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Effect of conservation tillage on moisture conservation, soil-physical conditions, seedling emergence and grain yield of rainfed maize (*Zea mays*) and wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted during 1992–95 in maize (*Zea mays* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol.) sequence under rainfed condition to evaluate the effect of different management practices on moisture conservation, soil-physical conditions and seedling emergence of wheat, and grain yields of maize and wheat. The different management practices were : T₁, *Lantana* spreading after harvest of each crop and sowing with minimum tillage and *Lantana* residue mulch; T₂, *Lantana* standing in maize on receding monsoon and sowing of wheat with minimum tillage and *Lantana* residue mulch; T₃, same as T₂ but incorporation of *Lantana* at sowing of wheat; T₄, conventional tillage to maize and deep tillage to wheat; T₅, deep tillage to maize and conventional tillage to wheat; and T₆, conventional tillage and farmyard manure incorporation at sowing of crop. The study revealed that T₂ treatment conserved sufficient moisture and resulted in timely sowing of rainfed wheat with higher seedling emergence and grain yield. The T₁ treatment was the next best alternative for timely sowing of maize and wheat. Application of *Lantana* either as mulch (T₁ and T₂) or incorporated (T₃) helped in the build-up of soil-organic carbon. The treatment of minimum tillage done to both crops (T₁) did not increase the bulk density to the extent of causing ill effect on plant growth.

Key words : moisture conservation, conservation tillage, seedling emergence, consumptive water use, soil-organic carbon, soil-bulk density, maize, wheat, *Zea mays*, *Triticum aestivum*

In Himachal Pradesh maize (*Zea mays* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is the most important cropping sequence followed mostly under rainfed situations. Most of the rains in the state, except in the dry temperate and cold desert areas, are received during mid-June to mid-September (monsoon period). For the rest of year, especially during September – December and March – June, the evaporation exceeds rainfall, which depletes soil of its moisture reserves. These periods coincide with sowing of wheat and maize and delay in sowing results in lower yields.

The frequent light pre-monsoon showers are not sufficient for preparation of seed-bed for rainfed maize. Similarly, when monsoon rains recede, the soil profile is wet and continues to lose moisture, desiccating the seed zone. Quite often inadequate moisture at sowing of maize and wheat leads to poor germination and poor grain yield.

One way to conserve moisture *in-situ* for small holdings is to apply mulch to the previous standing maize on receding monsoon rains (Prihar *et al.* 1979, Sandhu *et al.* 1992, Acharya

and Kapur 1993). Wild sage (*Lantana camara* L.) is one of the organic wastes available in plenty and is difficult to control. The application of tender twigs of wild sage to the previous standing maize helps in conservation and carry-over of moisture (Acharya and Kapur 1993). Its application immediately after harvest of maize and wheat crops may help in the conservation of rain-water, particularly the pre-monsoon showers, for sowing the rainfed maize. The efficiency of the conserved moisture may increase on providing minimum exposure given to the seed-zone depth by seeding crops through minimum tillage. The objective of the present study was to evaluate different management practices for *in-situ* conservation and carry-over of moisture in maize-wheat sequence.

MATERIALS AND METHODS

A field experiment was conducted on a silty clay-loam soil for 3 years during 1992–95 with maize-wheat cropping sequence at the research farm of university at Palampur. The soil was Alfisol, typic Hapludalf. In the surface (0–0.15 m) layer the sand, silt and clay contents were 29.1, 49.5 and 21.2% respectively. The surface (0–0.15 m) soil had pH 5.6, cation-exchange capacity, 14 Cmol (P⁺)/100 g and organic carbon

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content 0.80 %. The soil was medium in available N, P and K (264, 15 and 224 kg/ha respectively). At 33 and 1 500 kPa suction, the soil retained 0.31 and 0.16 m³/m³ moisture. The mean weight diameter of the aggregates for the surface layer was large (1.8 mm), leading to poor water retentivity of the soil and high infiltration (5.68 cm/hr).

The treatments of moisture-conservation practices were imposed in maize-wheat sequence and were: T₁, *Lantana* mulch spreading after harvest of each crop and sowing with minimum tillage and *Lantana* residues as mulch; T₂, maize under conventional tillage and *Lantana* spreading as mulch in standing maize on receding monsoon and sowing wheat with minimum tillage and *Lantana* residues as mulch; T₃, maize under conventional tillage and *Lantana* spreading in standing maize on receding monsoon and incorporation of *Lantana* residues at sowing of wheat; T₄, conventional tillage to maize and deep tillage to wheat; T₅, deep tillage to maize and conventional tillage to wheat; and T₆, conventional tillage with farmyard manure incorporation @ 10 tonnes/ha at sowing of crops. In treatments where *Lantana* was applied, its tender twigs @ 50 tonnes/ha (on fresh-weight basis) in 2–3 lots were applied to cover the soil surface completely. In minimum tillage treatment no preparatory tillage was done and only a furrow was opened with a hand-driven plough to place seed and fertilizer. In deep-tillage treatment the tillage was done with a spade up to 0.25–0.30 m depth, whereas conventional tillage involved digging and seed-bed preparation with spade up to 0.15 m depth. The treatments, each in 5 m x 3 m plot, were replicated 6 times. 'Parvati' maize was sown in rows 0.60 m apart at 0.25 m spacing during 1992, 1993 and 1994, whereas 'S 308', 'HS 277' and 'VL 616' wheat were sown in rows 0.20 m apart and at 0.05 m spacing during 1992–93, 1993–94 and 1994–95 respectively. The crops were fertilized with 120 kg/ha N as urea, 26 kg/ha P as single superphosphate and 25 kg/ha K as muriate of potash. One-third N and the whole P and K were given basal and the remaining N was given in 2 equal splits at knee-high and pre-tasselling stages in maize and around maximum tillering and flowering stages in wheat when the soil was wet after rains.

Water content before sowing, at sowing and harvest of crops was determined gravimetrically and values were converted to volume basis, using bulk density determined at sowing and harvest of crops by core method (Jamison *et al.* 1950). The emergence of wheat seedling was counted daily in each plot from initiation of germination till it became constant in all the treatments. The emergence velocity was calculated as:

$$\text{Emergence velocity} = \frac{\text{Emergence (\%)}}{\text{Days to constant emergence}} \quad (\% \text{ per day})$$

The water-extraction rate during the wheat-crop growth was determined by the method described by Ogata *et al.* (1960). The consumptive water use was calculated by multiplying the rate with number of days of crop growth.

The organic carbon content in 0–0.15 m soil layer was estimated by wet digestion method (Walkley and Black 1934).

RESULTS AND DISCUSSION

Rainfall distribution

The rainfall pattern before sowing, at sowing and during early establishment of maize and wheat crops indicated that there was 32.3, 49.1 and 9.3 mm rain in last week of May 1992, 1993 and 1994 respectively. In the first week of June, light drizzle of 2.6 mm was observed during June 1992 and no rain during June 1993 and 1994. The drought period of 82 days was observed during October–December 1992–93, of 88 days during October–first week of January 1993–94 and of 58 days during October–November 1994–95. Some light showers received during these drought periods were of little significance with respect to the crop demand.

