# Dairy Manure Compost Improves Soil and Increases Tall Wheatgrass Yield

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## ABSTRACT

There is a need to identify alternative uses for composted manure applications. The objectives in this study were to 1) document the effect of composted dairy manure on soil agronomic characteristics, and 2) evaluate tall wheatgrass yield response to six rates of composted dairy manure. A field trial with a split-plot randomized complete block design and four replications was initiated on a Windthorst sandy loam soil (Udic Paleustalfs) in north-central Texas near Stephenville in September of 2001. Main plots were 1 by 7 m and received a single application of composted manure prior to planting Tall wheatgrass at 17 kg $ha^{-1}$. Composted dairy manure rates of 0, 11.2, 22.4, 44.8, 89.6, and 179.2 Mg dry matter (DM) $ha^{-1}$of a commercial source were applied. Subplots were 1 by 3.5 m and received annual split applications of 224 or 336 kg N $ha^{-1}$ $yr^{-1}$. Application of compost improved or increased soil OM, soil pH, soil infiltration, soil P levels, and soil K levels, which, in turn increased tall wheatgrass DM yields (by 96% at the greatest rate compared to the control in 2002-03 and by 58% in 2003-04) yielding up to 9536 kg DM $ha^{-1}$ in 2002-03 and 6097 kg DM $ha^{-1}$ in 2003-04. Compost also increased the concentration of forage P (by 56 and 64%) and K (by 40 and 29%) at the greatest compost rate in 2002-03 and 2003-4, respectively. Tall wheatgrass responded to improved soil fertility, and could be utilized to grow forage of high nutritive value (up to 231 g CP $kg^{-1}$ for the greatest compost rate in 2002-03, a 11.6% increase over the control, and a 9.5% increase, 175 g CP $kg^{-1}$, in 2003-04).

**Abbreviations**: OM, organic matter, EC, electric conductivity, DM, dry matter, EDTA, ammonium acetate-ethylenediaminetetraacetic acid; NS, not significant; CP, crude protein

In areas of intensive agricultural and livestock production, soils with plant-available P exceeding the levels required for optimum crop yields have increased (Alley, 1991; Sims, 1992). For example, approximately 200,000 cattle in confined animal feeding operations generate an estimated 1.8 million metric tons $yr^{-1}$ of manure in Erath county, TX (Brazos River Authority, 1993), which has led to an excess buildup of composted dairy manure. In order to avoid environmental problems related to P surface water runoff (Sharpley and Withers, 1994), there is a need to identify alternative uses for composted manure, especially where soil P levels are low.

The use of compost promotes soil aggregation, which improves soil structure and pH, increases water infiltration, and improves water holding capacity (Murray, 1981; USDA NRCS, 2004). The N-P-K percentages of finished compost are relatively low, but their benefit lies in the slow release of N and P in the soil so that plants can use them effectively before they are lost through leaching (Gershuny and Martin, 1992).

Forage P uptake from soils is highly variable and is a direct function of soil P content, soil physical properties, forage biomass, and forage P concentration, the latter often species-specific (Pierzynski and Logan, 1993). The application of dairy manure compost to soils can increase forage yields resulting in greater plant P concentrations and P yields, a phenomenon observed when compost is applied to summer annual dicots (Muir et al., 2001a), annual monocots (Muir et al., 2001b) or perennial grass (Sanderson and Jones, 1997). The efficacy of using composted manure on cool-season perennial grasses, however, has not been widely tested. Tall wheatgrass is a cool-season perennial grass that may have potential to provide forage of high nutritive value during the winter months, when the dominant warm-season grasses are dormant. However, the P fertility requirement and P removal rate for tall wheatgrass are unknown.

