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Full Length Research Paper

Mulching and synergistic use of organic and chemical fertilizers enhances the yield, nutrient uptake and water use efficiency of sorghum

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Crop yields in arid lands are generally low and highly variable because of sparse and erratic precipitation leading to water stress. A greenhouse study was conducted to determine the effect of integrated nutrient management and mulching on the yield, nutrient uptake and water use efficiency (WUE) of sorghum. The treatments compared were: control, full N + P fertilizer, compost, manure, ½ N + P fertilizer + compost, and ½ N + P fertilizer + manure. Straw mulch was applied at the rate of 28 g pot^{-1} to one set of this experiment, while the other set did not receive straw mulch. Mulching gave statistically superior results over no mulch with respect to grain and stover yields, total N and P uptake, and water use efficiency (WUE), and it also reduced total water used. Among the nutrient management treatments, full N + P fertilizer gave the best results, however, it differed non significantly for ½ N + P fertilizer + compost and ½ N + P fertilizer + manure treatments for grain yield, total N and P uptake, and WUE. Difference between compost and manure applied either alone or with ½ N + P fertilizer was non-significant to all the crop parameters mentioned before. It was concluded that when mulch water was used more efficiently, it produces higher crop yield as compared to no-mulch. Similarly, combined use of organic and mineral fertilizers reduced the amount of water used by the crop; still the crop yield and WUE were comparable with NP fertilizer.

Key words: Integrated nutrient management, mulching, NP fertilizers, sorghum yield, WUE.

INTRODUCTION

Rain-fed agriculture is predominant in the world. About 80% of the agricultural land is under rain-fed production systems, sharing 60% of the world food production. In semi-arid regions, rain-fed agriculture experiences unreliable rainfall and recurrent droughts with subsequent production failures. Although irrigation plays an important role in food production, the possibilities of further extension seem to be limited since water resources of good quality have become scarce or too expensive (Stroosnijder, 2003).

Sorghum is one of the main staples ranking fifth globally. The crop is genetically suited to hot and dry agro ecologies where it is difficult to grow other food grains. In many of these agro-ecologies, sorghum is a dual-purpose crop, as both grain and stover are high value commodities. In most of the developing world, stover accounts for 50% of the total value of crop, especially in drought years (Abdelrahman, 1998). Developing countries represent about 90% of the world's sorghum area and 70% of total production (FAO/ICRISAT, 1996).

Adequate soil water or rainfall for timely planting, together with favorable growing season rainfall, allow for good yields of dryland sorghum (Unger and Baumhardt, 1997). However, water normally becomes limited during the critical reproduction and grain-filling growth stages and severely reduces grain yield (Bandaru et al., 2006). The

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use of surface organic mulch or straw can store more precipitation water in soil by reducing storm runoff, increasing infiltration, and decreasing evaporation (Schertz and Kemper, 1998).

Bayu et al. (2006) reported a positive effect of integrating farm yard manure and inorganic fertilizer on sorghum growth and yield. Enhanced maize growth, yield and nutrient uptake were recorded through balanced nutrition both from inorganic and biological sources (Jilani et al., 2007). Nutrient deficiencies can reduce water use efficiency (WUE) due to reduced yield and greater soil evaporation (Fisher and Turner, 1978). Akram et al. (2007) observed a significant positive effect of P and K fertilization on the biological and grain yield, nutrients uptake and fertilizer use efficiency of sorghum. Zaongo et al. (1997) obtained the highest WUE with the combined treatment of irrigation, mulch and N fertilizer.

So, there is a need to find farm inputs and practices that would reduce water losses and favour water efficient utilization. This study was conducted to evaluate integrated nutrient management along with mulching as water conservation practice for sorghum [*Sorghum bicolor* (L.) Moench] yield.

