# ROOT GROWTH, YIELD AND ECONOMICS OF WINTER SORGHUM AS INFLUENCED BY TILLAGE DEPTHS, ORGANIC MATERIALS AND NITROGEN APPLICATION IN SEMI–ARID TROPICAL INDIA

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***Abstract***

*Deep tillage as compared to shallower tillage depths improved the root growth, increased the grain yield, gross returns, net returns and benefit cost ratio of winter sorghum. Grain yield increased by 23 and 57% during 1994–95 and 14 and 34% during 1995–96 in medium and deep tillage, respectively, over shallow tillage. Greater root length (67.0 cm), root spread (53.1 cm) and root weight (13.62 g) was observed in deep tillage as compared to medium and shallow tillage. Deep tillage recorded significantly higher gross returns (400.87 and 385.35 \$ ha$^{-1}$), net returns (197.35 and 182.30 \$ ha$^{-1}$) and benefit cost ratio (1.97 and 1.90) during 1994–95 and 1995–96, respectively. Among organic materials, application of Leucaena loppings as compared to vermicompost increased the grain yield by 9% (mean of 1994–95 and 1995–96), improved the root growth, gross and net returns and benefit cost ratio over farmyard manure and vermicompost. Grain yield increased significantly after application of 25 kg N ha$^{-1}$ during 1994–95 and 50 kg N ha$^{-1}$ during 1995–96. Greater net returns (275.43 \$ ha$^{-1}$), benefit cost ratio (2.51) were observed in deep tillage with application of Leucaena loppings and 25 kg N ha$^{-1}$ during 1994–95, whereas, during 1995–96 a further increase in N application to 50 kg ha$^{-1}$ increased the gross returns (465.34 \$ ha$^{-1}$), net returns (283.27 \$ ha$^{-1}$) and benefit cost ratio (2.56).*

**Key words:** black soil, root growth, deep tillage, organic materials, nitrogen, economics.

## INTRODUCTION

Scientific land management and efficient water conservation plays an important role in sustainable crop production. The land resource in India is degrading at an alarming rate through different human induced and natural processes. Soil erosion due to agricultural activities alone in India accounts to 5334 Mt per year (Narayana, 1986). As soil erodes, nutrients are lost especially from topsoil and topsoil becomes increasingly shallow. In India, most of the land is degraded due to water erosion. The present situation in India demands for conservation of rainwater *in situ.* In vertisols, tillage practices are most commonly followed for improving the soil properties, conserving the rainwater *in situ*, and reducing runoff and soil loss. Deep tillage with a moldboard plow loosens the upper layer of the subsoil, thus resulting in deeper and wider spread of roots that results in greater uptake of water and nutrients from deeper soil horizons ultimately leading to better plant growth with reduced erosion and increased productivity.

In addition to the water, nutrient availability also limits the crop growth in the SAT vertisols in India. In these soils, there is a little available N, the availability of P is very moderate due to strong P fixation, and the same applies to available K even though total K is high. In recent times, increased use of fertilizers by producer, especially in dryland farming is threatened due to increase in the price of fertilizers. This has reduced the use of fertilizer and resulted in persistent nutrient depletion from these soils, posing a further threat to sustainable agriculture in the region. Preliminary studies indicate that these vertisols exhibit a slow infiltration rate (<10 mm h$^{-1}$) with large amounts of runoff, a deficit in nutrient content and availability and little water available to the crops grown during the post–monsoon (*rabi*) season on receding soil water. Applications of nutrients through organic and inorganic materials increase the use efficiency of fertilizer and enhance the root growth beyond topsoil depth (>0.30 m soil depth) and increase the yields on sustainable basis (Durgude *et al.*, 1996). In addition to increase in yields, economics of the system plays a major role in the livelihood of the dryland farmers' in the region.

Based on this overview, a field study was conducted for two years (1994–95 and 1995–96) to know the effects of tillage depths, organic materials and nitrogen application on root growth, yield and economics of winter sorghum in semi–arid tropical India.

## MATERIALS AND METHODS

**Soil and site characteristics.** A field experiment was conducted during the post–rainy seasons of 1994–95 and 1995–96 on a vertisol belongs to Managuli series classified as Typic–Chromusterts at Regional Research Station, Bijapur, situated in the Northern Dry Zone of Karnataka State, India, at 16°49' N latitude, 75° 42' E longitude and 594 m above mean sea level. These soils are derived from deccan trap and granite gneiss (Chromic Vertisols). Safflower (*Carthamus tinctorious* L.) was grown at the experimental site during the winter season of 1993–94.

