0.038) and potassium (1.6+_0.323) in plant tissues of *Chloris roxburghiana* in the open grasslands. These results of *Acacia tortilis-Panicum maximum* interactions suggest that induced disturbances created by clearing of *Acacia tortilis* trees in the long term will cause shifts in nutrient relations with significant implications on nutrient quality and productivity of C4 grasses.

Keywords: *Acacia tortilis, Panicum maximum*, nutrient quality, truncated ecosystems.

INTRODUCTION

An experiment was conducted in a semi arid area to investigate the effect of cutting isolated *Acacia tortilis(A.tortilis)* trees on the soil and herbaceous understorey plant mineral content relations in the created micro sites in south central Kenya. The effects of fire, defoliation, soil texture, soil nutrients, radiation and water in relation to the dynamics of tree-grass co-existence in natural ecosystems have been studied (Belsky *et al.* 1990, 1993, 1994, Higgins *et al.* 2000, Ludwig *et al.* 2004, Tietjen and Jeltsch, 2007, Lortie and Callaway 2006, Maranga 1986, Muthuri *et al.* 2009, Murphy and Bowman 2012, Ward *et al.* 2013, Bertness and Altieri 2013 Dohn, 2015, Maranga 2016). The influence of trees on carbon sequestration, soil nutrient concentration and fluxes of N, P, and cations is well documented in the literature (Belsky *et al*. 1989, Scholes and Archer 1997). Evidence of accumulation of soil nutrients under tree canopies and nitrogen enrichment under leguminous trees has been reported (Belsky *et al*. 1993, Scholes and Archer 1997). However, little is known about the effects of soil- plant-nutrient relations in altered environmental conditions due to human activities. The present study was designed to contribute to our understanding of the ecological implications of cutting *A. tortilis* trees on the nutrient quality of *Panicum maximum (P.maximum)* which is a dominant species beneath *A. tortilis* canopies in the semi arid ecosystems in Kenya. It was hypothesized that exposure of the canopy environment to full sun by clearing of these trees would affect soil fertility relations and nutrient quality of *P. maximum*. Scientific data authenticating the influence of trees on soil fertility and nutrient relations of herbaceous understorey plant species is required in shaping natural resource exploitation policy and in the development of tree-grass management interventions.

MATERIALS AND METHODS

Study sites

Experimental trees were located in two study sites in Makueni, south central Kenya (*Muuni* and *Four Corners*) on research land under the Kenya Agricultural and Livestock Research Organization (KALRO), National Range Research Centre, Kiboko.

There were dominant *A. tortilis* trees that supported a dense matrix of *P. maximum* Jacq. in the study area. The sun tolerant grasses outside the canopy area of *A. tortilis* trees included *Digitaria milanjiana (D.milanjiana),Themeda triandra (T.triandra), Cenchrus ciliaris (C.ciliaris)* and *Chloris roxburghiana (C.roxburghiana)*. *A. tortilis* trees were interspersed with isolated bushes with dominants such as *Acacia Senegal*, *Commiphora africana, Commiphora riparia, Acacia mellifera, Grewia bicolor* and *Duosperma species*. A bimodal rainfall regime with distinct wet-dry cycle defines the water pulses of the study area. The period from March to May is described as the long rainfall season. The short rains span the period from October to December. A short dry season occurs between June and September. Makindu surface weather station about 3 kilometres from the study locations receives a mean annual rainfall of 600mm (based on 70 years of rainfall data). Ambient air temperatures range from 28.0 ^{o}C (mean maximum) to 16.5 ^{o}C (mean minimum). The highest temperatures occurred in February (36.1^{o}C) whereas the lowest temperatures were observed in July (8.8 ^{o}C). Relative humidity varied between 47% at 1200 GMT and 78% at 0600 GMT. The soils are classified as acri-rhodic ferralsols, deep and reasonably well drained (Michieka and Van der Pour, 1977).Water stress is a common feature during the dry season.Tree felling and herbivory characterizes the ecological dynamics of the study locations.