Soil-water content

The soil-water content determined before sowing, at sowing and at harvest of crops showed that the treatment with application of *Lantana* mulch to standing maize at the time of receding monsoon (T₂ and T₃) conserved sufficient moisture until sowing of wheat compared with the rest of the treatments (Table 1). Acharya and Kapur (1988, 1993) obtained 2 cm more depth of water in 0–60 cm depth at sowing

Table 1 Soil-water content (m³/m³) in seed-zone depth (0–0.15 m) before sowing, at sowing and at harvest of rainfed maize and wheat crops

Treat- ment	1992						1993						1994						1995		
	20	21	30	5	5	18	20	24	27	3	4	6	11	17	21	23	30	2	5	18	
	Jun	Oct	Oct	Nov	Dec	May	May	May	May	Oct	Oct	May	May	May	May	May	May	Oct	Oct	May	
	(MS)	(MH)			(WS)	(WH)			(MS)	(MH)	(WS)	(WH)				(MS)	(MH)		(WS)	(WH)	
T ₁	0.35	0.25	0.21	0.21	0.33	0.29	0.26	0.24	0.30	0.24	0.24	0.27	0.31	0.25	0.28	0.24	0.22	0.21	0.20	0.20	
T ₂ , T ₃	0.32	0.21	0.20	0.21	0.32	0.27	0.25	0.18	0.29	0.27	0.26	0.28	0.30	0.22	0.24	0.22	0.24	0.22	0.21	0.19	
T ₄	0.33	0.12	0.14	0.15	0.20	0.22	0.20	0.16	0.24	0.22	0.21	0.26	0.28	0.21	0.24	0.20	0.20	0.18	0.16	0.17	
T ₅	0.33	0.14	0.18	0.17	0.20	0.26	0.24	0.19	0.29	0.20	0.20	0.27	0.29	0.21	0.22	0.21	0.19	0.17	0.16	0.16	
CD (<i>P</i> = 0.05)	0.04	0.03	0.03	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.02	0.01	0.03	0.02	0.02	0.02	0.02	0.03	0.03	

MS, Maize sowing; WS, wheat sowing; MH, maize harvest; WH, wheat harvest
Details of treatments are given in text

of wheat with application of *Lantana* mulch in standing maize at the time of receding of monsoon, which conserved and maintained higher soil-water content compared with the conventional and deep tillage treatments. In maize the treatment with *Lantana* application after harvest of wheat (T_1) conserved and maintained higher soil-water content than with other treatments.

Seedling-emergence parameters

The higher water content under T_1 , T_2 and T_3 treatments at sowing and occurrence of light rainfall of 1.5 and 2.1 mm at 1 and 2 days after sowing wheat during 1993-94, and 3.3, 0.1 and 0.9 mm at 10, 20 and 22 days after sowing wheat during 1994-95 helped in early germination, took lesser time for attaining constant emergence and had higher emergence (%) and emergence velocity compared with other treatments (Table 2). Kapur *et al.* (1978) reported higher wheat-germination velocity in mulched treatment due to moderation of hydro-thermal regime. During 1994-95, wheat germination under T_4 , T_5 and T_6 treatments started only after the occurrence of winter rains in December. Similar situation was encountered in 1992, as after sowing wheat in the first week of December the rains were received only during January 1993.

Soil-bulk density

The soil-bulk density did not change from 1.11 Mg/m³ (at sowing maize in 1992) and 1.12, 1.17, 1.14, 1.03, 1.04 and 1.10 Mg/m³ under treatments T_1 , T_2 , T_3 , T_4 , T_5 and T_6 respectively at harvest of wheat in 1994-95 (Table 3). The lower values under T_4 and T_5 were due to loosening of soil owing to deep or conventional tillage done to maize or wheat as per the treatment sequence. Gupta (1987) also reported

lower values of bulk density with deep tillage. The treatment T_1 , in which continuous minimum tillage was done for 3 years in maize as well as wheat, had negligible effect on bulk density due to presence of *Lantana* mulch at the surface, which prevented compaction of the untilled layer compared with T_2 , where *Lantana* was applied only to wheat crop. Acharya and Sharma (1994) reported that bulk density under no-tillage without mulch increased and resulted in compaction of surface depth, which had a deleterious effect on crop growth. This effect, however, was mitigated when no tillage was done with mulch.

Consumptive-water use

Consumptive water use (CWU) determined during wheat-crop growth indicated that treatments T_1 , T_2 and T_3 (*Lantana* applied either as mulch or incorporated) had higher CWU values of 496, 567 and 389 in 1993-94; and of 591, 686, and 547 mm in 1994-95 respectively, compared with T_4 and T_5 (conventional or deep tillage) having corresponding values of 289 and 292 mm (1993-94) and 410 and 501 mm in 1994-95. Bhagat and Acharya (1987) also observed higher water-use in term of water-extraction rate with mulch application.

Grain yield

The grain yield (Table 4) of maize under T_1 was higher than under T_4 and T_5 , whereas that of wheat under T_2 was higher than under the remaining treatments, primarily due to better hydro-thermal regime, resulting in better germination, early establishment and crop growth. In spite of low seed-zone moisture and resultant low emergence velocity, wheat yields under T_1 , T_2 and T_3 during 1994-95 were higher, as rainfall episodes during December were favourable for crop growth. In 1993-94 no-rain was received from second week

Table 2 Effect of moisture-conservation practices on seedling-emergence parameters on rainfed wheat

Treatment	Initiation of emergence (day)	Constant emergence (day)	Emergence (%)	Emergence velocity (% day)
1993-94				
T_1	5.3	20.4	78.8	3.86
T_2	5.2	12.6	88.5	7.02
T_3	6.1	31.7	88.5	7.02
T_4	6.6	29.3	42.3	1.44
T_5	6.4	28.3	59.6	2.11
T_6	6.7	31.2	57.7	1.85
CD ($P=0.05$)	0.7	2.7	2.1	0.13
1994-95				
T_1	5.3	41.6	79.3	1.91
T_2	5.2	31.3	81.3	2.60
T_3	5.6	90.3	80.7	0.89
T_4	72.3	110.3	76.3	0.69
T_5	74.6	111.3	75.9	0.68
T_6	74.7	107.9	76.7	0.71
CD ($P=0.05$)	0.6	21.9	2.1	0.10

Details of treatments are given in text

Table 3 Effect of moisture-conservation practices on soil-bulk density (Mg/m^3) in surface (0–0.15 m) layer

Treatment	Maize 1993		Wheat 1993–94		Maize 1994		Wheat 1994–95	
	AS	AH	AS	AH	AS	AH	AS	AH
T ₁	1.15	1.26	1.11	1.19	1.16	1.14	1.14	1.12
T ₂	1.23	1.16	1.15	1.21	1.22	1.17	1.18	1.17
T ₃	1.24	1.20	1.21	1.12	1.13	1.15	1.12	1.14
T ₄	1.20	1.16	1.09	1.09	1.08	1.03	1.02	1.03
T ₅	1.04	1.11	1.10	1.11	1.10	1.08	1.09	1.10
T ₆	1.27	1.20	1.17	1.16	1.15	1.10	1.09	1.10
CD ($P = 0.05$)	0.04	0.03	0.03	0.04	0.04	0.03	0.04	0.03

AS, At sowing; AH, at harvest

Initial value (at sowing maize 1992) = 1.1 ± 0.03

Details of treatments are given in text

Table 4 Effect of moisture-conservation practices on grain yield (tonnes/ha) of rainfed maize and wheat

Treatment	Maize 1992	Wheat 1992–93	Maize 1993	Wheat 1993–94	Maize 1994	Wheat 1994–95
T ₁	3.82	2.03	4.33	1.91	2.49	3.49
T ₂	2.82	1.87	3.61	1.93	1.44	4.64
T ₃	2.87	1.68	3.62	1.25	1.42	3.79
T ₄	3.46	1.59	3.63	0.93	0.75	1.97
T ₅	3.13	1.48	3.37	0.80	0.22	1.97
T ₆	4.03	2.23	3.96	1.42	0.32	0.41
CD ($P = 0.05$)	0.55	0.54	0.57	0.42	0.32	0.41

Details of treatments are given in text

of November to first week of January, which adversely affected the crop growth. In 1994–95, 12 rains amounting to 62.7 mm were received during December, which helped in better establishment of the crop and thereby led to higher grain yield resulting in greater water use compared with that in 1993–94. Deep tillage done either to maize (T₅) or wheat (T₄) did not prove beneficial, probably due to inadequate soil moisture at sowing, producing poor seed-soil contact owing to loosening of soil (lower bulk density) and thereby resulted in poor germination.

