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By Robert W. Taylor, Sidat Yaffa, David A. Mays , Teferi Tsegaye, Wubishet Tadesse & Karamat R. Sistani

Alabama A&M University, United States

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POULTRYLITTERAFFECTSFORAGEDRYMATTERYIELDANDTOTALNANDPUPTAKE

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Robert W. Taylor [α], Sidat Yaffa [σ], David A. Mays [ρ], Teferi Tsegaye [Ѡ], Wubishet Tadesse [¥] & Karamat R. Sistani [§]

Abstract- Forage crops play an important role in removing P and N from poultry litter-amended soils there byminimizing environmental pollution. A three year study was conducted at Crossville, AL to compare dry matter yield and total P and N removal efficiencies by forage crops from a poultry litter-amended soil. Forage crops including alfalfa (Medicago sativa, L.), rye (Secalecereale, L.), corn (Zea mays, L.), sorghum-sudangrass (Sorghum bicolor, L.) cv. Unigraze II, tall fescue (Festucaarundinacea, L.) cv. KY31, and Russell bermudagrass (Cynodondactylon, L.) were investigated. The soil type at the site was a Hartsells fine sandy loam (fine-loamy, siliceous, thermic TypicHapludults).The highest dry matter yield in 2001 was observed with sorghum-sudangrass and in 2002 and 2003 it was observed with Russell bermudagrass, respectively. In 2001, the lowest dry matter yield was observed with alfalfa, in 2002 it was observed with corn, and in 2003 it was observed with sorghum-sudangrass, alfalfa, and Russell bermudagrass, respectively. Sorghum-sudangrass showed the highest N uptake in 2001, alfalfa and Russell bermudagrass showed the highest N uptake in 2002 and 2003, respectively. Tall fescue showed the highest P uptake in the three-year study. Russell bermudagrass appears to be the most effective forage crop for removal of N and tall fescue for the removal of P from soils amended with poultry litter.

Keywords: N, P, PL, forage crop.

I. Introduction

The rapidly expanding poultry industry in the state of Alabama, now ranked third in the United States behind Georgia and Arkansas in terms of broiler chicken (Gallusgallus, L.) production, is geographically concentrated in several areas of the state (Alabama Agric. Statistics Serv., 2004). About 1.8 million tons of poultry litter (PL) is produced yearly in Alabama, creating a major waste disposal problem. The disposal of this large amount of litter is confined mainly to relatively small areas of perennial tall fescue (Festucaar-undinacea, Schreb) pastureland (Molnar and Wu, 1989). Several counties in the Sand Mountain region of Alabama account for approximately 43% of the state's total broiler production and generate nearly 0.7 million tons of litter annually (Alabama Agric. Statistics Serv., 2004; Payne and Donald, 1990). Indiscriminate use of PL may lead to harmful effects on the environment. The main problems that can arise from excessive PL application on the land are pollution of both ground and surface waters due to leaching and runoff of nutrients and soil accumulation of heavy metals (Payne and Donald, 1990). According to Blitzer and Sims (1988), excessive application of PL in some forage cropping systems has resulted in NO-3-N contamination of groundwater. High concentrations of total P in surface waters, largely resulting from surface runoff of sediment-loaded P, causes eutrophication (Schindler, 1977; Sharpley et al., 1996).

Pastures are common sites for poultry litter applied as fertilizer on forages used for cattle (Bostaurus) grazing or hay production in Alabama. Cattlegrazing removes relatively few nutrients from the farm throughmilk or meat production (Ball et al., 1991). Nutrient amountstaken up by plants are similar to nutrient amounts releasedfrom manure deposited back on the pasture by animals grazingthe plants. Mechanical removal of harvested forage crops from thefarm will reduce the buildup of nutrients in soils fertilizedwith PL. Forage crops have been traditionally fertilized withPL to meet the plant N requirements. But, PL appliedto meet plant N requirement contains more P than required bythe plant and P buildup in the soil will occur (Kingery et al., 1993 and Sharpley et al., 1998). In many counties of Alabama, P from PL meets or exceeds plant uptake (Potashand Phosphate Inst., 1998). The effect of this excess P on waterquality is becoming a major concern in Alabama (Sharpley et al., 1998).

Research on nutrient uptake from soils treated with PLhas considered relatively few forage crops. In most cases studieshave used a single crop or mixture of crops as a catchcrop while evaluating other treatment variables (Vervoort et al., 1998). A study reported by Honeycutt et al. (1998) showed that forage dry matter yield of bermudagrass [Cynodondactylon (L.) Pers.] tall fescue (FestucaarundinaceaSchreb.) and a tall fescue–red clover (Trifoliumpratense L.) – whiteclover (T. repens L.) mixture was increased with increasingrates of PL. It was reported that plant N and P uptake increased withrate of PL application on bluegrass (PoapratensisL.) – tall fescue and bermudagrass–tall fescue pastures (Lucero et al., 1995; Vervoort et al., 1998). Kingery et al. (1993) reported that long-term PLapplication on tall

Authors α σ ρ Ѡ ¥: Dept. of Plant and Soil Science, Alabama A&M University, P.O. Box 1208, Normal, Alabama 35762.
e-mails: syaffa@utg.edu.gm, ksidat@netscape.net
Author §: USDA/ARS Crop Science Research Laboratory, Waste Management and Forage Research Unit, Western Kentucky University, 1 Big Red Way, Bowling Green, KY 42101-3576. *Financial assistance provided through the USDA capacity building grant.*

fescue pastures increased plant N, P, andK concentration. There is a wide range of forage crops that are adapted for growth in the southeastern USA (Ball et al., 1991), but little is known about the nutrient uptake of these crop species under PL fertilization.