Field studies

Field experiments were conducted on two sites with four micro sites in each site. One of the sites served as a control. In this site four isolated *A. tortilis* trees were left intact. These trees supported a dense matrix of *P. maximum* beneath their canopies. Experimental treatments consisted of four other microsites where *A.*

Plate 1: Experimental *Acacia tortilis* tree with a dense matrix of *Panicum maximum* in the canopy area

tortilis trees were removed to expose *P. maximum* to full sun. The criterion for the selection of the experimental trees was a well-developed canopy with a continuous grass layer beneath the canopy. The canopies of the experimental trees did not overlap. A minimum distance of about 25m between the experimental trees was maintained. Four trees were cut down approximately 40cm above the ground surface in each experimental area seven months before the beginning of the collection of soil and plant samples for chemical analysis of nutrient concentrations. The microsites created by the presence and absence of *A. tortilis* canopies provided experimental units for the evaluation of the impact of induced changes on understorey plant nutrient quality (Plates 1 and 2). Shrubs and standing senescent plant material were removed from the experimental plots prior to data collection.

Plate 2: Stump of *Acacia tortilis* tree showing exposed *Panicum maximum* in the study microsite

Soil chemical analysis

Soil samples were obtained from beneath *A. tortilis* canopies and from the exposed microsites at the beginning of the study. These data were necessary for the characterization of antecedent soil fertility conditions of the study microsites (Table 1). Soil samples were analysed for nitrogen (N, %), organic carbon (C, %), phosphorous (P, ppm), potassium (K, me/100gm), magnesium (Mg, me/100gm), calcium (Ca, me/100gm) and manganese (Mn, me/100gm). Standard methods (AOAC 1975) were used in the determination of soil mineral nutrients. All the soil sample chemical analyses were done at the National Agricultural Research Laboratories of the Kenya Agricultural Research Institute (KARI), Nairobi, Kenya.

Table 1: Chemical and physical properties of the Acri-rhodic ferralsol of the experimental plots on the National Range Research Centre, Kiboko.

SOIL CHEMICAL COMPOSITION [a]

Depth(0-30cm)	**Mn**	**Ca**	**Mg**	**K**	**P**	**C**	**N**	**C/N**	**pH**
	Me/ 100g	**Me/ 100g**	**Me/ 100g**	**Me/ 100g**	**ppm**	**%**	**%**		**pH-H_20 (1:1 v/v)**
Under *A.tortilis* canopies	0.30	6.0	3.15	1.76	22	2.0	0.2	10	6.40
Exposed microsites	0.20	4.60	2.60	0.94	38	1.50	0.15	10	5.68

Soil mineral analyses; P, K, Na, Ca, Mg, and Mn

Soil samples from the field were oven dried at 105 ^{0}C for 24 hours and nutrient elements extracted in a 1:5 ratio (w/v) with a mixture of 0.1m HCl and 0.025 M H_2SO_4 (Morgan's solution). Na, Ca. and K were determined by a flame spectrophotometer. Phosphorus was determined by the molybdenum blue calorimetry procedure (Murphy and Riley 1962).

Total organic carbon

The Modified Mebius Method (AOAC 1975) was used to determine total organic carbon. Organic carbon in the soil sample was oxidized by acidified dichromate at 150 ^{0}C for 30 min, until complete oxidation occurred. Barium chloride was then added to the cool digest, mixed and allowed to stand overnight. Total organic carbon concentration was read on the atomic absorption spectrophotometer at 600nm wavelength.

Total nitrogen

The Kjeldahl Method was used to determine total nitrogen content of the soil samples (AOAC 1975). The samples were digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350 ^{0}C. Total nitrogen was then determined calorimetrically on a flow analyzer.

Soil pH- water

The soil pH was measured in a 1:1 (w/v) soil: water suspension using a pH meter.