**Treatments.** The field experiment was laid out in split–split plot of randomized complete blocks design with three main plots (tillage practices), each were split for three sub–plots (organic materials), which in turn were split for three further sub–plots (N application) with 3 replications on land having 1.0% slope. Each smallest sub–sub plot measured 5.4 m × 6.0 m = 32.4m$^2$. Tillage treatments were imposed during the June 3$^{rd}$ week in 1994 and July 3$^{rd}$ week during 1995. In the main plot, deep tillage to a depth of 0.22 to 0.30 m was achieved with a tractor drawn–moldboard plow; medium tillage to a depth of 0.15 m by bullock–drawn moldboard plow, and shallow tillage to a depth of 0.08 m was by bullock–drawn harrow. In the sub–plots, *Leucaena* loppings (at 2.5 t ha$^{-1}$) and farmyard manure (at 2.5 t ha$^{-1}$) on fresh weight basis were incorporated manually in the top 0.10 m soil depth during August 3$^{rd}$ week. Vermicompost (at 1.0 t ha$^{-1}$) was applied manually at the time of sowing. The nutrient content of *Leucaena* loppings is on dry weight basis, whereas, farmyard manure and vermicompost were analysed from the same samples which were incorporated in the experimental plots (Table 1). In the sub–sub plots, N fertilizer as urea (0, 25 or 50 kg ha$^{-1}$) was applied before sowing together with 25 kg phosphorus per ha as single super phosphate. A post–rainy season sorghum (cv. M35–1) was sown at a depth of 5 cm at 15 cm apart in 60 cm rows (Table 2). Weeds were controlled manually. Grain and straw yield from experimental plots was harvested, sun–dried and weighed.

**Root studies.** A root studies in the experimental plots was conducted at the end of second season (1995–96), after harvest of sorghum crop. The soil profile in the experimental plots was saturated to a depth of 0.60 m a day prior to the root studies. The water was sprayed to the roots from the surface to a depth up to which the roots were spread and roots were removed and measured for their length, spread and were oven–dried to record weight.

**Economics.** The cost of cultivation for individual treatments was worked out by the prices prevailing during winter season of 2003–04, whereas, gross returns were worked out based on the market rates prevailing for grain and straw yields of winter sorghum during March 2004. All the costs were converted into American Dollars (46 Indian rupees were considered equivalent to one American Dollar). Net returns were calculated by deducting the cost of cultivation from gross income per ha. Benefit: cost ratio was worked out as follows.

$$\text{Benefit Cost Ratio} = \frac{\text{Gross returns (American Dollars per ha)}}{\text{Cost of cultivation (American Dollars per ha)}}$$

**Statistical analysis.** The data were analyzed using a computerized statistical MSTAT–C package (Gomez and Gomez, 1984). Probabilities less than 0.05 were considered significant. When analysis of variance indicated significant difference, the LSD test was used to separate the treatment means (tillage practices, organic materials and N application), and for comparing across them. All significant main effects besides interactions were considered.

## RESULTS

**Rainfall.** The rainfall received during 1994–95 and 1995–96 was 90 (585.8 mm) and 97% (629.4 mm) of the average of past 56 years (650 mm) (Table 2). During 1994–95, only 6.6 mm rainfall was received during September, as against the 56 years average (156.7 mm), resulting in late sowing of sorghum crop (5 October). During October the greater than the average rainfall (339.5 mm), that received has compensated for a small volume in September during 1994–95. The onset of monsoon was from September 2$^{nd}$ week during 1995–96, resulted in timely sowing of *rabi* sorghum (15 September). Crop season rainfall during 1994–95 was slightly greater (394.4 mm) than 1995–96 (370 mm).

**Root studies**

**Tillage practices.** The rooting depth was greater in deep tillage (67.0 cm) compared to medium (57.6 cm) and shallow tillage (41.8 cm). Greater root spread (53.1 cm) was observed for deep tillage than for medium tillage (47.6 cm) and shallow tillage (37.1 cm) (Table 3). Deep tillage recorded significantly greater root weight (13.62 g plant$^{-1}$) compared to shallow tillage (9.40 g plant$^{-1}$).

**Organic materials.** Incorporation of *Leucaena* loppings resulted in greater root depth (62.0 cm) compared to farmyard manure (54.9 cm) and vermicompost (49.5 cm) (Table 3). The root spread after incorporation of *Leucaena* loppings was greater (49.1 cm) than vermicompost (42.8 cm). *Leucaena* application recorded greater root biomass (12.20 g plant$^{-1}$); followed by application of farmyard manure (11.95 g plant$^{-1}$) and vermicompost (10.72 g plant$^{-1}$).

**Nitrogen application.** Increase in N application to 25 kg ha$^{-1}$ increased the root depth (56.7 cm), root spread (47.2 cm) and root dry weight (11.87 g plant$^{-1}$) over control. Further increase in N rate to 50 kg ha$^{-1}$ improved the root growth marginally (Table 3).

Deep tillage with *Leucaena* loppings and 50 kg N ha$^{-1}$ application recorded the greater root depth (82.6 cm), with a similar trend observed in root spread and root weight (Table 3).

**Grain and straw yield**

**Tillage practices.** In medium tillage, grain yield increased by 23 and 14% and in deep tillage by 57 and 34% over shallow tillage during 1994–95 and 1995–96, respectively (Table 4). In the pooled analysis, grain yield increased by 18% in medium and 45% in deep tillage as compared to shallow tillage. The trend in straw yield was also similar to that of grain yield with different tillage practices.

**Organic materials.** Application of *Leucaena* loppings recorded significantly greater grain yield of 1625 (1994–95), 1647 (1995–96) and 1636 kg ha$^{-1}$ (pooled) as compared to vermicompost application during both the years of study and in pooled data (Table 4).