The objectives of this study were to (i) compare the dry matter yield of different forage crops and (ii) compare N and Puptake efficiencies of forage crops fertilized with PL.

II. Materials and Methods

a) *Field Methods*

The field experiment was initiated in September 1999 at Auburn University's Sand Mountain Research and Extension Center, which is located at Crossville, Alabama (latitude 34o 30' N and longitude 85o 50' W) on a Hartsells fine sandy loam (fine-loamy, siliceous, thermic TypicHapludults). The soil had been fertilized with PL at the rate of 5.6 Mg ha-1 yr-1 for 12 yrs. The soil test results in 1999 at 45 cm depth were: pH 5.8, P-215, K-465, Mg-263, and Ca- 1523 kg ha-1, respectively. Temperature and rainfall data were collected from the weather station at the research station. No supplemental irrigation was provided. The forage crops were Russell bermudagrass (Cynodondactylon, L.), sorghum-sudangrass (Sorghum bicolor, L.) cv. Unigraze II, alfalfa (Medicago sativa, L.), tall fescue (Festucaarundinacea, L.) cv. KY31, rye (Secalecereale. L.), and corn (Zea mays, L.). The fertilizer treatments were 0, 224, and 448 kg ha-1 P from triple superphosphate, which was applied at the beginning of the experiment in order to create a soil P variable. The experimental design was a randomized complete block design with four replications of 18 treatments per replication. The plot size was 2.1 m x 6 m with 3.6 m distance between tiers of plots.

The forages were planted thus: Tall fescue was planted in the fall with a no-till drill at 22.4 kg of seed ha-1, alfalfa was hand-planted on a tilled soil at 22.4 kg of seed ha-1 in the fall, corn was planted using a no-till drill in 90 cm rows at the rate of 62,000 plants ha-1, rye was planted by using a no-till drill at the rate of 22.4 kg of seed ha-1, bermudagrass was hand-planted by using sprigs at the rate of 134 kg of sprigs ha-1, and sorghum-sudangrass was planted by a no-till drill at the rate of 28 kg of seed ha-1. Forage was harvested by using a 1.5 m flail type plot harvester, weighed on an electronic scale, and sub-samples taken for dry matter determination. Tall fescue was harvested in mid-May, early July, and late October; alfalfa in May, June, July, and September; rye once in late April; corn once in August or September; sorghum-sudangrass and Russell bermudagrass three times at monthly intervals. The samples were finally dried in an oven at 49OC for 72 h, ground to pass a 2-mm sieve, and then used for chemical analysis.

Soil samples from the treatment plots were collected once at the beginning of the experiment with a hand-held auger from 0 to 100 cm depth, with 20 cm intervals as a baseline information on soil P and N. In successive years of the experiment, soil sampling was done with the same auger but only two depths (0 – 30 and 30 – 45 cm) were considered for soil P and N determination. The soils were collected at the beginning of and at the end of each growing season.

b) *Laboratory Analyses*

There were two analyses methods employed for extracting total N and P from both plant and soil samples: total P (Digestion first then Murphy – Riley Method, using a spectrophotometer (Spectronic 501&601 model by Milton Roy)) and total N (using Kjeldahl Method (Kjeltec Auto 2400 Analyzer)).

c) *Statistical Analyses*

Data for soil and plant parameters were analyzed statistically using the MIXED procedure of SAS (Little et al., 1996). Sources of variation included forage crop, P and N fertilization, date of sampling, and their interactions. The least square means test was used to determine the significant difference between the means when treatment interactions were significant. Correlation analysis was used to determine the relationship between forage crop dry matter yield, soil N and P, forage N and P uptake on mean values of 4 replications. Statistical significance was set at $P \leq 0.05$

III. Results and Discussion

a) *Climate*

The temperature and rainfall from 2001 to 2003 near the field study site are shown in Fig. 1a and Fig. 1b. The highest monthly temperature was observed in July of each year (21oC) and the lowest temperature was observed in January of each year (0 to -1oC) (Fig. 1a). The average monthly rainfall for January, 2002 and for April, 2003 were the highest for the study period (Fig. 1b). The lowest monthly rainfall was observed in October 2001 and 2002, respectively and in January 2003. Total rainfall was 128 cm for 2001, 125 cm for 2002, and 176 cm for 2003, respectively.

b) *Baseline Soil Total N and P (%)*

There was a significant difference in the amount of baseline soil total N (%) and total P (%) in 2001 as influenced by depth (Table 1). We found that as soil depthincreased, the amount of soil total N and P decreased significantly because P has been shown to be relatively immobile and because of accumulated organic matter from dead roots and other decayed plant parts is greater near the soilsurface. For example, we found that the amount of total N in the first 20 cm of the soil profile was more than twice what was found in the 80-100 cm depth. The first 20 cm depth of the soil had over three times as much total P as the 80-100 cm depth showing that P does not move much in the soil and accumulates in the surface layers. This finding agrees with the work of Holford (1997).