Sample preparations for determinations of Na, K, Mg, N, P, Zn, and Mn

Plant samples of *P. maximum* from beneath the *A. tortilis* canopies; *C. roxburghiana* and *T. triandra* from the exposed microsites were obtained by clipping the shoot at 5cm above the ground. Samples for chemical analyses were dried at 60 ^{0}C in a forced draft oven and ground through a 1 mm sieve. Approximately 0.3gm of the ground plant material was transferred into a digestion tube containing 2.5 ml of a digestion mixture made from concentrated sulphuric acid, salicylic acid (monohydroxybenzoic acid with the formula CHO_3), H_2O_2 and selenium and left overnight. Thereafter samples were heated on a digestion block at 100^{0}C for two hours and allowed to cool. Successive 1 ml aliquots of H_2O_2 were added into the digestion mixture and heated on a digestion block at 330 ^{0}C for approximately two hours, until a clear or light yellow digest was obtained. After cooling, 48.3 ml of distilled water was added to the digest and the various elements determined as described in the following sections.

Plant tissue analysis

In situ plant tissue analyses for determinations of magnesium (Mg, %), calcium (Ca, %), manganese (Mn, mg/kg), potassium (K, %), phosphorous (P, %), iron (Fe, mg/kg), zinc (zn mg/kg), copper (Cu, mg/kg) and nitrogen (N, %) were conducted at the beginning of the growth cycle (onset of the short rainfall season in December) end of the growth cycle (prior to the beginning of the dry season in July) and at the conclusion of the study (second growth season in June).Plant tissue analyses for mineral element determinations were carried out at the KARI National Agricultural Laboratories, Nairobi, Kenya.

Determinations of N, P, Ca, Mg, Zn, Mn, Na and K

Nitrogen and phosphorus were determined using a Segmented Flow Analyser with absorptions at 660nm and 880 nm respectively (AOAC 1975). Ca, Mg, Zn, and Mn were determined using atomic absorption spectro photometry (AOAC 1975). Na and K were determined by means of a flame photometer (AOAC 1975).

Data analysis

Statistical parameters were computed to describe variations in soil mineral content and nutrient quality of C4 grasses in the contrasting environments. These parameters included measures of dispersion as well as the associated standard errors (Little and Hills 1975).

RESULTS AND DISCUSSION

Soil mineral concentrations in the contrasting microsites

Table 2(a) : Mean soil mineral content beneath *A. tortilis* canopies *(A.t.c)*, areas around *A. tortilis* stumps *(A.A.t.s)* and adjacent open grasslands *(a.a)* June and July

PLANT SPECIES	Mn Me/100g	Ca Me/100g	Mg Me/100g	K Me/100g	P ppm	C %	N %
P.maximum (A.t.c) July	0.30	6.0	3.15	1.76	22.0	2.0	0.2
P.maximum(A.A.t.s) June	0.42	6.8	4.20	1.95	35.5	2.1	0.33
Exposed microsites (a.a) July	0.20	4.60	2.60	0.94	38.0	1.50	0.15

Generally, soils around the tree stumps of A*. tortilis* trees had slightly higher extractable manganese, calcium, magnesium, potassium, carbon and nitrogen than soils under intact *A.tortilis* canopies and the adjacent open grasslands within 0-30cm soil profile (Tables 1 and 2). However, soils in the disturbed microsites and adjacent open grasslands had higher phosphorus content than the canopy microsites.

The higher soil fertility around the tree stumps may be attributed to additional input of organic nutrients due to root decay. The demonstration of higher fertility around *A.tortilis* stumps is consistent with the findings of Tiedeman and Klemmedson (1986) who found higher concentrations of nutrients around isolated dead trees (13years after the trees died) than in the adjacent open grasslands in the North American savannas. The studies of Mwonga (1991), Belsky *et al*. (1989) and Belsky (1994) in the savanna ecosystems of Kenya and those of Bernhard-Reversat (1982), Anderson *et al*. (2001) and Dohn 2015, confirmed the presence of 'islands of fertility' around large isolated trees in relation to adjacent open areas.

The mechanism of mineral concentration around large isolated trees and dead trees is not clearly understood (Scholes and Archer 1997; Ludwig *et al*. 2004). Surficial nutrient pumping, also known as the "nutrient pump hypothesis", has been proposed as a plausible mechanism (Scholes 1990). According to this hypothesis trees transfer nutrients vertically and laterally from the deeper soil horizons and deposit these nutrients in the surface profiles beneath the canopy. Nutrients such as P and K are likely to come from the deeper soil profiles while N enrichment may be due to nitrogen fixation by *A.tortilis* in addition to N mineralization due to denitrification of litter fall and root decay (Ludwig *et al.* 2004).

