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Effect of moisture conservation, sowing methods and split application of nitrogen on sustainable profitability of pearlmillet under arid inceptisols

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ABSTRACT

A field experiment was conducted for 4 years (2007 to 2010) on pearlmillet in an arid Inceptisol at Agra in north India to identify a profitable moisture conservation practice alongwith split nitrogen application practices. Five moisture conservation practices [flat bed + broadcast sowing; flat bed + broadcast sowing + conservation furrow; flat bed + line sowing; flat bed + line sowing + conservation furrow; ridges and furrows]; and 5 nitrogen levels [control; 60 kg N ha^{-1} at sowing; 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering); 60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing); 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)] were tested. The rainfall received from sowing to harvest ranged from 315.7 to 758.4 mm in different years. Based on analysis of variance, the effects of moisture conservation, nitrogen application and their interaction were significant during all the years of experimentation. The ridges and furrows method gave significantly higher mean yield of 2986 kg ha^{-1} and rainwater use efficiency (RWUE) of 9.46 kg ha^{-1} mm^{-1} over different nitrogen application practices; while 60 kg N ha^{-1} in 3-equal splits gave mean yield of 3106 kg ha^{-1} with RWUE of 9.84 kg ha^{-1} mm^{-1} over moisture conservation practices. When compared with control, the 3-equal splits of N gave mean yield increase of 77.9%, followed by 3-unequal splits with 69.8%, 2-equal splits with 53.5% and 100% nitrogen application as basal with 32.8% over years. Similarly, when compared with 100% N as basal, the 3-equal splits of N gave yield increase of 34.7%, followed by 3-unequal splits with 28.5% and 2-equal splits with 16.2% over years. By adopting ridges and furrows together with 60 kg N ha^{-1} in 3-equal splits, the farmers could get sustainable pearlmillet yield of 3807 kg ha^{-1} with RWUE of 7.27 kg $ha^{-1}mm^{-1}$; gross returns of ₹ 29,512 ha^{-1} with benefit-cost ratio of 2.59; and nitrogen use efficiency of 63.5% over years under arid Inceptisols.

1. INTRODUCTION

Among different cereal crops, pearlmillet is an important crop grown by farmers under rainfed conditions. It is grown as a sole crop and an intercrop as well and is suitable for any soil and agro-climatic condition. Pearlmillet is grown in area of 9.5 m ha with production of 9.79 m t and yield of 1030 kg ha^{-1} during 2007-08 (Anonymous, 2009). Rajasthan is leading with area of 5.08 m ha, production of 4.22 m t and yield of 832 kg ha^{-1}; followed by Maharashtra with area of 1.28 m ha, production of 1.13 m t and yield of 878 kg ha^{-1}. Pearl millet has more resistance to drought than sorghum and yields well in poor sandy soil on which most crops fail. The grain of pearlmillet is superior in nutritive value than sorghum grain but inferior in feeding value. Pearlmillet grain contains about 12.4% moisture, 12.6% protein, 5%

fat and 67.3% carbohydrates. Under rainfed condition, productivity depends on rainfall and its distribution received during crop growing period (Maruthi Sankar *et al.,* 2011). Apart from rainfall, efficient management of (i) rainwater with suitable moisture conservation practice; and (ii) nitrogen application is needed for attaining sustainable yield of pearlmillet. Among different moisture conservation practices, conservation furrow is identified as an indigenous practice for *in-situ* moisture conservation and is adopted by farmers under semi-arid conditions (Srinivasa Rao *et al.,* 2014). This practice is disappearing due to non-availability of animal draft power and reduction in size of holding. Sowing through tractor drawn seed drill is not solving the problem of runoff disposal. Combined adoption of both indigenous and modern techniques could provide an opportunity to harvest more rainwater for getting higher yield (Mishra *et al.,* 2002a, 2002b). This would ensure significantly higher rainwater use efficiency (RWUE) under low and erratic rainfall conditions under any soil and agro-climatic condition. There is a need to identify a suitable moisture conservation practice in order to efficiently utilize the low and erratic rainfall received during crop growing period and maximize RWUE of crops under rainfed condition. Sharma *et al.* (2014) described on the need for efficient soil management practices for improving the soil physical condition, soil fertility and quality under hot semi-arid inceptisols.

Amir *et al.* (1991) examined the water use efficiency as influenced by management practices in wheat under arid condition. Zougmore *et al.* (2004) reported benefits of combining soil and water conservation and fertilizer practices on sorghum. They found that combining compost with stone rows or grass strips significantly increased yield and monetary returns. Peterson *et al.* (1996) observed a significant effect of crop and tillage treatments on RWUE. Siva Kumar and Salaam (1999) studied the effects of years with varying rainfall and fertilizer on water use efficiency of pearlmillet. With a better water use efficiency, the fertilizer use efficiency was found to improve in pearlmillet based on the study. Apart from a suitable moisture conservation practice, there is a need of split nitrogen application in optimum number of splits for effective utilization of rainwater and attaining maximum profitability under rainfed condition. Significant interaction of nitrogen application and sowing dates on growth, development and millet yield were reported by Bacci *et al.* (1999). A suitable date of sowing with optimal level of nitrogen application would provide significantly higher level of yield. Similar results were reported by Bationo *et al.* (1990), who examined nitrogen application and plant density effects on pearlmillet yield. Bationo and Ntare (2000) found significant effect of nitrogen application on pearlmillet, cowpea and groundnut yield under rotation, apart from influencing soil nutrients in a sandy soil. Optimum soil test based fertilizer dose with maximum N use efficiency is desirable for attaining maximum yield and monetary returns from any crop. Maman *et al.* (1999) found a significant influence of N on yield and plant N uptake of pearlmillet and managed N for maximum N use efficiency. Fechter *et al.* (1991) studied effects of timing and N dose on yield and protein content in wheat.