c) Total Annual Forage Dry Matter Yield (kg ha-1) in 3-yr

The highest annual forage dry matter yield over four replications in 2001 was observed with sorghum-sudangrass (8,000 kg ha-1) and the lowest yield was observed with alfalfa (2,000 kg ha-1) (Fig. 2). In 2002, the highest forage dry matter yield was observed with Russell bermudagrass (19,000 kg ha-1), and the lowest dry matter yield was observed with corn (4,000 kg ha-1). Finally, in 2003, the highest forage dry matter yield was observed with Russell bermudagrass (13,000 kg ha-1) and the lowest dry matter yield was observed under sorghum-sudangrass (3,000 kg ha-1), alfalfa (3,000 kg ha-1), and rye (5,000 kg ha-1), respectively. Except for corn, which had a poor stand, all the other crops had the highest dry matter yield in the second year of the study. There was a significant difference in forage dry matter yield between Russell bermudagrass and the rest of the crops in 2002 and 2003 (Fig. 2). In 2002, Russell bermudagrass total dry matter yield (19,000 kg ha-1) was 47% more than sorghum-sudangrass and tall fescue (10,000 kg ha-1, respectively), 53% more than alfalfa (9,000 kg ha-1), 79% more than corn (4,000 kg ha-1), and 66% more than rye (6,500 kg ha-1) (Fig. 2). In 2003, the same Russell bermudagrass total dry matter yield (13,000 kg ha-1) was 69% more than sorghum-sudangrass and alfalfa (4,000 kg ha-1, respectively), 38% more than tall fescue (8,000 kg ha-1), 15% more than corn (11,000 kg ha-1), and 62% more than rye (5,000 kg ha-1) (Fig. 2). There was no significant difference in forage dry matter yield between sorghum-sudangrass, tall fescue, and alfalfa in 2002. Corn (4,000 kg ha-1) in 2002 and alfalfa (4,000 kg ha-1) and sorghum-sudangrass (4,000 kg ha-1) in 2003 produced the least amount of forage dry matter yield. This was because in 2003 most of the forage crops had already reached their maturity stage of growth and therefore absorbed less nutrients and moisture from the soil and/or the soil was depleted of nutrients to support more forage growth.

d) Total Forage Dry Matter Yield (kg ha-1) in 3-yr

The total forage dry matter yield for the experiment was as follows: Russell bermudagrass had the highest total dry matter yield (37,880 kg ha-1) and rye (11,378 kg ha-1) for 2 yrs only) was the lowest (Fig. 3). Total dry matter yield for Russell bermudagrass was significantly higher than the rest of the forage crops. There was no significant difference in total dry matter yield between sorghum-sudangrass (20, 793 kg ha-1) and tall fescue (23,182 kg ha-1) and between alfalfa (14,448 kg ha-1), corn (12,880 kg ha-1), and rye (11,378 kg ha-1), respectively (Fig. 3). Growing rye and sorghum-sudangrass as winter and summer crops on the same plots produced the second highest total dry matter yield per year. Total Russell bermudagrass yield was 45% more than sorghum-sudangrass, 39% more than tall fescue, 62% more than alfalfa, 66% more than corn, 70% more than rye, and 15% more than rye and sorghum-sudangrass together. This shows that Russell bermudagrass has a high potential for being used as a suitable forage crop for dry matter yield purposes.

e) Total Forage N and P Uptake (kg ha-1) from 2001 – 2003

Total N uptake (kg ha-1) for each forage crop in each year over average of all P rates were measured (Table 2). In 2001, we found a significant difference in total N uptake between sorghum-sudangrass and the other forage crops. This could probably be due to the quick establishment of sorghum-sudangrass than the other forage crops. There was no significant difference in total N uptake between Russelbermudagrass, tall fescue, and alfalfa in 2001 (Table 2). Total N uptake could not be measured for corn and rye because the two forage crops were a replacement for eastern gamagrass (Tripsacumdactyloides, L) and triticale (Triticale hexaploide, Lart), respectively, in years 2 and 3. In 2002, alfalfa exhibited the highest total N uptake (340 kg ha-1) and corn the lowest (18 kg ha-1) (Table 2). Alfalfa is a nitrogen-fixing crop and that could be the reason for its high N uptake than the rest of the forage crops in 2002. There was a significant difference in total N uptake between alfalfa and the rest of the forage crops (Table 2). Overall, there was a significant difference in total N uptake between all the forage crops in 2002. In 2003, tall fescue showed the highest total N uptake (182 kg ha-1), which was significantly different from the rest of the other forage crops, and sorghum-sudangrass showed the lowest total N uptake (20 kg ha-1) (Table 2). We found no significant difference in total N uptake between sorghum-sudangrass and corn and between corn and rye in 2003 (Table 2). Except for sorghum-sudangrass, total N uptake was lower for all forage crops in 2001 than in 2002 and 2003. This is probably because the crops were not fully established in 2001 and they yielded less than in later years and therefore took up less N. Across all forage crops, total N uptake was highest in 2002 than in 2001 and 2003 (Table 2). This was probably because the crops had established vigorous root systems in 2002 than other years and therefore they were able to uptake most N.

We found no significant difference in total P uptake between Russell bermudagrass and sorghum-sudangrass in 2001 (Table 3). Total P uptake was not measured for corn and rye because they were not planted in 2001 as for the same reason explained under total N uptake. There was no significant difference in total P uptake between Russell bermudagrass, sorghum-sudangrass, and tall fescue in 2002. Corn, on the other hand, showed the lowest total P uptake in

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2002 (Table 3). The highest total P uptake in 2003 was exhibited by tall fescue (29 kg ha-1), which was significantly different from the rest of the forage crops. Also, there was no significant difference in total P uptake between Russell bermudagrass and alfalfa and between corn and rye (Table 3). For all forage crops except for corn, total P uptake was higher in 2002 than in 2001 and 2003, respectively (Table 3). This was due to all the crops except corn yielding more forage in 2002 than in 2001 and 2003. Tall fescue was the only crop that maintained a somewhat consistent total P uptake from 2001 to 2003. This suggests that tall fescue could be used as a suitable forage crop for total P removal from soils amended with excess poultry litter.

