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Productivity, economics and quality of henna (*Lawsonia inermis* L) as affected by spacing and nitrogen in semi-arid Lithic Calciorthids

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Abstract : A field experiment conducted during 1997-2001 at Regional Research Station, Pali-Marwar (Rajasthan), involving five different crop spacings (inter and intra row) with four levels of nitrogen indicate that production of dry leaf increased significantly by 32.5% at 45 cm × 30 cm spacing and 27.2% at 60 cm × 30 cm spacing over 30 cm × 30 cm spacing that yielded 682 kg ha^{-1} dry leaf yield of henna. The interaction effect of year and spacing on dry leaf yield was significant. Nitrogen at 60 kg ha^{-1} being at par with 90 kg produced significantly higher dry leaf yield by 12.1% *i.e.* 680 kg ha^{-1}(control). The crop spacing that gave maximum dry leaf yield had low dye content. Application of nitrogen had significant effect on leaf dye content of henna. The leaf nutrient limit shows 2.45% nitrogen, 0.14% phosphorus, 0.95% potassium, 0.24% sulphur and 0.22% calcium concentration in this crop.

Additional key words : *Crop geometry, dry regions, lawsone, leaf yield, nutrient content*

Introduction

Henna (*Lawsonia inermis* L) is a perennial shrub grown for its dye lawsone (2-hydroxy-1, 4-napthaquinone) bearing leaves under coppice system in rainfed condition. About 70% of its gross production meets domestic requirements whereas 30% is exported to other countries. Rajasthan alone produced 37, 790 tonnes henna dry leaves during the year 2007-08. The hot and arid climate of Western Rajasthan, where primary production and life support system are constrained by low and erratic rainfall, high evapo-transpiration and poor soil physical and fertility conditions, cultivation of henna affords some assured income to the farmers due to its drought hardiness and deep root system (Rao *et al.* 2002).

Improving productivity while maintaining high leaf quality is an important step towards its widespread cultivation and analogous application to other arid and semi-arid regions. The low rainfall combined with high density plantation (30 cm × 30 cm) of henna often yield 0.5 to 0.6 tonnes dry leaves per hectare (ICAR 1980). Manipulation of planting configuration for higher productivity is an acceptable practice in dry areas (Arnon 1992) and this must be true for this crop also. As this crop is harvested for leaves, nitrogen application will promote plant growth and leaf quality. The objective of the present study was to evaluate effect of crop spacing and nitrogen application on dry leaf yield and quality of henna leaves.

Materials and Methods

A field experiment was conducted during 1997-2001 at Central Arid Zone Research Institute, Regional Research Station, Pali-Marwar. The experimental soil was fine-loamy, mixed, hyperthermic Lithic Calciorthids. The experimental soil had pH 7.9, EC 0.16 dS m^{-1}, 213.0 kg ha^{-1} available N, 11.0 kg ha^{-1}

available P and 250.0 kg ha^{-1} exchangeable K and 6.0 ppm available S in 0-15 cm soil depth.

The treatment comprised of 5 crop geometries namely, 30 cm × 30 cm (111, 000 plants ha^{-1}) as control, 45 cm × 15 cm (148,000 plants ha^{-1}), 45 cm × 30 cm (74,000 plants ha^{-1}), 60 cm × 15 cm (111, 000 plants ha^{-1}), 60 cm × 30 cm (55,500 plants ha^{-1}) spacing between inter rows and intra rows and 4 N levels (0 , 30, 60, 90 kg ha^{-1}. The treatments were laid out in split plot design with crop geometry in main plots and N in sub-plots and replicated thrice. The amount of rainfall received during the crop growth period in 1997, 1998, 1999, 2000 and 2001 were 718, 145, 349, 246 and 500 mm, respectively. The crop was raised as rainfed by transplanting 3-4 months old seedlings (raised by seeds) during July 1997 as per treatment allocations. The N was applied through urea in two equal splits. The crop was harvested in November 1997 by whole plant cuttings (above ground). In subsequent years, only N was applied (2 splits) and henna re-growth was harvested at 100-110 days of growth (after first rainfall) during September. The plant performance was adjudged from the final above ground dry matter, dry leaf yield and dye content. The biometric observations and chemical determinations were based on representative plant samples (200 plants per replicate, 10 plants from each sub-plot). Data were recorded year-wise and presented for 1999 to 2001 as this crop gives economic yield 3rd year onwards. The pooled analyses of data were carried out as described by Gomez and Gomez (1984). Input and output prices of commodities as it prevailed during year of experimentation were taken for working out the economics. The economic optimum dose of nitrogen (x) was calculated from the following formula;

$$x = \frac{q - bp}{2cp}$$

where q, price of input in rupees kg^{-1}(N from urea: Rs 12/- kg^{-1}) ; p, price of output in rupees kg^{-1} (henna dry leaf : Rs 18/- kg^{-1}); b and c are the coefficients of x and x^2 in a quadratic equation.