In order to minimize risk of crop failure or low productivity, it is essential to apply fertilizer N in optimum splits for efficient utilization of rainfall received during crop growing period from sowing to harvest of a crop under any soil and agro-climatic condition. The information is lacking on suitable moisture conservation and nitrogen application for enhancing productivity and profitability of pearlmillet under rainfed condition. Based on a field experiment conducted for 4 years in the same site, we have assessed the efficiency of moisture conservation practices and split nitrogen application practices for attaining sustainable productivity, profitability and N use efficiency by growing pearlmillet under arid inceptisols.

2. MATERIALS AND METHODS

Experimental Details

A field experiment on pearlmillet with variety 'Pro-Agro-9330' was conducted in the same site under arid conditions in an Inceptisol at Agra in northern India for 4 years during *kharif* 2007 to 2010. Agra is located at a Latitude of 27.2 North, Longitude of 77.9 East and Altitude of 163.4 m above msl. The soils are deep loamy alluvium derived soils (occasionally saline and sodic phases) with medium available water capacity of 5 to 6 cm. The soil texture of experimental site is sandy loam with pH of 7.8, electrical conductivity of 0.69 dS m^{-1}, cation exchange capacity of 25.2 cmol (p+) kg^{-1}, sand of 64.6%, silt of 21.4% and clay of 14.0% with 1 m soil depth. The soil fertility of the experimental field ranged from 139 to 150 kg ha^{-1} of N; 15 to 20 kg ha^{-1} of P_2O_5; and 100 to 125 kg ha^{-1} of K_2O in the study period. The field experiments were conducted in the same site with 25 treatment combinations based on 5 each of moisture conservation and split nitrogen application practices. The moisture conservation practices tested were (i) flat bed + broadcast sowing; (ii) flat bed + broadcast sowing + conservation furrow; (iii) broadcast sowing + line sowing; (iv) line sowing + conservation furrow; and (v) ridges and furrows. The fertilizer practices were (i) control; (ii) 60 kg N ha^{-1} at sowing (no split); (iii) 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering); (iv) 60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing); and (v) 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing). The field experiments were conducted in a split-plot design with 4 replications in a net plot size of 4 x 2.7 m. The moisture conservation practices were superimposed to the main plots, while the nitrogen application practices were superimposed to the subplots. Under ridges and furrows practice, the ridge had a height of 25 cm. A distance of 90 cm was maintained between two furrows (from center point). A uniform fertilizer dose of P_2O_5 @ 50 kg ha^{-1} as single super-phosphate and K_2O @ 50 kg ha^{-1} as muriate of potash were applied at the time of sowing in each plot every year. A seed rate of 5 kg ha^{-1} and row x plant spacing of 45 x 15 cm were adopted every year (Mishra *et al.,* 2010).

Rainfall and its Distribution during Crop Growing Period

At Agra, the probable week of onset of monsoon is 27th standard meteorological week (SMW) and withdrawal of monsoon is 38th SMW. The location received a normal annual rainfall of 665.0 mm (mean of 45 years), out of which 589.1 mm is received during June to September. During 2007 to 2010, the crop growing period (CGP) of pearlmillet ranged from 86 to 101 days depending on the onset and withdrawal of the monsoon in different years. The crop was sown on 10th July (28th SMW) and harvested on 11th October (41st SMW) with CGP of 94 days in 2007; while it was sown on 27th June (26th SMW) and harvested on 5th October (40th SMW) with CGP of 101 days in 2008; sown on 16th July (29th SMW) and harvested on 9th October (41st SMW) with CGP of 86 days in 2009; and sown on 25th July (30th SMW) and harvested on 18th October (42nd SMW) with CGP of 86 days in 2010. During the crop growing period, there was a total rainfall of 315.7 mm in 2007, 758.4 mm in 2008, 379.4 mm in 2009 and 641.2 mm in 2010. Maximum weekly rainfall of 74.8 mm occurred in 35th SMW; followed by 71.0 mm in 31st SMW in 2007. In 2008, maximum weekly rainfall of 124.9 mm occurred in 33rd SMW; followed by 115.6 mm in 27th SMW; 83.2 mm in 24th SMW; 71.3 mm in 38th SMW; and 63.7 mm in 31st SMW. In 2009, the highest weekly rainfall of 150.0 mm in the 4-year study occurred in 33rd SMW. In 2010, maximum weekly rainfall of 115.2 occurred in 33rd SMW; followed by 104.4 mm in 37th SMW; 100.9 mm in 38th SMW; and 98.7 mm in 31st SMW.

The rain water use efficiency (RWUE, kg ha^{-1}mm^{-1}) is derived for each treatment as ratio of yield (kg ha^{-1}) and crop seasonal rainfall (mm) received during crop growing period. The increase (%) in yield of a treatment over control is derived to assess its superiority. Similarly, the increase (%) of yield due to spilt nitrogen application is derived by comparing yield attained by split application treatment with yield attained under no-spilt application, *i.e.,* 100% recommended dose applied at sowing. The net returns (₹ ha^{-1}) was derived as a difference of gross returns and cost of cultivation to assess the profitability of treatments. The benefit-cost ratio (BCR) was derived as a ratio of gross returns (₹ ha^{-1}) and cost of cultivation (₹ ha^{-1}) of a treatment.