**Nitrogen application.** Grain and straw yield increased significantly with 25 kg N ha$^{-1}$ application over control during 1994–95. During 1995–96 and in the pooled data, increase in N applications to 50 kg ha$^{-1}$ increased the grain yield significantly over lower N rates. In the pooled data, grain yield increased significantly to 1607 kg ha$^{-1}$ and 1708 kg ha$^{-1}$ with application of 25 and 50 kg N ha$^{-1}$, respectively over control (1393 kg ha$^{-1}$) (Table 4). Straw yield increased by 14 and 20% with application of 25 and 50 kg N ha$^{-1}$ over control.

**Interactions (Grain yield)**

During 1994–95, application of 25 kg N ha$^{-1}$ increased the grain yield significantly in deep (2047 kg ha$^{-1}$) and medium tillage (1576 kg ha$^{-1}$) over control (Fig 2). At the same N application, grain yield increased significantly in deeper tilled plots as compared to shallower tilled plots (medium and shallow tillage). In the pooled data, grain yield increased significantly in deep tillage and the application of 50 kg N ha$^{-1}$ (2074 kg ha$^{-1}$), whereas, a significant response was realized only up to 25 kg N ha$^{-1}$ in medium and shallow tilled plots.

**Economics**

**Tillage practices.** Significantly greater gross, net returns and benefit cost ratio was observed in deep tillage as compared to medium and shallow tillage during 1994–95, whereas, deep tillage recorded significantly greater gross returns, net returns over shallow tillage during 1995–96. Higher benefit cost ratio of 1.90 was observed in deep tillage (Tables 5 and 6).

**Organic materials.** Gross returns increased significantly with *Leucaena* loppings and farmyard manure application over vermicompost during 1994–95 and 1995–96, respectively (Tables 5 and 6). *Leucaena* loppings application recorded significantly greater net returns (179.67 and 185.73 \$ ha$^{-1}$) and benefit cost ratio (2.12 and 2.15) during 1994–95 and 1995–96, respectively.

**Nitrogen application.** Increase in N application to 50 kg ha$^{-1}$ increased the cost of cultivation and gross returns during both the years of study. During 1994–95, application of 25 kg N ha$^{-1}$ increased net returns (273.04 \$ ha$^{-1}$) and benefit cost ratio (1.85) significantly, whereas, during 1995–96 application of 50 kg N ha$^{-1}$ recorded significantly greater net returns (234.47 \$ ha$^{-1}$) and benefit cost ratio (1.94) over lower N rates (Tables 5 and 6).

## DISCUSSION

**Root studies.** The rate and amount of water and nutrient uptake by plants depends mainly on root development especially during drought years under dryland conditions. The greater root depth, it's spread and weight, with deep tillage compared to shallower tillage depths was attributed to loosening of top and subsoil and increased soil water content (Fig. 1). Increase in rooting depths and root density in crops following the use of a subsoiler at the time of seedbed preparation have been earlier reported (Bennie and Botha, 1986; Ross 1986; Barbosa *et al.*, 1989; Nitant and Pratap Singh, 1995; Pratap Singh and Verma 1996). *Leucaena* loppings application recorded greater root depth, root spread and root weight. *Leucaena* loppings incorporation recorded greater root weight (12.20 g plant$^{-1}$) as compared to farmyard manure (11.95 g plant$^{-1}$) vermicompost (10.72 g plant$^{-1}$) and it might be attributed to improved soil properties with greater water and nutrient availability (Patil, 1998).

Better root development i.e. root depth, root spread and root weight with increased N application to 50 kg ha$^{-1}$ was attributed to greater N availability (Patil, 1998). Deep tillage with application of *Leucaena* loppings and 50 kg N ha$^{-1}$ resulted in greater root depth (82.6 cm) with similar trend observed in root spread (57.7 cm) and root weight (16.03 g plant$^{-1}$) was attributed to improved soil properties (Patil, 1998).

**Grain and straw yield.** In the pooled analysis, grain yield increased by 18% in medium and 45% in deep tillage as compared to shallow tillage was attributed to greater profile water content in top 0.60 m soil depth in deep tillage at sowing and harvest during both years of study (Table 4 and Fig. 1). Greater in sorghum yield with deep tillage as compared to shallower tillage during 1994–95 though crop –experienced drought at physiological maturity as compared to 1995–96, when the crop was sown early with uniform distribution of rainfall and without water stress during cropping season was attributed to better response of winter sorghum to conserved moisture and nutrients in deeper tillage. The results of present studies are in accordance with the findings of Surkod (1993) and Patil (2001). Greater water conservation, particularly in years with lower than average precipitation in conservation tillage increased the wheat yield nearly by 3 times over traditional tillage in the sandy clay loam of Spain (Moreno *et al.*, 1997)

*Leucaena* loppings application increased grain and straw yields by 9 and 8% over vermicompost (pooled). The greater yields with *Leucaena* loppings application compared to vermicompost were attributed to improved soil properties with better root development and greater soil water in the profile at different stages of crop growth (Patil, 1998).

