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Effect of soil fertility on the establishment of improved grass and legume species grown in fallows in Chivi district, Zimbabwe

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A pot experiment was conducted to investigate the effect of soil fertility on the establishment of two improved grasses (*Pennisetum purpureum* and *Cynodon nlemfluensis*) and two legumes (*Desmodium uncinatum* and *Neonotonia wightii*) in soils collected from different fallow periods [0 to 2, 3 to 5, 6 to 10, 11 to 20 years and uncultivated field (control)] in Chivi district in south central Zimbabwe. Five soil samples per fallow period were characterized for soil fertility in terms of mineral Nitrogen (N), Potassium (K), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Sodium (Na), pH and soil texture. A four by five factorial design replicated three times was used to assess the establishment of legumes as measured by percent emergence of legume seeds and grass species as measured by survivability of the grass cuttings at 4 weeks. The data was analyzed using a general linear model (GLM). Overall soil fertility was low. There was no significant difference (P > 0.05) across all the fallow periods. The rate of establishment of the grasses and legumes was not significantly different (P > 0.05) across fallow periods. There were, however, significant differences between species (P < 0.05). A 100% establishment was recorded for grasses, and 67.33 and 50.33% for *D uncinatum* and *N wightii*, respectively. The good establishment potential of both improved grasses and legumes indicated that this could be a viable way of improving the productivity of fallows in Chivi district and in similar areas in Zimbabwe.

Key words: Fallows, soil fertility, improved grasses, legumes, establishment.

INTRODUCTION

In Zimbabwean communal areas, which account for 70% of the national population, the quantity and quality of forage is a major constraint to livestock production, especially during the dry season (Mapiye et al., 2009; Tuwei et al., 2003; Van et al., 2005). Reinforcement with improved grass and legume species that provide high yields of good quality herbage, can improve livestock productivity in such rangelands. Range reinforcement technology has several advantages. It is a cheap alternative to commercial feeds, improves forage quality and can enhance soil fertility (Tarawali, 1999). In fallow lands, which are a growing phenomenon in Zimbabwean communal areas (Manzungu and Mtali, 2012), introduction of improved grasses and legumes can assist in fast restoration of the rangelands (Carsky et al., 2001a; Chikowo, 2004; Mapfumo et al., 2005; Mapiye et al., 2006a;

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Nyambati et al., 2010). Among the many improved grass species and forage legumes evaluated in semi-arid regions of Zimbabwe, bana grass (*Pennisetum purpureum* var Schumm), star grass (*Cynodon nlemfluensis* var Robustus), silverleaf desmodium (*Desmodium uncinatum)* and (*Neonotonia wightii*) have shown promise in terms of ease of establishment, drought tolerance and yield (Mhere et al., 2002, Mapiye et al., 2006a; Mapiye et al., 2006b; Clatworthy et al., 1986). However, Carsky et al. (2001b) suggested that merely introducing improved forages into fallows or rangelands is not sufficient where soil fertility is limiting. Nutrient status, pH, and texture have been found to affect the establishment of legumes (Hague et al., 2008). This makes the challenge of reinforcing fallows in Zimbabwean communal areas, as they are characterized by low soil fertility (Chikowo, 2004).

Apart from affecting plant establishment, soil fertility also affects growth (plant height, leaf count and tiller count) as well as biomass production (Tena and Beyene, 2011). Many studies on veld reinforcement in Zimbabwe have paid little attention to the possible effect of soil fertility on plant establishment. The vast majority of studies have concentrated on how rainfall availability affects plant establishment and subsequent growth. The objective of the study was to investigate the effect of soil fertility on the establishment of two improved grass species (*P. purpureum* and *C. nlemfluensis*) and two legume species (*D. uncinatum* and *N. wightii*) grown in soils collected from different fallow periods (0 to 2, 3 to 5, 6 to 10, 11 to 20 years and uncultivated soil) in Chivi district. The study hypothesized that differences in fallow period in Chivi district resulted in differences in levels of soil fertility, which in turn affected plant establishment as measured by percentage emergence of legume seeds and survivability of grass cuttings.