Two soil P testing methods, historically used to measure soil-P for both agronomic and regulatory purposes, ammonium acetate-ethylenediaminetetraacetic acid ($NH_4OAc$-EDTA) (Hons et al., 1990) and Mehlich III (Mehlich, 1984), can vary considerably in their estimation of plant-available soil-P (Butler et al., 2006). It is unclear which soil testing method should be utilized to predict available soil P. The objectives in this study were to 1) document the effect of composted dairy manure on selected Windthorst soil characteristics, 2) determine the appropriate soil test for measuring soil P in a Windthorst soil, and 3) evaluate tall wheatgrass yield response to six rates of composted dairy manure.

## MATERIALS AND METHODS

A field study was initiated on a Windthorst sandy loam soil (Udic Paleustalf) in north-central Texas near Stephenville (N 32$^o$ 15', W 98$^o$ 12', altitude 395 m) in September of 2001. Initial soil test indicated pH= 5.1, 6 mg N $kg^{-1}$, 6 mg P $kg^{-1}$ ($NH_4OAc$-EDTA extractant), and 205 mg K $kg^{-1}$. Treatments were arranged in a split-plot randomized complete block design with four replications, six main treatments (compost application rate) and two sub-treatments (N fertilizer rate). Main plots were 1 by 7 m and received a single application of composted manure prior to planting tall wheatgrass at 17 kg $ha^{-1}$. Composted manure rates of 0, 11.2, 22.4, 44.8, 89.6, and 179.2 Mg $ha^{-1}$of a commercial source of composted dairy manure from Producers Compost, Stephenville, TX, was incorporated to 15 cm depth using a roto-tiller. Compost analysis averaged 150 g $kg^{-1}$ OM, 782 g $kg^{-1}$ DM, 7.2 g $kg^{-1}$ N, 3.9 g $kg^{-1}$ P, and 15.7 g $kg^{-1}$ K. Subplots were 1 by 3.5 m and received annual split applications of 224 or 336 kg N $ha^{-1}$ $yr^{-1}$. Nitrogen (urea-ammonium sulfate blend) applications were surface-applied, with half applied in October and the remainder in February. Tall wheatgrass was sprayed with diclofop-methyl 2-[4-(2,4-dichlorophenoxy) phenoxy]propanoate at 0.84 kg ai $ha^{-1}$ at the 5th-leaf stage to control annual ryegrass (*Lolium multiflorum* Lam.), since annual ryegrass will out-compete tall wheatgrass during establishment (Butler et al., 2005).

Plots were harvested with an Almaco small-plot harvester (Almaco, Nevada, IA) three times (December through May) during 2002-03 and 2003-04. Plots were not harvested during the establishment year, since tall wheatgrass is slow to establish. Sub-samples were used to determine forage DM yield by drying approximately 400 g of plant material in a forced-air oven at 55°C until weight loss ceased. Total aboveground DM production was estimated each year by totaling all yields from each year. Representative forage sub-samples from each sub-plot and year were ground through a Wiley mill (Thomas-Wiley Co., Philadelphia, PA) equipped with 1-mm screen. Samples from each treatment and harvest were analyzed for N, P, K, and S. Nitrogen concentration was multiplied by 6.25 and reported as crude protein (CP) (Van Soest, 1994). Concentrations of these plant components are reported as season-long weighted averages for each subplot.

Approximately 15 soil cores were taken to a 15 cm depth for each subplot at the end of each growing season and composited by subplot to determine treatment differences. Soils were analyzed for pH using 1:2 ratio of soil to deionized water