During 1994–95, grain and straw yield increased significantly with 25 kg N ha$^{-1}$ application over control, whereas, during 1995–96 and in the pooled data increase in N applications to 50 kg ha$^{-1}$ increased the grain yield significantly over lower N rates. Grain and straw yield increased significantly by 15 and 14% and 23 and 20% with application of 25 and 50 kg N ha$^{-1}$, respectively over control in the pooled data (Table 4). These soils are low in available N, application of increased N rates resulted in increased N availability with improved root growth, dry matter production and its translocation to ear as indicated by increased grain and straw yield (Patil, 1998). Patil *et al.* (1989) indicated that application of 50 kg N ha$^{-1}$ significantly increased the winter sorghum grain yield over bwer N rates.

The difference in response to N applications during both the years of study was attributed to difference in sowing time, rainfall distribution and available water in the profile during different stages of crop growth. Late sowing (5 October) with low water availability in the top 0.60 m soil profile and water stress especially at reproductive stages of crop growth during 1994–95 resulted in response of winter sorghum to only 25 kg N ha$^{-1}$, whereas, during 1995–96 timely sowing (15 September) with greater water availability during different stages of crop growth resulted in response of winter sorghum to 50 kg N ha$^{-1}$ (Fig. 1 and 2 and Table 4). The present study results are also supported by the findings of Rama Mohan Rao *et al.* (1995), as they reported that the response to applied N varied from 27 to 33 kg ha$^{-1}$ during below normal rainfall years and 38 to >60 kg ha$^{-1}$ during normal and above normal rainfall years in farmers' field and at Research Farm, respectively in the Bellary region (Northern Dry Zone of Karnataka State) of semi–arid tropics in South India. The above results clearly indicate the interaction and additive effect between soil water and increased N rates in the profile for winter sorghum when crop was grown in receding soil water.

**Interactions.** Grain yield increased significantly with application of 25 kg ha$^{-1}$ over control in medium tillage (1576 kg ha$^{-1}$) and deep (2047 kg ha$^{-1}$) and a further increase in N application to 50 kg N ha$^{-1}$ increased the grain yield marginally during 1994–95 (Fig. 2). Grain yield increased significantly in deep tillage and application of 50 kg N ha$^{-1}$ (2074 kg ha$^{-1}$), whereas, a significant response was realized only up to 25 kg N ha$^{-1}$ in medium and shallow tilled plots in the pooled data. Similar responses were observed in different crops by Howard (1987) and Lopez–Bellido *et al.* (1996).

**Economics.** During 1994–95 and 1995–96 the cost of cultivation was higher in deep tillage (203.53 and 203.04 \$ ha$^{-1}$) compared to medium (180.13 and 180.41 \$ ha$^{-1}$) and shallow tillage (165.04 and 162.23 \$ ha$^{-1}$). Significantly greater gross returns, net returns and benefit cost ratio was observed in deep tillage during 1994–95 and 1995–96 was attributed to greater grain and straw yields in deep tillage.

Application of *Leucaena* loppings proved beneficial during 1994–95 and 1995–96 with greater gross (340.73 and 346.85 \$ ha$^{-1}$), net returns (179.67 and 185.73 \$ ha$^{-1}$) and benefit cost ratio (2.12 and 2.15) over farmyard manure and vermicompost. Greater net returns and benefit cost ratio with *Leucaena* loppings was attributed to lower cost of cultivation and greater grain and straw yields.

Increase in cost of cultivation and gross returns with increased N application to 50 kg ha$^{-1}$ was attributed to increased cost of fertilizer and increased grain and straw yields during both the years of study. Significant increase in grain and straw yield during 1994–95 resulted in significant increase in net returns and benefit cost ratio up to 25 kg N ha$^{-1}$, whereas, during 1995–96 net returns and benefit cost ratio increased significantly up to 50 kg N ha$^{-}$

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**Tab.1. :** Nutrient content of organic materials

| **Organic materials** | **N (%)** | **P (%)** | **K (%)** |
|---|---|---|---|
| Vermicompost | 1.00 | 0.20 | 0.45 |
| *Leucaena* loppings | 2.70 | 0.27 | 1.40 |
| Farmyard manure | 0.60 | 0.40 | 0.70 |

**Tab. 2. :** Rainfall distribution at experimental site with sowing and harvest dates

| **Particulars** | **1994–1995** | **1995–1996** |
|---|---|---|
| Total rainfall (mm) (rainy days) | 585.8 (40) | 629.4 (50) |
| Crop season rainfall (mm) (rainy days) | 394.4 (15) | 370.0 (22) |
| Crop season + antecedent rainfall (mm) | 394.4 + 31.7 = 426.1 | 370.0 + 55.2 = 425.2 |
| Sowing date | 5.10.1994 | 15.09.1995 |
| Harvest date | 17.02.1995 | 27.01.1996 |

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**Tab. 3.:** Root length, spread and weight of winter sorghum as influenced by tillage practices, organic materials and nitrogen application at harvest (1995–96).

