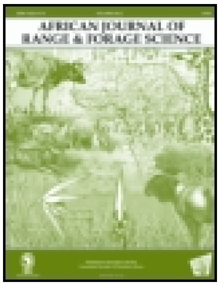

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Influence of undersowing perennial forages in maize on grain, fodder yield and soil properties in the sub-humid region of western Ethiopia

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In the densely populated mixed farming areas of western Ethiopia, the integration of forages with food crops may be crucial to the achievement of sustainable crop and livestock production. This study investigated the effects of pure grass (*Chloris gayana),* legumes (*Stylosanthes hamata*, *Desmodium intortum* and *Macrotyloma axillare)* and grass/legume mixtures of the same species undersown in maize, on maize grain yields, fodder yields and soil parameters. The forages were undersown six weeks after planting the maize. After harvesting the maize, pastures were maintained as fodder crops for the subsequent two seasons. Maize, grown with and without fertiliser, and native grass fallow were control treatments. In the year of establishment, the undersown forages increased ($p < 0.001$) total fodder production without depressing ($p < 0.05$) maize grain yield. During the following two improved fallow years, the cultivated forages produced much higher ($p < 0.05$) DM yields than the traditional fallow. Amongst the improved fallows, the average forage DM yield was highest on *C. gayana* and the grass legume mixtures than on the pure legume stands ($p < 0.05$). During year four only *D. intortum* and *S. hamata* treatments produced maize grain and residue yields comparable to moderately fertilised maize ($p < 0.05$). Maize grain and stover yields from the other fallows and unfertilised maize treatments were lower ($p < 0.05$) than that of fertilized maize. Integrating *D. intortum* and its grass legume mixture and *S. hamata* as improved fallow, maximised the overall nett return compared to pure maize with or without fertiliser and the traditional fallow.

Key Words: feed production, forage undersowing, improved fallow, maize yield, soil parameters

Introduction

In the sub-humid environment of western Ethiopia land shortage, as a result of rapid growth in population, has led to the replacement of the traditional fallow system by continuous cereal monocropping with minimal recycling of nutrients or regeneration of fertility. This, coupled with the limited use of mineral fertilisers, has resulted in a continued decline in soil fertility and a corresponding decrease in crop productivity. Where farmers do use mineral fertilisers for crop production, the application rates are sub-optimal because of high prices (Dadi *et al*. 1987). In 1995 the withdrawal of the government fertiliser subsidy increased mineral fertiliser prices by over 78%, making them unaffordable for most smallholder farmers.

Integrating cultivated forages, particularly legumes, in cereal monocropping systems is a potentially viable option to overcome soil fertility problems in smallholder mixed farming systems (Hassen *et al*. 2006). Besides increasing soil fertility, such cultivated forages can benefit livestock enterprises by providing more nutritious fodder, which is also in short supply in the study area (Dadi *et al*. 1987, Hassen *et al*. 2006). The potential benefits of integrating cultivated forages into the cereal cropping systems has already been demonstrated (Mohamed-Saleem and Otsyina 1986; Jones *et al*. 1991; Tarawali 1991; Kouane *et al*. 1993; Hassen *et al*. 2006). In western Ethiopia, a number of cultivated forage crops (e.g. *Chloris gayana*, *Panicum coloratum*, *Desmodium intortum*, *Stylosanthes hamata*, *Stylosanthes guianensis*, *Macrotyloma axillare*, *Lablab purpurus*, *Vicia atropurpura*) have been found to be well adapted to the sub-humid environment (Gizachew and Tadesse 1989). The suitability of various forage species to grow in association with food crops has, however, not yet been studied adequately. The present study, therefore, assessed the effects of undersowing perennial forages as pure stands or as grass/legume mixtures in maize on soil parameters and on forage, maize grain and maize stover yields.