(Schofield and Taylor, 1995), $NO_3$-N by Cd reduction (Kenney and Nelson, 1982), and P, K, S, Na, Mg, and Ca based on two soil-extractant methods, acidified $NH_4$OAc-EDTA (TAMU) and Mehlich III (Mehlich, 1984; Hons et al., 1990). Elements in both extractants were measured using ICP-OES (Spectro Radial Modula ICP, Spectro Analytical Instruments, Marlborough, MA.). Soil OM concentration was determined by using the Loss-On-Ignition Method (LOI) (Nelson and Sommers, 1996). Soil samples were air dried and ground to <0.4 mm. A 1.00 to 3.00 g sample for each subplot was placed in a crucible and heated in an oven for 24 h at 105°C. Samples were then cooled in a dessicator and weighed to a tolerance of 0.1 mg. Samples were then placed in a muffle furnace for 16 h at 400°C, cooled, dessicated, and weighed. Infiltration rate of water into the soil was measured with a Turf-tec double ring infiltrometer obtained from Turf-tec International (Coral Springs, FL), by averaging three readings from each subplot at the end of each growing season. The infiltration rate was determined as the amount of water per surface area and time unit which penetrated the soil (Bouwer, 1986).

Data were subjected to analyses of variance using PROC GLM (SAS, 1999) with differences less than $P$=0.05 reported as significant. Means, where appropriate, were separated using Fisher's Protected LSD test at $P$=0.05 level of significance. Differences in rainfall distribution (but not total) among growing seasons (September-June) were apparent (Figure 1). Precipitation in the 2002-03 season totaled 782 mm and the 2003-04 season totaled 787 mm, however there was poor distribution of moisture in the early months of 2003-04.

## RESULTS AND DISCUSSION

### Soil Nutrient Status

Year, year X compost rate, year X N rate, and year X compost X N rate interactions were not significant (Table 1), therefore data are pooled across years for soil pH, N, P, K, OM, and infiltration. Soil S, Na, Mg, and Ca, and did not differ among year, compost level, or extraction method (data not shown).

**Soil OM**

Soil OM increased as composted dairy manure rates increased (Table 4). Soil OM in the untreated plots averaged 13 g $kg^{-1}$ compared to 20 g $kg^{-1}$ in the plots with the greatest compost rate. The addition of compost OM to the soil can increase CEC from 20 to 70% of the original CEC (Mott, 1974; Halvin et al., 1999). Not all composted manures increase soil OM or organic carbon (Helton, 2004), primarily because some composts have low levels of OM since they originate from drylot scrapings high in soil content.

**Soil pH**

Soil pH increased as composted dairy manure rates increased (Table 4). Soil pH in the untreated plots averaged 4.5 compared to 7.0 at the greatest compost rate (179.2 Mg $ha^{-1}$), and increased an average 0.5 unit as compost rate doubled in magnitude from 11.2 to 179.2 Mg $ha^{-1}$. Seedling establishment and soil pH were also increased with applications of compost elsewhere (Murray, 1981). The increase in soil pH can be partially attributed to the increase in soil OM and the high pH of the compost itself, a result of a high concentration of calcareous soil particles in the dairy compost generated by north Texas dairies (Helton, 2004). Soil pH decreased as N rate increased from 224 to

336 kg $ha^{-1}$, which was expected in the top 15 cm of soil (Haby et al., 1999). Dairy manure and its compost have the potential to raise pH of acidic soils receiving N fertilizer (Sanderson and Jones, 1997; Helton, 2004) or mitigate the acidification of soils receiving soil-acidifying forms of N fertilizer.

**Soil Infiltration**

Soil infiltration with water increased linearly (Table 4) with increasing rates of compost dairy manure. Infiltration increased by 100%, 242%, 292%, 408%, and 550% for 11.2, 22.4, 44.8, 89.6, and 179.2 Mg $ha^{-1}$, respectively, when compared to the untreated control. Increase in infiltration can be attributed to increased OM. Improvements in soil moisture retention due to the increase in soil OM have been reported by others (Hoitink and Fahy, 1986; Boehm et al., 1993).

**Soil $NO_3$-N**

Dairy manure compost had little effect on soil N levels, although there was a numeric trend for greater compost manure rates having lower soil N levels, which could be related to greater forage DM yields in those plots. Composting dairy manure tends to lower $NH_4$–N levels vis-à-vis the original manure, but $NO_3$-N tends to be more stable in compost; in at least one study looking at both dairy manure and its compost, however, $NH_4$–N concentrations were more stable in the soil than was $NO_3$-N (Helton, 2004). Soil N level with 336 kg $ha^{-1}$ was 41% greater than at the 224 kg $ha^{-1}$ rate.

