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Optimizing subsoiling tillage and nitrogen rates for fodder productivity and ethanol production of sorghum *(Sorghum bicolar* L.) in Northern Himalayas

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Introduction

In India, sorghum occupies 4.09 million ha area with production and productivity of grain about 3.48 million tons 849 kg grain/ha, respectively (Agricultural Statistics at a Glance, 2020). Presently sweet sorghum (*Sorghum bicolar* (L.) Moench.) is gaining popularity among farming communities mainly because of its fast growing habit, wide adaptability, tolerance to abiotic stress, higher grain productivity, good quality of green fodder and moreover the potential source of energy. Its stalk contains 15-17% fermentable sugars, 47% juice with 7.24% sugar content (Hugar, 2010). Besides, single cut sweet sorghum produced 35-50 t ha^{-1} stalk, 1.5-2.5 t ha^{-1} grain and 2760 lakh ha^{-1} ethanol (Ratnavathi *et al*., 2004). Sweet sorghum is a promising source of biofuel like ethanol, jaggery and syrup that can produce nearly 2000-2800 lha^{-1} and grains can also be used for making potable ethanol with a recovery rate of 400 lt^{-1} of grain (Singh, 2010). In general, sorghum plant attains height up to 3.50m, leaves are broad ~12 cm and long ~125cm and the stalk contributes 70-80% to biomass.

Tillage and balanced fertilization are two basic indices for sustainable crop production. The heavy tillage with regular use of disc harrow has now been obsolete in view of conservation tillage mainly because traditional tillage pulverizes top 15 to 20 cm soil leading to formation of hard pan (Kumar, 2003) resulting into reduced percolation. Hence water stagnation creates a reduced rhizosphere which is unfavorable for nutrient absorption and root growth. Subsoiling and differential rate of deep tillage along with fertilizer application have proved the suitability for not only breaking the hard pan but also making nutrients available at different depths for higher crop productivity (Manoj *et al*., 2022). Chen and Haung (1972) reported that differential rate of subsoiling at a depth of 25-30 and 60-90 cm improved the yield of autumn planted cane.

Fertilizer broadcasting results in low fertilizer use efficiency due to various losses (Rababi, 2006) as surface applied nitrogenous fertilizers are more prone to volatilization. That is, 40 to 50% of applied nitrogen and only 22 to 30% of applied phosphorus and potassium fertilizers are effectively used by the crop and the remaining get either washed away, volatilized, leached to ground water or get fixed with soil (Rowse and Stone, 1980).

Broadcasting is a common method of fertilizer application just before last tillage or seeding. These fertilizers are localized in the upper layer of soil, so the soil's larger, deeper portion is less available to plant roots. Therefore, it is essential to place P and K fertilizers in root zone for higher availability and its use efficiencies. Thakur and Mandal (2010) reported greater nutrient uptake and higher sugarcane yield under sub-soiling, with deep and differential rate placement of fertilizers in the root zone of the crop. Besides demonstrating such great importance of deep and differential place of fertilizers, very little research work has been conducted so far on commercial crops including sweet sorghum. Considering the above facts, the present study was carried out to study the effect of subsoiling tillage and nitrogen levels on fodder productivity and ethanol production of sorghum *(Sorghum bicolar* L.) in the Northern Himalayas.

Methods

The field experiment was conducted during the *Kharif* crop season (June to October)-2011 and 2012 at the Instructional Dairy Farm, Nagla, G.B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar (Uttarakhand), India. The climate of the experimental site was humid sub-tropical with hot summers and cold winter. The mean annual rainfall is 1554.1mm of which 80 to 90 per cent is received from June to October. The total rainfall received during the crop period in 2011 and 2012 was 2007.8mm and 752.8mm, respectively. The soil of the experimental field was well drained with a slight silty clay loam texture and pH 7.21. The available organic carbon was 0.72% and available nitrogen and phosphorus and potash were 272.3, 29.0 and 236.1kg/ha, respectively. The experiment consisted of four tillage levels in main plot i.e. conventional tillage (CT), subsoiling (20cm) followed by (fb) rotavator x1(SS fb R), subsoiling-cum-deep placement (40cm) fb rotavator x1(DP fb R) and subsoiling-cum-differential rate fertilizer placement (25 & 50 cm) fb rotavator x1(DRF fb R) and four N levels in sub plot i.e. control (zero nitrogen), 40, 80 and 120 kg N/ha, was laid out in split plot design with four replications. The recommended dose of phosphorus (60 kg/ha) and potash (40 kg/ha) was deep placed as per the subsoiling treatments, while in conventional tillage it was applied at last tillage. The nitrogen was applied manually as per treatments in two equal splits i.e. 50 % basal and 50% at 30 days after sowing in all treatments. Sweet sorghum variety SPSSV-6 was planted on 27 May 2011 and 4 May 2012. The crop was harvest at pre heading stage and green, dry fodder yield were recorded. The ethanol yield was estimated with the help of sugar yield (Spencer and Meade, 1955) as given below;