IV. Residual Total Soil N and P in Percentage

Residual total soil N (%) and P (%) were measured for two years (2002 and 2003). The level of soil N and P (%) at 0-30 cm and 30-45 cm depth was determined. Except P treatment, depth*P treatment, and P treatment*year, we found that depth, crop, year, depth*crop, and crop*year interactions were significant at $P \leq 0.05$ for soil N. (Table 4). The soil samples were collected after each forage harvest in 2002 and 2003 to determine how much N and P were left in the soil as residual N and P. There was a decrease in N (54%) between 0-30 cm and 30-45 cm depths in both years (Fig. 4). We found more N in the 0-30 cm depth (0.11%) than in the 30-45 cm depth (0.05%) (Fig. 4). Another reason for this difference in soil N could be that the 0-30 cm depth had much more living and dead-decomposing plant roots than the 30-45 cm depth. This was probably due to the accumulation of foliage on the soil surface from the previous 2-yr and followed by the slow mineralization of PL that was applied to the soil surface. Also most roots are found in the top 30 cm of the soil. This finding is similar to work done by Sistani et al. (2004), who studied soil nutrient dynamics in Bowling Green, KY. and found that total N content for 0-5 and 5-10 cm soil depths was 1.50 and 0.50 g kg-1, respectively, in January 2000. They concluded that high N concentration in the soil surface was due to surface application of broiler litter without any incorporation. Nitrogen leaching in the NO-3-N form is a known research fact. However, total N in this study includes both organic and inorganic N that is found in both fresh and decomposed organic matter which does not leach much. Thus, total N would be expected to be higher at the soil surface.

Soil N under various summer growing forage plots ranged from 0.06% to 0.08% as follows: alfalfa (0.08%), tall fescue (0.06%), Russell bermudagrass (0.07%), sorghum-sudangrass (0.07%), corn (0.06%), and rye (0.13%) (Fig. 5). Soil under rye had the highest residual N concentration (0.13%) and was significantly different from the rest of the forage crops (Fig. 5). This could mean that rye removed less N from the soil. The ability of a forage crop to remove more N from the soil depends on the crop species, the maturity of the crop when harvested and the amount of N supply in the soil. For example, compared to tall fescue, soil under rye had about 42% more residual N at the end of the study. There was no significant difference in soil N under alfalfa (0.08%), bermudagrass (0.07%), and sorghum-sudangrass (0.07%). Finally, soil N under bermudagrass, sorghum-sudangrass, corn, and tall fescue were not significantly different although bermudagrass had the highest residual soil N. In soils under grasses, N concentration is determined by plant uptake, NO3--N leaching and also depends on the amount of available N in the soil. In soils under legumes like alfalfa, the amount of N concentration also depends on the amount of N in the soil. However, fixation of N in legume nodules provides the rest of the N needed, resulting in soils under legumes having a more constant N supply regardless of soil N availability. It is important to note that total N measurements cannot be used as an index of N movement because N movement is determined by measuring NO-3-N. So, there could have been leaching of N as NO-3-N(Tsegaye et al., 2002; Boggs et al., 2001). The year 2002 had about 22% more N (0.09%) in the soil as residual N than in 2003 (0.07%) (Fig. 6). This could be due to slow mineralization or immobilization of N from accumulated foliage on the soil surface in 2002 than in 2003, N leaching due to greater rainfall in 2003 than in 2002 (Fig. 1b), or N loss due to volatilization .

Depth, crop, and crop*year interactions were the only significant variables for residual total soil P (Table 4). The P treatment applied at the beginning of the study to create a P variable did not have a significant effect on soil N (data not shown). This suggests that inorganic P application to a soil that already has received PL over years will not have any significant effect on soil N. There was no significant difference in residual soil P at 0-30 cm depth (0.02%) and at 30-45 cm depth (0.01%) for the 2-yr study (Fig. 6). This was due to lack of downward movement of P in the 30-45 cm depth. Holford (1997) reported that slow mobility of P in many agricultural soils is necessary to ensure plant productivity. The recovery of applied P by crop plants in a growing season is very low, because in the soil more than 80% of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form. There was no significant difference in residual soil P between rye (0.02%) and sorghum sudangrass (0.02%); between sorghum-sudangrass (0.02%) and tall fescue (0.02%); and between tall fescue (0.02%), alfalfa (0.02%), Russell bermudagrass (0.01%), and corn (0.01%) (Fig. 5). This suggests that rye and sorghum-sudangrass are less efficient at P removal from the soil compared to the rest of the forages in the study. Over half of residual total P under tall fescue, alfalfa, Russell bermudagrass, and corn combined is found under ryegrass and sorghum-sudangrass (Fig. 5). Residual P in 2002 (0.02%) and 2003 (0.02%) were not significantly different (Fig. 6). This is because P does not leach well unless soil is very porous, low in CEC, and low in specific surface area.