The leaves were analysed for nitrogen (Lindner 1944), phosphorus, potassium, calcium (Richards 1954), and sulphur (Tabatabai and Bremner 1970). Leaf dye content was estimated by the standard procedure (BIS 1984) as stated below.

Take 2.0 g finely grounded henna leaf powder in 100 ml volumetric flask and dissolve in 5% sodium bicarbonate solution and makeup the volume. Swirl it after every half an hour for 8 hours and keep it for overnight. Take 10 ml aliquot in 25 ml volumetric flask and makeup the volume. Take 10 ml of this aliquot in 100 ml volumetric flask and makeup the volume. Keep it for half an hour and read at 490 NM on UV spectrophotometer. Standard curve is prepared by lawsone (2-hydroxy-1, 4-napthaquinone).

Results and Discussion

Yield parameter and Yield

Significant differences in leaf dry weight (g plant^{-1}) were observed due to different crop geometries across the year (Table 1). Highest leaf dry weight was observed at 60 cm × 30 cm spacing followed by 45 cm × 30 cm in all the years of experimentation. On pooled basis, crop spacing of 60 cm × 30 cm gave maximum leaf dry weight of 19.6 g followed by 45 cm × 30 cm spacing that gave 18.9 g leaf dry weight as compared to 13.3 g recorded at 30 cm × 30 cm spacing (control). Similarly, biomass production also increased significantly by 30.1% at 45 cm × 30 cm and 22.2% at 60 cm × 30 cm spacing over 30 cm × 30 cm spacing that recorded 1612 kg ha^{-1}. The improvements in leaf dry weight at wider spacing of 60 cm × 30 cm and 45 cm × 30 cm may be ascribed to better distribution of plant over the cropped area coupled with reduced competition between plants for growth resources leading to increased biomass production (Arnon 1992). The effect of N on leaf dry weight was varied between the years and significant effects were observed during 2000 and 2001. On pooled basis, N at 60 kg ha^{-1} being at par with 90 kg, significantly increased leaf dry

Table 1. Effect of crop geometry and nitrogen on leaf weight, total biomass production and dry leaf yield

Treatment	Leaf dry weight (g plant^{-1})				Biomass (kg ha^{-1})				Dry leaf yield (kg ha^{-1})			
	1999	2000	2001	Pooled	1999	2000	2001	Pooled	1999	2000	2001	Pooled
Crop geometry												
30 cm × 30 cm	10.6	9.5	19.8	13.3	873	1090	2873	1612	401	403	1242	682
45 cm × 15 cm	7.6	7.9	17.9	11.1	786	1033	2615	1478	295	387	1119	600
45 cm × 30 cm	15.7	16.3	24.8	18.9	1238	1897	3285	2140	510	803	1400	904
60 cm × 15 cm	11.4	10.7	20.3	14.1	854	1047	2644	1515	339	376	1139	618
60 cm × 30 cm	17.7	16.3	24.8	19.6	991	1861	3178	2010	426	778	1398	868
CD (P=0.05)	2.3	2.1	2.8	1.3	174	165	350	125	74	86	206	69
CD for Y × S		2.2		* *		210		* *		120		* *
Nitrogen (kg ha^{-1})												
0	11.8	10.4	19.6	13.9	895	1305	2685	1628	382	511	1145	680
30	12.6	12.2	21.1	15.3	963	1366	2864	1731	396	544	1227	722
60	12.9	12.8	22.3	16.0	961	1440	3025	1809	390	568	1327	762
90	13.1	13.1	23.0	16.4	976	1431	3101	1836	409	576	1340	775
CD (P=0.05)	NS	1.5	2.2	1.0	NS	NS	214	95	NS	NS	144	55
F- test												
Year				* *				* *				* *
Y × N				NS				NS				NS
N × S				NS				NS				NS

weight by 15.1% and biomass production by 11.1%, over control.