Statistical Analysis

Based on the analysis of variance (ANOVA) of splitplot design, the effects of moisture conservation, split nitrogen application and their interaction on pearl millet yield (kg ha^{-1}) and rainwater use efficiency (kg ha^{-1}mm^{-1}) were tested in each season and also pooled over different seasons (Gomez and Gomez, 1984). The treatments which provided a significantly higher yield could be identified based on the Least Significant Difference (LSD) criteria at $p < 0.05$ level of significance.

3. RESULTS AND DISCUSSION

Performance of Moisture Conservation and Split Application of Nitrogen

Different treatment combinations of moisture conservation and split doses of nitrogen application gave pearlmillet grain yield in the range of 1036 to 2764 kg ha^{-1} with mean of 1899 kg ha^{-1} and variation of 21.8% in 2007; 1876 to 3847 kg ha^{-1} with mean of 2794 kg ha^{-1} and variation of 18.8% in 2008; 1525 to 4310 kg ha^{-1} with mean of 2882 kg ha^{-1} and variation of 21.8% in 2009; 1560 to 4309 kg ha^{-1} with mean of 2644 kg ha^{-1} and variation of 24.9% in 2010. The control gave lowest yield, while the ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) gave highest yield in all the 4 years. The treatments gave higher yield under higher crop seasonal rainfall of 758.4 mm in 2008 and 641.2 mm in 2010 compared to lower rainfall of 315.7 mm in 2007 and 379.4 mm received in 2009. A higher RWUE was observed under lower crop seasonal rainfall received in 2007 and 2009, while a lower RWUE was observed under higher crop seasonal rainfall received in 2008 and 2010. The RWUE ranged from 3.28 to 8.75 kg ha^{-1}mm with mean of 6.02 kg ha^{-1}mm^{-1} in 2007 which received a rainfall of 315.7 mm; 4.02 to 11.36 kg ha^{-1}mm^{-1} with mean of 7.60 kg ha^{-1}mm^{-1} in 2009 with rainfall of 379.4 mm. It ranged from 2.47 to 5.07 kg ha^{-1}mm^{-1} with mean of 3.68 kg ha^{-1}mm^{-1} in 2008 with rainfall of 758.4 mm; and 2.43 to 6.72 kg ha^{-1}mm^{-1} with mean of 4.12 kg ha^{-1}mm^{-1} in 2010 with rainfall of 641.2 mm from sowing to harvest. The treatment-wise yield and RWUE attained in different years, along with the mean and coefficient of variation (%) over years are given in Table 1.

Analysis of Variance of Yield and Rainwater Use Efficiency

The F-test based on ANOVA of yield and RWUE attained in different years indicated that the main effects of moisture conservation and fertilizer treatments and their interaction were significant at $p < 0.05$ level of significance in all the 4 years. The mean yield attained by different treatments, standard error of mean along with the Least Significant Difference (LSD) values for comparison of

Table: 1
Effect of moisture conservation and split nitrogen application treatments on pearlmillet yield and rain water use efficiency in different years

Treatment	Grain yield (kg ha^{-1})					Rain water use efficiency (kg ha^{-1} mm^{-1})				
	2007	2008	2009	2010	Mean	2007	2008	2009	2010	Mean
M1 F1	1036	1876	1525	1560	1499	3.28	2.47	4.02	2.43	2.86
M1 F2	1643	2434	2025	1937	2010	5.21	3.21	5.34	3.02	3.84
M1 F3	1992	2842	2475	2182	2373	6.31	3.75	6.52	3.40	4.53
M1 F4	1673	3005	2875	2726	2570	5.30	3.96	7.58	4.25	4.91
M1 F5	1586	2900	3000	2800	2572	5.02	3.82	7.91	4.37	4.91
M2 F1	1296	1900	1940	1735	1718	4.10	2.51	5.11	2.71	3.28
M2 F2	1695	2489	2485	2312	2245	5.37	3.28	6.55	3.61	4.29
M2 F3	2041	2995	2805	2655	2624	6.46	3.95	7.39	4.14	5.01
M2 F4	2119	3255	3150	3050	2893	6.71	4.29	8.30	4.76	5.53
M2 F5	2159	3322	3345	3125	2988	6.84	4.38	8.82	4.87	5.70
M3 F1	1090	1930	1795	1620	1609	3.45	2.54	4.73	2.53	3.07
M3 F2	1483	2520	2431	2237	2168	4.70	3.32	6.41	3.49	4.14
M3 F3	1868	2879	2700	2550	2499	5.92	3.80	7.12	3.98	4.77
M3 F4	2039	3240	3030	3005	2829	6.46	4.27	7.99	4.69	5.40
M3 F5	2160	3100	3219	2850	2832	6.84	4.09	8.48	4.45	5.41
M4 F1	1345	1990	2200	1890	1856	4.26	2.62	5.80	2.95	3.54
M4 F2	1960	2545	2764	2547	2454	6.21	3.36	7.29	3.97	4.69
M4 F3	2098	2938	3220	2880	2784	6.65	3.87	8.49	4.49	5.32
M4 F4	2244	3265	3485	3350	3086	7.11	4.31	9.19	5.22	5.89
M4 F5	2512	3592	3756	3470	3332	7.96	4.74	9.90	5.41	6.36
M5 F1	1491	1990	2525	2074	2020	4.72	2.62	6.66	3.23	3.86
M5 F2	2176	2625	3190	2682	2668	6.89	3.46	8.41	4.18	5.09
M5 F3	2385	2983	3675	3189	3058	7.55	3.93	9.69	4.97	5.84
M5 F4	2625	3386	4125	3374	3378	8.31	4.46	10.87	5.26	6.45
M5 F5	2764	3847	4310	4309	3807	8.75	5.07	11.36	6.72	7.27
Mean	1899	2794	2882	2644	2555	6.02	3.68	7.60	4.12	4.88
CV(%)	24.1	19.8	24.3	24.9	22.6	24.1	19.8	24.3	24.9	22.6