**Soil-P**

Soil P levels increased with both soil extractants, as composted dairy manure increased (Table 4); however, soil extractants differed in their estimate of plant-available P. At very low soil P levels, the Mehlich extractant soil P was approximately 1.5 times greater than the EDTA extractant P, but there were no differences between extractants when available soil P was very high with the heaviest compost rate (Table 2). The highest compost rate (179.2 Mg $ha^{-1}$) which yielded 124 mg P $kg^{-1}$ soil, did not exceed the maximum soil P threshold of 200 mg P $kg^{-1}$ allowed by environmental regulatory agencies in Texas (Texas Administrative Code, 1997), indicating that these low-P soils can incorporate very high rates of compost before this limit is reached. In contrast, Helton (2004), in a perennial warm-season grass study in which he surface-applied 57 Mg compost $ha^{-1}$ to a similar Windthorst soil with a control plot containing 22 mg P $kg^{-1}$ soil, measured plant-available P well in excess of the 200 mg P $kg^{-1}$ soil limit (EDTA) in the top 15 cm. The main difference may have been that Helton (2004) did not incorporate compost to a 15-cm depth as was done in the present study.

Fertilizer N rate had little effect on plant-available soil P. The Texas Cooperative Extension Soil, Water and Forage Testing Laboratory adopted the statewide use of the Mehlich III method in Jan. 2004, following the determination that the $NH_4OAc$-EDTA method dissolved non-plant available apatite in certain calcareous soils (personal communication, T. Provin, 2004).

**Soil-K**

Soil K levels also increased as compost rate increased (Table 4), a phenomenon observed in other compost studies (Schlegel, 1992; Helton, 2004); however, the extractants differed in their estimation of plant-available K. The EDTA extractant measured greater levels of plant-available K compared to the Mehlich extractant, which is the reverse trend of plant-available soil P. Mehlich III uses a 5-minute shaking time compared to 45 minutes for the EDTA, resulting in a more complete release of soil-bound K (Mehlich, A. 1984; Hons et al., 1990) which tends to be more weakly bound to soil particles compared to P in its $HPO_2$ and $H_2PO_4$ forms (Pierzynski et al., 2005). Soil K levels were adequate even in the untreated plots; therefore it is unlikely that the increased levels of K influenced crop yield. Nitrogen fertilizer rate had little effect on available soil K.

### Tall Wheatgrass

Year and year X compost interactions were apparent for DM yield, N removal, P removal, and K removal (Table 1), therefore data are reported by year. Sulfur concentrations of tall wheatgrass tissue and S levels of soil did not differ among treatments, so S removal rates are not reported.

#### Forage DM Yield

In both growing seasons, DM yield increased with application of composted dairy manure (Table 3; Table 4). Forage DM yield was lowest where compost was not applied (4857 kg $ha^{-1}$ for 2002-03 and 3858 for 2003-04) and increased by 32, 44, 64, 85, and 96% with 11.2, 22.4, 44.8, 89.6, and 179.2 Mg compost $ha^{-1}$, respectively in 2002-03 and by 31, 33, 37, 42, and 58% in 2003-04 (Table 4). The greatest DM yields occurred with the highest compost rate (179.2 Mg $ha^{-1}$) with yields of 9536 and 6097 kg $ha^{-1}$ in each growing season respectively, which is similar to the maximum yields reported for other cool-season grasses. Reported yearly DM yields of timothy (*Phleum pretense* L.), orchardgrass (*Dactylis glomerata* L.), reed canarygrass (*Phalaris arundinaceae* L.), smooth brome (*Bromus inermis* Leyss.), and tall fescue (*Festuca arundicaea Schreb*.) averaged 9770, 7970, 9707, 7881, and 9968 kg DM $ha^{-1}$, respectively (Cherney and Cherney, 2005). Butler et al., (2006) reported DM yields of annual ryegrass (*Lolium* *multiflorum* Lam.) under the same environment as this study, which ranged from 4550 to 10510 kg DM ha$^{-1}$ when fertilizer rates ranged from 0 to 40 kg P ha$^{-1}$. Forage yields did not differ between the N rates in either year, indicating that N rates lower than 224 kg ha$^{-1}$ may suffice to attain maximum forage yields. These data illustrate that tall wheatgrass responds to application of composted manure, which improves soil fertility, especially soil P, and that tall wheatgrass has forage potential for the region.