Sugar yield (t/ha) = Available sugar (%) x Juice yield (kl/ha) /100

Ethanol yield (l/ha) = Sugar yield (t/ha) x 3.78 x1000 x 0.8

Results and Discussion

a. Effect of tillage options

Tillage options had significant impact on the green and dry fodder yields (Table.1). The pooled values of two years of field experimentation indicated that DRF *fb* R produced significantly highest green fodder yield (Fig.1). The DRF *fb* R had 6.3, 13.5 and 23.8% greater green fodder yield than DP *fb* R, SS *fb* R and CT respectively. Similarly DP *fb* R gave 6.6, while SS *fb* R gave 9.1% more green fodder yield than SS *fb* R and CT, respectively. The dry fodder yield was also recorded significantly higher under DRF *fb* R, while DP *fb* R produced 6.7% higher dry fodder yield than SS *fb* R which also had 1.9% higher dry fodder yield than CT. DP fb R and DRF *fb* R also had 8.6% and 19.3% higher dry fodder yield than CT, respectively. Further, it was also noted that DP *fb* R and DRF *fb* R also produced 6.7% and 17.1% more dry fodder yield than SS fb R, respectively (Fig.3). The higher values of green and dry fodder yield under differential rate fertilizer placement favoured better utilization of nutrient and moisture resulting into higher growth attributes. Kumar *et al.* (2022) also reported significantly higher green and dry fodder yields than CT and SS fb R.

The ethanol yield varied significantly among tillage options during both the years (Table.1. Significantly highest ethanol yield was obtained under DRF *fb* R followed by DP *fb* R, SS *fb* R and the lowest under CT, during both the years. Based on pooled values, the DRF *fb* R yielded 23.2, 41.7 and 45.1% higher ethanol than DP *fb* R, SS *fb* R and CT, respectively (Fig.5). The higher ethanol yield was ascribed to higher stalk juice yield. Singh (2008) supported these findings.

b. *Effect of nitrogen levels*

The green and dry fodder yield increased with increasing nitrogen levels with highest values at 120 kg nitrogen/ha (Table.1). The pooled values showed that application of 120 kg N/ha produced 6.9 and 14.7% higher green fodder yield than 80 and 40 kg N/ha, respectively, while it was 8.2% higher at 80 kg than 40 kg N/ha. Similarly at 40 kg nitrogen, the green fodder yield was 4.7% higher than the control (Fig.2). A similar trend was also observed in dry fodder yield which was 7.1% higher at 120 kg than 80 kg N/ha (Fig.4). The higher values of fodder yields were attributed to taller plants, higher leaf area index and dry matter accumulation. The results of Moghimi and Emam (2015) and Kumar *et al.* (2022) support these findings, however they had different field ecologies and crop varieties. The ethanol yield was increased with increasing level of nitrogen and the highest values were recorded at 120 kg N/ha during both the years (Table.1). The pooled values showed 29.3, 57.8 and 62.8% higher ethanol yield at 120 kg N/ha, respectively (Fig.6). The higher ethanol yield was the result of higher green stalk yield and juice percentage. Shehab and Guo (2020) also recorded similar results.