M1: Flat bed + broadcast sowing; M2: Flat bed + broadcast sowing + conservation furrow; M3: Flat bed + line sowing M4: Flat bed + line sowing + conservation furrow; M5: Ridges and furrows; F1: Control; F2: 60 kg N ha^{-1} at sowing (no-split); F3: 60 kg N ha^{-1} in 2-splits (½ at sowing + ½ at tillering); F4: 60 kg N ha^{-1} in 3-unequal splits (½ at sowing+¼ at tillering+¼ at earing); F5: 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)

Table: 2
ANOVA of effects of moisture conservation and split nitrogen application and their interaction on pearlmillet yield in different years

Treatments	Grain yield (kg ha^{-1})				
	2007	2008	2009	2010	Mean
Moisture conservation					
Flat bed + broadcast sowing	1586	2611	2380	2240	2204
Flat bed + broadcast sowing + conservation furrow	1862	2792	2745	2575	2494
Flat bed + line sowing	1728	2734	2635	2452	2387
Flat bed + line sowing + conservation furrow	2032	2866	3085	2827	2703
Ridges and furrows	2288	2966	3565	3125	2986
Sem ±	64	80	59	71	69
LSD ($p < 0.05$)	197	247	183	219	213
Split nitrogen application					
Control	1251	1937	1997	1776	1740
60 kg N ha^{-1} at sowing (no split)	1791	2522	2579	2343	2309
60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	2076	2927	2975	2691	2667
60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	2140	3230	3333	3101	2951
60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	2236	3352	3526	3311	3106
Mean	1899	2794	2882	2644	2555
Sem ±	59	65	77	51	35
LSD ($p < 0.05$)	166	183	218	144	99
Moisture conservation x Fertilizer N					
Sem ±	132	148	169	119	88
LSD ($p < 0.05$)	374	419	477	337	250
Crop seasonal rainfall (mm)	315.7	758.4	379.4	641.2	523.7

treatments are given in Table 2. The moisture conservation treatments gave significantly higher mean yield (RWUE) of 2882 kg ha^{-1} (9.13 kg ha^{-1}mm^{-1}) in 2009, 2794 kg ha^{-1} (8.85 kg ha^{-1}mm^{-1}) in 2008, 2644 kg ha^{-1} (8.38 kg ha^{-1}mm^{-1}) in 2010 compared to 1899 kg ha^{-1} (6.01 kg ha^{-1}mm^{-1}) attained in 2007.

Based on the LSD criteria examined for moisture conservation practices, the ridges and furrows was superior with higher mean yield of 2288 kg ha^{-1} (RWUE of 7.25 kg ha^{-1} mm^{-1}) compared to flat bed + broadcast sowing with yield of 1586 kg ha^{-1}(5.02 kg ha^{-1}mm^{-1}); flat bed + broadcast sowing + conservation furrow with yield of 1862 kg ha^{-1} (5.90 kg ha^{-1} mm^{-1}); flat bed + line sowing with yield of 1728 kg ha^{-1} (5.47 kg ha^{-1}mm^{-1}); and flat bed + line sowing + conservation furrow with yield of 2032 kg ha^{-1} (6.44 kg ha^{-1}mm^{-1}) under crop seasonal rainfall of 315.7 mm received in 2007; while it gave significantly higher mean yield of 3565 kg ha^{-1} (11.29 kg ha^{-1}mm^{-1}) compared to 2380 (7.54 kg ha^{-1}mm^{-1}), 2745 kg ha^{-1} (8.69 kg ha^{-1}mm^{-1}), 2635 kg ha^{-1} (8.35 kg ha^{-1}mm^{-1}) and 3085 kg ha^{-1} (9.77 kg ha^{-1}mm^{-1}) attained by the respective treatments in 2009 which received a rainfall of 379.4 mm. In 2008, the ridges and furrows was superior with significantly higher mean yield of 2966 kg ha^{-1} (9.39 kg ha^{-1}mm^{-1}) compared to flat bed + broadcast sowing with yield of 2611 kg ha^{-1} (8.27 kg ha^{-1} mm^{-1}), while it was statistically at par with other treatments. In 2010, the ridges and furrows was superior with significantly higher mean yield of 3125 kg ha^{-1} (9.90 kg ha^{-1}mm^{-1}) compared to other moisture conservation practices with yield in the range of 2240 (7.10 kg ha^{-1}mm^{-1}) to 2827 kg ha^{-1} (8.95 kg ha^{-1}mm^{-1}) in 2010.

The pooled data indicated the superiority of ridges and furrows with significantly higher mean yield of 2986 kg ha^{-1} (9.46 kg ha^{-1}mm^{-1}) compared to other treatments with yield range of 2204 kg ha^{-1} (6.98 kg ha^{-1}mm^{-1}) to 2703 kg ha^{-1} (8.56 kg ha^{-1}mm^{-1}). The flat bed+broadcast sowing + conservation furrow and flat bed + line sowing were at par in all the years, while flat bed + broadcast sowing and flat bed + line sowing were at par in 2007, 2008 and 2010. Similarly, the flat bed + broadcast sowing + conservation furrow and flat bed + line sowing + conservation furrow were at par in 2007 and 2008.