Materials and methods

The study was conducted at Bako Agricultural Research Centre (BRC) (09º6'N, 37º09'E and 1650m a.s.l.) in western Ethiopia, over a period of four years (1994–1997). The weather data for the trial site for the duration of the study is presented in Figure 1. The total annual rainfall recorded during the experimental period was in the range of 936 to 1564mm, with the dry season lasting on average five months. The soil of the trial site belongs to the Nitosols series and is reddish brown in colour. Analysis of samples of surface soil (0–30cm) at the beginning of the experiment indicated that the soil was a sandy clay with organic matter (OM) 3.14%, cation exchange capacity (CEC) 13.8 meq 100g^{-1}, pH5.62, total N 0.14% and available P (Bray II) 1.8ppm. Prior to this study the traditional fallow was applied for two consecutive years on the experimental site. Land preparation at the start of the fallow period was done by tractor-drawn implements. In the subsequent years seedbed preparations were, however, executed exclusively by hand hoes.

Soil samples were taken at a depth of 0–30cm, using an auger at the beginning of the experiment and again immediately before the start of the fourth-year seedbed preparation. Soil analyses were carried out on air-dried samples. The soil pH values were measured potentiometrically in 1:1 soil:water suspension using a pH-meter with a combined glass electrode. Exchangeable cations were extracted by molar neutral ammonium acetate (pH7) and cation exchange capacity (CEC) was determined by the ammonium acetate method (Cottenie 1980). Total N was determined following the semi-micro-Kjeldahl method (Bremner and Breitenbeck 1983). Available P was extracted according to the Olsen *et al*. (1954) procedure. OM was determined by the Walkley and Black (1934) method.

The list of treatments is shown in Table 1. Pure grass (*Chloris gayana*), pure legumes (*Desmodium intortum, Stylosanthes hamata* and *Macrotyloma axillare*) and the grass/legume mixtures of the above species were under-

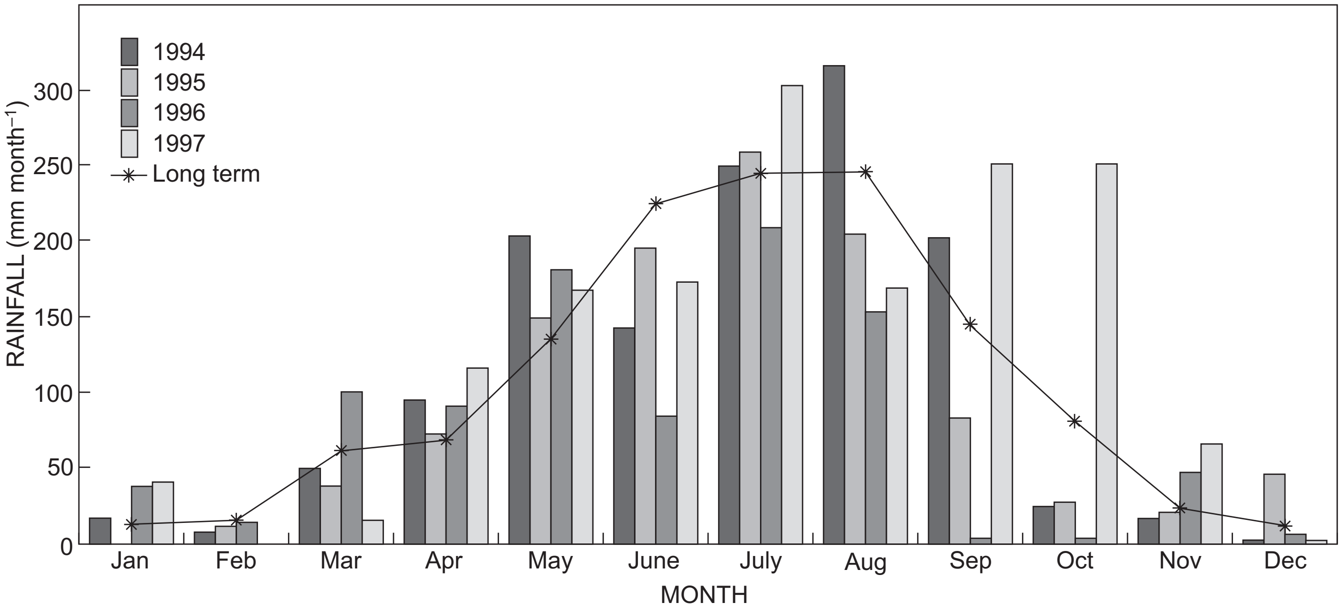

Figure 1: Long-term (18 years) and actual monthly rainfall (mm month^{-1}) during the trial period at the trial site

