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Phenotypic nutrient up-take differences in an alley cropping system in semi-arid Machakos, Kenya

D.N. Mungai[1], C.L.Coulson[2], C.J. Stigter[3*], J.K. Ng'ang'a[4], D.N.Mugendi[5]

(1. Department of Geography, University of Nairobi, Nairobi, Kenya; 2. Department of Botany, University of Nairobi, Nairobi, Kenya; 3. Department of Environmental Sciences, Graduate School of Production Ecology, Wageningen University, Duivendaal 2, 6701 AP, The Netherlands; 4. Department of Meteorology, University of Nairobi, Nairobi, Kenya; 5. Kenya Forestry Research Institute (KEFRI), Nairobi, Kenya)

Abstract: Alley cropping of *Cassia siamea* and maize was studied in semi-arid Kenya for soil fertility improvement. Katumani composite maize was planted except in the short rains of 1988 (SR88) when a hybrid variety was sown. Therefore the grain yield per row increased differently in the alley cropped maize (CM). Sole maize (SM) and CM yields were higher in SR88 than in the long rains of 1988 (LR88) by 62% and 38%, while yields from the same treatments in LR89 were only 21% and 45% of those in SR88. These differences in relative maize yields are attributed to differences between the two maize varieties in competition under nutrient stress conditions.

Key words: alley cropping; *Cassia siamea*; maize nutrients; maize yield; semi-arid condition; soil moisture; Kenya

Introduction

In the Fifth Framework Programme of the European Commission (EC, 1999), under "tools for sustainable development", there was recently a special call for proposals for "Technologies for sustainable plant and animal production: building blocks for improvement (for small-scale or environmentally-constrained systems)". One of the major subjects called for was: "agronomic techniques for improving soil fertility such as agroforestry". In this context, particular alley cropping data already collected nearly a decade ago (Mugendi, 1991; Mungai, 1991) get new importance. Our basic results on the fertility aspects of this alley cropping research were published earlier (Mugendi, 1994; 1997). Elements of the special research approach and detailed quantitative results on the microclimatology of this agroforestry system did also appear (Mungai, 1996; 1997; 1999).

Alley cropping is one form of agroforestry that has been proposed as an alternative to shifting cultivation (Kang, 1984; 1990). It is a traditional practice in Indonesia and for example farmers in southeastern Nigeria are known to have practiced some aspects of alley farming on acid ultisols using *Acioa barterii* (Kang, 1990). As a practice alley cropping was further developed at the International Institute of Tropical Agriculture (IITA, Ibadan, Nigeria) in the 1970s. Research results from (sub-) humid tropical environments indicated that alley cropping has the potential to improve yields of arable crops without using expensive inorganic fertilizers (Kang, 1984).

Already some early studies have examined how various forms of alley cropping systems affect the soil chemical and physical conditions and how these impact on agricultural productivity (Kang, 1984; Yamoa, 1986; Lal, 1989a; 1989b; 1989c). Presently, good theoretical approaches in agroforestry, backed by less abundant experimental evidence, are available (Ong, 1996a). Microclimatic aspects are presently better known (Stigter, 1995; Baldy, 1997), while the need for fertility enhancement is clearly remaining (Ong, 1996b).

Much of the early alley cropping work was haunted by the possibility of tree roots invading control plots, while such interactions should be prevented (Ong, 1995). In our agroforestry plots each fourth row of *Zea mays L*. was replaced by pruned *Casia siamea Lam*. hedge. (Long after the work was terminated and some publications had already appeared, ICRAF started to rename the *Cassia* as *Senna*. We have kept the name originally used, to prevent confusion). Excavation showed that the non-replaced maize rows in the controls suffered most from this additional competition, but these rows were not used for yield determinations. Moreover, in the relative yields that we are discussing here, any remaining influence is largely canceled in the comparisons made.

Particular evidence is reported here on the existence of root competition for nutrients and its impact on yields in

* Corresponding author; E-mail: Kees.stigter@user.metair.wau.nl

alley cropping of *Cassia hedges* and maize in semi-arid Machakos, Kenya. Katumani Composite B, which is a fast maturing maize variety, had been planted since SR83. but in SR88 a longer maturing hybrid variety (H511) was sown. To illustrate the surprising repercussions of sowing the hybrid on the subsequent season, the results of LR88, SR88 and LR89 will be discussed.