**Crude Protein and N removal.**

Forage CP concentration (Table 3) was greater in 2002-03 (ranging from 207 to 231 g CP kg$^{-1}$) compared to 2003-04 (158 to 175 g CP kg$^{-1}$); however, all CP values would be considered adequate for most livestock classes (Ball et al., 2002). These relatively high values are greater than those reported for other cool-season perennial grasses. Cherney and Cherney (2005) reported CP values for timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue that averaged 105, 122, 123, 132, and 110 g kg$^{-1}$, respectively. Butler et al. (2006) reported CP values ranging from 202 to 248 g kg$^{-1}$ for annual ryegrass. Crude protein was greatest at the two highest compost rates (89.6 and 179.2 mg ha$^{-1}$) in 2002-03 but did not differ between compost rates in the 2003-04 growing season (Table 4). Crude protein values did not differ between the two N rates in 2002-03. However, CP was 10% greater with the 336 kg N ha$^{-1}$ rate in 2003-04, but this is probably not of biological importance.

The amount of N removed, which is a function of N concentration and DM yield, followed a similar trend to that of yield. As compost rate increased, the amount of N removed also increased up to 119%, ranging from 161 to 353 kg N ha$^{-1}$ in 2002-03 and 98 to 169 kg N ha$^{-1}$ in 2003-04 (72% increase) (Table 4). Nitrogen rate did not affect N removal in 2002-03, however the 336 kg N ha-1 rate removed 17% more N due to the greater concentration of N in forage that season. These data illustrate that the amount of nutrient removal is closely related to DM yield, and, as yield increases, the nutrient removal rate also will increase.

**Phosphorus concentration and P removal.**

Forage P concentrations (Table 3) in 2002-03 ranged from 1.8 to 2.8 g P $kg^{-1}$, greater than in 2003-04 (ranging from 1.4 to 2.3 g P $kg^{-1}$). These values are similar to those reported for grasses other than wheatgrass. Cherney and Cherney (2005) reported that P concentrations of timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue averaged 2.35, 2.87, 3.20, 3.08, and 2.78 g K $kg^{-1}$, respectively and ranged from 2.41 to 3.32 g P $kg^{-1}$ depending on the year. Butler et al. (2006) reported that annual ryegrass, when grown in the same environment as this study and fertilized with 0 to 48 kg P $ha^{-1}$ $yr^{-1}$, had P concentrations from 1.9 to 4.0 g P $kg^{-1}$. These values are slightly greater than the values measured in the present study with tall wheatgrass. Tall wheatgrass P concentrations increased 6 to 56% in 2002-03 and 14 to 64% in 2003-04, from the lowest to highest compost rate (Table 4).

The amount of P removed ranged from 5.4 to 26.7 kg P $ha^{-1}$ and increased with compost rate (Table 3), primarily due to greater forage yields and P concentrations resulting from compost application. Butler et al. (2006) also reported that annual ryegrass removed from 8 to 40 kg P $ha^{-1}$, depending on the P fertilizer rate. In the 2002-03 growing season, removal of P increased by 40 to 206% as compost rate increased and by 50 to 159% in 2003-04 (Table 4). However, the cumulative P recovery rates when combining P removal for both growing seasons were 0.141, 0.106, 0.084, 0.058, 0.038

for composted manure rates of 11.2, 22.4, 44.8, 89.6, 179.2 Mg ha$^{-1}$, respectively. Fertilizer N rate had little effect on P concentration or the amount of P removed from the soil. These data indicate that tall wheatgrass could potentially be utilized on high P soils to remove excess P.