Table 1: Maize grain, stover, forage and total fodder yield of pure maize and forage undersown maize in the establishment year (Year 1)

Type of association	Grain yield (kg ha^{-1})[1]	Stover DM yield (kg ha^{-1})	Forage DM yield (kg ha^{-1})*	Total fodder DM yield (kg ha^{-1})
Traditional fallow (TF)	–	–	3 180	3 180^{d}
Maize without fertiliser (M_1)	5 240^{b}	7 960	–	7 960^{c}
Maize with fertiliser (M_2)	7 500^{a}	9 100	–	9 100^{bc}
C. gayana + (M_2)	6 500^{ab}	9 940	2 460 (0)	12 400^{a}
S. hamata + (M_2)	7 640^{a}	8 540	2 480 (100)	11 020^{ab}
D. intortum + (M_2)	7 540^{a}	8 550	2 280 (100)	10 830^{ab}
M. axillare + (M_2)	7 530^{a}	8 920	2 900 (100)	11 820^{a}
C. gayana/S. hamata + (M_2)	6 760^{ab}	8 840	2 310 (12.3)	11 150^{a}
C. gayana/D. intortum + (M_2)	6 490^{ab}	8 330	3 150 (34.8)	11 480^{a}
C. gayana/M. axillare + (M_2)	5 900^{ab}	8 090	2 940 (32.3)	11 030^{ab}
CV (%)	16.4	13.9	18.90	12.77
P level	0.0548	ns	ns	0.001

[1] Means in the same column followed by different superscripts differ ($p < 0.05$)

* Values within parenthesis indicate percent legume contribution

sown in maize six weeks after maize planting. Natural grass fallow and maize crop grown in a pure stand, with or without fertiliser, were used as control treatments. The maize used was an open-pollinated composite variety (Beletech). A randomised complete block design with four replicates was used.

A 4m x 8m plot size was used. A seeding rate of 30kg ha^{-1} (44 444 plants ha^{-1}) was used for the maize and 4kg ha^{-1} for *C. gayana* and the three legume species. Each forage species was sown at half these seeding rates in the grass/legume mixtures. Inter-row spacing of 75cm and intra-row spacing of 25cm was used for maize. In forage-undersown maize plots the forage seeds were drilled in two rows between the rows of maize at a spacing of 20cm from the maize and 35cm from each other. The grass legume mixtures were spaced similarly but sown in separate alternate rows.

In the first year of the study, except for the traditional fallow and unfertilised pure maize stands, all treatments received the recommended fertiliser rate for maize (75/75 N/P_2O_5kg ha^{-1}). P (di-ammonium phosphate-DAP) was applied at maize planting, while N (Urea) was applied in two equal dressings; one at planting and the remaining half six weeks later. During the second and the third years of the study, the cultivated forage plots received 100kg ha^{-1} DAP fertiliser annually. The traditional fallow and unfertilised pure maize plots received no fertiliser. At the termination of the fallow period (in the fourth year) all plots were planted with maize but fertiliser was only applied to pure maize plots receiving the recommended fertilisation rates. The pure maize and forage undersown maize plots were kept weed free manually by hoeing and slashing.

At maize maturity (26 weeks after planting), maize plants and cultivated forages from the middle rows were harvested 12cm and 5cm from the ground, respectively. Maize ears (cobs plus grain) and maize residues were partitioned and weighed on site. Grain yield was determined following shelling and adjusting the moisture content to 12.5%. About 75% and 50% heading were used as benchmarks for the harvest of grass and legumes, respectively. Grass/legume mixtures were harvested at the optimum harvesting stage of the grass component. Grass growth from the traditional fallow was cut at a similar height and time as the *C. gayana*. Sub-samples from maize residue (including cob), forage crops and herbage biomass from traditional fallow, which had been dried in a forced draught oven at 65ºC to a constant weight, were used to determine fodder dry matter (DM) yield.