MATERIALS AND METHODS

This was a greenhouse experiment conducted at West Texas A&M University, Canyon, Texas, USA during April – July, 2007. Thirty six pots (30 cm diameter) were used to triplicate twelve treatment combinations (6×2) with a two factor factorial completely randomized design. The pots were lined with plastic bags from inside to restrict leaching. Each pot was filled with 10 kg soil after grinding and screening through 2 mm sieve. The soil was Amarillo fine sandy loam (fine loamy mixed, thermic, Aridic Paleustalfs) with a field capacity of 14% by weight, pH 7.65, organic matter 0.67%, NO_3 - N 6.23 mg kg^{-1}, and available P 12 mg kg^{-1}.

Treatments

Chemical and organic fertilizers

T_1 = Control
T_2 = 100 mg N kg^{-1} soil as urea + 50 mg P kg^{-1} soil as diammonium phosphate (DAP).
T_3 = Compost to supply 100 mg N kg^{-1} soil.
T_4 = Manure to supply 100 mg N kg^{-1} soil.
T_5 = 50 mg kg^{-1} N as urea + 50 mg P kg^{-1} as DAP + compost to supply 50 mg N kg^{-1} soil.
T_6 = 50 mg N kg^{-1} as urea + 50 mg P kg^{-1} as DAP + manure to supply 50 mg N kg^{-1} soil.

Mulching

M_1 = Wheat straw mulch applied at 2 g kg^{-1} soil (equivalent to 4 t ha^{-1}).
M_2 = No mulch was applied.

The organic and inorganic fertilizer treatments were mixed with soil while filling the pots as per treatments. Nine seeds of sorghum were sown at equal distance in each pot at 2 cm depth by hand on April 03, 2007. Equal amount of water viz. 1400 mL was added to each pot slowly. This amount of water was calculated on the basis of its predetermined field capacity. Pots were weighed daily to measure the water loss through evapo-transpiration, and deficit water was added to maintain the soil water at field capacity level. After emergence, extra seedlings were discarded to maintain five plants per pot. The position of each pot was randomized and changed weekly in the greenhouse to ensure uniform environ-mental conditions. During the study, maximum temperature inside the greenhouse was about 40°C and the minimum was 20°C.

Sorghum was harvested on 12th July, 2007, by cutting the plants at the level of soil surface. The plants were then separated into heads and stover, and each treatment samples were kept in separate bags. Plant samples were oven dried at 70°C till constant weight, grains were threshed and data were recorded as g pot^{-1} for stover and grain weight.

Chemical analysis

The compost and manure were analyzed by Servi-Tech Laboratories, Amarillo, TX, USA. Analyses showed the following composition of compost and manure:

Compost: 1.94 % total nitrogen, 1.11 % P;
Manure: 1.03 % total nitrogen and 0.47 % P.

Grain and stover samples were grinded and sub samples were taken to digest with H_2SO_4 and H_2O_2 for 7 h (Lu, 2000). Total nitrogen concentration in the digest was analyzed by continuous flow analysis (Chemlab, 1988) and P was determined by the molybdate-blue method (Lu, 2000). Uptake of N and P in grains (or stover) was calculated by multiplying yield of grain (or stover) by percentage of N and P in grains (or stover). The WUE (kg m^{-3}) was determined by dividing the biomass yield with total amount of water used. Total water used was the amount of water applied to crop during crop growth period from sowing till harvest.

Statistical analysis

Data was statistically analyzed using M-STAT C software and least significant difference (LSD) test was applied for treatment means at $p \leq 0.05$ (Steel et al., 1997).

RESULTS AND DISCUSSION

Sorghum yield

The highest grain yield was produced by full N + P fertilizer treatment and it was 110% greater than in the control (Table 1). Data also indicated statistically higher stover yield by full N + P fertilizer and it showed 54% increase over control. Application of ½ N + P fertilizer along with compost or manure produced statistically similar grain yield but lower stover yield as with full N + P fertilizer. Compost or manure applied singly could not give yield comparable to NP fertilizer. Mulching with wheat straw was significantly superior to no mulch for sorghum grain and stover yields. The interaction of nutrient sources and mulching was statistically non-significant for both grain and stover yield of sorghum.

Yield increase as a result of mulch conditions was due to the fact that water conservation improved physical and chemical properties of soil and enhanced biological

Table 1. Effect of integrated nutrient management and mulching on the yield of sorghum.