**Potassium Concentration and K removal**

Forage K concentration followed a similar trend as P, ranging from 19.7 to 27.5 g kg$^{-1}$ in 2002-03 and from 18.9 to 24.4 g kg$^{-1}$ in 2003-04. Cherney and Cherney (2005) reported K concentrations of timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue averaging 14.5, 15.9, 16.3, 17.8, and 15.1 g kg$^{-1}$, respectively and varying from 14.1 to 21.4 g K kg$^{-1}$, depending on the year. In the present study, K concentration increased by 9 to 40% in 2002-03 and 6 to 29% in 2003-04 from the lowest to highest rate of compost application. The amount of K removed ranged from 96 to 262 kg K ha$^{-1}$ in 2002-03 and 73 to 149 kg K ha$^{-1}$. Cherney and Cherney (2005) also reported that timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue removed from 100 to 159 kg K ha$^{-1}$ from the soil. Several cool-season grasses have been reported to be luxury consumers of K (Cherney et al., 1998). Tall wheatgrass could also be considered a luxury consumer since for K concentrations increased as soil K increased with compost rates despite adequate soil K the untreated plots. Nitrogen fertilizer had little effect on K concentrations or the amount of K removed from the soil.

## CONCLUSIONS

Application of dairy manure compost increased soil OM, soil pH, soil infiltration, soil P levels, and soil K levels, which, in turn, increased tall wheatgrass DM yields and P and K concentrations in the forage. Tall wheatgrass is similar to other cool-season grasses in that it will respond to improved soil fertility, especially soil P, and could be utilized to provide forage of relatively high nutritive value with similar DM yields and P removal rates to that of other cool-season grasses.

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Table 1. Analysis of variance for soil and forage parameters of Jose tall wheatgrass in the 2002-04 growing seasons at Stephenville, TX.

| | Soil Parameters | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | P | | K | | S | | |
| Source | pH | OM | Infiltration | $NO_3$-N | EDTA | Mehlich | EDTA | Mehlich | EDTA | Mehlich | EC |
| Year | NS† | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Compost | *** | *** | *** | *** | *** | *** | *** | *** | NS | NS | NS |
| Year*Compost | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| N rate | *** | NS | NS | *** | NS | NS | NS | NS | NS | NS | NS |
| Year* N | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Compost*N | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Year*Compost*N | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

†NS, not significant; *, **, ***, 0.05, 0.01, and 0.001 level of significance, respectively; OM, organic matter; DM. dry matter; EDTA, ethylenediaminetetraacetic acid; EC, electric conductivity.

| | Forage Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | DM yield | N % | N removed kg $ha^{-1}$ | P % | P removed kg $ha^{-1}$ | K % | K removed kg $ha^{-1}$ | S % | S removed kg $ha^{-1}$ |
| Source | | | | | | | | | |
| Year | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| Compost | *** | NS | *** | *** | *** | *** | *** | ** | *** |
| Year*Compost | *** | NS | *** | NS | *** | NS | * | NS | * |
| N rate | NS | ** | *** | NS | * | NS | * | NS | * |
| Year* N | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Compost*N | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Year*Compost*N | NS | NS | NS | NS | NS | NS | NS | NS | NS |

Table 2. Response of soil parameters (pH, NO3-N, P, K, OM†, and infiltration) to dairy manure compost averaged over the 2002-03 and 2003-04 growing seasons in Stephenville, TX.