The crop geometry significantly influenced dry leaf yield of henna over the years. The dry leaf yield increased significantly under a spacing of 45 cm × 30 cm by 27.2, 99.3 and 12.7% over 30 cm × 30 cm spacing in the year 1999, 2000 and 2001, respectively (Table 1). On pooled basis, dry leaf yield increased significantly by 32.5% at 45 cm × 30 cm spacing and 27.3% at 60 cm × 30 cm spacing over 30 cm × 30 cm spacing that recorded 682 kg ha^{-1} dry leaf yield. A further analysis of data show that plant performances at 45 cm × 15 cm or 60 cm × 15 cm spacing was very poor than 30 cm × 30 cm spacing.

Nitrogen at 60 kg ha^{-1} significantly increased dry leaf yield by 15.9% over control during 2001 only and further increase in N level up to 90 kg was not beneficial in this respect. The lack of response of applied N to henna may be ascribed to its under-utilization owing to below normal rainfall during the year 1999 and 2000. On pooled basis, nitrogen at 60 kg ha^{-1} being at par with 90 kg produced significantly higher dry leaf yield by 12.1% over control that had recorded 680 kg ha^{-1}. The moderate increase in dry leaf yield under N application was because of increase in availability of N to plant roots that might have facilitated the absorption of nutrients from a larger area in the soil and caused higher photosynthetic rate leading to the production of more carbohydrate. Khandelwal (1998) reported maximum foliage yield of henna on N application at 120 kg ha^{-1}.

Further, to estimate the economic optimum dose of N for two best spacings, the following regression equations were worked out.

45 cm × 30 cm

$$y = 836.6 + 2.60\,x - 0.0157\,x^2 \qquad r = 0.975$$

60 cm × 30 cm

$$y = 829.5 + 1.04\,x - 0.0028\,x^2 \qquad r = 0.965$$

where *y*, yield of dry leaves (kg ha^{-1}); and *x*, the input dose of nitrogen (kg ha^{-1}).

A dose of 62 kg N ha^{-1} was computed as economic optimum under the crop spacing of 45 cm × 30 cm which gave the highest net return of Rs. 3.27 per rupee spent over control and at this spacing 937 kg ha^{-1} dry leaf yield was estimated. The economic optimum dose at 60 cm × 30 cm spacing was 67 kg N ha^{-1} with net return of Rs. 2.17 per rupee spent with 886 kg ha^{-1} dry leaf yield.

The variation in henna growth and yield over years was significant (Table 3). This effect was mainly due to variation in amount and distribution of rainfall received. Since the crop was grown under rainfed condition and the seasonal growth was harvested by whole plant cutting, the effect of age was diminutive. The significant and positive correlation between dry leaf yield and rainfall (r = 0.875**) support this contention. The interaction effect of year and spacing on leaf dry weight per plant, biomass production and dry leaf yield was also significant (Table 1). The effect of wider spacing *viz.* 45 cm × 30 cm or 60 cm × 30 cm over control on dry leaf yield was more impressive under low rainfall year and less significant under good rainfall year.

Leaf dye content and dye yield

Leaf dye content varies significantly due to different crop spacings across the year (Table 2). Unlike leaf yield, maximum dye content of 30.9 mg g^{-1} was observed with the crop spacing of 60 cm × 15 cm followed by 30.0 mg g^{-1} under 45 cm × 15 cm and 27.6 mg g^{-1} under 30 cm × 30 cm during the year 2000. The corresponding dye content of above spacing was 27.8, 24.8 and 24.8 mg g^{-1} during the year 2001. The treatments that gave maximum dry leaf yield were low in dye content during both the years. The correlation between dry leaf yield and dye content was high (r = -0.69) during low rainfall year (2000) and low (r = -0.24) during high rainfall year (2001) which support the contention that growth resources were not limited under high rainfall conditions leading to higher dry leaf production and hence there was net dilution effect. Smirnoff (1995) reported exposure of plants to drought stress does tend to build up of range of secondary metabolites. This fact is supported by negative

Table 2. Effect of crop geometry and nitrogen on leaf dye content, dye yield and leaf nutrient composition