Nutrient sources	Grain yield (g pot^{-1})			Stover yield (g pot^{-1})		
	Mulch	No mulch	Means	Mulch	No mulch	Means
Control	21.9 ^{NS}	18.4	20.2 C**	28.9 ^{NS}	27.3	28.1 C**
Full N + P fertilizer	44.3	40.2	42.3 A	46.5	39.9	43.2 A
Compost	30.8	28.2	29.5 B	32.7	27.5	30.1 C
Manure	32.9	27.0	30.0 B	32.4	28.2	30.3 C
½ N + P + compost	44.1	34.0	39.1 A	37.7	35.5	36.6 B
½ N + P + manure	42.8	35.0	38.9 A	39.6	34.3	36.9 B
Means	36.2 A**	30.5 B		36.3 A**	32.1 B	

** Means in a column/row followed by same letter(s) are statistically non-significant at $p \leq 0.01$; ^{NS} Non-significant difference among means or interactions of treatments at $p \leq 0.05$.

Table 2. Effect of integrated nutrient management and mulching on N uptake by sorghum.

Nutrient sources	N Uptake by grain (g pot^{-1})			N Uptake by stover (g pot^{-1})		
	Mulch	No mulch	Means	Mulch	No mulch	Means
Control	0.18 ^{NS}	0.17	0.17 D*	0.09 ^{NS}	0.09	0.09 ^{NS}
Full N + P fertilizer	0.53	0.55	0.54 A	0.20	0.19	0.19
Compost	0.29	0.31	0.30 C	0.36	0.10	0.23
Manure	0.28	0.28	0.28 C	0.10	0.11	0.11
½ N + P + compost	0.45	0.42	0.44 B	0.15	0.14	0.14
½ N + P + manure	0.48	0.46	0.47 B	0.15	0.14	0.14
Means	0.37 ^{NS}	0.36		0.18 ^{NS}	0.13	

* Means in a column/row followed by same letter(s) are statistically non-significant at $p \leq 0.05$; ^{NS} Non-significant difference among means or interactions of treatments at $p \leq 0.05$.

activities (Deng et al., 2006; Ramakrishna et al., 2006). Surface mulching reduces evaporation and increases infiltration which result into more water availability for crop growth. Bayu et al. (2006) reported that the main effects of farm yard manure (FYM) and inorganic fertilizers were the increased stover yield by 8 - 21% and 14 - 21%, respectively. Use of FYM with inorganic fertilizers, in addition to nutrient supply and improvement of soil physical conditions, checks N losses and conserves soil N by forming organic-mineral complexes, thus ensuring continuous N availability and greater yields (Satyanarayana et al., 2002).

Nutrient uptake

The mean values of nutrient sources have significant difference for N uptake by sorghum grain but not by stover (Table 2). The highest N uptake to grain was under N + P fertilizer treatment, and it was statistically superior to all other treatments. The combined use of compost or manure with ½ N + P fertilizer also gave significantly higher N uptake by grains as compared to their sole use. Nitrogen uptake both by grain and stover under mulching had non-significant difference with no mulch treatment, although greater values with mulching. Interaction of nutrient sources with mulch treatments was also non-significant for N uptake by both grains and stover.

Bayu et al. (2006) found that inorganic fertilizer application at 50 and 100% of the recommended rate increased N uptake in 14 and 20% in the grain; 10 and 21% in the stover. Yang et al. (2004) reported the highest N uptake in wheat grain and straw with integrated nutrient application. Higher N uptake under N + P fertilizers was due to their fast release of nutrients rather than from organic sources. Sharma and Mittra (1991) reported that unlike mineral fertilizers, nutrients contained in organic manures are released more slowly and are stored for a longer time in the soil.

Phosphorus uptake to sorghum is shown in Table 3, for both grain and stover there was significantly higher P uptake with mulching as compared to no-mulch treatment. All the nutrient management treatments were statistically similar for P uptake to grain, and the highest value was obtained with full N + P fertilizer that showed 103% increase over control. Phosphorus uptake values of stover under nutrient management treatments were statistically alike with control at $p \leq 0.05$. Similarly, interaction of mulching with nutrient treatments was also

Table 3. Effect of integrated nutrient management and mulching on P uptake by sorghum.