MATERIALS AND METHODS

Site description

The study was conducted in Chivi district, Ward 28 which is located in south central Zimbabwe. The district extends from 20° 14' S to 20° 24' S and lies between 30° 13' E and 30° 57' E. The area receives low and unreliable rainfall ranging from 450 to 600 mm per annum (Mapanda and Mavengahama, 2011; Nemarundwe and Kozanayi, 2003), which makes the area less suitable for crop production. Major soil types are derived from coarse-grained granite and include the chromic luvisols, ferric luvisols and eutric regosols (Anderson and Ingram, 1993).

Experimental procedure

An open environment pot experiment was set up to evaluate the establishment potential of improved grasses and legumes in Chivi soils under optimal moisture conditions achieved by irrigation. Soil moisture was maintained at near field capacity through regular watering. Two legumes (*N. wightii* and *D. uncinatum*) and two grass species (*P. purpureum*) commonly known as Bana grass, and *C. nlemfluensis* (commonly known as Star grass No. 2) were planted in plastic pots (118 × 110 mm surface area). A four by five factorial design replicated three times was used. The main factors were plant species and soil from fields of different fallow periods [0 to 2, 3 to 5, 6 to 10, 11 to 20 years and uncultivated land (control)]. The soil to fill in the pots was taken to a depth of 20 cm depth from the five different fallow fields. Ten seeds of forage legumes were sown in each pot. Two cuttings per grass species were planted in the pots. *P. purpureum* (Bana grass) and *C. nlemfluensis* (Star grass) cuttings were collected from Makoholi Research Station, while *N. wightii* and *D. uncinatum* seeds were collected from Henderson Research Station. To improve germination, *N. wightii* legume seeds were scarified by immersing them in boiling water for a minute (Naveh, 1966).

Data collection

Soil analysis

Five soil samples per fallow period were randomly collected from the fields of different fallow periods (see experimental procedure). Soil was collected using a soil auger to a depth of 20 cm and placed into polythene bags. Samples were kept in incubators at low temperature, whilst in transit to the laboratory. This was followed by an analysis for pH, cation exchange capacity (CEC), 14 days mineral Nitrogen (mineral N), Calcium (Ca), Phosphorus (P), Sodium (Na), Potassium (K), Magnesium (Mg) as well as for the percentage sand, silt and clay components analysis.

Laboratory analysis was done at the Department of Soil Science and Agricultural Engineering at the University of Zimbabwe. Mineral N was determined as ammonium-N and nitrate-N (using Devardas alloy), analyzed after incubating the soil for 14 days at 32°C and extracting using acidified 1M KCl in 0.1M HCl. Colour was developed on the distillate using the Nessler reagent method. Reading was done using the Spectronic 20 at 460 nm. This method was based on a modification of total nitrogen method as prescribed by Anderson and Ingram (1993). Available phosphate was determined using diethylenetriaminepentacetic acid (DTPA) extractant as prescribed by Fresen (1990). Exchangeable bases (Ca, Mg, K, and Na) were determined using the atomic absorption spectrophotometer (AAS) after extracting with 1m ammonium acetate at pH 7.0 based on Summer and Miller (1996). pH was measured with a pH meter in a 1:5 soil: $CaCl_2$ suspension (Anderson and Ingrams, 1993). The relative proportion of sand, silt and clay in the soil from each treatment was determined using the *Bouyoucos* hydrometer method (Gee and Bauder, 1986). The soil texture triangle (Food and Agricultural Organisation, 1990) was used to determine the texture of the different soils.

Assessment of plant establishment

Plant establishment was assessed by comparing the germination percentage of the legume seeds and the survivability of the grass cuttings at 4 weeks. This is in line with the procedure recommended by Tarawali et al. (1995) for forage establishment in sub-Saharan Africa.

Statistical analysis

Soil fertility

Soil data were analyzed using one-way analysis of variance (ANOVA). This was calculated by using general linear model (GLM) procedures of Statistical Analysis Systems (SAS), 9th edition of (2004) edition. Confidence level was at 5%.

Table 1. Soil fertility status of soils collected from different fallow periods in Chivi district.