Mean tissue (leaf) nitrogen, phosphorus and carbon content

Panicum maximum leaves had higher N content (1.96%) but lower iron content than *Chloris roxburghiana* (1.53%) at the end of the growth cycle in June. *P. maximum* in the intact microsites and around the stumps of *A. tortilis* had higher P, K, Ca, Mg, Cu and Zn content than *C. roxburghiana* and *T. triandra* in the open grasslands(Table 2b and 3). It is instructive to note that the N content for *P.maximum* in the disturbed microsites was slightly higher than that from the intact microsites.

Table 2b: Summary of averages (M) standard deviations (SD) and standard errors (SE) of plant tissue analysis of nutrient quality of *Panicum maximum (canopy microsite* and *Chloris roxburghiana (open microsite)*

	Panicum maximum			***Chloris roxburghiana***		
	M	**SD**	**SE**	**M**	**SD**	**SE**
N (%)	2.23	1.052	0.5262	1.4	0.420	0.243
P (%)	0.17	0.048	0.0239	0.16	0.066	0.038
K (%)	2.83	1.210	0.6052	1.6	0.560	0.323
Ca (%)	0.40	0.136	0.0679	0.28	0.121	0.069
Mg (%)	0.34	0.153	0.0764	0.12	0.025	0.015
Mn(mg/kg)	37.13	8.270	4.1351	38.9	14.39	8.311
Fe(mg/kg)	379.8	206.869	103.435	407.33	473.51	273.383
Zn(mg/kg)	34.0	9.940	4.9702	29.23	7.80	4.504
Cu(mg/kg)	6.17	3.044	1.5222	3.28	0.387	0.223

Table 3: Mean leaf mineral content of *P. maximum* from around *A.tortilis* tree stumps (*A.A.t.s*), beneath *A.tortilis* canopies (*A.t.c*), *T. triandra* and C. *roxburghiana* from the adjacent grasslands *(a.a)*

PLANT SPECIES	**Mn mg/ kg**	**Ca %**	**Mg %**	**K %**	**P %**	**Zn mg/kg**	**Cu mg/kg**	**N %**
P .maximum (A.t. c)	38.5	0.20	0.20	3.08	0.13	22.8	6.0	1.96
P.maximum(A.A.t.s)	42.2	0.22	0.30	4.30	0.20	33.4	7.1	2.46
C. roxburghiana(a.a)	42.8	0.15	0.10	1.95	0.22	20.7	3.5	1.53
T. triandra (a.a)	62	0.35	0.11	0.51	0.10	19	Trace	0.55

This was also true for P content that was higher in *P.maximum* from the disturbed microsites than the intact microsites. The magnesium leaf content of *C.roxburghiana*, and *T. triandra* in the open grasslands were slightly lower than those of *P.maximum* from canopy microsites and around the tree stumps (Table 3).

Higher levels of carbon and nitrogen in soils under the canopies of *A.tortilis* than in the open grasslands provided a stable source of N, C, and energy for microbiological organisms involved in nitrification and de-nitrification processes (Table 2a). The fact that *P. maximum* thrived under the *A.tortilis* trees suggested that N was not limiting in such microsites. Stitt *et al*. (1994) found that excess addition of N in RubisCO, which catalyses photosynthetic reactions was associated with increases in CO_2 assimilation rates. Increased synthesis of RubisCO has been associated with increased water use efficiency (Stitt and Schulze, 1994). Mwonga, (1991) found that the potential mineralization rate of nitrogen was 61% higher ($p \leq 0.05$) in *A.tortilis* canopies than in the adjacent open areas in a savanna in southern Kenya. The disturbed microsites were higher in soil mineral content with regard to Mn, Ca, Mg, K, and P than the canopy microsites and open grasslands (Table 2a). Soil Mn, Ca, Mg, K, P contents were closely related to the levels found in plant tissues of *P.maximum, C. roxburghiana* and *T. triandra* in the contrasting microsites (Table 2b and 3).