1 Materials and methods

1.1 Experimental site

The research was conducted at Katumani National Dryland Farming Research Center (1°35′ S, 37°14′ E; altitude, 1560m) which is about 10 km south of Machakos town. The area is semi-arid to sub-humid (Braun, 1983), with a mean annual rainfall of 700 mm——which is still higher than the below 500 mm values mentioned for "marginal" lands in Kenya by Muniafu *et al*. (Muniafu, 1999)——and potential reference evaporation of about 1800 mm. The rainfall is highly variable and occurs mainly in two rainy seasons. Each rainy season receives on average about 300 mm of rainfall. The first cropping season starts in March and ends in August while the second one starts in October and ends in February. The soils of the experimental site are haptic Lixisols which are weakly to moderately leached, friable, well drained, and dark-reddish in color. They are weakly acidic in reaction (pH 5.9—6.5), have a medium base saturation (about 50%—70%) and low levels of organic carbon (about 0.8% in the top soil).

1.2 Experimental design

The experimental design and treatment combinations had already been established under the Dryland Agroforestry Research Project (Arap, 1986). The experimental layout was a completely randomized design with each treatment replicated four times (Fig. 1). Within each plot, except in the control (SM), four *Cassia hedges* were established in November 1983 at between row spacing of 3.6m and within row spacing of 0.25m for treatment CM1 and 1m for treatment CM2. Three rows of maize were planted in each alley parallel to the approximately North-South hedgerows at a spacing of 0.9m by 0.3m. In SM, each hedgerow was replaced by a row of maize. The *Cassia* was pruned to a height of 50 cm two weeks before planting. Because of a higher decomposition rate but also necessary because of the windy conditions, the fresh biomass was incorporated into the soil, which should also be seen as a form of mulching (Stigter, 1984). SM did not receive any mulch. The present study was carried out in treatment CM1 and SM. CM1 is called CM from here onwards.

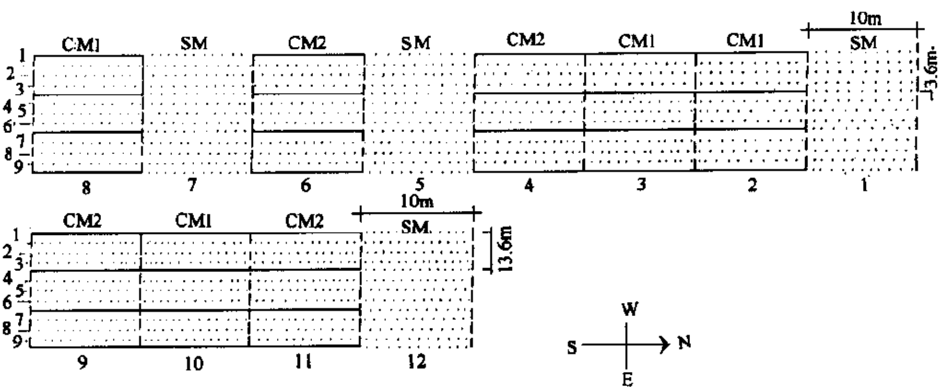

Fig. 1 Layout of the alley cropping experiment

(CM1, CM2 and SM are the 0.25m, 1.0m and control spacing of *Cassia Siamea* respectively;

——*Cassia Siamea* headge; ……rows of maize)

Preliminary field root observations indicated that the highest maize root length density occurred at the 20—40 cm depth while *Cassia* roots were found mainly at 30—60 cm depth. This observation was later confirmed (Umaya, 1991; 1999; Mungai, 1991). Soil moisture was therefore monitored at 30, 40 and 60 cm depths with Soil Moisture Equipment Corporation (Santa Barbara, CA, USA) gypsum blocks (Mungai, 1999). In two middle alleys in CM and one in SM, five sampling points were selected across the alley, one in each row of maize between two maize plants, and one 30 cm from each hedge in the middle between two *Cassia* trees. This measurement strategy wad designed to detect horizontal (across row) and vertical gradients of soil moisture over relatively short distances, for which an often recommended instrument like the neutron probe would be less suitable, particularly under dry conditions, because of large spheres of influence (Mungai, 1999; Ibrahim, 1999).