Soil component	N	Fallow period (years)					±SE
		0 - 2	3 - 5	6 - 10	11 - 20	Uncultivated	
pH ($CaCl_2$)	25	4.96	4.96	4.66	4.90	4.94	0.11
Ca mg eq/100 g	25	0.40	0.31	0.17	0.99	0.38	0.35
Mg mg eq/100 g	25	0.68	0.63	0.55	1.01	0.89	0.22
K mg eq/100 g	25	0.69	0.99	0.87	1.17	0.94	0.17
Na mg eq/100 g	25	0.01	0.01	0.02	0.03	0.03	0.007
CEC assuming (Ca, Mg, K, Na)	25	1.79	1.95	1.62	3.19	2.25	0.61
14 day mineral-N (ppm)	25	6.30	7.40	6.40	7.80	8.90	2.23
Phosphorus (ppm)	25	5.33	3.79	3.20	4.71	4.53	0.97
% sand	25	90.30	88.80	88.60	88.70	88.90	1.08
% silt	25	6.10	8.10	8.10	8.80	9.10	0.97
% clay	25	3.60	3.10	3.30	2.50	4.00	0.63

There were no significant differences ($P > 0.05$) among different fallow periods for all the soil parameters measured.

Percent plant establishment at 4 weeks

Plant establishment data were statistically analyzed using the GLM of SAS 9th edition of (2004). Confidence level was at 5%.

RESULTS

Soil fertility

Soils in fallows were found to be generally of very low fertility (Table 1). There were no significant differences (P > 0.05) in levels of the nutrients (mineral N, P, K, Ca, Mg, Na and CEC) across all the fallow treatments. Mineral N ranged from 6.3 to 8.90 parts per million (ppm), across all the fallow periods, while K mean values ranged from 0.69 to 1.67 mg eq/100 g. Available soil P ranged from 5.55 ppm in fallow period 0 to 2 years to mean estimates of 3.20 ppm observed in the 6 to 10 years fallow period. Available P levels in fallow periods; 0 to 2 years, the 11 to 20 years and the uncultivated field were very similar and generally high compared to levels observed in 3 to 5 and 6 to 10 years fallow periods. However, the observed differences were not significant. Ca ranged between 0.17 to 0.99 mg eq/100 g for soil from the different fallow periods, whilst Mg ranged between 0.55 and 1.01 mg eq/100 g. CEC mean values ranged from 1.62 to 2.25 in the 6 to 10 fallow period and uncultivated field (control) soil, respectively.

Soil pH mean values ranged from 4.66 to 4.94 and were not significantly different (P > 0.05) across fallow periods. Soil texture was not significantly different (P > 0.05) across all the fields. The soil was found to be composed of mainly sand ranging from 88.9 to 90.3%, followed by silt (6.10 to 9.10%) with clay component being the lowest (2.5 to 4%) across all fallow periods.

Plant establishment

There was interaction between length of the fallow period and species on plant establishment (Figure 1). *C. nlemfluensis* and *P. purpureum* which were vegetatively propagated, were established successfully at 4 weeks. There was 100% survivability across all five fallow periods (Figure 1). The establishment of *D. uncinatum* increased with increase in length of fallow period. *N. wightii* establishment was low across all fallow periods as shown in Figure 1.

Significant differences were observed on the establishment of different plant species (P < 0.05). The establishment of the grasses was similar and significantly higher than that observed in the legumes (Table 2). The establishment of the legumes differed significantly (P < 0.05) with emergence of 67.33 and 50.57% observed in *D. uncinatum* and *N. wightii*, respectively.

DISCUSSION

Percentage seed emergence and grass cuttings survivability indicate the probability of successful plant establishment in fallows (Tarawali et al., 1995; Jingura, 2000). The length of fallow had no effect on soil fertility and on grass establishment. The rate of plant establishment was comparable with the results reported by Jingura (2000). Seed and grass cuttings establishment were estimated at between 65 and 90% for *C. nlemfluensis, P. purpureum and D. Uncinatum.* The differences observed among *D. uncinatum* and *N. wightii* species in terms of percentage seed germination can be explained by the intrinsic properties of the seeds such as dormancy and integumental hardness (Mganga et al., 2010). Seed dormancy varies between species (Amodu et al., 2002) and is known to prevent successful establishment of new pastures. The relatively high percent seed germination of *D. uncinatum* (67.37%) may be explained by its dormancy mechanism which involves only the integument. *N. wightii* species have both the embryo and/or the integument related dormancy which is