Based on the LSD criteria, the mean yield and RWUE (kg ha^{-1}mm^{-1}) attained by each split nitrogen application practice over the 5 moisture conservation practices were compared. Application of 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering+1/3 at earing) was superior with significantly higher mean yield of 2236 kg ha^{-1} (RWUE of 7.08 kg ha^{-1}mm^{-1}) in 2007, 3352 kg ha^{-1} (10.62 kg ha^{-1}mm^{-1}) in 2008, 3526 kg ha^{-1} (11.17 kg ha^{-1}mm^{-1}) in 2009, and 3311 kg ha^{-1} (10.49 kg ha^{-1}mm^{-1}) in 2010 compared to control and application of 60 kg N ha^{-1} at sowing (no-split). The 3-equal split application of nitrogen gave significantly higher mean yield of 3352 kg ha^{-1} (10.62 kg ha^{-1}mm^{-1}) compared to other treatments with yield in the range of 1937 kg ha^{-1} (6.14 kg ha^{-1}mm^{-1}) to 3230 kg ha^{-1} (10.23 kg ha^{-1}mm^{-1}) in 2008; while it gave significantly higher yield compared to control with yield of 1251 kg ha^{-1} (3.96 kg ha^{-1}mm^{-1}) and 60 kg N ha^{-1} application at sowing with 1791 kg ha^{-1} (5.67 kg ha^{-1}mm^{-1}) in 2007; control with 1997 kg ha^{-1} (6.33 kg ha^{-1}mm^{-1}), 60 kg N ha^{-1} at sowing with 2579 kg ha^{-1} (8.17 kg ha^{-1} mm^{-1}) and 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering) with yield of 2975 kg ha^{-1} (9.42 kg ha^{-1}mm^{-1}) in 2009. In 2010, nitrogen application in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with significantly higher mean yield of 3311 kg ha^{-1} (10.49 kg ha^{-1}mm^{-1}). Our results are in agreement with the N use efficiency observed by Bationo *et al.* (1990) in case of pearlmillet grown in Niger. In a study by Rockstrom *et al.* (2003), the authors have reported similar results of rainwater use efficiency attained under small farmers' field conditions.

Similar trend was observed when the data were pooled over years and tested for the effect of split application of N on pearlmillet yield. The 3-equal split application of N gave significantly higher mean yield of 3106 kg ha^{-1} (9.84 kg ha^{-1}mm^{-1}) over years compared to other treatments. The analysis indicated that application of 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was at par with application of N in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing) in 2007, 2008 and 2009. Under low crop seasonal rainfall received in 2007, application of 60 kg N ha^{-1} in 2-equal splits was at par with 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing) and 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing). The ANOVA of effects of moisture conservation and split nitrogen application practice on RWUE in different years are given in Table 3.

Increase in Yield Attained by Treatments over Control

The pearlmillet yield increased due to nitrogen application either with or without split nitrogen dose under all the 5 moisture conservation practices considered in the study. The increase in yield was relatively higher in 2007 and 2009 under lower crop seasonal rainfall compared to 2008 and 2010 under higher rainfall. The mean increase (%) in yield attained by split nitrogen application practice over control under 5 moisture conservation practices are given in Table 4. Application of 60 kg N ha^{-1} at sowing (no-split) gave maximum yield increase of 43.4% over control in 2007 compared to 30.2% in 2008, 29.7% in 2009 and 31.9% in 2010. However, there was a significantly higher mean yield increase due to split nitrogen application practice over control in different years. Application of 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering) was superior with mean yield increase of 67.4% in 2007 compared to 51.2% in 2008, 49.8% in 2009 and 51.3% in 2010; while

Table: 3
ANOVA of effects of moisture conservation and fertilizer treatments and their interaction on rain water use efficiency in pearlmillet in different years

Treatments	Rain water use efficiency (kg ha^{-1} mm^{-1})				
	2007	2008	2009	2010	Mean
Moisture conservation					
Flat bed + broadcast sowing	5.02	8.27	7.54	7.10	6.98
Flat bed + broadcast sowing + conservation furrow	5.90	8.84	8.69	8.16	7.90
Flat bed + line sowing	5.47	8.66	8.35	7.77	7.56
Flat bed + line sowing + conservation furrow	6.44	9.08	9.77	8.95	8.56
Ridges and furrows	7.25	9.39	11.29	9.90	9.46
Sem ±	0.20	0.11	0.16	0.11	0.13
LSD ($p < 0.05$)	0.62	0.33	0.48	0.34	0.41
Fertilizer N					
Control	3.96	6.14	6.33	5.63	5.51
60 kg N ha^{-1} at sowing (no split)	5.67	7.99	8.17	7.42	7.31
60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	6.58	9.27	9.42	8.52	8.45
60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	6.78	10.23	10.56	9.82	9.35
60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	7.08	10.62	11.17	10.49	9.84
Mean	6.01	8.85	9.13	8.38	8.09
Sem ±	0.19	0.09	0.20	0.08	0.07
LSD ($p < 0.05$)	0.53	0.24	0.57	0.22	0.19
Moisture conservation x Fertilizer N					
Sem ±	0.42	0.20	0.45	0.19	0.17
LSD ($p < 0.05$)	1.18	0.55	1.26	0.53	0.48
Crop seasonal rainfall (mm)	315.7	758.4	379.4	641.2	523.7

60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing) gave yield increase of 71.0% in 2007, 66.7% in 2008, 68.3% in 2009 and 75.2% in 2010. Application of 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with highest yield increase of 78.0% in 2007, 72.8% in 2008, 78.0% in 2009 and 85.4% in 2010 over control. This indicated that pearl millet significantly responded to nitrogen application irrespective of moisture conservation and split application practices over control in all the years.