The heights of maize and *Cassia* were measured from the ground surface to the highest point of ten randomly selected plants per row. Grain yield on a per row basis was determined at maturity of the maize. Plant nutrient analysis was carried out for the two rainy seasons of 1988. Composite (made up from different plants) samples of *Cassia siamea* were taken for nutrient analysis at the time of lopping. The maize leaves opposite the cob were sampled for nutrient analysis at cob setting. Grain samples were taken after the crop was harvested and threshed. The Kjeldal method was used to determine total N and the Walkley method to determine C (Black, 1965). K and Na were determined flame photometrically, P calorimetrically and Mg and Ca spectrophotometrically, while S was determined by the turbidimetric method (Evenhuis, 1978; IITA, 1979; NAL, 1986). An analysis of variance was carried out, with significance taken at the 5% level, using an INSTAT programme.

2 Results

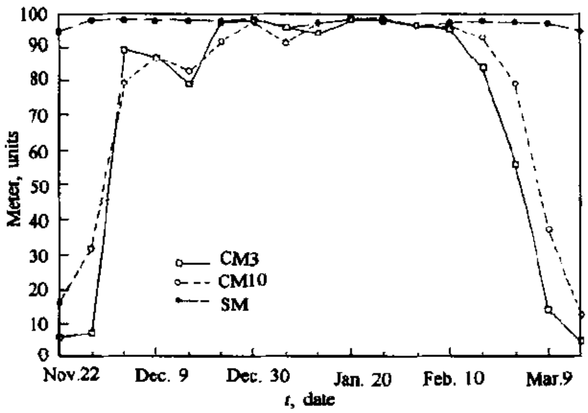

Fig. 2 Between and within treatment soil moisture extraction differences at 60 cm depth at 30 cm from the *Cassia hedge* and at a comparable area in SM, short rains 1988. Moisture extraction was the highest in CM (3), well comparable in CM(10) and clearly least in SM

2.1 Soil moisture

Generally, soil moisture extraction was higher in CM compared to SM. Whenever there were differences between plots in the growth of above-ground parts of the maize, such differences correlated with soil moisture depletion patterns. An example for relative soil moisture data is shown in Fig. 2, where higher meter units mean more soil moisture (Mungai, 1999). Above 90 units, errors were too small to be shown. Below that, those of CM(3) and CM (10) often overlapped or came close. Supported by gravimetrical data, it was additionally found that in CM, soil moisture depletion was greater in the middle maize row than in maize rows nearest to the hedges, while the latter maize was taller (Umaya, 1999).

2.2 Plant height

Contrary to both rainy seasons in 1987 and the short rains of 1989, in the three consecutive seasons singled out here, total rainfall was above the long term seasonal average (300 mm) with rather good distributions within the growing season. SR88 was particularly wet (531 mm) while the previous LR88 had still 407 mm and LR89 334 mm only (Table 1).

Table 1 Maize grain yield (kg per row), applied mulch (kg/m²) and total seasonal rainfall (mm) for 1988 (long rains (LR) and short rains (SR)) and 1989 (LR), with several yield intercomparisons for sole maize (SM) and maize alley cropped between *Cassia siamea* (CM) pruned trees

	LR88		SR88		LR89	
	CM	SM	CM	SM	CM	SM
Yield	3.1	2.35	4.3	3.85	1.95	0.8
Mulch	0.62	–	0.49	–	1.09	–
RainfallQD	407.4		531.2		334.2	
CM/SM, %	132		112		244	
SM (SR88)/SM (LR88), %	162		SM (LR89)/SM (SR88), %			21
CM (SR88)/CM (LR88), %	138		CM (LR89)/CM (SR88), %			45

In LR88, maize plants in plot CM(3) were at 64 days after sowing (DAS) higher than those in CM(10), consistently for each row (Table 2). SM had the smallest maize plants, for which the three averages of 20 plants were within 123 ± 10 cm. Compared with the same averages of CM(3), of 186 ± 6 cm, and CM(10), of 160 ± 7 cm, these differences have no overlapping error limits (Table 2).