V. Conclusion and Recommendations

As soil depthincreased, itwasfoundthat the amount of soil total N and P decreased significantly because P has been shown to be relatively immobile and because of accumulated organic matter from dead roots and other decayed plant parts is greater near the soil surface. The highest annual forage dry matter yield over four replications in 2001 was observed with sorghum-sudangrass (8,000 kg ha-1) and the lowest yield was observed with alfalfa (2,000 kg ha-1). In 2002, the highest forage dry matter yield was observed with Russell bermudagrass (19,000 kg ha-1), and the lowest dry matter yield was observed with corn (4,000 kg ha-1). Finally, in 2003, the highest forage dry matter yield was observed with Russell bermudagrass (13,000 kg ha-1) and the lowest dry matter yield was observed under sorghum-sudangrass (3,000 kg ha-1), alfalfa (3,000 kg ha-1), and rye (5,000 kg ha-1), respectively. Except for corn, which had a poor stand, all the other crops had the highest dry matter yield in the second year of the study.

There was no significant difference in total dry matter yield between sorghum-sudangrass (20, 793 kg ha-1) and tall fescue (23,182 kg ha-1) and between alfalfa (14,448 kg ha-1), corn (12,880 kg ha-1), and rye (11,378 kg ha-1), respectively. In 2001, a significant difference in total N uptakewasfound between sorghum-sudangrass and the other forage crops. This could probably be due to the quick establishment of sorghum-sudangrass than the other forage crops.

There was no significant difference in total P uptake between Russell bermudagrass and sorghum-sudangrass in 2001. There was no significant difference in total P uptake between Russell bermudagrass, sorghum-sudangrass, and tall fescue in 2002. Corn, on the other hand, showed the lowest total P uptake in 2002. The highest total P uptake in 2003 was exhibited by tall fescue (29 kg ha-1), which was significantly different from the rest of the forage crops.For all forage crops except for corn, total P uptake was higher in 2002 than in 2001 and 2003, respectively. This was due to all the crops except corn yielding more forage in 2002 than in 2001 and 2003. Tall fescue was the only crop that maintained a somewhat consistent total P uptake from 2001 to 2003.

There was a decrease in N (54%) between 0-30 cm and 30-45 cm depthsin 2002 and 2003. More Nwasfound in the 0-30 cm depth (0.11%) than in the 30-45 cm depth (0.05%). A reason for this difference in soil N could be that the 0-30 cm depth had much more living and dead-decomposing plant roots than the 30-45 cm depth. This was probably due to the accumulation of foliage on the soil surfacefrom the previous 2-yr followed by the slow mineralization of PL that was applied to the soil surface.

The following are the recommendations suggested by the researchers.

(a) In order to harvest the largestamount of forage crop for livestockconsumption or for someother use, Russel bermudagrassis the best choice forage crop to grow.
(b) To remediate an excessively PL-amendedsoilthrough N uptake, sorghumsudan-grasscould serve as a better forage cropbecauseitquicklyestablishesthanmany forage crops for the samepurpose.
(c) Tall fescue grass is the most suitable forage crop for total P removal from soils amended with excess poultry litter.

VI. Acknowlegements

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Table 1 : Baseline soil total N (%) and total P (%) as influenced by depth in 2001.

Depth(cm)	N(%)	P(%)
0-20	0.17a	0.03a
20-40	0.14b	0.02b
40-60	0.12c	0.01c
60-80	0.09d	0.008d
80-100	0.08e	0.008d

Means with the same letter are not significantly different at P ≤ 0.05

Table 2 : Total forage N uptake (kg ha-1) over average of all P rates (kg ha-1) from 2001-2003.

	N Uptake (kg ha^{-1})		
	2001	2002	2003
Crop			
RB	62b	274b	153b
SS	106a	82d	20e
T	56b	203c	182a
A	50b	340a	126c
C	-	18e	56de
R	-	45de	79d

N uptake with the same letter are not significantly different at P≤0.05

RB: Russell bermudagrass *SS:* Sorghum-sudangrass *T:* Tall fescue

A: Alfalfa *C:* Corn *R:* Rye

Table 3 : Total forage P uptake (kg ha-1) over average of all P rates (kg ha-1) from 2001-2003.

	P Uptake (kg ha^{-1})		
Crop	2001	2002	2003
RB	11a	37a	14b
SS	15a	37a	8bc
T	8b	29a	29a
A	5b	17b	12b
C	-	7c	9bc
R	-	13b	5c

N uptake with the same letter are not significantly different at P≤0.05

RB: Russell bermudagrass *SS:* Sorghum-sudangrass *T:* Tall fescue

A: Alfalfa *C:* Corn *R:* Rye

Table 4 : Analysis of Variance of residual soil total N and P concentrations (%) in 2002 and 2003

Source	N	P
Depth	***	***
Crop	***	***
P Treatment	NS	***
Year	***	NS
Depth*Crop	***	NS
Depth*P Treatment	NS	NS
Depth*Year	*	NS
Crop*P Treatment	*	NS
Crop*Year	***	***
P Treatment*Year	NS	NS
Depth*Crop*P Treatment*Year	*	NS

* and *** Significant at P≤0.05 and 0.001, respectively; NS, not significant.