Nutrient sources	P Uptake by grain (g pot^{-1})			P Uptake by stover (g pot^{-1})		
	Mulch	No mulch	Means	Mulch	No mulch	Means
Control	0.06 ^{NS}	0.06	0.06 B*	0.010 ^{NS}	0.010	0.010 ^{NS}
Full N + P fertilizer	0.11	0.11	0.11 A	0.043	0.023	0.033
Compost	0.10	0.09	0.09 A	0.017	0.010	0.013
Manure	0.10	0.09	0.09 AB	0.027	0.017	0.022
½ N + P + compost	0.13	0.10	0.11 A	0.017	0.010	0.013
½ N + P + manure	0.12	0.10	0.11 A	0.017	0.013	0.015
Means	0.10 A*	0.09 B		0.022 A*	0.014 B	

* Means in a column/row followed by same letter(s) are statistically non-significant at $p \le 0.05$; ^{NS} Non-significant difference among means or interactions of treatments at $p \le 0.05$.

Table 4. Effect of integrated nutrient management and mulching on water use efficiency.

Nutrient sources	Quantity of water used (L)			Water use efficiency (kg m^{-3})		
	Mulch	No mulch	Means	Mulch	No mulch	Means
Control	17.1 g*	22.8 c	19.9 D**	1.29 ^{NS}	0.81	1.05 D**
Full N + P fertilizer	23.3 c	26.4 a	24.9 A	1.90	1.51	1.71 A
Compost	18.3 f	23.3 c	20.8 C	1.69	1.18	1.45 BC
Manure	19.6 e	23.1 c	21.4 C	1.71	1.17	1.44 C
½ N + P + compost	21.6 d	25.5 b	23.85 B	2.04	1.32	1.68 AB
½ N + P + manure	21.4 d	24.9 b	23.2 B	1.97	1.39	1.68 AB
Means	20.2 B**	24.3 A		1.77 A**	1.23 B	

* Interaction means of nutrient sources with mulch / no mulch treatments having similar letter(s) are statistically non-significant at $p \le 0.05$; ** Means in a column/row followed by same letter(s) are statistically non-significant at $p \le 0.01$. ^{NS} Non-significant difference among means or interactions of treatments at $p \le 0.05$.

statistically non-significant. Parmar and Sharma (1996) found that P uptake increased with a higher amount of P fertilizer under mulch conditions.

Quantity of water used and water use efficiency

Total quantity of water used by plants under mulched and non-mulched treatments is shown in Table 4; no-mulch treatment consumed significantly higher quantity of water. Figure 1 shows that starting from 20 DAS and throughout the study period of 90 days water used by non-mulch treatment increased. It was mainly due to more evaporation from the bare soil surface without mulch. Use of surface organic mulch (straw) can result in storing more precipitation water in soil by reducing storm runoff, increasing infiltration, and decreasing evaporation (Schertz and Kemper, 1998). It was also reported that straw mulch increased soil water storage, decreased soil evaporation and increased plant transpiration (Raeini-Sarjaz and Barthakur, 1997). The mulch layer on the field surface reduces the intensity of turbulent exchange between the atmosphere and soil water, which causes soil moisture to be prevented from evaporating, and thus reduces ineffective water consumption (Dong and Qian, 2002). Ahmad et al. (2007) indicated that increased rate of wheat straw mulch from 1 to 4 t ha^{-1} enhanced the soil water contents progressively at various stages of crop growth.

Data in Table 4 also presents a comparison of various nutrient management treatments. With full rate of N + P fertilizers a higher quantity of water was used by the crop. Bar diagram shown in Figure 2 shows that the N+P fertilizer treatment (T_2) used more water than the integrated nutrient treatments (T_5 and T_6) did, but the yield of N+P fertilizer treatment was at par with these treatments. This was due to the fact that chemical fertilizers being a quick source of nutrients enhanced the vegetative growth of plants which resulted in more transpiration compared to that with organic fertilizers. Increasing N fertilization up to 100 or 150 kg ha^{-1} resulted in more forage and dry matter production (Turgut et al., 2005).