Increase in Yield attained by Split Application of Nitrogen over No-split Application

The nitrogen use efficiency (NUE, %) was measured by comparing the yield attained by nitrogen split application treatments with 100% N application at sowing and control treatments. The mean increase in pearl millet yield due to either 2 or 3-equal or unequal splits of application of fertilizer N compared to complete dose of N at sowing (no split) attained during 2007 to 2010 are given in Table 4. Application of 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering) gave yield increase of 16.8% in 2007, 16.1% in 2008, 15.6% in 2009 and 14.7% in 2010; while application of nitrogen in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing) gave yield increase of 19.9, 28.0, 29.8 and 32.9% compared to complete dose at sowing in the respective years. However, nitrogen application in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with maximum yield increase of 24.9% in 2007, 32.7% in 2008, 37.2% in 2009 and 40.8% in 2010 compared to 100% N at sowing. Application of nitrogen in 3-equal splits gave relatively higher yield increase (%), followed by 3-unequal splits and 2-equal splits compared to 'no split' of nitrogen application. The mean increase in yield was relatively higher in 2010, followed by 2009, 2008 and 2007 under any combination of moisture conservation practice. However, the variation (%) was highest in 2007, followed by 2009, 2010 and 2008 for different treatments. Although the crop seasonal rainfall was higher in 2008 and 2010 compared to 2007 and 2009, the yield, rainwater use efficiency and yield increase over control or no-split nitrogen application practice were lower in 2008 and 2010 due to high and erratic rainfall distribution. This is because the high and erratic rainfall which occurred on a particular day was not beneficial to the crop and resulted in lower response to fertilizer application and N use efficiency. Maruthi Sankar *et al.* (2011) observed similar results of yield response, rainwater use efficiency and fertilizer use efficiency in case of finger millet under semi-arid alfisols. Maman *et al.* (1999) have also observed that pearl millet yield was greatly influenced by fertilizer N application and accordingly optimized N in order to derive maximum N use efficiency.

The NUE increased from 2007 to 2008, static from 2008 to 2009 and decreased from 2009 to 2010. It is observed that NUE was maximum under 3-equal split (1/3 at sowing + 1/3 at tillering + 1/3 at earing), while it was minimum under 100% N as basal (no-split) application under different moisture conservation practices in

Table: 4
Increase in pearlmillet yield due to split application of nitrogen in different years

Treatment	Yield increase (%) over no-split application					Yield increase (%) over control				
	2007	2008	2009	2010	Mean	2007	2008	2009	2010	Mean
M1 F2						58.6	29.7	32.8	24.2	34.1
M1 F3	21.2	16.8	22.2	12.6	16.6	92.2	51.5	62.3	39.8	58.3
M1 F4	1.8	23.5	42.0	40.7	26.3	61.5	60.2	88.5	74.7	71.4
M1 F5	-3.5	19.1	48.1	44.6	26.4	53.1	54.6	96.7	79.5	71.6
M2 F2						30.7	31.0	28.1	33.3	30.7
M2 F3	20.4	20.3	12.9	14.8	18.0	57.4	57.6	44.6	53.0	52.7
M2 F4	25.0	30.8	26.8	31.9	30.2	63.5	71.3	62.4	75.8	68.4
M2 F5	27.3	33.5	34.6	35.2	34.4	66.6	74.8	72.4	80.1	73.9
M3 F2						36.0	30.6	35.4	38.1	34.7
M3 F3	25.9	14.2	11.1	14.0	16.6	71.3	49.1	50.4	57.4	55.3
M3 F4	37.5	28.6	24.6	34.3	31.9	87.1	67.9	68.8	85.5	75.8
M3 F5	45.7	23.0	32.4	27.4	32.1	98.2	60.6	79.3	75.9	76.0
M4 F2						45.7	27.9	25.6	34.8	32.2
M4 F3	7.0	15.4	16.5	13.1	14.9	56.0	47.6	46.4	52.4	50.0
M4 F4	14.5	28.3	26.1	31.5	27.4	66.8	64.1	58.4	77.3	66.3
M4 F5	28.1	41.1	35.9	36.2	37.5	86.7	80.5	70.7	83.6	79.5
M5 F2						45.9	31.9	26.3	29.3	32.1
M5 F3	9.6	13.6	15.2	18.9	14.8	59.9	49.9	45.5	53.8	51.4
M5 F4	20.6	29.0	29.3	25.8	26.8	76.1	70.2	63.4	62.7	67.2
M5 F5	27.0	46.5	35.1	60.7	42.9	85.4	93.3	70.7	107.8	88.5
2-equal splits (½ at sowing + ½ at tillering) vs No-split										
Mean	16.8	16.1	15.6	14.7	16.2	67.4	51.2	49.8	51.3	53.5
CV (%)	48.2	16.6	27.4	17.1	8.4	22.5	7.6	14.7	13.0	6.2
3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing) vs No-split										
Mean	19.9	28.0	29.8	32.9	28.5	71.0	66.7	68.3	75.2	69.8
CV (%)	66.2	9.7	23.7	16.4	8.5	14.9	6.9	17.4	10.9	5.5
3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) vs No-split										
Mean	24.9	32.7	37.2	40.8	34.7	78.0	72.8	78.0	85.4	77.9
CV (%)	71.1	35.6	16.7	31.0	17.7	23.0	21.3	14.2	15.0	8.5
100% N at sowing vs Control										
Mean						43.4	30.2	29.7	31.9	32.8
CV (%)						24.7	5.0	14.4	16.8	5.0

M1: Flat bed + broadcast sowing; M2: Flat bed + broadcast sowing + conservation furrow; M3: Flat bed + line sowing M4: Flat bed + line sowing + conservation furrow; M5: Ridges and furrows; F1: Control; F2: 60 kg N ha^{-1} at sowing (no-split); F3: 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering); F4: 60 kg N ha^{-1} in 3-unequal splits (½ at sowing+¼ at tillering+¼ at earing); F5: 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)

different years. The NUE increased in all fertilizer practices only under ridges and furrows practice from 2008 to 2009 with maximum being under 3-equal split (1/3 at sowing + 1/3 at tillering + 1/3 at earing) application. This was due to an efficient interaction of fertilizer and moisture conservation practices even under low crop seasonal rainfall of 379.4 mm received in 2010. The NUE was static under ridges and furrows + 3-equal split (1/3 at sowing + 1/3 at tillering + 1/3 at earing), while it decreased under all other nitrogen application practices from 2009 to 2010.