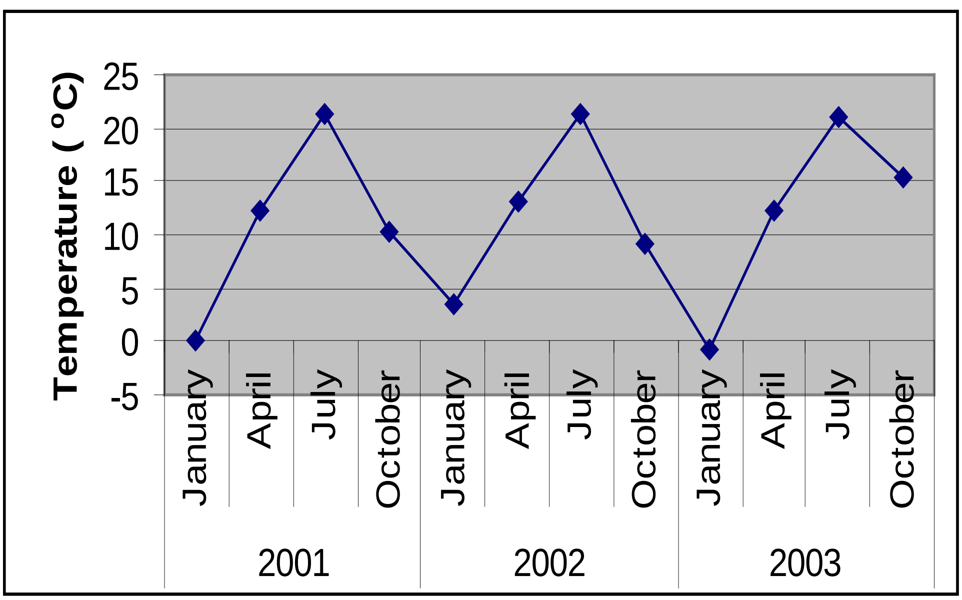

Figure 1 a : Average monthly temperature (oC) at the field study site from 2001-2003.

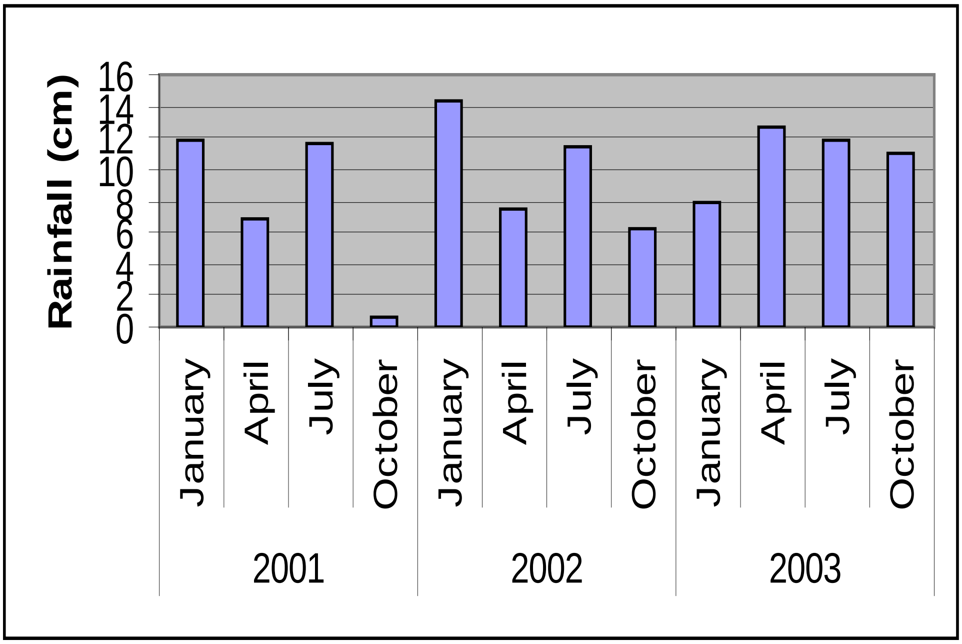

Figure 1 b : Total monthly rainfall (cm) at the field study site from 2001-2003.

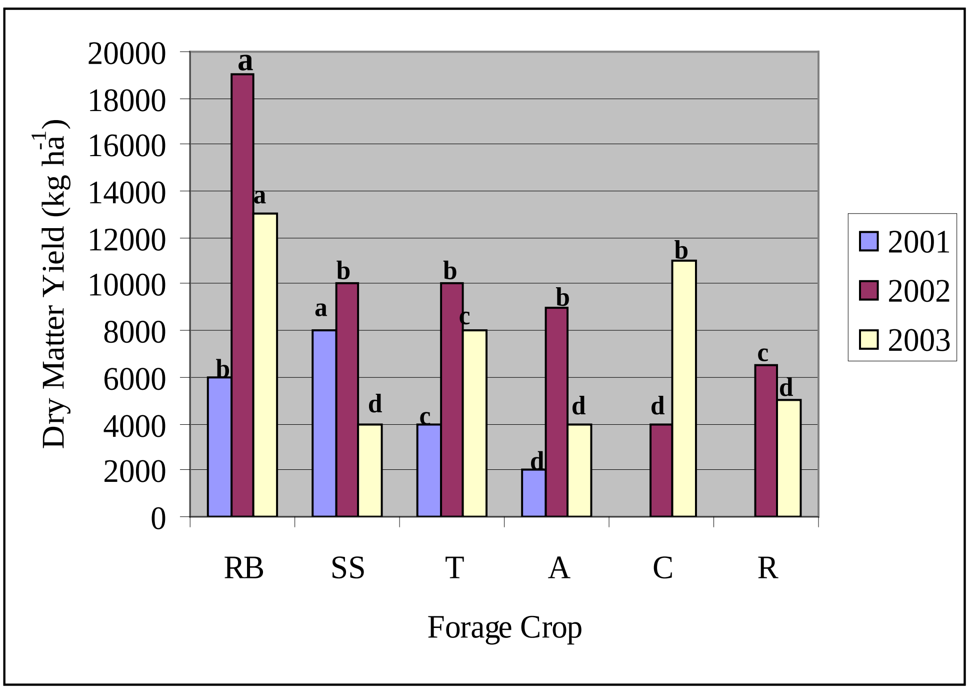

Figure 2 : Total annual forage dry matter yield (kg ha-1) in 3-yr.Means with the same letter are not significantly different at P≤0.05