| Treatment | | Root length (cm) | | | | Root spread (cm) | | | | Root weight (g plant$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** |
| Tillage practices | Organic materials | Nitrogen application (kg ha$^{-1}$) | | | | Nitrogen application (kg ha$^{-1}$) | | | | Nitrogen application (kg ha$^{-1}$) | | | |
| | FYM (2.5 t ha$^{-1}$) | 57.4 | 66.0 | 74.4 | 65.9 | 46.8 | 56.0 | 53.7 | 52.2 | 12.73 | 14.23 | 14.53 | 13.83 |
| Deep tillage | VC (1.0 t ha$^{-1}$) | 54.2 | 62.8 | 55.2 | 57.4 | 46.1 | 50.8 | 54.6 | 50.5 | 11.30 | 12.33 | 14.23 | 12.62 |
| | *LEU* (2.5 t ha$^{-1}$) | 72.5 | 78.0 | 82.6 | 77.7 | 55.8 | 56.7 | 57.7 | 56.7 | 12.87 | 14.27 | 16.03 | 14.39 |
| | Mean | 61.4 | 68.9 | 70.7 | 67.0 | 49.6 | 54.5 | 53.3 | 53.1 | 12.30 | 13.61 | 14.93 | 13.62 |
| | FYM (2.5 t ha$^{-1}$) | 49.1 | 56.4 | 63.5 | 56.3 | 43.7 | 49.5 | 49.4 | 47.5 | 10.30 | 13.47 | 13.27 | 12.34 |
| Medium tillage | VC (1.0 t ha$^{-1}$) | 46.3 | 55.5 | 62.1 | 54.6 | 42.4 | 44.8 | 47.0 | 44.7 | 10.03 | 11.10 | 12.30 | 11.14 |
| | *LEU* (2.5 t ha$^{-1}$) | 57.5 | 60.5 | 67.6 | 61.9 | 48.4 | 50.7 | 52.7 | 50.6 | 11.83 | 12.13 | 12.30 | 12.09 |
| | Mean | 51.0 | 57.5 | 64.4 | 57.6 | 44.8 | 48.3 | 49.7 | 47.6 | 10.72 | 12.23 | 12.62 | 11.86 |
| | FYM (2.5 t ha$^{-1}$) | 36.2 | 44.7 | 46.0 | 42.3 | 32.0 | 39.7 | 42.3 | 38.0 | 8.83 | 10.57 | 9.63 | 9.68 |
| Shallow tillage | VC (1.0 t ha$^{-1}$) | 33.0 | 37.3 | 39.4 | 36.6 | 29.2 | 34.4 | 35.9 | 33.2 | 8.27 | 8.17 | 8.77 | 8.40 |
| | *LEU* (2.5 t ha$^{-1}$) | 40.5 | 48.7 | 49.9 | 43.4 | 35.8 | 42.3 | 41.9 | 40.0 | 9.03 | 10.57 | 10.73 | 10.11 |
| | Mean | 36.6 | 43.6 | 45.1 | 41.7 | 32.3 | 38.8 | 40.0 | 37.1 | 8.71 | 9.77 | 9.71 | 9.40 |
| | FYM (2.5 t ha$^{-1}$) | 47.6 | 55.7 | 61.3 | 58.9 | 40.8 | 48.4 | 48.5 | 45.9 | 10.62 | 12.76 | 12.48 | 11.95 |
| Mean | VC (1.0 t ha$^{-1}$) | 44.5 | 51.9 | 52.2 | 49.5 | 39.3 | 43.3 | 45.8 | 42.8 | 9.87 | 10.53 | 11.77 | 10.72 |
| | *LEU* (2.5 t ha$^{-1}$) | 56.8 | 62.4 | 66.7 | 62.0 | 46.7 | 49.9 | 50.8 | 49.1 | 11.24 | 12.32 | 13.02 | 12.20 |
| | Mean | 49.6 | 56.7 | 60.1 | 55.5 | 42.3 | 47.2 | 48.4 | 45.9 | 10.58 | 11.87 | 12.42 | 11.62 |
| Treatment | | S.Em± | LSD ($P$=0.05) | | | S.Em ± | LSD ($P$=0.05) | | | S.Em ± | LSD ($P$=0.05) | | |
| Tillage practices | | 3.2 | 12.6 | | | 1.6 | 6.4 | | | 0.70 | 2.76 | | |
| Organic materials | | 1.5 | 4.7 | | | 1.3 | 4.0 | | | 0.35 | 1.07 | | |
| Nitrogen application | | 1.6 | 4.6 | | | 1.5 | 4.2 | | | 0.36 | 1.03 | | |
| Interactions | | Interactions were not significant | | | | Interactions were not significant | | | | Interactions were not significant | | | |

Note: FYM=Farmyard manure, VC=Vermicompost, *LEU=Leucaena* loppings

**Tab. 4 .:**Grain and straw yield of winter sorghum as influenced by tillage practices, organic materials and nitrogen application.