Our results on the superiority of N application at sowing, tillering and earing stages in 3 equal doses for maximum NUE in pearl millet are in conformity with the results reported by Huggins and Pan (2003) on assessing NUE in cereal-based agro-ecosystems; and Nakano and Morita (2008) on effects of amount of N and application method on total matter yield in rice. Similarly, Ohnishi *et al.* (1999) examined NUE for 18 cultivars of low land rice in Thailand. They observed improvement in NUE by better management comprising of N rates in frequent split urea application and use of organic matter and slow release fertilizer. Gary Jolliff *et al.* (1993) studied effects of rate and timing of N on meadow foam oil yield and oil components.

Profitability of Moisture Conservation and Split Nitrogen Application Practices

The mean and variation (%) of cost of cultivation (₹ ha^{-1}) incurred; and the gross and net monetary returns (₹ ha^{-1}) and benefitcost ratio attained under different combinations of moisture conservation and split nitrogen application practices over years are given in Table 5. The lowest cost of cultivation of ₹ 7325 ha^{-1} in 2007, ₹ 11485 ha^{-1} in 2008, ₹ 10973 ha^{-1} in 2009 and ₹ 12372 ha^{-1} in 2010 was incurred under flat bed + broadcast sowing + control; while the highest was incurred under ridges and furrows + 60 kg N ha^{-1} in 3-unequal or equal splits in 2007 (₹ 8463 ha^{-1}); flat bed + broadcast sowing + conservation furrow and flat bed + line sowing + conservation furrow in combination with 3-unequal or equal splits of 60 kg N ha^{-1}

Table: 5
Profitability of moisture conservation and split nitrogen application practices in pearlmillet (mean of 4 years)

Moisture conservation	Fertilizer N	CC	GR	NR	BC
Flat bed + broadcast sowing	Control	10539	19520	9107	1.86
Flat bed + broadcast sowing	60 kg N ha^{-1} at sowing (no-split)	11478	22192	10840	1.95
Flat bed + broadcast sowing	60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	11291	23943	12778	2.15
Flat bed + broadcast sowing	60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	11347	25167	13946	2.24
Flat bed + broadcast sowing	60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	11347	25799	14571	2.30
Flat bed + broadcast sowing + conservation furrow	Control	10784	20527	9744	1.91
Flat bed + broadcast sowing + conservation furrow	60 kg N ha^{-1}at sowing (no-split)	11723	23200	11476	2.00
Flat bed + broadcast sowing + conservation furrow	60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	11536	24951	13415	2.20
Flat bed + broadcast sowing + conservation furrow	60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	11592	26174	14582	2.29
Flat bed + broadcast sowing + conservation furrow	60 kg N ha^{-1} a in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	11592	26807	15207	2.34
Flat bed + line sowing	Control	10539	20938	10400	1.99
Flat bed + line sowing	60 kg N ha^{-1} at sowing (no-split)	11478	23611	12132	2.08
Flat bed + line sowing	60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	11291	25362	14071	2.28
Flat bed + line sowing	60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	11347	26585	15238	2.37
Flat bed + line sowing	60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	11347	27218	15863	2.43
Flat bed + line sowing + conservation furrow	Control	10686	21931	11208	2.04
Flat bed + line sowing + conservation furrow	60 kg N ha^{-1} at sowing (no-split)	11626	24603	12940	2.13
Flat bed + line sowing + conservation furrow	60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	11438	26354	14878	2.34
Flat bed + line sowing + conservation furrow	60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	11495	27578	16046	2.43
Flat bed + line sowing + conservation furrow	60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	11495	28211	16671	2.48
Ridges and furrows	Control	10708	23232	12524	2.16
Ridges and furrows	60 kg N ha^{-1} at sowing (no-split)	11648	25904	14257	2.25
Ridges and furrows	60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering)	11460	27655	16195	2.45
Ridges and furrows	60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing)	11517	28879	17363	2.54
Ridges and furrows	60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing)	11517	29512	17988	2.59
Mean		11313	25034	13738	2.23
CV (%)		3.2	10.6	17.4	9.1

CC: Cost of cultivation (₹ ha^{-1}); GR: Gross returns (₹ ha^{-1}); NR: Net returns (₹ ha^{-1}); BC: Benefit-cost ratio in 2008 (₹ 12893 ha^{-1}); flat bed + broadcast sowing + conservation furrow + 60 kg N ha^{-1} at sowing in 2009 (₹ 12224 ha^{-1}); and flat bed + broadcast sowing + conservation furrow + 60 kg N ha^{-1} in 3-unequal or equal splits in 2010 (₹ 13789 ha^{-1}).

The ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with maximum gross returns of ₹ 21339 ha^{-1}, ₹ 32632 ha^{-1}, ₹ 36201 ha^{-1} and ₹ 27876 ha^{-1}; net returns of ₹ 12847 ha^{-1}, ₹ 19829 ha^{-1}, ₹ 24952 ha^{-1} and ₹ 14324 ha^{-1}; while flat bed + broadcast sowing + control gave minimum gross returns of ₹ 13595 ha^{-1}, ₹ 24512 ha^{-1}, ₹ 22214 ha^{-1} and ₹ 17760 ha^{-1}; and net returns of ₹ 6270 ha^{-1}, ₹ 13027 ha^{-1}, ₹ 11745 ha^{-1} and ₹ 5388 ha^{-1} in 2007, 2008, 2009 and 2010, respectively. The analysis indicated that ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) gave maximum benefitcost ratio of 2.53 in 2007, 2.55 in 2008, 3.24 in 2009 and 2.06 in 2010; while minimum benefitcost ratio of 1.86 in 2007, 2.03 in 2009 and 1.44 in 2010 was attained under flat bed + broadcast sowing + control and 2.10 in 2008 was attained under flat bed + broadcast sowing + conservation furrow + control.

It is observed that the mean net returns and benefit-cost ratio over split nitrogen application practices increased under all the moisture conservation practices from 2007 to 2008, while they increased only under ridges and furrows and static under other practices from 2008 to 2009. They decreased under all the moisture conservation practices from 2009 to 2010, with minimum decrease under ridges and furrows. This indicated the superiority of ridges and furrows over years. A similar trend was observed when averaged over moisture conservation practices. Application of 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with increased mean net returns and benefit-cost ratio from 2007 to 2009, while it decreased in 2010. In fact all the fertilizer practices increased the net returns and benefit-cost ratio from 2007 to 2009, and decreased from 2009 to 2010, with highest decrease under control and lowest decrease under ridges and furrows treatment. This decrease was due to high and erratic rainfall received in standard meteorological weeks of 31, 33, 37 and 38 during 2010. Mishra *et al.* (2002a, 2002b) also observed that when both indigenous and modern techniques are adopted in combination, they would be highly beneficial to farmers for harvesting more rainwater and attain higher monetary returns. There was no significant build-up of soil N compared to the initial soil N fertility. At the end of the 4-year study, the mean post-harvest soil N was found to be about 145 kg ha^{-1}. Our findings are in conformity with those observed by Sharma *et al.* (2014) who stressed on the need for an efficient soil management practice for best utilizing the soil fertility, rainwater and different inputs used for pearl millet grown under semi-arid inceptisols.

When the data were pooled over years, the cost of cultivation ranged from ₹ 10,539 ha^{-1} under flat bed + broadcast sowing + control and flat bed + line sowing + control to ₹ 11,723 ha^{-1} under flat bed + broadcast sowing + conservation furrow + 60 kg N ha^{-1} at sowing with mean of ₹ 11,313 ha^{-1} and variation of 3.2%. The ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) was superior with maximum mean gross returns of ₹ 29,512 ha^{-1}, net returns of ₹ 17988 ha^{-1} and benefit cost ratio of 2.59; while flat bed + broadcast sowing + control gave minimum gross returns of ₹ 19,520 ha^{-1}, net returns of ₹ 9,107 ha^{-1} and benefitcost ratio of 1.86. This indicated that we can attain maximum profit by growing pearlmillet with ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing). Our results are in conformity with the findings of Cassman *et al.* (1998), who reported on the opportunities for increasing NUE in irrigated rice systems by efficiently managing the resources for attaining maximum profit. Similar results on profitability of combining moisture conservation and nutrient management through organic and inorganic fertilizers for sorghum were reported by Zougmore *et al.* (2004). The findings of our study on rain water and NUE are in conformity with those reported by Nema *et al.* (2008) for pearlmillet in an arid Inceptisol.

Thus based on the 4 year study, 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) gave maximum yield increase of 72.8% in 2008 to 85.4% in 2010 over control; while it gave maximum yield increase of 24.9% in 2007 to 40.8% in 2010 over 100% N at sowing. Maximum pearl millet yield of 3807 kg ha^{-1}, RWUE of 7.27 kg ha^{-1} mm^{-1}, NUE of 63.5%; gross returns of ₹ 29,512 ha^{-1}, and benefitcost ratio of 2.59 could be attained by ridges and furrows + 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tiering + 1/3 at earing). This practice could be adopted by the farmers for doubling the yield and monetary returns by growing pearlmillet under similar soil and agro-climatic conditions in the country.

4. CONCLUSIONS

Five moisture conservation practices *viz.,* flat bed + broadcast sowing; flat bed + broadcast sowing + conservation furrow; flat bed + line sowing; flat bed + line sowing + conservation furrow; ridges and furrows; and 5 fertilizer practices of control; 60 kg N ha^{-1} at sowing; 60 kg N ha^{-1} in 2-equal splits (½ at sowing + ½ at tillering); 60 kg N ha^{-1} in 3-unequal splits (½ at sowing + ¼ at tillering + ¼ at earing); 60 kg N ha^{-1} in 3-equal splits (1/3 at sowing + 1/3 at tillering + 1/3 at earing) were tested. Ridges and furrows gave higher yield of 2986 kg

ha^{-1} and RWUE of 9.46 kg $ha^{-1}mm^{-1}$, while 60 kg N ha^{-1} in 3-equal splits gave yield of 3106 kg ha^{-1} with RWUE of 9.84 kg $ha^{-1}mm^{-1}$. The 3-equal N splits gave yield increase of 77.9% over control and 34.7% over 100% basal dose. Application of 60 kg N ha^{-1} in 3-equal splits was superior with yield increase of 72.8% in 2008 to 85.4% in 2010 over control; while it gave increase of 24.9% in 2007 to 40.8% in 2010 over 100% basal N. Pearl millet yield of 3807 kg ha^{-1}, RWUE of 7.27 kg ha^{-1} mm^{-1}, NUE of 63.5%; gross returns of ₹ 29,512 ha^{-1}, and benefitcost ratio of 2.59 were attained by ridges and furrows + 60 kg N ha^{-1} in 3-equal splits.

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