R: Rye, *RB:* Russell Bermudagrass, *C:* Corn, *T:* Tall fescue, SS: Sorghum- sudangrass, *A:* Alfalfa

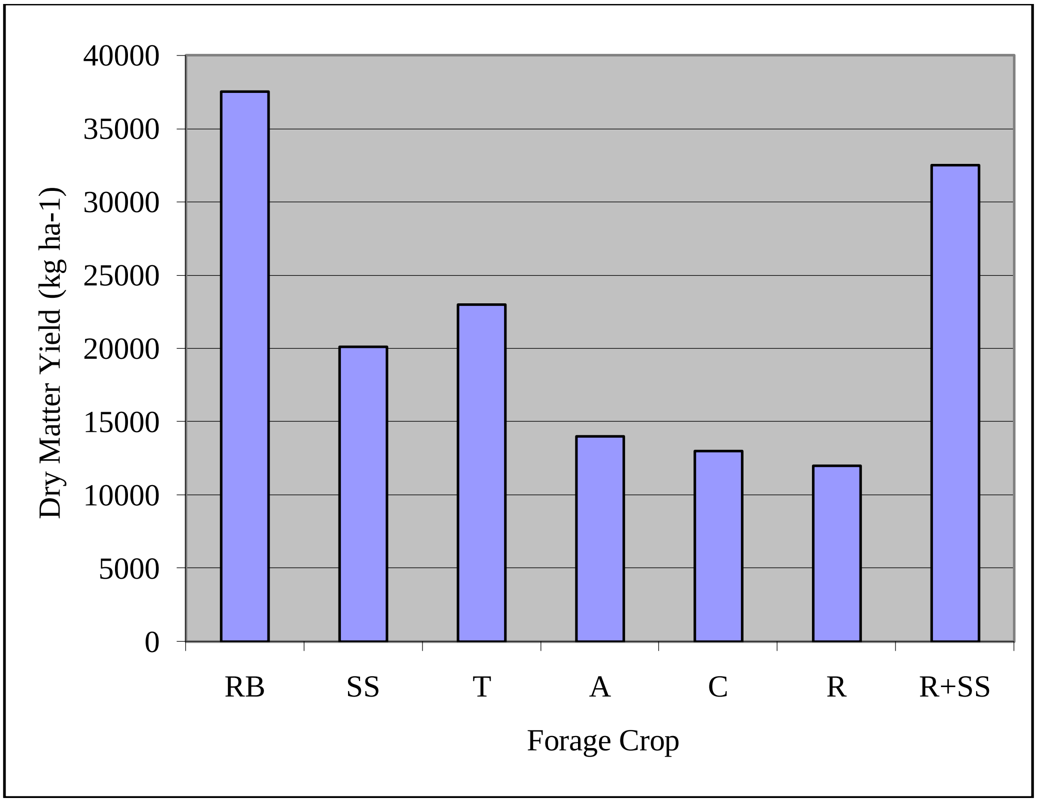

Figure 3 : Total forage dry matter yield (kg ha-1) IN 3-yr. Yields with the same letter are not significantly different at P≤0.05

R: Rye *RB:* Russell bermudagrass *C:* Corn *T:* Tall fescue *SS:* Sorghum-sudangrass *A:* Alfalfa *R+SS:* Rye and sorghum-sudangrass grown on the same plot

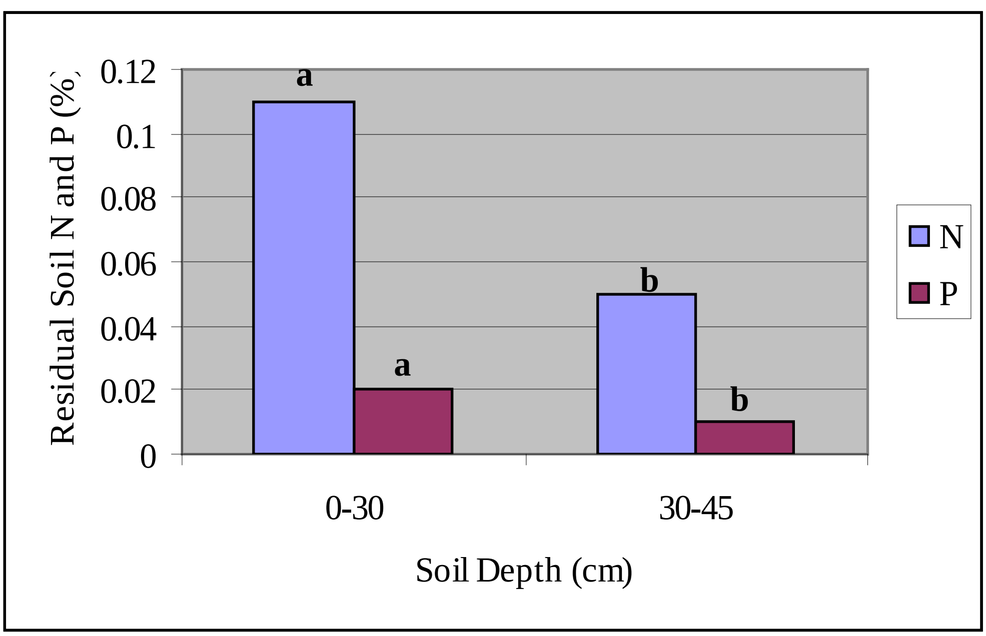

Figure 4 : Residual soil total N and P (%) as influenced by soil depth (cm) in 2002 and 2003.Means with the same letter are not significantly different at P ≤0.05