A simple economic assessment based on partial budget analyses was performed for each year separately to determine the annual nett return in Ethiopian currency (Birr) per hectare (ETB ha^{-1}) from the various cropping systems. Nett return (ETB ha^{-1}) was calculated by deducting the cost of fertiliser allocated for grain or forage production from the gross income due to the selling of maize grain (0.80ETB kg^{-1}) and estimated value of maize stover (0.158ETB kg^{-1}), grass (0.401ETB kg^{-1}) and legume forages (0.802ETB kg^{-1}). The percentage increase or loss in average nett return associated with undersowing of perennial forages or grass/legume mixtures in the maize, pure maize with fertiliser and traditional fallow, were calculated using pure maize, without fertiliser, as a benchmark.

The maize grain, stover, forage and total fodder DM data were analysed by ANOVA using the general linear model procedures of the statistical analysis system (SAS 2001). Significant differences between means were separated using Duncan's multiple range tests.

Results and discussion

Effect of forage undersowing on maize production (Year 1)

In Table 1, the effects of forage undersowing in maize on the first-year maize grain and stover yields are shown. The differences between grain yield of fertilised pure maize and maize undersown with cultivated forages in the first year of the study were not significant ($p > 0.05$). This result contradicts previous findings, where integrating cultivated forages into the cropping system was shown to reduce the grain yield of the companion cereal crops (Shelton and Humphreys 1975, Mohamed-Saleem 1985, Chamberlin *et al*. 1986, Nnadi and Haque 1988). The depressing effects of the associated forages on the main crop in this study may have been reduced by the delayed planting date of the forage (Hassen *et al*. 2006). The appreciable grain yield advantage ($p < 0.05$) of fertilised pure maize cropping (43.1%) or maize/forage associations (12.6–45.8%) over the unfertilised pure maize cropping emphasised the need for greater attention to be paid to soil fertility.

Undersowing of forages in maize also did not affect ($p > 0.05$) maize stover DM yields. The forage DM yields of the undersown plots were similar ($p > 0.05$) during the establishment year. The combined fodder (forage plus maize stover) yields from most cultivated forage undersown plots, however, exceeded forage yields from traditional fallow or stover yield from unfertilised or fertilised pure maize culture ($p < 0.001$). The improved availability of fodder as a result of integrating cultivated forages into the cereal cropping system has also been reported elsewhere (Shelton and Humphreys 1975, Mohamed-Saleem 1985, Nnadi and Haque 1988, Kouane et al. 1993, Hassen et al. 2006).

Maize production during the subsequent seasons (years 2 and 3)

In the second and third years of the experiment it was only the two pure maize treatments (with vs. without fertiliser) plots that were planted with maize. In the same period, the traditional fallow and the forage undersown plots were only assessed in terms of forage production. During this period, the fertilised pure maize plots produced 56% and 54.2% more grain yield over the unfertilised counterpart during years 2 and 3, respectively (Table 2). Stover yields were significantly higher ($p < 0.05$) in the fertilised pure maize plots than in the unfertilised counterparts in year 2, but not significantly different in year 3. Considering the inherent low fertility status of the soils and high nutrient demand of the maize crop, the observed yield margin between fertilised and unfertilised plots was as expected. The financial return was increased by an average of 36.7% due to fertiliser application compared to its unfertilised counterparts (Table 3).