| **Treatments** | **Grain yield (kg ha$^{-1}$)** | | | **Straw yield (t ha$^{-1}$)** | | |
|---|---|---|---|---|---|---|
| | **1994–95** | **1995–96** | **Pooled** | **1994–95** | **1995–96** | **Pooled** |
| Tillage practices | | | | | | |
| Deep tillage | 1919 | 1835 | 1877 | 2.09 | 2.12 | 2.10 |
| Medium tillage | 1509 | 1562 | 1535 | 1.69 | 1.91 | 1.80 |
| Shallow tillage | 1223 | 1368 | 1296 | 1.48 | 1.68 | 1.58 |
| SEm+ | 42 | 47 | 32 | 0.04 | 0.07 | 0.04 |
| LSD (*P*=0.05) | 164 | 186 | 103 | 0.16 | 0.29 | 0.14 |
| Organic materials | | | | | | |
| **Farmyard manure** (at 2.5 t ha$^{-1}$) | 1540 | 1605 | 1572 | 1.74 | 1.92 | 1.83 |
| Vermicompost **(at 1.0 t ha$^{-1}$)** | 1487 | 1512 | 1500 | 1.67 | 1.83 | 1.75 |
| *Leucaena* loppings **(at 2.5 t ha$^{-1}$)** | 1625 | 1647 | 1636 | 1.84 | 1.96 | 1.90 |
| SEm± | 51 | 41 | 28 | 0.05 | 0.05 | 0.03 |
| LSD (*P*=0.05) | 164 | 126 | 82 | 0.14 | NS | 0.09 |
| **Nitrogen application (kg ha$^{-1}$)** | | | | | | |
| **0** | 1540 | 1410 | 1393 | 1.57 | 1.71 | 1.64 |
| **25** | 1620 | 1595 | 1607 | 1.82 | 1.91 | 1.87 |
| **50** | 1657 | 1759 | 1708 | 1.86 | 2.09 | 1.97 |
| SEm± | 27 | 33 | 21 | 0.03 | 0.04 | 0.03 |
| LSD (*P*=0.05) | 78 | 98 | 59 | 0.09 | 0.12 | 0.07 |

Note: NS=Non–significant.

**Tab. 5 .:** Cost of cultivation ($ $ha^{-1}$), gross and net income ($ $ha^{-1}$) and benefit cost ratio as influenced by tillage practices, organic materials and nitrogen application during 1994 –95

| Tillage practices | Organic materials | Cost of cultivation | | | | Gross returns | | | | Net returns | | | | Benefit cost ratio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** |
| | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | |
| DT | FYM at 2.5 t ha$^{-1}$ | 186.57 | 197.03 | 203.16 | 195.58 | 315.23 | 425.71 | 429.14 | 390.02 | 128.66 | 228.67 | 225.98 | 194.44 | 1.69 | 2.16 | 2.11 | 1.99 |
| | VC at 1.0 t ha$^{-1}$ | 224.42 | 233.47 | 240.85 | 232.91 | 305.76 | 397.71 | 411.60 | 371.68 | 81.34 | 164.24 | 170.75 | 138.78 | 1.36 | 1.70 | 1.71 | 1.59 |
| | *LEU* at 2.5 t ha$^{-1}$ | 174.28 | 182.49 | 189.58 | 182.12 | 403.67 | 457.92 | 460.97 | 440.84 | 229.41 | 275.43 | 271.41 | 258.74 | 2.32 | 2.51 | 2.43 | 2.42 |
| | Mean | 195.09 | 204.33 | 211.17 | **203.53** | 341.55 | 427.12 | 433.88 | **400.87** | 146.48 | 222.78 | 222.71 | **197.33** | 1.75 | 2.09 | 2.05 | **1.97** |
| MT | FYM at 2.5 t ha$^{-1}$ | 164.80 | 172.87 | 179.38 | 172.34 | 300.00 | 344.26 | 321.32 | 321.84 | 135.21 | 171.38 | 141.94 | 149.50 | 1.82 | 1.99 | 1.79 | 1.87 |
| | VC at 1.0 t ha$^{-1}$ | 163.85 | 210.39 | 218.10 | 210.12 | 256.31 | 321.06 | 350.00 | 309.10 | 54.41 | 110.67 | 131.90 | 99.00 | 1.27 | 1.53 | 1.60 | 1.47 |
| | *LEU* at 2.5 t ha$^{-1}$ | 150.34 | 158.15 | 165.45 | 157.99 | 288.82 | 324.01 | 337.94 | 316.94 | 138.48 | 165.87 | 172.50 | 158.95 | 1.92 | 2.05 | 2.04 | 2.00 |