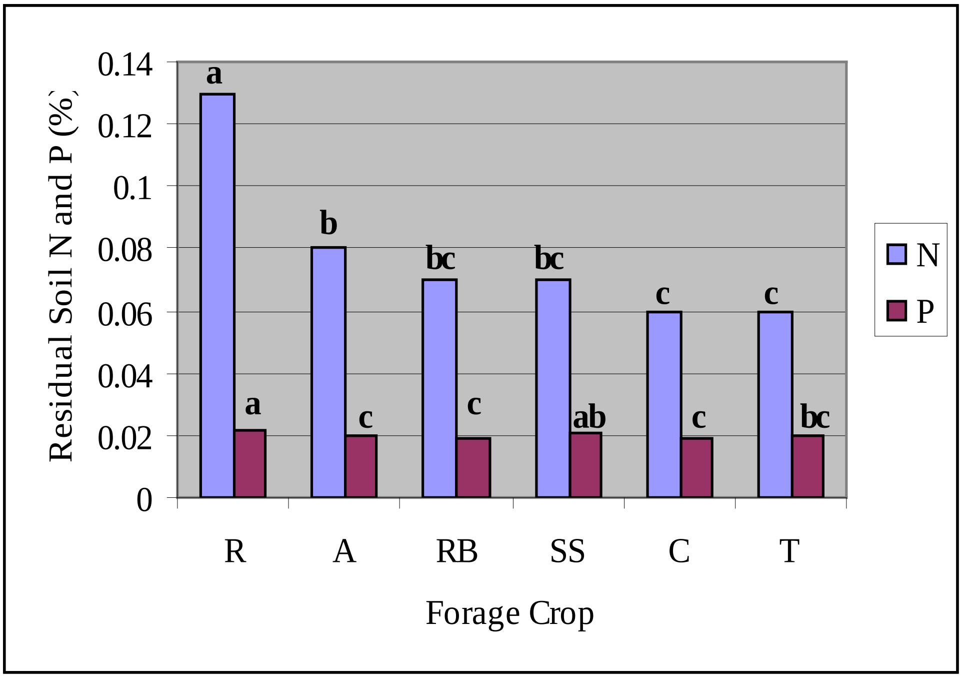

Figure 5 : Residual soil total N and P (%) as influenced by forage crop in 2002 and 2003. Means with the same letter are not significantly different at P≤0.05

R: Rye, *RB:* Russell bermudagrass, *C:* Corn, *T:* Tall fescue, *SS:* Sorghum-sudangrass.

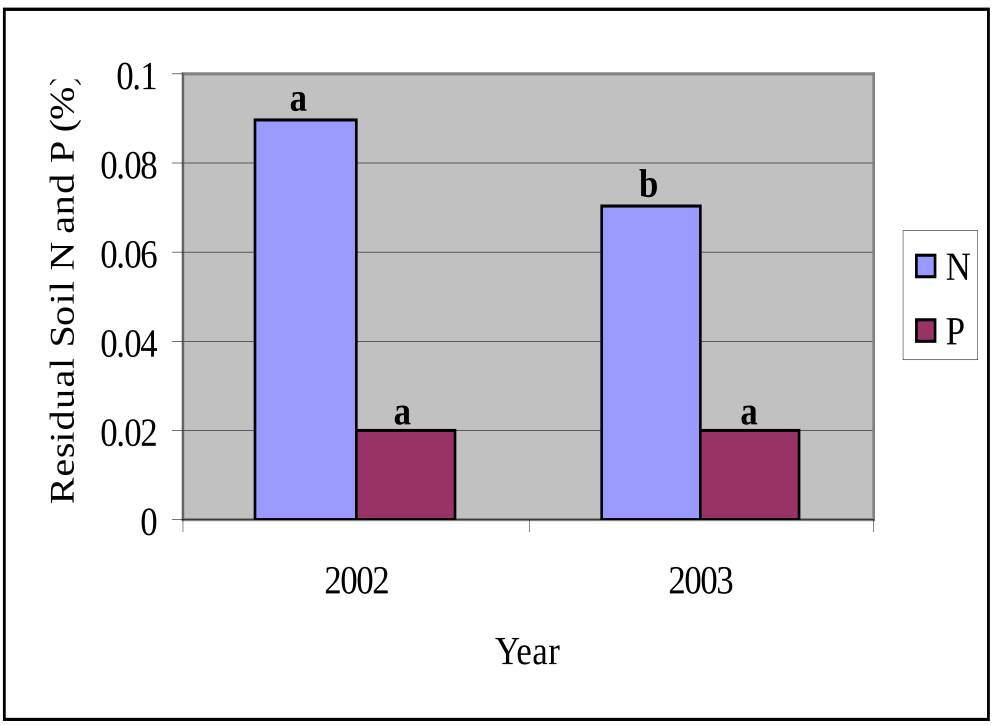

Figure 6 : Residual soil total N and P (%) at 0-30 and 30-45 cm depths as influenced by year. Means with the same letter are not significantly different at P≤0.05