Organic matter retains more water and releases nutrients slowly than the chemical fertilizers do. Compost or manure along with ½ N + P fertilizer used comparatively less amounts of water during sorghum growth but they gave grain yield similar to that with full N + P fertilizer. The application of FYM has been reported to improve soil physical and chemical conditions and to help

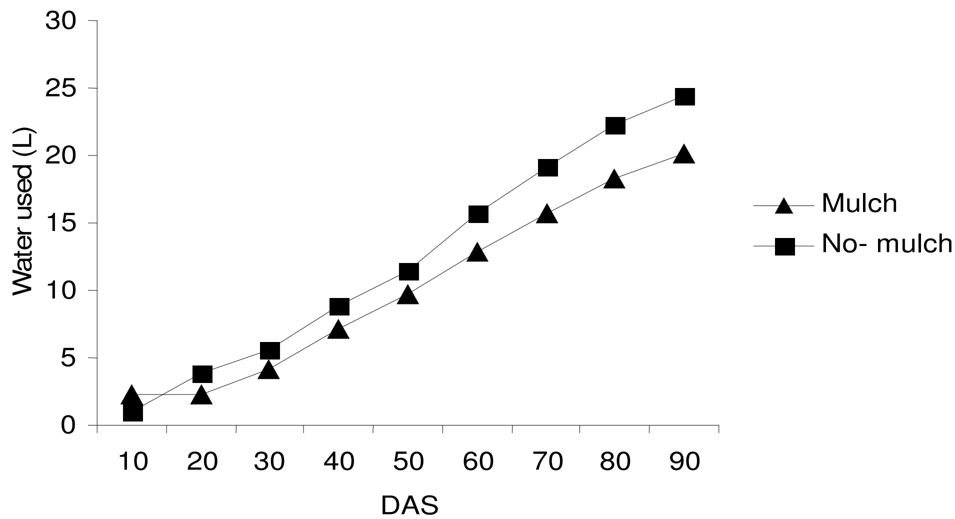

Figure 1. Water used affected by mulch and non-mulch treatments during sorghum growth.

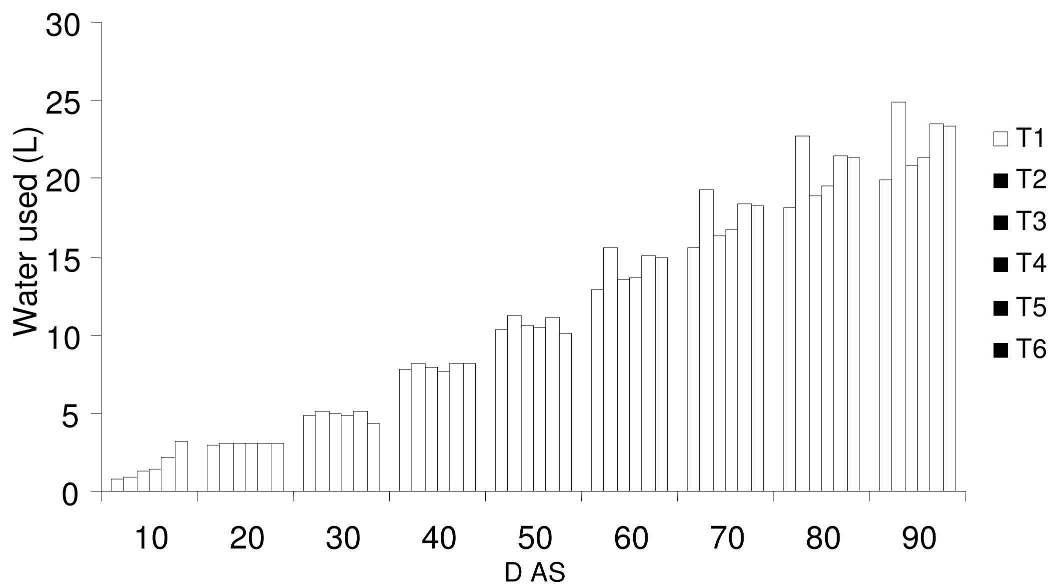

Figure 2. Total amount of water used by integrated nutrient management treatments during sorghum growth period. T_1= Control; T_2= Full N + P fertilizer; T_3= Compost; T_4= manure; T_5= ½ N + P + compost; T_6= ½ N + P + manure.

soil moisture conservation (Sattar and Gaur, 1989; Son et al., 1995).