Soil-organic carbon

The organic carbon determined in 0–0.15 m soil layer at the end of experiment (at harvest of wheat in 1994–95) indicated that application of *Lantana* either incorporated (T₃) or applied as mulch (T₁ and T₂) had significantly higher organic carbon compared with conventional or deep tillage (T₄ and T₅). Also, the treatment T₃ showed higher organic carbon compared with T₆. The organic carbon content increased with time, from 0.8% (initial value) to 1.20, 1.10, 1.28, 0.99, 0.92 and 1.20% under T₁, T₂, T₃, T₄, T₅ and T₆ respectively at the end of experiment. Bakajev *et al.* (1981) in long-term experiment of 12 years observed that mulching with straw increased the organic matter in 0–0.10 m layer by 0.17 and 0.58 % for mulch @ 2 and 4 tonnes/ha.

The study indicated that application of organic waste like *Lantana* to previous standing maize on receding of monsoon conserved sufficient moisture in the seed-zone depth for

timely sowing and early establishment of rainfed wheat. For maize the application of *Lantana* after harvest of wheat conserved pre-monsoon showers. The minimum tillage + *Lantana* mulch helped in better germination, seedling emergence and early establishment of rainfed crops, resulting in higher grain yield. Thus conservation tillage not only helped in moisture conservation but also effected energy saving, as it did not require any elaborate preparatory tillage. It also improved the soil-physical condition.

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Effect of tillage and moisture-conservation practices on productivity, water use and water-use efficiency of pearl millet (*Pennisetum glaucum*) on light soils under dryland condition

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ABSTRACT

A field experiment was conducted during the rainy season (*khari*) of 1989 and 1990 to study the effect of deep summer tillage with and without incorporation of farmyard manure and soil mulching on grain yield, water use and water-use efficiency of pearl millet [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz]. Pearl millet yield varied significantly due to tillage practices only in 1990. The highest grain yield (2.25 tonnes/ha) was obtained with no summer ploughing and lowest (1.52 tonnes/ha) with chiselling + deep summer ploughing + farmyard manure. Seasonal water use was highest with no summer ploughing in both the years. Water-use efficiency was highest (10.41 kg grain/ha-mm) with chiselling + deep summer ploughing + farmyard manure in 1989, and with no summer ploughing (6.0 kg grain/ha/mm) in 1990. Net return was highest (Rs 4 313 kg/ha) with deep summer ploughing + farmyard manure in 1989 and with no summer ploughing (Rs 4 852/ha) in 1990. However, net return/rupee invested was highest with no summer ploughing in both the years, being Rs 1.45 and 1.67 in 1989 and 1990 respectively. Soil mulching showed beneficial effect on yield only in 1989. The highest grain yield (2.30 tonnes/ha) was obtained with dust mulch, closely followed by straw mulch (2.18 tonnes/ha). Soil mulching caused considerable increase in water use and water-use efficiency only in 1989. Though dust mulch resulted in higher seasonal water use than straw mulch, there was no marked difference between these 2 for water-use efficiency. Net return (Rs 4 601/ha) as well as net return/rupee invested (Rs 1.32) were highest with dust mulch in 1989. However, net return (Rs 5 965/ha) and net return/rupee invested (Rs 1.36) were highest with no mulch in 1990.

Key words : pearl millet, *Pennisetum glaucum*, tillage practice, moisture conservation, farmyard manure

There has been no sustainable rise in productivity of rainfed pearl millet [*Pennisetum glaucum* (L.) R.Br. emend. Stuntz], mainly because of soil-moisture deficiency, usually at critical stages of growth. The soils of the pearl millet-growing regions being mostly light in texture embody low moisture-holding capacity. Efforts have been made to augment the soil-moisture retentivity by adopting various tillage practices and addition of organic matter. Gerard and Bordersky (1984) recorded increase in moisture-storage capacity of tilled soils on account of decrease in run-off, evaporation and erosion. Kumar *et al.* (1984) reported that application of farmyard manure in sandy soils resulted in progressive increase in the volume of water retained at a given suction, together with a small increase in available water and

decrease in hydraulic conductivity and infiltration rate. However, the water so retained in the root zone has very little significance unless conserved properly. Kaushik and Gautam (1991) and Lal *et al.* (1992) reported beneficial effect of various mulches on the moisture conservation and crop yields under dryland condition. Hence an experiment was conducted to determine an effective and economical practice of tillage and soil mulching to increase the productivity and water-use efficiency of pearl millet.

MATERIALS AND METHODS

The field experiment was conducted on sandy loam soil during the rainy seasons (*khari*) of 1989 and 1990. It was laid out in split-plot design with 6 tillage practices as main plot, viz T₀, no summer ploughing; T₁, deep summer ploughing; T₂, deep summer ploughing + farmyard manure; T₃, chiselling + deep summer ploughing; and T₄, chiselling + deep summer ploughing + farmyard manure; and 3 moisture-conservation practices as subplot treatments, viz M₀, no mulch; M₁, straw mulch; and M₂, dust mulch. The experiment

Based on complete Ph D thesis submitted by the first author to Indian Agricultural Research Institute, New Delhi, in 1992 (unpublished)

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was replicated 4 times. Pearl millet hybrid 'BK 560-230' was sown on 11 August 1989 and 7 July 1990. The crop was fertilized with a uniform dose of 60 kg N/ha through urea and 12 kg P/ha through single superphosphate, after deducting the quantity of N and P available through farmyard manure. Other cultural operations were carried out as per recommendation.

Chiselling and deep summer ploughing were done well before commencement of rains. Chiselling was done up to 40 cm depth and deep summer ploughing up to 20 cm. Farmyard manure was incorporated manually in open furrows along with summer ploughing. Straw mulch @ 5 tonnes/ha was applied over the soil surface in the third week of August in 1989 and the second week of September in 1990. Similarly, dust mulch was created by hoeing at the same time when straw mulch was applied in respective years. Seasonal water use was computed by pan-evaporation method and water-use efficiency was calculated in terms of grain (kg) produced per unit of water (mm) used. N concentration in grain and stover was estimated at harvest by the modified Kjeldahl method (Jackson 1967), P by Olsen's method (Olsen 1954) and K by flame-photometer method (Toth and Prince 1949).

The rainfall pattern during the crop-growth period was different during both the seasons. The total rainfall received during 1989 and 1990 was 172.2 and 662.8 mm respectively. The rainfall was scanty in 1989 but well distributed over the entire growing period of the crop (July, 45.4 mm; August, 31.8 mm; and September, 95.0 mm). Rainfall during 1990 was also well distributed (July, 135.8; August, 218.4; and September, 308.6 mm), but heavy rainfall in early September accompanied with high-velocity winds caused lodging of the crop particularly in summer deep-tilled plots. The mean evaporation measured through USWB class 'A' open pan during the crop season was 5.20 mm/day in 1989 and 6.15 mm/day in 1990.