Forage production during fallow period (Year 2 and 3)

In the mixed farming area of Bako, crop production is as much dependent on livestock, for draft power and manure, as livestock is dependent on crops, for crop residues. The productivity of livestock is, however, constrained by the low supply of quality feed (Dadi *et al*. 1987). Growing cultivated forages, in association with food crops, can contribute to the improvement of the qualitative and quantitative supply of livestock feed. Farm income during the pasture phase can thus be sustained by improved livestock nutrition and production. In the second season, the re-growth of undersown cultivated forages was higher than 8t ha^{-1} DM (Table 4). For the undersown forages herbage production peaked in the second year and fell sharply in the third year (Table 4). Deterioration of DM yield was particularly pronounced in the pure *M. axillare* and *C. gayana/M. axillare* mixture. Similar DM production trends have been documented previously, where these species were grown as pure stands and grass/legume mixtures (Gizachew and Tadesse 1993). The total forage DM yield during the improved fallow period was the highest for *C. gayana/M. axillare* mixture and *C. gayana* improved fallow in year 2 and year 3, respectively. The lowest DM yield was recorded in both years for the natural pasture of the traditional fallow ($p < 0.05$).

The average forage DM yield for grass/legume mixtures exceeded DM yield from pure legume stands (Table 4). However, the overall nett return (ETB ha^{-1}) was higher in pure legume improved fallow than the grass legume mixtures (Table 3). Being high in CP, herbage from high-producing pure legumes (*D. intortum* and *S. hamata*) may, however, supply more nutritious feed per unit area of land than herbages from pure *C. gayana* or grass/legume mixtures (Hassen *et al*. 1995). Among the grass/legume mixtures, the contribution of the legumes towards the total biomass varied between the legume species. The highest DM contribution to total DM was made by *D. intortum* (Table 4). The overall nett return from *D. intortum* improved fallow and its grass/legume mixture were the highest followed by *S. hamata* improved fallow and fertilised pure maize (Table 3). The proportion of legumes in the total available DM biomass can also affect the N contribution of forage legumes to the soil system.

Effects of improved fallow on grain and stover yields (Year 4)

Higher grain yields were obtained from pure maize plots which had been fertilised throughout the study, and from those plots kept under *D. intortum* ($p < 0.01$) for the preceding three years. This result suggests that the N returned to the soil through symbiotic N-fixation and mineralisation of leaf dropping from *D. intortum* can be comparable to a similar level applied to the maize crop (75kg N ha^{-1}). For

Table 2: Maize grain and stover production from pure maize plots with or without fertiliser during the subsequent seasons (year 2 and 3)

Fallow types	Grain yield (kg ha^{-1})		Stover yield (kg ha^{-1})	
	Year 2	Year 3	Year 2	Year 3
Pure maize without fertiliser	3758^{b}	3850^{b}	5400^{b}	6700
Pure maize with fertiliser	5860^{a}	5935^{a}	8360^{a}	9210
CV (%)	5.85	13.70	4.62	18.1
p	0.0018	0.0218	0.001	ns

[1] Means in the same column followed by different superscripts differ ($p < 0.05$)

Table 3: Nett estimated financial return (ETB ha^{-1}) from the various cropping systems and additional profit or loss (%) as compared to pure maize without fertiliser

Type of fallow	Nett return (ETB/ha^{-1})*					
	Year 1	Year 2	Year 3	Year 4	Average	Percentage increase or loss in average nett return compared to pure maize without fertiliser
Traditional fallow	1 275.18	2 061.14	1 936.83	4 666.20	2 484.84	43.43
Maize without fertiliser	5 449.68	3 859.60	4 138.60	4 121.02	4 392.23	0.00
Maize with fertiliser	6 831.71	5 402.79	5 597.09	6 176.01	6 001.90	36.65
C. gayana fallow	7 150.89	4 654.23	4 469.77	4 044.80	5 079.92	15.66
S. hamata fallow	8 844.19	7 449.84	4 848.23	5 895.92	6 759.55	53.90
D. intortum fallow	8 605.37	6 887.80	5 052.42	7 279.26	6 956.21	58.38
M. axillare fallow	9 153.07	5 149.06	2 818.39	5 106.88	5 556.85	26.52
C. gayana/*S. hamata* fallow	7 238.88	5 840.57	3 943.55	4 874.70	5 474.42	24.64
C. gayana/*D. intortum* fallow	7 604.78	7 511.15	5 719.74	5 485.46	6 580.28	49.82
C. gayana/*M. axillare* fallow	6 951.87	6 121.27	2 935.61	4 483.22	5 122.99	16.64