Water use efficiency (WUE) was significantly higher with mulching as compared to non-mulch treatment (Table 4). Among nutrient management treatments, the highest WUE was recorded for full N + P fertilizer that was statistically at par with ½ N + P + compost and ½ N + P + manure. This was due to the fact that grain yields with these treatments were statistically similar. Nutrient deficiencies can reduce water use efficiency due to reduced yield and greater soil evaporation. Zaongo et al. (1997) reported 27% increase in WUE with mulch treatments. Huang et al. (2005) reported that straw mulch decreased evapo-transpiration and increased water use efficiency. Mulches modify the microclimate and growing conditions of crops (Albright et al., 1989), conserve more water and increase water use efficiency (Zhao et al., 1996). Mulches increase WUE as these reduce the soil water evaporation by reducing soil temperature, impeding water vapour diffusion, absorbing water vapor onto mulch tissue and reduce wind speed gradient at the soil-atmosphere interface (Sauer et al., 1996).

Conclusions

From the results of this study it was found that mulching is effective in enhancing the sorghum yield, phosphorus uptake and water use efficiency by the crop. Similarly, synergistic uses of organic and mineral nutrient sources also improve these attributes to the level of full NP fertilizer. Therefore, application of organic matter either as mulch or as supplementary nutrient source bears a significant beneficial impact on soil water conservation and nutrient supply for crop production.

REFERENCES

Abdelrahman AH (1998). Trends in Sudanese Cereal Production, Consumption, and Trade. Working Paper 98-WP 198. Center for Agricultural and Rural Development (CARD), Iowa State University, Ames, Iowa, USA. p. 4.

Ahmad ZI, Ansar M, Iqbal M, Minhas NM (2007). Effect of planting geometry and mulching on moisture conservation, weed control and wheat growth under rainfed conditions. Pak. J. Bot., 39(4): 1189-1195.

Akram A, Fatima M, Ali S, Jilani G, Asghar R (2007). Growth, yield and nutrients uptake of sorghum in response to integrated phosphorus and potassium management. Pak. J. Bot., 39(4): 1083-1087.

Albright LD, Wolfe D, Novak S (1989). Modeling row straw mulch effects on microclimate and yield - II. J. Am. Soc. Hort. Sci., 114: 569-578.

Bandaru V, Stewart BA, Baumhardt RL, Ambati S, Robinson CA, Schlegel A (2006). Growing dryland grain sorghum in clumps to reduce vegetative growth and increase yield. Agron J., 98: 1109-1120.

Bayu W, Rethman NFG, Hammes PS, Alemu G (2006). Effect of farmyard manure and inorganic fertilizers on sorghum growth, yield and nitrogen use in semi-arid area of Ethiopia. J. Plant Nutr., 29: 391-407.

Chemlab (1988). Instruction Manual. Chemlab Instruments Ltd.: Essex, England.

Deng XP, Shan L, Zhang HP, Turner NC (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. Agri. Water Manage., 80(1-3): 23-40.

Dong ZY, Qian BF (2002). Field investigation on effects of wheat-straw/corn-stalk mulch on ecological environment of upland crop farmland. J. Zhejiang Univ. Sci. B. 3(2): 209-215.

Fisher RA, Turner NC (1978). Plant productivity in the arid and semiarid zones. Annl. Rev. Plant Physio., 29: 277-317.

Food and Agriculture Organization (FAO) and International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) (1996). The World Sorghum and Millet Economies Facts, Trends and Outlook. FAO and ICRISAT. Rome, Italy.