An interaction was found between subsoiling and nitrogen levels (Table.2). The ethanol yield was increased with increasing level of nitrogen with significant highest values at 120 kg N/ha except under DP fb R, SS fb R and CT that had non-significant values between 0 to 40 and 40 to 80 kg N/ha. The conventional tillage gave the lowest ethanol yield at all the nitrogen levels and the values were non- significant between 0 and 40 as well as 40 and 80 kg N/ha and a similar trend was observed an SS *fb R* and DP *fb R* produced higher yield at 40 kg N than CT, Similarly the ethanol yield was noted significantly highest under DRF *fb R* at all the nitrogen levels but DP *fb R* and DRF *fb R* were non-significant at 80 kg N/ha. In general the ethanol yield was recorded as non-significant under CT, SS *fb R* and DP *fb R* at both control and 40 kg N/ha, whereas DP *fb R* gave significantly higher ethanol yield at both 80 and 120 kg N/ha.

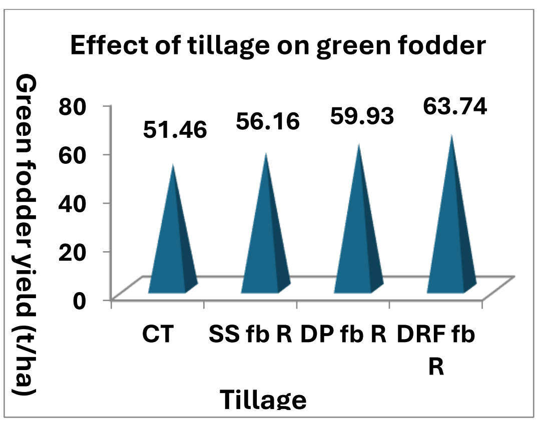

Fig.1. Effect of tillage on green fodder yield (pooled values of two years)

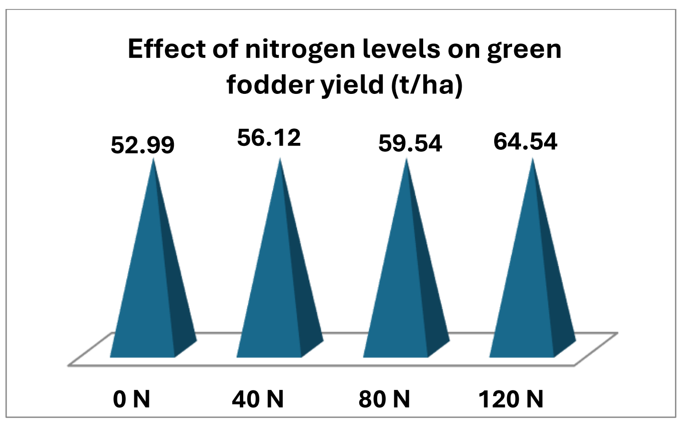

Fig.2. Effect of tillage on green fodder yield (pooled values of two years)

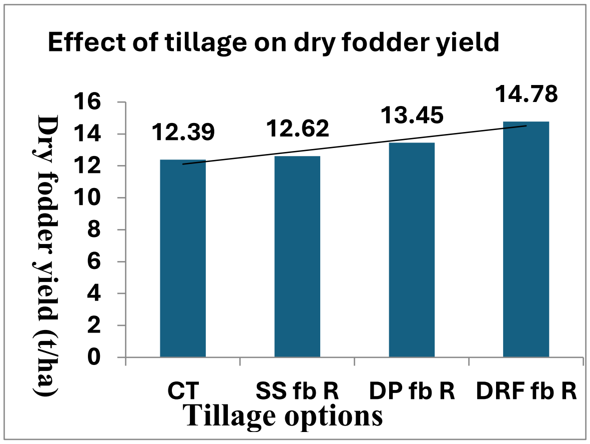

Fig.3. Effect of tillage on dry fodder yield (Pooled values of two years)

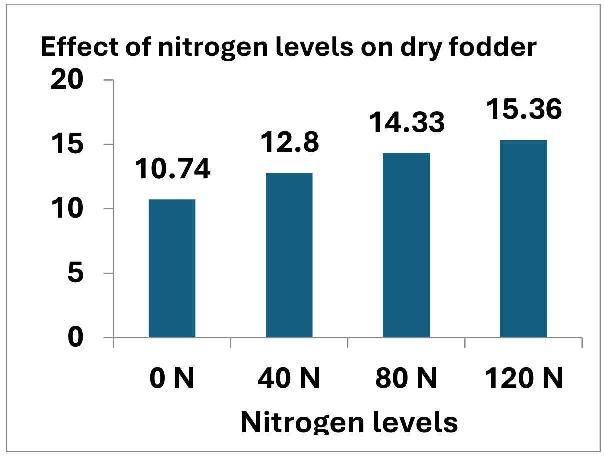

Fig.4. Effect of nitrogen level on dry fodder yield (Pooled values of two years)