RESULTS AND DISCUSSION

Growth and yield components

Tillage practices caused great variation in plant height, dry-matter accumulation and 1 000-grain weight in 1990 (Table 1), being highest under treatment T_0 and lowest under T_4 . The decrease in various growth and yield components was in the order : T_4 , T_3 , T_2 and T_1 , which could be attributed to the corresponding higher percentage of crop lodging under various tillage practices (Table 1). However, maximum number of tillers/plant was recorded under treatment T_4 , followed in order by T_3 , T_2 and T_1 . The increase in tillers/plant due to summer tillage showed that there was no adverse effect of lodging on tillering of the crop.

Moisture conservation greatly improved the growth and yield components only in 1989 (Table 1). Adequate availability of water to plants results in cell turgidity and eventually higher meristematic activity, leading to more foliage development, greater photosynthetic rate and consequently better plant growth (Arnon 1975). There was no measurable difference between the 2 mulches except that dust mulch proved significantly superior to straw mulch for tillers/plant.

Grain and stover yields

The tillage practices decreased grain and straw yields in 1990 (Table 2). T_0 gave significantly highest grain and stover yields, followed by T_1 , T_2 , T_3 and T_4 . The decreased productivity of pearl millet under summer tillage treatments could be attributed to adverse effect of lodging of the crop under these treatments during this year (Table 1).

Use of mulch increased the grain and stover yields significantly only in the drought year 1989. Increased productivity of pearl millet due to soil mulching was apparently because of favourable effect of moisture on various

Table 1 Effect of tillage and moisture-conservation practices on growth, yield-contributing characters and lodging of pearl millet

Treatment	Plant height (cm)		Tillers/plant		Dry weight/plant (g)		1 000-grain weight (g)		Lodging (%)	
	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
<i>Tillage practice</i>										
T_0	165	201	2.86	2.44	50.0	55.3	5.74	7.81	0	1.67
T_1	166	198	2.91	3.04	50.8	53.5	5.81	7.10	0	6.67
T_2	172	195	3.00	3.29	52.4	52.4	6.04	6.82	0	10.00
T_3	169	171	2.91	3.33	51.0	46.0	5.94	5.91	0	13.33
T_4	173	163	3.04	3.55	52.9	43.8	6.22	5.49	0	16.67
CD ($P=0.05$)	NS	5	NS	0.17	NS	1.7	NS	0.33	NS	1.40
<i>Moisture conservation</i>										
No mulch	150	188	2.61	3.00	45.4	50.7	5.17	6.76	0	9.50
Straw mulch	174	185	3.01	3.17	53.0	50.3	6.24	6.53	0	9.60
Dust mulch	183	184	3.22	3.22	55.8	49.7	6.44	6.59	0	9.90
CD ($P=0.05$)	9	NS	0.17	NS	3.1	NS	0.38	NS	NS	NS

Details of treatments are given under Materials and Methods

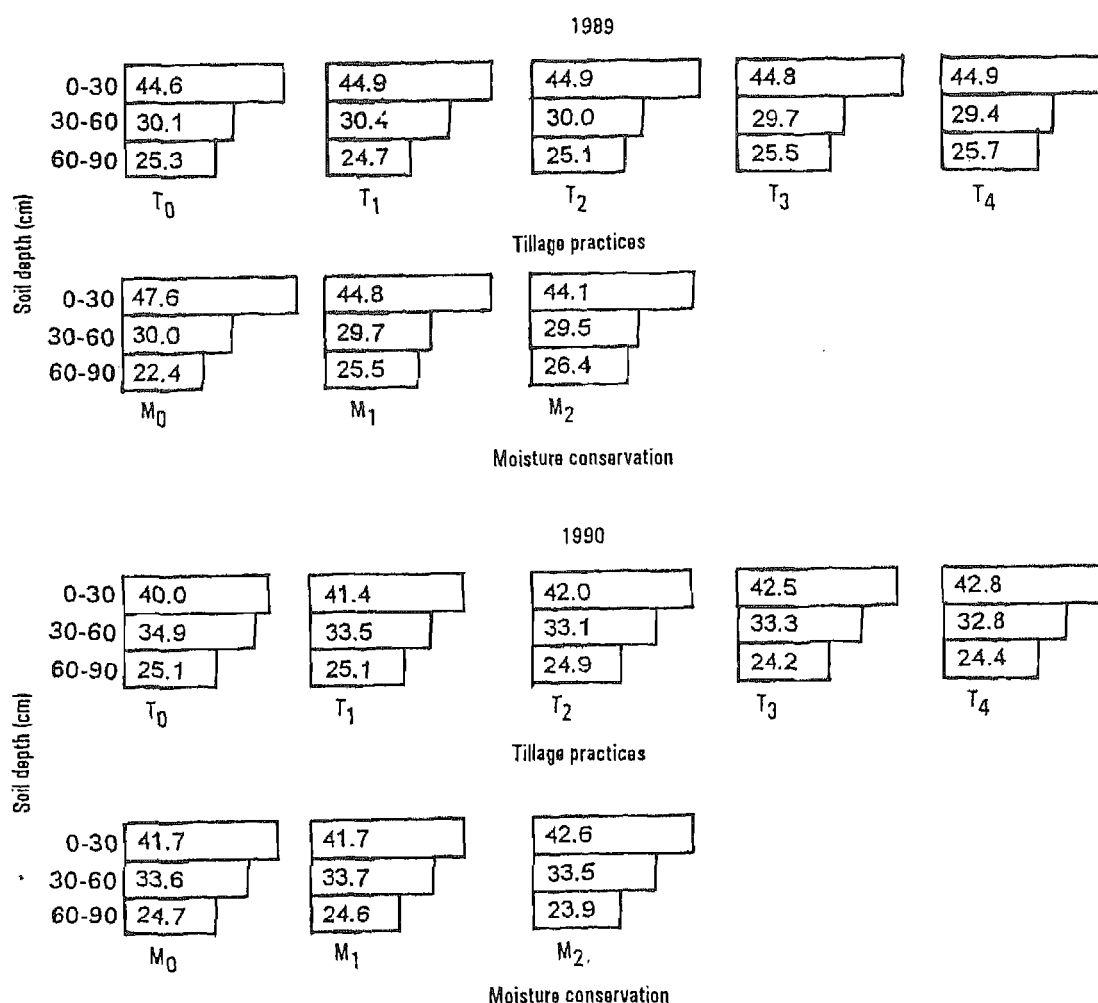


Fig 1 Pattern of soil-moisture depletion (%) as affected by tillage practices and moisture conservation (details of treatments are given under Materials and Methods)

Table 2 Effect of tillage and moisture-conservation practices on yield and total uptake of nutrients by pearl millet

Treatment	Grain yield (tonnes/ha)		Stover yield (tonnes/ha)		Total uptake of nutrients (kg/ha)					
					N		P		K	
	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
<i>Tillage practice</i>										
T ₀	2.04	2.25	7.37	7.97	88.0	93.8	11.6	13.6	261	304
T ₁	2.08	2.02	7.53	7.80	88.1	88.5	12.2	12.7	266	290
T ₂	2.15	1.92	7.82	7.76	92.1	87.8	13.0	12.2	262	287
T ₃	2.09	1.62	7.51	6.79	88.0	75.4	12.5	10.4	262	246
T ₄	2.17	1.52	7.83	6.48	90.9	71.6	13.0	9.6	274	229
CD ($P=0.05$)	NS	0.08	NS	0.22	NS	3.6	NS	0.5	NS	10
<i>Moisture conservation</i>										
No mulch	1.85	1.90	6.75	7.44	79.0	84.5	10.0	11.9	238	274
Straw mulch	2.18	1.86	7.96	7.36	92.9	83.3	13.1	11.7	281	270
Dust mulch	2.30	1.85	8.13	7.28	96.0	82.7	13.4	11.5	287	268
CD ($P=0.05$)	0.12	NS	0.41	NS	5.3	NS	0.8	NS	15	NS

Details of treatments are given under Materials and Methods

growth and yield components (Table 1). There was no marked difference between straw and dust mulch for grain and stover

yields. The result confirms the finding of Kaushik and Gautam (1991).