| | Mean | 172.34 | 180.48 | 187.64 | **180.13** | 281.72 | 329.75 | 336.42 | **315.95** | 109.38 | 149.28 | 148.79 | **135.82** | 1.63 | 1.83 | 1.79 | **1.75** |
| ST | FYM at 2.5 t ha$^{-1}$ | 149.56 | 157.24 | 164.50 | 157.12 | 232.00 | 255.85 | 273.19 | 256.22 | 82.44 | 106.23 | 108.69 | 99.10 | 1.55 | 1.68 | 1.66 | 1.63 |
| | VC at 1.0 t ha$^{-1}$ | 187.97 | 195.20 | 202.09 | 195.09 | 247.01 | 260.23 | 253.52 | 253.56 | 59.05 | 65.01 | 51.43 | 58.47 | 1.31 | 1.33 | 1.25 | 1.30 |
| | *LEU* at 2.5 t ha$^{-1}$ | 135.63 | 142.89 | 150.47 | 143.01 | 247.36 | 259.58 | 286.00 | 264.32 | 111.74 | 116.67 | 135.56 | 121.33 | 1.82 | 1.82 | 1.90 | 1.85 |
| | Mean | 157.69 | 161.30 | 172.38 | **165.03** | 242.11 | 261.10 | 270.90 | **258.00** | 84.42 | 95.99 | 98.53 | **92.98** | 1.54 | 1.62 | 1.57 | **1.56** |
| Mean | FYM at 2.5 t ha$^{-1}$ | 167.00 | 175.72 | 182.35 | **175.00** | 282.43 | 344.49 | 341.22 | **322.68** | 115.43 | 168.75 | 158.87 | **147.68** | 1.69 | 1.96 | 1.87 | **1.84** |
| | VC at 1.0 t ha$^{-1}$ | 204.75 | 213.01 | 220.31 | **212.70** | 269.69 | 326.31 | 338.36 | **311.47** | 64.94 | 113.10 | 118.06 | **98.75** | 1.32 | 1.53 | 1.54 | **1.46** |
| | *LEU* at 2.5 t ha$^{-1}$ | 153.39 | 161.19 | 168.49 | **161.04** | 313.29 | 347.18 | 361.64 | **340.73** | 159.90 | 185.99 | 193.15 | **179.67** | 2.04 | 2.15 | 2.15 | **2.12** |
| | Mean | **306.32** | **320.78** | **333.22** | – | **504.81** | **593.78** | **607.37** | – | **198.47** | **273.04** | **274.17** | – | **1.65** | **1.85** | **1.82** | – |
| For comparing means of | | | | | | | S.Em± | LSD ($P$=0.05) | | | S.Em± | LSD ($P$=0.05) | | | S.Em± | LSD ($P$=0.05) | |
| 1. Tillage (T) | | | | | | | 8.61 | 33.83 | | | 8.44 | 33.11 | | | 0.053 | 0.208 | |
| 2. Organic materials (O) | | | | | | | 8.10 | 24.99 | | | 7.95 | 24.50 | | | 0.041 | 0.126 | |
| 3. O at same T | | | | | | | 14.04 | NS | | | 13.77 | NS | | | 0.071 | NS | |
| 4. N application | | | | | | | 5.67 | 16.36 | | | 5.55 | 16.01 | | | 0.028 | 0.081 | |
| 5. N at same T | | | | | | | 9.80 | 28.33 | | | 9.61 | 27.74 | | | 0.048 | 0.133 | |
| 6. N at same O | | | | | | | 9.80 | NS | | | 9.61 | NS | | | 0.048 | NS | |
| 7. N at same T and O | | | | | | | 16.99 | NS | | | 16.64 | NS | | | 0.084 | NS | |
| 8. T at same/different O | | | | | | | 14.33 | NS | | | 14.05 | NS | | | 0.078 | NS | |
| 9. O at same/different N | | | | | | | 11.39 | NS | | | 11.17 | NS | | | 0.057 | NS | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10. O at same T and N | | | | | | 19.74 | NS | | | 19.34 | NS | | | 0.098 | NS | |
| 11. T at same/different N | | | | | | 11.76 | 33.97 | | | 11.52 | 33.27 | | | 0.066 | 0.191 | |
| 12. T at same O and N | | | | | | 8.61 | NS | | | 8.44 | NS | | | 0.104 | NS | |