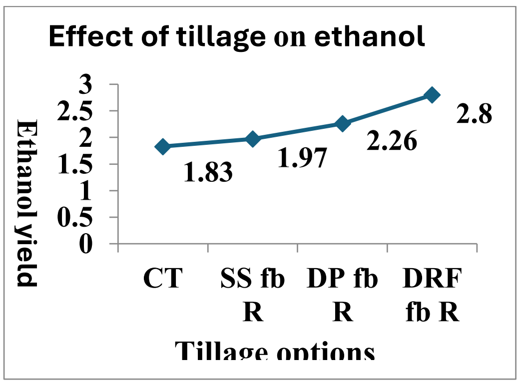

Fig.5. Effect of tillage on ethanol yield (Pooled values of two years)

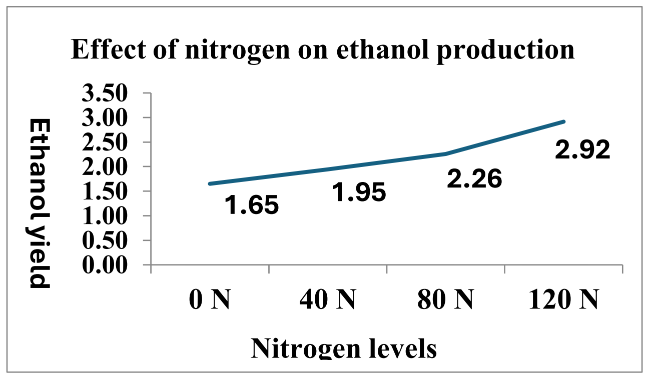

Fig.6. Effect of nitrogen level on ethanol yield (Pooled values of two years)

Table 1. Effect of tillage and nitrogen levels on fodder productivity and ethanol production of sorghum (Sorghum bicolor L.) during Kharif season 2011 and 2012

Treatment	Green fodder yield (t/ha)		Dry fodder yield (t/ha)		Ethanol production (kilo litre/ha)	
	2011	2012	2011	2012	2011	2012
A. Tillage options						
CT	52.68	50.24	13.01	11.78	1.85	1.81
SS *fb* R	56.44	55.88	13.27	11.97	2.02	1.92
DP *fb* R	60.22	59.65	14.18	12.80	2.38	2.14
DRF *fb* R	63.82	63.63	15.67	13.91	2.98	2.61
SEm±	0.35	0.90	0.18	0.20	0.80	0.80
CD at 5%	1.11	2.88	0.57	0.64	0.25	0.25
B. Nitrogen levels (kg/ha)						
0	52.99	52.87	11.27	10.20	1.70	1.60
40	56.12	54.68	13.48	12.13	1.90	1.99
80	59.54	59.33	15.32	13.55	2.26	2.25
120	64.54	62.53	16.15	14.52	2.96	2.87
SEm±	0.50	1.13	0.17	0.18	0.11	0.12
CD at 5%	1.45	2.21	0.48	0.53	0.31	0.33
Interaction	NS	NS	NS	NS	S	S

Table 2. Interaction between tillage and nitrogen level on Ethanol yield at harvest based on pooled data

Tillage	Ethanol yield (kilo litre/ha)			
	Nitrogen levels (kg/ha)			
	0	40	80	120
CT	1.3	1.6	1.9	2.4
SS fb R	1.4	1.7	2.0	2.7
DP fb R	1.8	1.9	2.4	2.8
DRF fb R	2.1	2.6	2.8	3.8
			S Em±	CD at 5%
For Comparing tillage at constant N level			0.13	0.40
For comparing N level at constant tillage			0.11	0.40

Conclusion and Implications

Based on pooled values of 2011 and 2012 field experimentation, it may be concluded that sweet sorghum may be grown under differential rate placements of P and K at 25 and 50 cm depth with application of a recommended 120 kg N/ha for higher fodder yield and ethanol production in Northern Himalayan regions of India. This may be able to be replicated in similar ecologies of the world.

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