Table 3 Effect of tillage and moisture-conservation practices on seasonal water use, water-use efficiency and economics of pearl millet

Treatment	Seasonal water use (mm)		Water-use efficiency (kg grain/ha-mm)		Net return (Rs/ha)		Net return/rupee invested	
	1989	1990	1989	1990	1989	1990	1989	1990
<i>Tillage practice</i>								
T ₀	235	370	8.75	6.09	4 204	4 852	1.45	1.67
T ₁	230	360	9.23	5.63	4 200	4 210	1.37	1.38
T ₂	221	351	9.96	5.47	4 313	3 863	1.35	1.21
T ₃	225	350	9.45	4.63	4 082	2 889	1.28	0.91
T ₄	215	344	10.41	4.42	4 232	2 421	1.27	0.73
<i>Moisture conservation</i>								
No mulch	208	360	8.88	5.23	3 575	5 965	1.23	1.36
Straw mulch	232	352	9.40	5.26	4 154	3 285	1.19	0.94
Dust mulch	235	353	9.80	5.25	4 600	3 303	1.32	0.97

Details of treatments are given under Materials and Methods

Nutrient uptake

Uptake of N, P and K decreased significantly due to tillage practices in 1990 (Table 2). The maximum uptake of these nutrients was recorded under T₀ treatment. This was because of higher grain and stover yields resulting from lowest percentage of lodging of crop under this treatment than under all summer tillage practices.

Nutrient uptake by pearl millet plants was significantly higher due to soil mulching than no mulch only in 1989 (Table 2). There was no measurable difference between straw and dust mulches. Adequate supply of moisture increases the growth and dry-matter production of crop directly as well as indirectly by increasing the availability and utilization of nutrients (Russel and Barber 1960).

Seasonal water use

The seasonal water use was higher during 1990 than during 1989 due to higher amount of rainfall (Table 3). The maximum seasonal water use was recorded under T₀ treatment and the minimum under T₄ in both the years. The tillage practice brought about no additional advantage over no summer ploughing either in scanty-rainfall year of 1989 or in good-rainfall year of 1990, in seasonal water use by the crop.

Soil mulching caused considerable increase in seasonal water use only in 1989 (Table 3). The crop used 27 and 24 mm more water due to dust and straw mulches respectively compared with no mulch. Water use by crop is mainly controlled by evaporative demand of the atmosphere and moisture availability to plants. Gupta (1980) reported that soil mulching resulted in improvement of moisture-retention capacity of the soil and decrease in soil temperature and hence less evaporation losses.

Water-use efficiency

Water-use efficiency (kg grain/ha-mm water used) was influenced considerably due to various tillage practices in both the years (Table 3). In 1989 the highest water-use efficiency was recorded under T₄ and lowest under T₀.

However, the reverse was true in 1990. In view of the similar trend of seasonal water use, the differential trend of water-use efficiency under different tillage treatments could be attributed to their differential trend in grain yield during both the years.

Moisture conservation brought about considerable increase in water-use efficiency only in 1989. Dust and straw mulches were equally effective in this regard. The increase in water-use efficiency due to soil mulching could be assigned to the increase in seasonal water use and partly to increased grain yield.

Pattern of soil-moisture extraction

Extraction of soil moisture by pearl millet from different layers varied due to various tillage practices only in 1990 (Fig 1). The highest depletion (%) from 0–30 cm soil layer was registered under T₄ and the lowest under T₀. However, the reverse was true for 30–60 cm soil layer. No definite pattern of soil-moisture depletion was observed in 60–90 cm soil layer under different tillage treatments.

Moisture conservation caused variation in the pattern of soil-moisture extraction only in 1989. Soil mulching resulted in minimum amount of moisture depletion in top soil layers (0–60 cm) and a corresponding decrease in subsequent layer (60–90 cm). Kaushik *et al.* (1986) stated that mulches act as a barrier between the incident radiation and soil surface, leading to a reduction in the evaporation loss. There was no marked difference between dust and straw mulches in this regard.

Economics

Net return (Rs 4 313/ha) and net return/rupee invested (Rs 1.45) were maximum under T₂ and T₀ respectively in 1989. However, the highest net return/ha (Rs 4 852) and net return/rupee invested (Rs 1.67) were obtained in 1990 under T₀ treatment.

Net return (Rs 4 600/ha) and net return/rupee invested (Rs 1.32) were highest with dust mulch in 1989. In 1990 the highest net return (Rs 5 969/ha) and net return/rupee invested

Thus deep summer-tillage practice did not prove advantageous under either extremely low or high rainfall conditions for productivity and water-use efficiency of pearl millet. Moisture conservation either with dust or straw mulch increased the pearl millet yield and water-use efficiency only in low-rainfall year.

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Effect of farmyard manure, nitrogen and source of fertilizer on growth, yield attributes and yield of indian mustard (*Brassica juncea*)

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ABSTRACT

A field experiment was conducted during winter season of 1992–93 and 1993–94 at Agronomy Farm of the college at Anand, to study the effect of farmyard manure, N and source of fertilizer on growth, yield attributes and yield of indian mustard [*Brassica juncea* (L.) Czernj. & Cosson]. Plant height, and primary and secondary branches/plant increased significantly on application of up to 10 tonnes/ha farmyard manure. Similarly, yield attributes, viz siliqua/plant, number of seeds/siliqua, seed yield/plant, 1 000-seed weight, and the seed and stover yields improved significantly on farmyard manure application. Its application @ 10 tonnes/ha was economical for yield and yield attributes. N @ 75 kg/ha significantly improved the yield parameters per plant such as siliquae, seed yield, number of seeds and 1 000-seed weight, and thereby the total seed yield of indian mustard also. A significant improvement in growth and yield attributes and the seed and stover yields was also noticed where S-containing fertilizers were applied compared with S-free source of fertilizers.

Key words : farmyard manure, nitrogen, source of fertilizer, indian mustard, *Brassica juncea*

Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson] is emerging as an important oilseed crop of Gujarat in recent years. The productivity of the crop in the state (1 293 kg/ha) is higher than the national average (944 kg/ha). Still the present yield levels are less than 50% of the potential yields. There is need to work out production technology specific to each agro-climatic region to increase the productivity level. Among the production practices nutrient management is the most important factor affecting the growth, yield and quality of indian mustard.