Note: T=Tillage; DT=Deep tillage; MT=Medium tillage; ST=Shallow tillage; O=Organic materials; FYM=Farmyard manure; VC=Vermicompost; *LEU* =*Leucaena* loppings; N=Nitrogen application;
NS=Non–significant

**Tab. 6. :** Cost of cultivation (\$ ha$^{-1}$), gross and net income (\$ ha$^{-1}$) and benefit cost ratio as influenced by tillage practices, organic materials and nitrogen application during 1995–96

| **Tillage practices** | **Organic materials** | **Cost of cultivation** | | | | **Gross returns** | | | | **Net returns** | | | | **Benefit cost ratio** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** | **0** | **25** | **50** | **Mean** |
| | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | | **Nitrogen application (kg ha$^{-1}$)** | | | |
| | FYM at 2.5 t ha$^{-1}$ | 186.95 | 194.93 | 203.30 | 195.09 | 335.13 | 378.49 | 437.76 | 383.78 | 148.17 | 183.56 | 234.47 | 188.70 | 1.79 | 1.94 | 2.15 | 1.97 |
| DT | VC at 1.0 t ha$^{-1}$ | 224.95 | 232.75 | 240.40 | 232.72 | 330.49 | 365.52 | 396.18 | 364.07 | 105.53 | 132.77 | 155.79 | 131.37 | 1.47 | 1.57 | 1.65 | 1.56 |
| | *LEU* at 2.5 t ha$^{-1}$ | 173.06 | 181.32 | 182.07 | 181.35 | 352.63 | 406.61 | 465.34 | 408.21 | 179.57 | 225.30 | 283.27 | 226.85 | 2.04 | 2.24 | 2.56 | 2.25 |
| | Mean | 195.00 | 202.97 | 211.10 | **203.04** | 339.43 | 383.51 | 433.09 | **385.35** | 144.41 | 180.55 | 221.99 | **182.30** | 1.74 | 1.89 | 2.05 | **1.90** |
| | FYM at 2.5 t ha$^{-1}$ | 164.73 | 172.73 | 180.37 | 172.60 | 296.05 | 341.37 | 370.00 | 335.81 | 131.32 | 168.65 | 189.65 | 163.21 | 1.80 | 1.98 | 2.05 | 1.95 |
| MT | VC at 1.0 t ha$^{-1}$ | 202.55 | 210.46 | 217.84 | 210.26 | 285.74 | 326.57 | 344.45 | 318.92 | 83.20 | 116.11 | 126.61 | 108.66 | 1.41 | 1.55 | 1.58 | 1.52 |
| | *LEU* at 2.5 t ha$^{-1}$ | 150.69 | 158.25 | 165.95 | 158.25 | 307.84 | 331.43 | 364.30 | 334.51 | 157.15 | 173.18 | 198.36 | 176.26 | 2.04 | 2.09 | 2.20 | 2.11 |
| | Mean | 172.64 | 180.48 | 188.06 | **180.41** | 296.56 | 333.11 | 359.59 | **329.75** | 123.90 | 152.64 | 171.54 | **149.36** | 1.72 | 1.85 | 1.91 | **1.83** |
| | FYM at 2.5 t ha$^{-1}$ | 150.38 | 157.92 | 165.50 | 157.92 | 270.11 | 295.14 | 319.38 | 294.88 | 119.72 | 137.22 | 153.88 | 136.96 | 1.80 | 1.87 | 1.93 | 1.87 |
| ST | VC at 1.0 t ha$^{-1}$ | 156.36 | 195.39 | 203.23 | 185.01 | 240.82 | 276.05 | 305.90 | 274.26 | 84.46 | 80.66 | 102.67 | 89.25 | 1.54 | 1.41 | 1.51 | 1.48 |
| | *LEU* at 2.5 t ha$^{-1}$ | 135.85 | 143.85 | 151.45 | 143.69 | 260.40 | 303.05 | 329.88 | 297.76 | 124.55 | 159.22 | 178.43 | 154.07 | 1.92 | 2.11 | 2.18 | 2.07 |
| | Mean | 147.58 | 165.76 | 173.41 | **162.23** | 257.13 | 291.41 | 318.38 | **288.98** | 109.57 | 125.65 | 144.99 | **126.75** | 1.74 | 1.76 | 1.84 | **1.78** |
| | FYM at 2.5 t ha$^{-1}$ | 167.35 | 175.19 | 183.07 | **175.23** | 300.42 | 338.33 | 375.73 | **338.17** | 133.07 | 163.14 | 192.66 | **162.94** | 1.80 | 1.93 | 2.05 | **1.93** |
| Mean | VC at 1.0 t ha$^{-1}$ | 194.60 | 212.89 | 220.50 | **209.35** | 285.67 | 322.72 | 348.86 | **319.08** | 91.07 | 109.83 | 128.36 | **109.73** | 1.47 | 1.52 | 1.58 | **1.52** |
| | *LEU* at 2.5 t ha$^{-1}$ | 153.20 | 161.12 | 169.07 | **161.12** | 306.97 | 347.03 | 386.52 | **346.85** | 153.77 | 185.92 | 217.46 | **185.73** | 2.00 | 2.15 | 2.29 | **2.15** |
| | Mean | **186.95** | **194.93** | **203.30** | **–** | **335.13** | **378.49** | **437.76** | **–** | **148.17** | **183.56** | **234.47** | **–** | **1.73** | **1.84** | **1.94** | **–** |
| For comparing means of | | | | | | | S.Em± | LSD ($P$=0.05) | | | S.Em± | LSD ($P$=0.05) | | | S.Em± | LSD ($P$=0.05) | |
| 1. Tillage (T) | | | | | | | 10.20 | 40.02 | | | 10.78 | 42.35 | | | 0.059 | NS | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. Organic materials (O) | | | | | | 8.42 | 25.94 | | | 8.96 | 27.60 | | | 0.052 | 0.160 | |
| 3. O at same T | | | | | | 14.58 | NS | | | 15.51 | NS | | | 0.089 | NS | |
| 4. N application | | | | | | 6.95 | 20.07 | | | 6.14 | 17.72 | | | 0.032 | 0.092 | |
| 5. N at same T | | | | | | 12.04 | NS | | | 10.64 | NS | | | 0.056 | NS | |
| 6. N at same O | | | | | | 12.04 | NS | | | 10.64 | NS | | | 0.056 | NS | |
| 7. N at same T and O | | | | | | 20.86 | NS | | | 18.43 | NS | | | 0.097 | NS | |
| 8. T at same/different O | | | | | | 15.66 | NS | | | 16.63 | NS | | | 0.094 | NS | |
| 9. O at same/different N | | | | | | 12.95 | NS | | | 12.48 | NS | | | 0.069 | NS | |
| 10. O at same T and N | | | | | | 22.42 | NS | | | 21.60 | NS | | | 0.119 | NS | |
| 11. T at same/different N | | | | | | 14.16 | NS | | | 13.84 | NS | | | 0.074 | NS | |
| 12. T at same O and N | | | | | | 23.15 | NS | | | 10.78 | NS | | | 0.122 | NS | |

Note: T=Tillage; DT=Deep tillage; MT=Medium tillage; ST=Shallow tillage; O=Organic materials; FYM=Farmyard manure; VC=Vermicompost; *LEU*=*Leucaena* loppings; N=Nitrogen application;
NS=Non–significant

**Fig. 1. :** Soil water content (mm) in 0.6 m profile at different stages of crop growth as influenced by tillage practices,organic materials and nitrogen application