Effects of removing A.tortilis trees on soil fertility

In this study mineral concentration was associated with the canopy microsites and areas around the *A.tortilis* stumps.The higher soil fertility around tree stumps may have been caused by additional input of organic nutrients (Table 1 and 2a).This indicates that soil fertility in the original canopy microsites of dead trees remains high as competition for available soil moisture probably diminishes. This is in conformity with the findings of Tiedeman and Klemmedson(1986) who found increased nutrient concentration around dead trees in relation to open sites 13 years after tree removal in a North American Savanna. Studies on soil nutrient pools have indicated that the microbial biomass of the soil fraction is a function of soil type and land use practices (Belsky, 1994). In her studies of the effects of trees on the nutritional quality of understorey graminoid plant species, Belsky (1992, 1994) found that changes in microbial composition influenced the rate of mineralization of humus, nitrification and de-nitrification. Soil microbial dormancy on the other hand has been associated with carbon substrate and nitrogen availability (Mwonga, 1991).

Although this study did not assess the soil microbial biomass in the study sites, previous similar studies on soil microbial activity in savanna rangelands of Kenya and Senegal (Bernhard-Reversat, 1982; Belsky, 1994) where changes in soil and land use management practices have resulted in shifts in soil carbon and nitrogen availability, soil microbial biomass levels were reported to increase with increase in C and N. Previous studies have shown that plant exudates into the soil rhizosphere are important sources of carbon and energy for microbial community and their availability influences microbial biomass dynamics (Bernhard- Reversat 1982, Mwonga, 1991; Akpo, 1997; Aerts and Chapin, 2000; Jagadamma *et al.* 2014). Soil microbial biomass involved in nitrificatioin and de-nitrification processes depend on energy and carbon sources provided through root exudation and / or decay of carbonaceous substrate (Fraser *et al.* 1988). Since *A. tortilis* trees are known to fix N required by soil microbial biomass community involved in decomposition and mineralization of N (Ludwig, *et al.* 2004), the removal of these trees should limit N mineralization activity and constrain N availability to associated *P. maximum.*

Although most studies in the savannas have recognized the presence of “islands of fertility” phenomenon around large isolated trees, the mechanism responsible for this phenomenon is not clearly understood (Belsky *et al* 1989; Belsky 1992, 1994; Scholes and Archer 1997, Ludwig *et al.* 2004, Dohn 2015). The “nutrient pump” hypothesis (Scholes and Archer 1997) which postulates that trees transfer nutrients from deeper soil horizons and deposit them in the surface layers beneath the canopy may account for the higher concentration of N, C, K, Mg, Ca, in the *A.tortilis* microsites. However, it does not account for the higher P levels around the *A.tortilis* tree stumps and in the open adjacent grasslands than in the tree canopies. The higher levels of N, Zn, P, K, Mg, and Ca found in the tissues of *P. maximum* than those of the species in the adjacent open grasslands (Table 2b and 3) supports the premise that tree cutting will constrain soil nutrient availability and diminish plant nutrient levels in these microsites. Although the impact of *A.tortilis* removal on N mineralisation rates due to induced N limiting conditions in the absence of N fixation was not assessed, it is evident from previous research (Mwonga 1991) that canopy microsites had 61% higher potential rate of N mineralization than the adjacent open grasslands. Evidently, tree cutting in the savanna has important implications on the dynamics of N sequestration in the light of increasing demands for cropping land, fuel wood and timber. Changes in land uses coupled with overgrazing are bound to negatively impact upon savanna nutrient balances, and tree grass coexistence.

CONCLUSIONS

Since soil mineral availability was higher in the canopy microsites with corresponding higher nutrient quality for *Panicum maximum* (except for P) than the open grasslands it is concluded that in the open grasslands where *C.roxburghiana* was dominant, the lower availability of N coupled with limiting soil moisture availability during the dry seasons limit nutrient quality. The higher levels of N, P, K Zn, Mg, and Ca found in plant tissues of *Panicum maximum* from the canopy microsites and from around the *A.tortilis* stumps compared to *C.roxburghiana* and *T.triandra* from the open grasslands suggest that the removal of this tree will constrain nutrient availability and probably cause a change from a P- limited to N-limited grasses.

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