MATERIALS AND METHODS

The field experiment was carried out during the winter season of 1992–93 and 1993–94 at Anand on loamy sand soil. The soil was low in organic matter (0.36%) and nitrogen (0.036%) and medium in available phosphorus (42.5 kg/ha) and potassium (274.8 kg/ha), having pH 7.9. The experiment was laid out in split-plot design with 6 replications, assigning 3 farmyard manure levels (0, 10 and 20 tonnes/ha; F_0 , F_{10} and F_{20}) to main plots and 6 combinations of N (25, 50 and 75 kg/ha) and source of fertilizer [S_1 , urea + diammonium phosphate (sulphur-free source) and S_2 , ammonium sulphate + single superphosphate (sulphur containing source)] to the subplots. The gross and net plot sizes were 12.15 and 6.48 m² respectively. 'Gujarat Mustard 1' was sown in rows spaced

45 cm apart with intra-row spacing of 15 cm on 22 October 1992 and 23 October 1993 and harvested 110 days after sowing. A uniform seed rate of 4 kg/ha was used. All the plots were uniformly fertilized with 50 kg P/ha basal. Full quantity of farmyard manure and half the N were applied basal and the remaining half N was top-dressed at 45 days after sowing in the respective treatments. The whole quantity of N (basal and top-dressed) and recommended dose of P (50 kg/ha) were applied from 2 treatment sources. Error variances were tested for their homogeneity before pooling the data by Bartlett's test (Panse and Sukhatme 1989) of variance, and the variances were found homogeneous.

RESULTS AND DISCUSSION

Effect of farmyard manure

Farmyard manure application (10 and 20 tonnes/ha) significantly increased the plant height and secondary branches/plant during 1993–94 (Table 1). Among yield-attributing characters, number of seeds/siliqua, seed yield/plant, number of siliquae/plant and 1 000-seed weight were higher under F_{20} followed by F_{10} compared with the control (F_0) during both the years (Table 2). Such a conducive effect of farmyard manure could be attributed to the supply of nutrients through mineralization and improvement of physico-chemical properties of the soil (Badiyala and Verma 1990). Increased vegetative growth and yield attributes due to farmyard manure application resulted in additional improvement in seed and stover yields. Seed yield increased

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Table 1 Effect of farmyard manure, nitrogen and source of fertilizer on growth of indian mustard

Treatment	Plant height (cm) at harvest		Primary branches/ plant		Secondary branches/plant	
	1992-93	1993-94	1992-93	1993-94	1992-93	1993-94
<i>Farmyard manure (tonnes/ha)</i>						
F ₀	179.3	183.0	3.7	4.3	11.5	8.4
F ₁₀	185.7	189.0	4.0	4.5	11.5	9.4
F ₂₀	187.1	187.5	4.1	4.6	12.1	9.4
CD (<i>P</i> = 0.05)	NS	3.94	NS	NS	NS	0.78
<i>N (kg/ha)</i>						
N ₂₅	178.9	182.6	3.7	4.2	10.1	7.7
N ₅₀	183.7	188.3	4.1	4.4	12.2	9.1
N ₇₅	189.5	188.6	4.0	4.7	12.9	10.3
CD (<i>P</i> = 0.05)	7.20	2.57	0.31	0.21	0.79	0.71
<i>Source of fertilizer (S)</i>						
S ₁	183.2	184.8	3.8	4.3	11.6	8.7
S ₂	184.8	188.2	4.1	4.6	11.8	9.4
CD (<i>P</i> = 0.05)	NS	2.10	0.25	0.18	NS	0.58

Details of treatments are given under Materials and Methods

Table 2 Effect of farmyard manure, nitrogen and source of fertilizer on yield attributes of indian mustard

Treatment	Siliquae/plant		Length of siliqua (cm)		No. of seeds/ siliqua		Seed yield/plant (g)		1 000-seed weight (g)	
	1992-93	1993-94	1992-93	1993-94	1992-93	1993-94	1992-93	1993-94	1992-93	1993-94
<i>Farmyard manure (tonnes/ha)</i>										
F ₀	297.2	279.3	4.6	4.2	11.2	11.8	17.8	16.1	4.7	4.7
F ₁₀	341.0	306.8	4.6	4.2	11.5	12.3	19.1	17.0	4.8	4.9
F ₂₀	372.2	311.2	4.7	4.3	11.6	12.7	19.3	17.8	4.9	4.9
CD (<i>P</i> = 0.05)	30.04	25.40	NS	NS	NS	0.62	NS	1.23	0.12	0.18
<i>N (kg/ha)</i>										
N ₂₅	304.6	270.5	4.6	4.2	11.3	12.0	16.2	15.4	4.8	4.7
N ₅₀	339.1	299.8	4.7	4.3	11.3	12.1	18.8	17.1	4.8	4.8
N ₇₅	367.1	327.1	4.6	4.3	11.6	12.7	21.2	18.5	4.9	4.9
CD (<i>P</i> = 0.05)	19.55	23.08	NS	NS	NS	0.64	1.03	0.84	NS	0.12
<i>Source of fertilizer (S)</i>										
S ₁	323.9	289.1	4.7	4.3	11.5	12.2	18.0	16.5	4.8	4.8
S ₂	350.0	309.2	4.6	4.2	11.3	12.3	19.5	17.4	4.9	4.8
CD (<i>P</i> = 0.05)	15.96	18.84	NS	NS	NS	NS	0.84	0.68	NS	NS

Details of treatments are given under Materials and Methods

significantly or farmyard manure application compared with no application during both the years as well as in pooled mean data (Table 3). This was due to the cumulative effect of improvement in growth and yield attributes. The result confirms the finding of Sardana (1993). Farmyard manure @ 10 tonnes/ha gave significantly higher stover yield than no farmyard manure; whereas 10 and 20 tonnes farmyard manure/ha were at par during 1992-93, though the latter gave the highest yield during 1993-94. The length of siliqua and harvest index remained unaffected due to various farmyard manure levels during both the years. Its application @ 10 and 20 tonnes/ha recorded net returns of Rs 18 353 and Rs 18 154/ha with net gains of Rs 1.06 and 0.42 per rupee invested respectively.

Effect of N

N application @ 75 kg/ha increased the plant height, and primary and secondary branches compared with 25 kg/ha (Table 1). The number of siliquae/plant showed significant progressive increase compared with the N levels during both the years (Table 2). The highest siliquae/plant were recorded with N₇₅, perhaps because increased supply of N might have increased the meristematic activity and development of floral primordia through differentiation of tissues from somatic to reproductive stages, resulting in more flowers and siliquae. The result confirms the finding of Mohan and Sharma (1992). In indian mustard the sink lies in siliqua and seeds and hence under optimum supply of N there is greater translocation of photosynthate from leaves to sink (siliquae and seeds),

Table 3 Effect of farmyard manure, nitrogen and source of fertilizer on yield, harvest index, net return and incremental cost : benefit ratio (ICBR)

Treatment	Seed yield (kg/ha)			Stover yield (kg/ha)			Harvest index (%)		Net realization (Rs/ha)	Net ICBR
	1992-93	1993-94	Pooled mean	1992-93	1993-94	Pooled mean	1992-93	1993-94		
<i>Farmyard manure (tonnes/ha)</i>										
F ₀	2 510	2 508	2 509	5 319	5 858	5 589	32.10	29.94	17 410	
F ₁₀	2 681	2 761	2 721	5 674	6 099	5 887	32.20	31.14	18 353	1 : 1.08
F ₂₀	2 767	2 831	2 799	5 713	6 604	6 159	32.20	29.98	18 154	1 : 0.42
CD (<i>P</i> = 0.05)	109.83	143.72	84.68	187.38	289.91	NS	NS	NS		
<i>N (kg/ha)</i>										
N ₂₅	2 360	2 489	2 424	5 109	5 969	5 539	31.65	29.39	16 104	
N ₅₀	2 709	2 764	2 737	5 733	6 294	6 013	32.14	30.55	18 505	1 : 8.03
N ₇₅	2 889	2 847	2 868	5 864	6 299	6 082	33.13	31.13	19 317	1 : 5.29
CD (<i>P</i> = 0.05)	107.60	145.66	88.82	278.50	269.50	190.92	NS	1.36		
<i>Source of fertilizer (S)</i>										
S ₁	2 549	2 564	2 556	5 357	6 056	5 707	32.29	29.66	17 297	
S ₂	2 756	2 836	2 796	5 781	6 319	6 050	32.33	31.05	18 644	1 : 1.85
CD (<i>P</i> = 0.05)	88.06	118.93	72.50	227.40	220.00	155.89	NS	1.11		