At 64 DAS maize height differences during SR88, when the hybrid was planted, were at 64 DAS in the same direction as in the previous season, although all plants were still shorter in SR88 at that time. In this case only the mean of the averages of CM(3) and CM(10) does not have an overlapping error limit with the average of all three SM rows (Table 2). The longer maturing hybrid maize ultimately grew taller and had an increased above ground biomass compared to the Katumani cultivar.

Table 2 Variation in height (cm) of maize and *Cassia* plants in 1988 and 1989 for sole maize (SM) and maize alley cropped with *Cassia siamea* (CM) pruned trees

Treatment	Position	n	(Ⅰ)[a]	(Ⅱ)[b]	(Ⅲ)[c]
CM(3)	East row	10	181 ± 32	127 ± 38	72 ± 22
CM(10)	East row	10	156 ± 23	109 ± 24	74 ± 30
SM	East row	20	122 ± 31	115 ± 26	55 ± 17
Cassia	East row	20	96 ± 6	102 ± 13	76 ± 6
CM(3)	Middle row	10	192 ± 13	175 ± 33	84 ± 27
CM(10)	Middle row	10	157 ± 26	141 ± 25	72 ± 17
SM	Middle row	20	113 ± 37	107 ± 31	48 ± 13
CM(3)	West row	10	186 ± 19	138 ± 50	89 ± 23
CM(10)	West row	10	167 ± 14	133 ± 40	106 ± 17
SM	West row	20	133 ± 29	120 ± 27	50 ± 16
Cassia	West row	20	89 ± 14	99 ± 20	74 ± 9
Average CM(3)			186 ± 6	147 ± 28	82 ± 10
Average CM(10)			160 ± 7	128 ± 19	84 ± 22
Average SM			123 ± 10	114 ± 7	51 ± 4

a: long rains (LR) 1988 at 64 DAS; b: short rains (SR) 1988 at 64 DAS; c: LR 1989 at 50 DAS. (3) and (10) refer to plot numbers in Fig. 1

The height differences between CM and SM are due to the incorporation of prunings of the former season in the CM plots. The differences between replicates must be due to spatial heterogeneity of the plots and the *Cassia*, although amounts of mulch did not differ significantly.

The LR89 crop, which followed the hybrid maize, showed striking differences (in color, stem diameter and height) between the treatments. Difference between row averages was small now for CM(3) and CM(10) and the ratio SM/CM was smallest here (Table 2).

2.3 Plant nutrients

The maize leaves and grain from CM had higher average concentration of nutrients and C than those from SM in the two seasons of 1988, with S and Ca for grains in SR88 as unimportant exceptions (Table 3). Leaf nutrient content differences for N, K, Ca and Mg were statistically significant in LR88 at the $p = 5\%$ level. In SR88, such differences were observed in N, P, K, Ca and Mg. All differences in grain nutrient contents except S in both seasons and Ca and Na in SR88 were also statistically significant. Differences in C were never statistically significant at this level (Table 3). Grain nutrient content differences between CM and SM were generally about half (for N less than half) for the hybrid maize compared to Katumani Composite B, with Mg, Ca and S as exceptions (Table 3).

2.4 Grain yield

Maize yield data, applied mulch, total seasonal rainfall and several yield intercomparisons are shown in Table 1. In LR88, CM outyielded SM by 32% but this difference reduced to 12% in SR88. In LR89, the difference between these treatments was 144%. CM yields increased by 38% from LR88 to SR88 while SM yields increased by as much as 62%. A comparison between the yields of SR88 and LR89 shows that SM yields in the latter had a greater decrease (till 21% of the previous season) than CM yields (45% of the previous season). The treatment yield differences were statistically significant at the 5% level (Mungai, 1991).

3 Discussion

For the same soil as ours and Katumani Composite B maize, the type of mulch and application rates appears well correlated with maize grain yield as well as with numerous plant parameters related to grain yield such as plant height, stem diameter and leaf area (Mwangi, 1990). The rate of release of some nutrients from the mulch (Mugendi,

1994) and their subsequent mobility in the soil and the plant, as well as phenotypic uptake differences, play an important role in crop growth. The results of the two seasons of 1988 and LR89 illustrate the effect of both phenotypic nutrient uptake differences and rainfall.