Treatment	Leaf dye content (mg g^{-1})			Dye yield (kg ha^{-1})			Leaf nutrient content (%) (2 years pooled data)				
	2000	2001	Pooled	2000	2001	Pooled	N	P	K	S	Ca
Crop geometry											
30 cm × 30 cm	27.6	24.8	26.5	11.1	30.9	21.0	2.43	0.13	0.96	0.25	0.20
45 cm × 15 cm	30.0	24.8	27.4	11.6	27.5	19.6	2.35	0.15	0.99	0.24	0.23
45 cm × 30 cm	25.9	22.3	24.7	20.8	31.2	26.0	1.98	0.13	0.92	0.26	0.20
60 cm × 15 cm	30.9	27.8	29.1	11.7	31.6	21.6	2.83	0.14	1.01	0.22	0.24
60 cm × 30 cm	26.2	23.7	24.6	20.3	32.9	26.6	2.12	0.14	0.87	0.25	0.21
CD (*P=0.05*)	2.0	3.0	1.9	1.9	NS	3.8	0.37	NS	0.11	NS	0.03
CD for Y × S			NS		4.2	*	NS	NS	NS	NS	NS
Nitrogen (kg ha^{-1})											
0	27.2	23.3	25.5	13.5	26.2	19.9	2.06	0.14	0.90	0.23	0.21
30	28.4	23.7	26.1	15.3	28.7	22.0	2.34	0.14	0.94	0.24	0.23
60	28.4	25.6	27.0	15.6	33.7	24.6	2.40	0.15	0.98	0.25	0.21
90	28.5	26.2	27.3	15.9	34.7	25.3	2.56	0.14	0.98	0.25	0.21
CD (*P=0.05*)	NS	2.3	1.5	1.73	3.01	1.9	0.31	NS	0.06	NS	NS
F- test											
Year			**			**	NS	NS	NS	NS	NS
Y × N			NS		2.8	*	NS	NS	NS	NS	NS
N × S			NS			NS	NS	NS	NS	NS	NS

Table 3. Variation in henna crop growth, yield and quality over years

Year	Leaf weight (g $plant^{-1}$)	Biomass (kg ha^{-1})	Dry leaf yield (kg ha^{-1})	L: S ratio	Dye content (mg g^{-1})	Dye yield (kg ha^{-1})	N uptake (kg ha^{-1})
1999	12.61	948	394	0.74	NA	NA	NA
2000	12.13	1386	550	0.66	28.1	15.1	12.5
2001	21.50	2919	1260	0.76	24.7	30.8	24.1
CD ($P=0.05$)	1.10	161	132	0.09	b	b	b

b – Reps. within year d.f. is not adequate for valid test of significance   NA - Data not available

correlation between rainfall and dye content (r = - 0.57).

Application of N had significant effect on leaf dye content. The effect of N on leaf dye content was non-significant during the year 2000 but it was significant during the year 2001. On pooled basis, N at 90 kg ha^{-1} significantly increased leaf dye content to 27.3 mg g^{-1} as compared to control (25.5 mg g^{-1}). Further, N application also increased N content of henna leaves linearly up to 90 kg ha mg g^{-1} (Table 2). The significant and positive correlation observed between leaf N content and dye content (r = 0.62) suggest greater role of N in accumulation of dye in henna leaves. Mairapetyan *et al.* (1988) reported the best leaf productivity of henna and dye content in the nutrient solution with N: P: K amount and ratio of N 6.3, P 1.0 and K 4.0 mmol L^{-1} in a hydroponic culture.

Dye yield increased significantly under crop spacing of 45 cm × 30 cm and 60 cm × 30 cm as compared to 30 cm × 30 cm spacing. Dye yield varied significantly between the two years. Since dye yield is a function of dye content and dry leaf yield, it is largely the level of dry leaf yield which reflects variation in dye yield and is directly correlated with the rainfall received. Application of N at 60 kg ha^{-1} being at par with 90 kg, significantly increased dye yield over control across the years. The interaction effect of years, crop spacing and N was significant on leaf dye yield (Table 4). Maximum dye yield of 36.1 kg ha^{-1} was observed during the year 2001 when there was good rainfall and 90 kg ha^{-1} N was applied at a crop spacing of 30 cm × 30 cm followed by 36.0 and 35.6 kg ha^{-1} recorded at 45 cm × 30 cm and 60 cm × 30 cm spacing, respectively.

Leaf nutrient content and uptake

Leaf nutrient concentration limit (Table 2) shows N content ranged from 1.98 to 2.83 %, P (0.13 to 0.15 %), K (0.87 to 1.01 %), S (0.22 to 0.26 %) and Ca (0.20 to 0.24 %). With the increase in the leaf yield under wider row spacing of 45 cm × 30 cm and 60 cm × 30 cm, N, K and Ca concentration underwent significantly but P and S concentrations did not change. On the other hand, crop spacing of 60 cm × 15 cm that did not increase leaf yield significantly but showed higher concentration of N, K and Ca. The comparatively higher biomass production at lower plant density decreased the nutrients concentration due to dilution effect. Nitrogen application significantly increased N and K content in leaves but had no effect on other nutrient elements.