Details of treatments are given under Materials and Methods

resulting in robust siliqua and seeds (Dubey and Khan 1993). This is clearly borne out of our result of 1993-94 on the number of seeds/siliqua and 1 000-seed weight. Significantly highest number of seeds/siliqua and 1 000-seed weight were recorded under 75 kg N/ha during 1993-94. Significant highest seed yield was recorded under 75 kg N/ha during 1992-93 and in pooled analysis, but in 1993-94 both the levels of 50 and 75 kg N/ha remained at par, increasing significantly the seed yield compared with 25 kg N/ha. The magnitude of average increase in seed yield under N₇₅ and N₅₀ was 444 and 313 kg/ha respectively. The treatment N₇₅ being at par with N₅₀ recorded significantly higher stover yield than N₂₅ in both the years as well as in the pooled mean data. Similar trend was also observed in harvest index during 1993-94. The result confirms those of Agarwal and Gupta (1991) and Chauhan *et al.* (1992). The increase in N level appreciably increased the net returns. The highest net return of Rs 19 317/ha was recorded under 75 kg/ha, followed by that under 50 kg N/ha (Rs 18 505). However, the highest net incremental cost ratio of 1 : 8.03 was registered under N₅₀, followed by 1 : 5.29 under N₇₅ level.

Effect of source of fertilizer

The source of fertilizer having sulphur (S₂) significantly increased the height during 1993-94. Primary and secondary branches were also significantly increased with ammonium sulphate + single superphosphate (S₂) during both the years except secondary branches during 1992-93 (Table 1). The length of siliqua, number of seeds/siliqua and 1 000-seed weight were not influenced by the source of fertilizer (Table 2). But source S₂ recorded significantly higher siliqua and seed yield/plant during both the years than urea +

diammonium phosphate (Source S₁). Similarly, S₂ significantly increased the seed and stover yields compared with S₁ during both the years and on pooled basis (Table 3). The higher seed yield was recorded under S₂ than S₁, which was 8.12, 10.61 and 9.39% during the first and second years and in combined analysis respectively. Improvement in growth and yield attributes led to higher seed yield/plant and total seed yield, because S activates some proteolytic enzymes and also helps in synthesis of some vitamins and co-enzymes (Bixby and Beaton 1985). Similar results were also obtained due to S addition in indian mustard by Singh *et al.* (1992) and Tiwari *et al.* (1992). The harvest index was significantly higher under S₂ than S₁ only during 1993-94. S₂ recorded Rs 18 644 more net return with incremental cost : benefit ratio of Rs 1.85 than S₁.

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Influence of rice (*Oryza sativa*)-cultivation method and cropping system on nutrient status of soil and productivity in Vertisols

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ABSTRACT

A field experiment was conducted during 1990–91 and 1991–92 to find out the influence of cultivation method of rice (*Oryza sativa* L.) and rice-based cropping systems on nutrient status of soil and total productivity of the system in Vertisols. The methods of rice cultivation such as direct sowing dry seed in dry seed-bed, direct sowing of sprouted seed on puddled wet soil and transplanting did not influence significantly the available nutrient status of the soil. Growing pigeonpea or redgram [*Cajanus cajan* (L.) Millsp.] in winter season (*rabi*) increased the soil-organic matter and the N and P status of the soil. It led to higher rice -equivalent yield in rice–redgram sequence (6 314 kg/ha) during succeeding year in comparison with that of rice–sorghum [*Sorghum bicolor* (L.) Moench]. But rice–safflower (*Carthamus tinctorius* L.) sequence recorded the overall best result in terms of rice-equivalent yield. Final nutrient status of the soil indicated that rice–pigeonpea sequence gives higher content of soil-organic carbon and the available N and P, whereas K and Zn availability declines in rice–sorghum and rice–safflower sequences.

Key words : *Oryza sativa*, rice-based cropping systems, soil-nutrient status, cultivation method, total productivity

A shift in rice (*Oryza sativa* L.) cultivation from transplanted to broadcast of sprouted seed saves labour, by utilizing short-duration modern varieties and cost-efficient herbicides. The possibility of growing many field crops in sequence with rice has been evaluated for their suitability and productivity, but little attention has been paid to the dynamics of the available nutrient status in the soil after rice and its effect on the subsequent crops. The demand for more irrigation water and labour with transplanting method of rice cultivation is the highest among all other methods of stand establishment in rice, and as such it signifies the importance of other methods such as dry sowing and dibbling of sprouted seeds in puddled soil to save water and also their effect on nutrient availability, which has to be studied (De Datta and Natasomsaran 1990). Therefore it is essential to identify suitable cropping system that is economically and environmentally sustainable. Hence an attempt was made to assess the available nutrient status and total productivity of the 3 rice-based cropping systems under different methods of its cultivation.

MATERIALS AND METHODS

The study was carried out during 1990–91 and 1991–92 at Rajendranagar, Hyderabad, in clay soil (Vertisol), having

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organic carbon 0.55%, pH 8.2, cation-exchange capacity (CEC) 45 meq/100 g soil and initial nutrient status 60.5 kg N/ha, 16.4 kg P/ha, 282 kg K/ha and 15.5 kg Zn/ha in the soil. The treatments arranged in split-plot design consisted of 3 methods of rice cultivation, viz M₁, direct sowing of dry seed in dry seed-bed, which was converted as wetland rice with onset of rains after 4 weeks of germination; M₂, direct sowing of sprouted seed on puddled wet soil; and M₃, transplanting of 4-week -old seedlings on puddled soil as main-plot treatment during rainy season (*kharif*). The sequence crops, viz 'ICPL 87' pigeonpea [*Cajanus cajan* (L.) Millsp.], 'M 35-1' sorghum [*Sorghum bicolor* (L.) Moench.] and 'No. 86-2-2' safflower (*Carthamus tinctorius* L.), were grown during winter season (*rabi*) were the subplot treatments.

The plot size was 7.5 m x 5 m. The crops were fertilized with recommended doses of nutrients applied through urea, single superphosphate and muriate of potash and were grown with recommended package of practices. The rainy-season (*kharif*) rice was sown @ 100 kg seed/ha, receiving N, P and K @ 100, 60, 40 kg/ha (N₁₀₀P₆₀K₄₀) respectively. Irrigation was given on alternate days as per crop requirement. Among winter-season (*rabi*) crops, pigeonpea, sorghum and safflower were sown @ 15, 20 and 8 kg/ha, receiving N₂₀P₃₀K₂₀, N₈₀P₄₀K₃₀ and N₂₀P₄₀K₃₀ respectively. The crops were irrigated twice in the cropping season.