| | Soil | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | OM | Soil | Infiltration | $NO_3$-N | P (mg $kg^{-1}$) | | K ( mg $kg^{-1}$) | |
| Compost Rate | % | pH | mm | mg $kg^{-1}$ | EDTA | Mehlich III | EDTA | Mehlich III |
| 0 Mg $ha^{-1}$ | 1.3 | 4.5 | 12 | 43 | 8 | 21 | 220 | 200 |
| 11.2 Mg $ha^{-1}$ | 1.4 | 5.0 | 24 | 39 | 11 | 26 | 265 | 245 |
| 22.4 Mg $ha^{-1}$ | 1.5 | 5.2 | 41 | 38 | 13 | 30 | 270 | 242 |
| 44.8 Mg $ha^{-1}$ | 1.6 | 5.9 | 47 | 30 | 20 | 40 | 294 | 269 |
| 89.6 Mg $ha^{-1}$ | 1.9 | 6.5 | 61 | 29 | 58 | 79 | 338 | 314 |
| 179.2 Mg $ha^{-1}$ | 2.0 | 7.0 | 78 | 31 | 124 | 122 | 400 | 368 |
| LSD | 0.2 | 0.3 | 4 | NS | 17 | 13 | 45 | 45 |
| | | | | | | | | |
| N Rate | | | | | | | | |
| 224 kg $ha^{-1}$ | 1.7 | 5.7 | 43 | 29 | 38 | 53 | 300 | 274 |
| 336 kg $ha^{-1}$ | 1.7 | 5.5 | 44 | 41 | 39 | 54 | 295 | 272 |
| LSD | N.S. | 0.2 | N.S. | 9.0 | N.S. | N.S. | N.S. | N.S. |

†OM, organic matter; EDTA, ethylenediaminetetraacetic acid; NS, not significant.

Table 3. Response of Jose tall wheatgrass to compost and nitrogen treatments at Stephenville, TX in the 2002-03 and 2003-04 growing seasons.

| | 2002-03 | | | | | | |
|---|---|---|---|---|---|---|---|
| | kg DM† $ha^{-1}$ | CP | N removal | P | P removal | K | K removal |
| Compost Rate | | $g\ kg^{-1}$ | $kg\ N\ ha^{-1}$ | $g\ kg^{-1}$ | $kg\ P\ ha^{-1}$ | $g\ kg^{-1}$ | $kg\ K\ ha^{-1}$ |
| 0 $Mg\ ha^{-1}$ | 4857 | 207 | 161 | 1.8 | 8.7 | 19.7 | 96 |
| 11.2 $Mg\ ha^{-1}$ | 6400 | 203 | 208 | 1.9 | 12.2 | 21.4 | 137 |
| 22.4 $Mg\ ha^{-1}$ | 7003 | 208 | 233 | 2.1 | 14.7 | 23.0 | 161 |
| 44.8 $Mg\ ha^{-1}$ | 7970 | 218 | 278 | 2.3 | 18.3 | 24.4 | 194 |
| 89.6 $Mg\ ha^{-1}$ | 8989 | 223 | 321 | 2.5 | 22.5 | 25.8 | 232 |
| 179.2 $Mg\ ha^{-1}$ | 9536 | 231 | 353 | 2.8 | 26.7 | 27.5 | 262 |
| LSD | 1475 | 10 | 46 | 0.2 | 3.3 | 2.1 | 33 |
| N Rate | | | | | | | |
| 224 $kg\ ha^{-1}$ | 7379 | 220 | 260 | 2.3 | 17.0 | 23.6 | 174 |
| 336 $kg\ ha^{-1}$ | 7540 | 217 | 262 | 2.2 | 16.6 | 23.6 | 178 |
| LSD | N.S. | N.S. | N.S. | N.S | N.S. | N.S. | N.S. |