Nitrogen uptake varied between the years (Table 5). The trend observed for dry leaf yield was also seen for N uptake. The crop spacing of 45 cm × 30 cm and 60 cm × 30 cm caused maximum N uptake during 2000 while it was not significant during 2001. This spacing also had high nitrogen use efficiency. Nitrogen levels significantly influenced N uptakes across the year. Nitrogen uptake was significantly higher at 90 kg N ha^{-1} followed by 60 and 30 kg N ha^{-1} over control. However, reverse trend was observed for nitrogen use efficiency with N application rate.

Economics

Khem Chand *et al.* (2002) reported that henna

Table 4. Combined effects of years, crop geometry and N on henna leaf dye yield (kg ha^{-1})

Nitrogen (kg ha^{-1})	Year 2000				Year 2001			
	0	30	60	90	0	30	60	90
30 cm × 30 cm	11.8	10.1	11.2	11.2	25.5	28.2	33.6	36.1
45 cm × 15 cm	11.3	13.5	10.7	11.0	18.7	22.9	35.2	33.4
45 cm × 30 cm	16.2	22.0	22.6	22.1	24.0	31.5	33.2	36.0
60 cm × 15 cm	9.4	11.5	13.3	12.5	31.4	29.8	32.8	32.3
60 cm × 30 cm	18.8	19.1	20.4	22.8	31.6	31.0	33.4	35.6
CD (*P=0.05*)	5.6							

Table 5. Economics of crop geometry and nitrogen on henna leaf production and N uptake

Treatment	Cost of cultivation (Rs ha^{-1})	Net return (Rs ha^{-1})			B: C ratio			N uptake (kg ha^{-1})		NUE	
		1999	2000	2001	1999	2000	2001	2000	2001	2000	2001
Crop geometry											
30 cm × 30 cm	6471	1554	2437	14648	1.24	1.38	3.26	9.72	25.64	9.0	27.6
45 cm × 15 cm	6628	-721	1919	12392	0.89	1.29	2.87	9.05	22.64	8.6	24.9
45 cm × 30 cm	6314	3877	11441	17480	1.61	2.81	3.77	16.11	23.45	17.8	31.1
60 cm × 15 cm	6471	307	1843	12890	1.05	1.28	2.99	10.84	23.33	8.4	25.3
60 cm × 30 cm	6236	2289	10960	14533	1.37	2.76	3.81	16.71	25.23	17.3	31.1
Nitrogen (kg ha^{-1})											
0	6028	1616	5262	13448	1.27	1.87	3.23	10.05	18.97	-	-
30	6292	1624	5723	14561	1.26	1.91	3.31	12.31	23.16	18.1	40.9
60	6556	1251	5994	15997	1.19	1.91	3.44	13.00	25.78	9.5	22.1
90	6820	1353	5900	15947	1.20	1.87	3.34	14.60	28.33	6.4	14.9

Henna leaf rate- Rs 20.0/-, 22.1/- and 17.0/- per kg during 1999, 2000 and 2001, respectively.
NUE - Nitrogen use efficiency (kg dry leaf kg^{-1} N applied)

being a perennial crop involves high initial cost of establishment for labour and transplanting of seedling and ploughing in the first year over the prescribed lifespan of the plantation. Once henna is established in the field operations like hoeing, weeding and harvesting are performed every year. The recurring cost involves mainly family labour and variable input. The cost of cultivation was high in 45 cm × 15 cm spacing due to more number of seedlings required for planting as compared to other spacings.

The crop spacing of 45 cm × 30 cm being at par with 60 cm × 30 cm, gave net return as high as Rs 2323/-, 9004/- and 2832/- ha^{-1} during 1999, 2000 and 2001 respectively, over control. The mean benefit cost ratio was also high 2.73 under spacing of 45 cm × 30 cm followed 2.65 under 60 cm × 30 cm spacing as against 1.96 calculated under control spacing of 30 cm x 30 cm. Nitrogen application increased cost of cultivation and net return during all the years of experimentation. The profound effect of N application was realized only during 2001 when there was good amount of rainfall that fetches higher net return of Rs 2549/- at 60 kg ha^{-1} over control. Maximum benefit cost ratio was calculated under N application at 60 kg ha^{-1}.

It can be concluded that growing of henna at inter row spacing of 45 cm and intra row spacing of 30 cm with a N dose of 62 kg ha^{-1} was optimum for getting higher total dry leaf yield, more net return with higher benefit : cost ratio in arid to semi arid subtropics.

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