Hybrid 511 is usually grown in wetter areas. N observation during its wet growing season (SR88) was that this cultivar ultimately grew taller and had an increased above ground biomass compared to the Katumani cultivar. This extra shoot height and biomass must have been reflected in a greater root biomass and a deeper root system than the Catamenia cultivar would normally have (Ledig, 1983; Gregory, 1987). This is the reason advanced here for the between season yield differences shown in Table 1.

Table 3 Nutrient content (%) of maize, leaves and grain, 1988 (Mugendi, 1991). Values with asterisks are statistically significant differences at the 5% level

	LR88			SR88		
	CM	SM	%	CM	SM	%
(a) Maize leaves						
N	3.72±0.27	3.12±0.24	19.2*	2.46±0.05	2.21±0.08	11.3*
P	0.28±0.03	0.24±0.00	16.7*	0.17+0.02	0.14±0.01	21.4*
K	1.75±0.28	1.25±0.14	40.0*	2.02±0.06	1.82±0.14	11.0*
Ca	0.98±0.09	0.78±0.04	25.6*	0.44±0.04	0.28±0.03	57.1*
Mg	0.38±0.02	0.28±0.02	35.7*	0.23±0.17	0.17±0.02	35.3*
S	0.08±0.01	0.07±0.00	14.3	0.05±0.01	0.04±0.00	25.0
Na	0.32±0.01	0.28±0.02	14.3	0.32±0.04	0.25±0.01	28.0
C	28.72±4.63	27.96±6.22	2.7	32.75±1.06	32.10±0.83	2.0
(b) Maize grain						
N	1.47±0.07	1.22±0.09	20.5*	1.53±0.08	1.41±0.19	8.5*
P	0.18±0.04	0.14±0.03	28.6*	0.22±0.04	0.19±0.02	15.8*
K	0.22+0.03	0.17±0.04	29.4*	0.23±0.02	0.20±0.02	15.0*
Ca	0.18±0.01	0.16±0.02	12.5*	0.15±0.01	0.16±0.01	−6.7
Mg	0.14±0.02	0.12±0.03	16.7*	0.13±0.01	0.11±0.01	18.2*
S	0.00±0.00	0.00±0.00	0.0	0.01±0.00	0.01±0.00	0.0
Na	0.06±0.02	0.04±0.02	50.0*	0.05±0.01	0.04±0.01	25.0
C	37.97±3.59	36.87±3.09	3.0	37.61±2.16	36.73±2.51	2.4

More rain was received in SR88 compared to LR88. Also, less mulch was available for application in SR88 than in LR88. In LR88, CM yield was much more above that of SM than in SR88. This difference came from a greater yield increase in SM in SR88. It is likely that the previous Katumani maize crops had extracted nutrients from SM to a certain depth of soil. The deeper hybrid maize roots exploited new mineral reserves. It also appears that the hybrid variety exploited more efficiently the nutrients in the shallower soil horizons, given the very low SM yields with Katumani Composite B in the subsequent season in comparison to the (also lower) CM.

Any difference from one season to the other in influence of *Cassia* roots invading the controls can only be a very small part of this picture. A comparison of the yields as a function of rainfall over 6 rainy seasons showed that only the SM yields of LR89 did seriously disturb the patterns (Mungai, 1995). The above findings also have consequences for crop rotation and agroforestry management in semi-arid areas with low fertility soils.

4 Conclusion

From the above discussion, a plausible explanation of the smaller yield difference between treatments in SR88 is that there was greater competition for nutrients between the hybrid maize and the *Cassia* because (1) less mulch was available during this season than in the previous one, and (2) the two maize varieties have different rooting patterns. The maize grain nutrient data support this argument. Our study appears to confirm that root competition, in this case under conditions of sufficient rain, and/or phenotypic differences, can strongly influence the crop yield under nutrient stress conditions. Despite the sufficient rainfall and higher available mulch in LR89, there were high yield reductions, but more in SM (79%) than in CM (55%). This must have been the result of better extraction of nutrients by the hybrid from the upper horizon during the previous season, that was not somewhat compensated by mulch as in the case of CM.

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