Return from sale of maize grain is calculated using 0.80 ETB kg^{-1}; for maize stover, grass and legume forage, it is estimated using 0.158 ETB kg^{-1}, 0.401 ETB kg^{-1} and 0.802 ETB kg^{-1}, respectively ($US1 = 8.5–8.6 ETB); cost of fertiliser calculated using 200 ETB 100kg^{-1} for urea and 250 ETB 100kg^{-1} for DAP

Caribbean stylo, for instance, it has been estimated that a stand, under short and long fallow, could provide the following sorghum crop with the equivalent of 15–85 N kg ha^{-1} (Jones *et al.* 1991). Positive effects of forage legumes on cereal crop yields have also been reported in similar studies conducted in sub-Saharan Africa and Australia (Vallis and Gardener 1984, Mohamed-Saleem and Otsyina 1986, Tarawali 1991, Hassen *et al.* 2006). The grain yield following the improved fallows of *C. gayana*, *M. axillare* and grass/legume mixtures as well as the traditional fallow were however, unsatisfactory (Table 5). The overall nett return was lower than fertilised pure maize throughout the study, but far better than the nett return derived from the traditional fallow.

Stover DM yield from continuously fertilised pure maize and forage legume undersown plots were superior ($p < 0.01$). As verified by stover DM yield, the *C. gayana*, grass/legume mixtures and traditional fallows were no better than plots grown to pure maize without fertilisation (Table 5). These fallow systems were thus less effective in restoring soil fertility within a short period of time. In general, the inferior maize and stover production from *C. gayana* and *C. gayana*/legume mixtures may be related to a high nutrient uptake of *C. gayana* as well as the inability of the grass to fix nitrogen. Gomez (1976) has indicated that at an annual DM production of 10t ha^{-1}, tropical grasses can extract 100kg N ha^{-1} year^{-1} from the soil.

Effect of improved fallow on soil parameters (Year 4)

Changes in soil chemical properties as a result of improved fallow are shown in Table 6. Since the soil analysis for each treatment was based on a single composite sample, it was not subject to statistical analysis. The interpretations of the soil parameters should thus be viewed with caution.

Over the duration of the study, soil pH generally tended to decrease with continuous maize or maize/forage production. The decrease in pH was greatest on pure maize and *C. gayana* plots. The slightly higher soil pH in legume undersown plots may be related to the relatively higher levels of the exchangeable cations, which were possibly contributed by the leaf fall from the legumes. The higher CEC values of the legume fallows correspond with the higher levels of the exchangeable cations. On the other hand, the OM build-up may be due to a higher root and above-ground biomass production of *C. gayana* fallow, which was higher than the remaining improved fallow and traditional fallow plots. Root biomass was not measured in

Table 4: Forage DM production of improved and traditional fallow during post-establishment years

Fallow types	Forage yield (kg ha^{-1})*			
	Year 2		Year 3	
Traditional fallow	5 140^{d}		4 830^{d}	
C. gayana fallow	12 230^{b}		11 770^{a}	
S. hamata fallow	10 830^{b}	(77.7)	7 710^{bc}	(51.1)
D. intortum fallow	8 900^{c}	(100)	7 000^{c}	(78.1)
M .axillare fallow	8 160^{c}	(64.1)	4 880^{d}	(8.4)
C. gayana/S. hamata fallow	12 470^{b}	(21.7)	8 840^{b}	(14.8)
C. gayana/D. intortum fallow	11 220^{b}	(72.4)	9 820^{b}	(31.3)
C. gayana/M. axillare fallow	14 510^{a}	(9.6)	6 890^{c}	(21.2)
CV (%)	16.91		14.08	
p	0.0001		0.0001	

[1] Means in the same column followed by different superscripts differ ($p < 0.05$).