| Compost Rate | 2003-04 | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 Mg ha$^{-1}$ | 3858 | 158 | 98 | 1.4 | 5.4 | 18.9 | 73 |
| 11.2 Mg ha$^{-1}$ | 5055 | 165 | 133 | 1.6 | 8.1 | 20.1 | 102 |
| 22.4 Mg ha$^{-1}$ | 5126 | 169 | 139 | 1.7 | 8.7 | 21.2 | 109 |
| 44.8 Mg ha$^{-1}$ | 5301 | 170 | 144 | 2.0 | 10.6 | 21.4 | 113 |
| 89.6 Mg ha$^{-1}$ | 5486 | 175 | 154 | 2.2 | 12.1 | 24.3 | 133 |
| 179.2 Mg ha$^{-1}$ | 6097 | 173 | 169 | 2.3 | 14.0 | 24.4 | 149 |
| LSD | 563 | N.S | 14 | 0.1 | 1.1 | 1.2 | 18 |
| N Rate | | | | | | | |
| 224 kg ha$^{-1}$ | 4956 | 160 | 127 | 1.8 | 8.9 | 22.0 | 109 |
| 336 kg ha$^{-1}$ | 5303 | 176 | 148 | 1.8 | 9.5 | 22.1 | 117 |
| LSD | N.S. | 8 | 9 | N.S. | N.S | N.S. | N.S. |

†DM, dry matter; CP, crude protein.

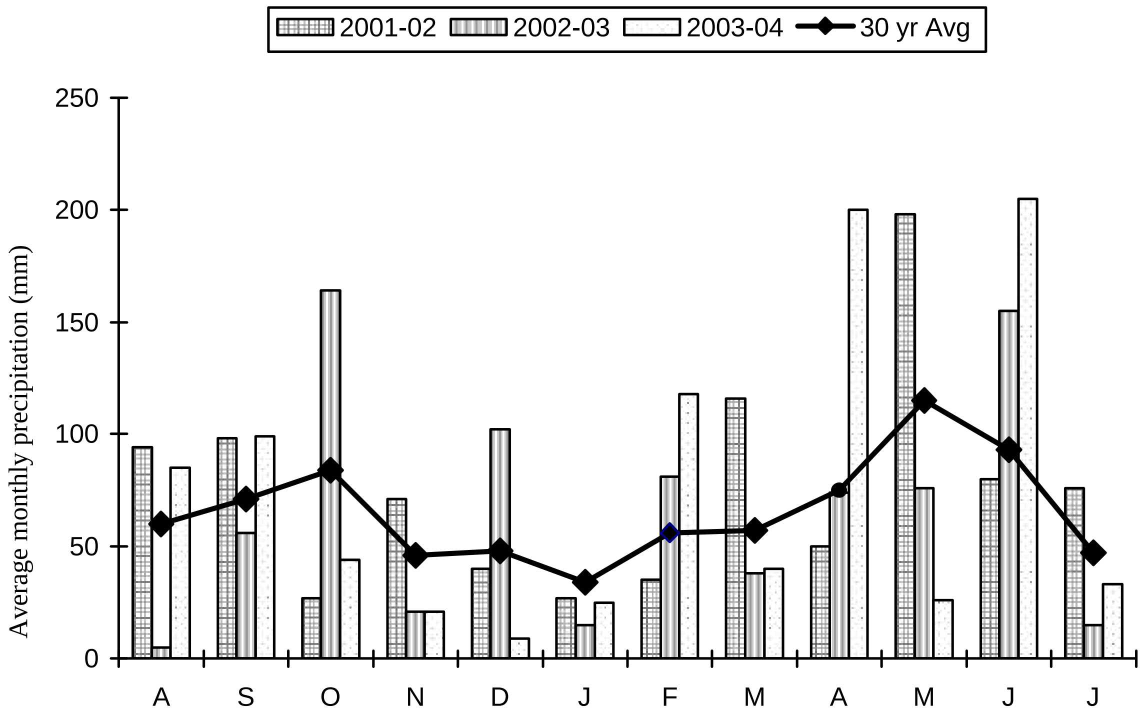


Figure 1. Monthly precipitation from August to July during three years and 30-yr average trend line at Stephenville, TX, USA.