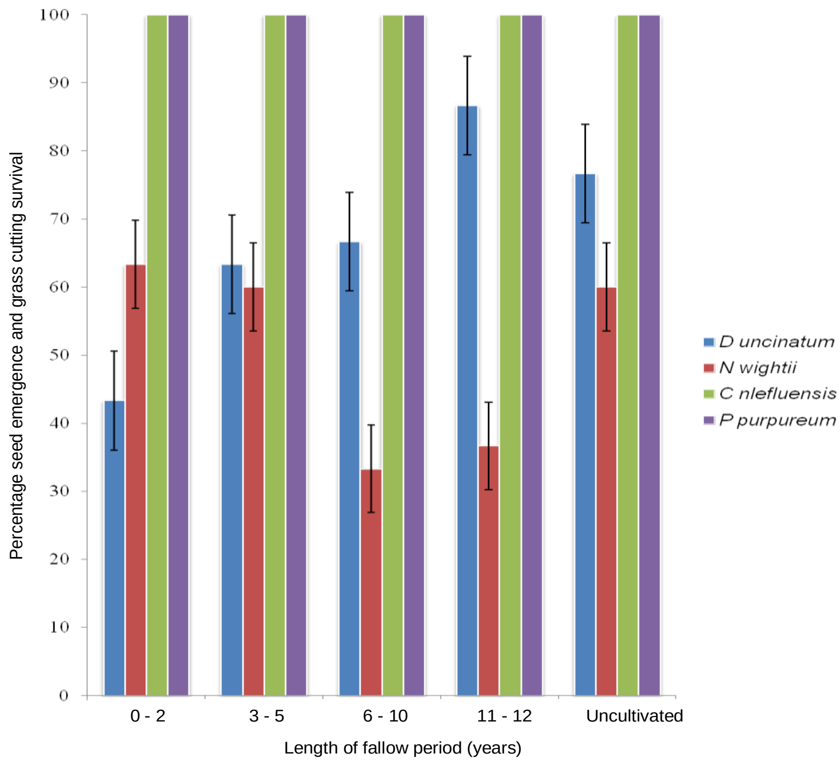

Figure 1. Plant establishment of improved grasses and legumes (% emergence and survivability) in different fallow period at 4 weeks post planting in Chivi district.

Table 2. Comparison of plant establishment of different plant species at 4 weeks after planting in fallow soils collected from Chivi district.

Plant species	Least square mean
D. uncinatum	67.33[b]
N. wightii	50.57[c]
C. nlemfluensis	100.00[a]
P. purpureum	100.00[a]

Means with different superscripts (a, b, c) differ significantly (*P*<0.05).

likely to have caused the low germination percentage in *N. wightii*.

Mnene (2006) noted that when forage seeds are viable, the main environmental factors that will stop forage seeds from germinating and establishing in the semi-arid rangelands are soil fertility provided water availability is optimum (Besma and Mounir, 2010). Survival of transplanted cuttings was higher than that of plants from direct seeding methods. The easy and successful establishment of the grasses that were vegetatively propagated was also due to adequate soil moisture since the pots were regularly watered. The requirement for adequate soil moisture in vegetative propagation is well documented (Jingura, 2000; Humphreys, 1994).

Rapid germination and early establishment of seedlings is very important as it contributes to the success of field plantings when other conditions such as moisture and temperature are optimum. Because the current experiment was carried out under inherent soil fertility without any addition of fertilizers, the results are very applicable to communal range management.

The inverse Ca to Mg ratio which was found in soils across all fallow periods with fallow 0 to 2 years and uncultivated showing a 0.37 to 0.63 and 0.28 to 0.72 Ca to Mg ratio, respectively, may negatively affect the establishment of forages. An inverse Ca to Mg ratio causes toxicity to the plants, which results in stunted plant growth (Flores et al., 2000). The low concentration of exchangeable bases like Ca, K, Na and Mg, and CEC which was observed across all fallow periods have also a negative impact on the establishment (Besma and Mounir, 2010) of forage species in Chivi district.

Conclusion

The results from this study indicate that *C. nlemfluensis* and *P. purpureum* have high establishment potential in fallow fields in Chivi district, which are characterized by soils of very low fertility. The legumes were shown to have relatively lower establishment potential in comparison to grasses. More research is needed to determine a wider range of species that can thrive under low fertility and with natural rainfall conditions.

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