* Values within parenthesis indicate per cent legume contribution

Table 5: Maize grain and stover yield at termination of fallow (Year 4)

Type of fallow	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
Traditional fallow	4 470de	6 900^{c}
Maize without fertiliser	3 830^{e}	6 690^{c}
Maize with fertiliser	6 710^{ab}	8 950^{ab}
C. gayana fallow	3 950^{e}	5 600^{c}
S. hamata fallow	5 940^{bc}	7 240^{bc}
D. intortum fallow	7 130^{a}	9 970^{a}
M. axillare fallow	4 930^{cde}	7 360^{bc}
C. gayana/S. hamata fallow	4 780^{cde}	6 650^{c}
C. gayana/D. intortum fallow	5 500^{cd}	6 870^{c}
C. gayana/M. axillare fallow	4 500d^{e}	5 590^{c}
CV (%)	14.31	16.35
p	0.0001	0.0003

[1] Means in the same column followed by different superscripts differ ($p < 0.05$)

Table 6: Effect of improved fallow on chemical properties of soil

Type of fallow	pH (H_2O)	Exchangeable cations (meq 100g^{-1} soil)				CEC (meq 100g^{-1} soil)	OM (%)	Total N (%)	Available P (ppm)
		Na	K	Ca	Mg				
Beginning fallow (Year 1)	5.62	0.27	0.68	6.99	1.17	13.8	3.41	0.14	1.82
Traditional fallow	5.55	0.19	0.33	7.98	2.08	23.0	4.74	0.18	1.46
Maize with fertiliser	5.05	0.19	0.38	8.98	1.95	20.6	3.62	0.15	9.04
Maize without fertiliser	5.13	0.19	0.49	7.49	1.17	16.2	3.28	0.15	2.90
C. gayana fallow	5.10	0.27	0.43	6.49	1.17	14.0	5.19	0.14	8.14
S. hamata fallow	5.41	0.31	0.65	8.98	2.00	24.0	4.64	0.18	4.56
D. intortum fallow	5.77	0.27	0.60	9.98	2.25	22.6	4.29	0.18	6.04
M. axillare fallow	5.40	0.23	0.58	9.48	2.00	25.6	2.93	0.21	2.48
C. gayana/S. hamata fallow	5.38	0.23	0.60	8.48	1.75	21.2	4.70	0.20	3.88
C. gayana/D. intortum fallow	5.26	0.23	0.60	7.49	1.42	20.2	4.19	0.17	2.58
C. gayana/M. axillare fallow	5.42	0.23	0.49	7.98	1.58	16.4	3.76	0.18	3.30

the present study, but in some tropical grass species it has been shown to constitute 53–76% of the total biomass (Kanno *et al.* 1999). The amount of total N in the traditional and improved (except *C. gayana*) fallows exceeded those values under continuous pure maize production. Compared to the beginning of the fallow period, the level of available P tended to increase slightly after the two years of improved fallow. In all the tested soil samples the level of available P (Table 6) was, however, still far below the suggested critical value of 10ppm (Cottenie 1980). This low available P particularly affects the efficiency of N-fixing symbiotic bacteria and the host legumes productivity. In general, most of the measured soil parameters were higher on plots undersown with legumes. Similar improvements in soil fertility following forage legume fallow, have been reported from studies conducted in West Africa and Australia (Vallis and Gardener 1984, Mohamed-Saleem and Otsyina 1986, Mulongoy and Kang 1986, Jones et al. 1991, Tarawali 1991, Tarawali and Ikwuegbu 1993).

Conclusions

D. intortum and *S. hamata* appear more suitable for undersowing in maize grown in this sub-humid environment. The overall nett return from *D. intortum* improved fallow and its grass/legume mixture was the highest followed by *S. hamata* improved fallow and pure maize fertilised throughout the study period. The other cultivated forages can also safely be established by undersowing, but were only as effective as the traditional fallow in restoring soil fertility. Apart from simultaneously alleviating the feed shortage and soil fertility problems, establishing cultivated forages, notably *D. intortum*, *C. gayana*/*D. intortum* mixture and *S. hamata* forages, using the undersowing technique, would optimise the use of farm labour, land and other input costs.

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