Huang Y, Chen L, Fu B, Huang Z, Gong J (2005). The wheat yields and water-use efficiency in the Loess plateau: straw mulch and irrigation effects. Agri. Water Manage., 72(3): 209-222.

Jilani G, Akram A, Ali RM, Hafeez FY, Shamsi IH, Chaudhry AN, Chaudhry, AG (2007). Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and biofertilizers. Ann. Microbiol., 57(2): 177-183.

Lu RK (2000). Analysis of water, dry matter, gross minerals, and N, P and K in plant samples. In: Methods of Soil and Agro-Chemistry Analysis. Chinese Agricultural Science and Technology Press, Beijing, China. pp. 302-316.

Parmar DK, Sharma PK (1996). Phosphorus and mulching effects on nutrient uptake and grain yield of wheat at different growth stages. Trop. Agric., 73: 196-200.

Raeini-Sarjaz, Barthakur NN (1997). Water use efficiency and total dry matter production of bush bean under plastic straw mulches. Agric. For. Meteorol., 87: 75-84.

Ramakrishna A, Tam HM, Wani SP, Long TD (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crops Res., 95(2-3): 115–125.

Sattar MA, Gaur AC (1989). Effect of VA-mycorrhiza and phosphate dissolving microorganism on the yield and phosphorus uptake of wheat (*Triticum vulgare*) in Bangladesh. Bangl. J. Agric. 14(3): 233-239.

Satyanarayana V, Prasad PVV, Murthy VRK, Boote KJ (2002). Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. J. Plant Nutr., 25: 2081-2090.

Sauer TJ, Hatfield JL, Prueger JH (1996). Corn residue age and placement effects on evaporation and soil thermal regime. Soil Sci. Soc. Amer. J., 60: 1558-1564.

Schertz DL, Kemper WD (1998). Crop-residue management system and their role in achieving a sustainable, productive agriculture. In: L.S. Bushan, I.P. Abrol and M.S. Rama Mohan Rao (eds.) Soil and Water Conservation: Challenges and Opportunities. Proc. 8th ISCO Conf., 1994. New Delhi. A.A. Balkema, Rotterdam, The Netherlands. pp. 1255-1265.

Sharma AR, Mittra BN (1991). Effect of different rates of application of organic and nitrogen fertilizers in a rice-based cropping system. J. Agric. Sci., 117: 313-318.

Son TT, Sing U, Padilla JL, Buresh RJ (1995). Management of urea and degraded soils of Red River Delta: Effect of growing season and cultural practice. In: GL Denning and VT Xuan (eds.), Proceedings of Conference of Vietnam and IRRI - A Partnership in Rice Research, May 4-7, 1994, Hanoi, Vietnam. IRRI, Manila, Philippines. pp. 161-175.

Steel RGD, Torrie JH, Dickey DA. (1997). Principles and Procedures of Statistics: A Biometrical Approach. 3rd Ed. WCB McGraw-Hill, New York. p.666.

Stroosnijder L (2003). Technologies for improving green water use efficiency in West Africa. Proceedings of Symposium and Workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa, Bloemfontein, South Africa. pp. 8-11.

Turgut U, Bilgili A, Duman, Acikgoz E (2005). Production of sweet sorghum (Sorghum bicolor L. Moench) increases with increased plant densities and nitrogen fertilizer levels. Acta Agri. Scan. Sec B-Soil and Plant, 55: 236_/240.

Unger PW, Baumhardt RL (1997). Factors related to dryland grain sorghum yield increases: 1939 through. Agron. J., 91: 870-875.

Yang S, Li F, Malhi SS, Wang P, Suo D, Wang J (2004). Long-term fertilization effects on crop yield and nitrate nitrogen accumulation in soil in northwestern China. Agron. J., 96: 1039-1049.

Zaongo CGL, Wendt CW, Lascano RJ, Juo ASR (1997). Interactions of water, mulch and nitrogen on sorghum in Niger. Plant Soil, 197: 119-126.

Zhao JB, Mei XR, Zhong ZZ (1996). The effect of straw mulch on crop water use efficiency in dryland. Sci Agric. Sinica, 29(2): 59-66.