Soil samples were collected from 0–15 cm depth initially

Table 1 Available nutrient status as influenced by different methods of rice cultivation and different rice-based cropping sequences after 2 cropping sequences in rainy and winter seasons

Treatment		N (kg/ha)		P (kg/ha)		K (kg/ha)		C (%)		Zn (ppm)	
		Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter
M ₁	C ₁ : pigeonpea	94.6	84.7	11.7	14.6	218	192	0.80	0.84	17.2	7.9
	C ₂ : sorghum	65.6	52.1	14.6	12.0	200	203	0.76	0.75	9.6	9.7
	C ₃ : safflower	105.8	45.7	12.5	12.5	196	184	0.71	0.72	9.6	8.4
M ₂	C ₁ : pigeonpea	70.1	86.2	14.4	18.2	206	191	0.78	0.78	11.6	12.2
	C ₂ : sorghum	77.2	58.5	14.5	16.5	202	190	0.76	0.70	7.6	7.4
	C ₃ : safflower	85.7	51.7	14.1	19.5	274	209	0.74	0.73	18.4	7.5
M ₃	C ₁ : pigeonpea	89.2	101.6	9.4	17.5	220	187	0.76	0.78	10.8	11.9
	C ₂ : sorghum	91.8	60.9	10.0	12.5	218	192	0.71	0.72	10.7	10.0
	C ₃ : safflower	97.3	49.1	9.5	14.2	212	188	0.72	0.68	15.0	11.1
Mean of M ₁		90.0	60.8	12.9	13.0	205	193	0.76	0.77	12.2	8.6
	M ₂	77.7	65.5	14.3	14.7	227	197	0.75	0.74	9.2	8.7
	M ₃	92.8	70.8	9.6	14.7	217	189	0.73	0.72	12.2	11.0
Mean of C ₁		85.9	90.8	11.8	16.7	215	190	0.78	0.80	13.2	10.3
	C ₂	78.2	57.2	13.0	13.6	207	195	0.74	0.72	9.4	9.0
	C ₃	96.3	49.1	12.0	12.0	227	194	0.72	0.71	11.0	9.0
Initial status		60.5	-	16.4	-	282		0.55		15.5	
CD (*P = 0.05)											
Main treatment		3.6*	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub-treatment		3.7*	7.6*	NS	2.5*	4.7*	NS	NS	0.03*	1.5*	0.96
Interaction											
Main x sub		6.3*	NS	NS	9.3*	NS	NS	NS	3.4*	NS	3.2*
Sub x main		6.4*	NS	NS	NS	NS	8.1*	NS	NS	2.7*	1.6

M₁, Direct sowing of dry seed; M₂, direct sowing of sprouted seed, M₃, transplanting

and after 2 cropping sequences in both the seasons, and analysed for organic carbon by Walkley and Black's methods (Jackson 1973), available N by alkaline permanganate method (Subbaiah and Asija 1956), available P by Olsen's extraction method (Olsen *et al.* 1954) and available K by neutral normal NH₄ OAc-extraction method (Jackson 1973). Grain yield was recorded and converted to rice-equivalent yield (REY) on the basis of prevailing market rates (Rs 300, 800, 400 and 1 000/100 kg) for rice, pigeonpea, sorghum and safflower respectively), and the gross return of each cropping system were computed.

RESULTS AND DISCUSSION

Soil-nutrient status

Organic carbon (%) : The organic carbon content of the soil was not influenced by the method of rice cultivation during both the seasons (Table 1). However, the rice-pigeonpea sequence recorded significantly higher organic carbon content (0.80) than other crop sequences after 2 years of study. It could be attributed to accumulation of root residues and shedding of leaves by the leguminous crops. Thakur and Sharma (1988) also reported similar result.

Available N content in soil (kg/ha) : The available N content during *kharif* was influenced significantly by the method of rice cultivation and rice-based cropping sequences. The available N content (77.2 kg/ha) was significantly lower

in direct sowing sprouted seed under puddled condition than in other 2 methods of rice cultivation. After rice, pigeonpea increased the available N content in the soil (90.8), which was significantly superior to rice-sorghum (57.2 kg/ha) and rice-safflower (49.1 kg/ha), indicating the contribution of biological N fixation by legumes and accumulated residues of roots and leaf fall of legumes.

Available P content in soil (kg/ha) : The available P status did not differ with the method of rice cultivation. However, soil-P status significantly increased after 2 crop cycles with the rice-pigeonpea sequence (16.7 kg/ha) compared with other sequence crops. This increase was marginal when compared with the initial status of the soil (16.4). Rice-sorghum and rice-safflower sequences depleted soil P by 18.6 and 28.1% respectively, which could be attributed to higher P requirement and rate of P absorption by dry-season crops, as also reported by Pati Ram *et al.* (1990).

Available K content in soil (kg/ha) : There was no influence of rice cultivation on available K status of the soil. In general, the available K content of the soil declined by 87–92 kg/ha from initial values of 282 kg/ha under rice-sequence crops, as the demand for potassium is high for sequence crops. Singh and Nambiar (1986) also reported similar finding of depletion of soil-available K content under different cropping sequences. Apart from demand, contribution of K through irrigation water during *rabi* is

Table 2 Mean grain yields (kg/ha) of rice and succeeding crops, rice-equivalent yields (REY) and gross returns as influenced by different treatments

Treatment	1990-91				1991-92			
	Rice in <i>kharif</i> 1990 (kg/ha)	Succeed- ing crops in <i>rabi</i> (kg/ha)	REY (kg/ha)	Gross return (Rs/ha)	Rice in <i>kharif</i> 1990 (kg/ha)	Succeed- ing crops in <i>rabi</i> (kg/ha)	REY (kg/ha)	Gross return (Rs/ha)
M ₁ : Direct sowing of dry seed								
C ₁ : pigeonpea	3 764	776	5 833	17 498	4 121	1 027	6 859	20 576
C ₂ : sorghum	3 986	1 700	6 247	18 741	3 585	1 549	5 645	16 935
C ₃ : safflower	3 875	952	7 047	21 141	3 444	1 123	7 187	21 561
M ₂ : Direct sowing of sprouted seed								
C ₁ : pigeonpea	4 475	709	6 365	19 095	4 121	773	6 182	18 546
C ₂ : sorghum	4 660	1 424	6 553	19 659	3 646	1 113	5 126	15 378
C ₃ : safflower	4 569	1 206	8 588	25 749	3 616	976	6 869	20 607
M ₃ : Transplanting								
C ₁ : pigeonpea	4 143	796	6 266	18 797	3 363	953	5 905	17 714
C ₂ : sorghum	4 294	1 385	6 136	18 408	3 252	1 619	5 405	16 215
C ₃ : safflower	4 226	1 564	9 438	28 314	3 404	1 148	7 230	21 690
Means of methods								
M ₁	3 875	1 143	6375	19 127	3 716	1 232	6 563	19 689
M ₂	4 568	1 113	7 167	21 501	3 794	954	6 059	18 177
M ₃	4 221	1 248	7 280	21 840	3 339	1 240	6 180	18 540
Means of crops								
C ₁	4 127	760	6 154	18 463	3 868	918	6 315	18 945
C ₂	4 313	1 503	6 312	18 936	3 494	1 428	5 392	16 176
C ₃	4 224	1 240	8 356	25 068	3 498	1 082	7 095	21 285
CD (<i>P</i> = 0.05)								
Main treatment			Sig 303*	Sig 909			NS	NS
Subtreatment			Sig 282*	Sig 846			Sig 724*	Sig 2 171
Interaction								
Main x sub			Sig 498*	Sig 1 494			NS	NS
Sub x main			Sig 489*	Sig 1 466			NS	NS

negligible, which might be another probable reason for low available K.

Available Zn (ppm) : The rice-cropping sequences had significant effect on available Zn status. It was higher in rice-pigeonpea sequence both during *kharif* and *rabi* compared with that of rice-safflower and rice-sorghum cropping sequence. Possible reason could be the addition of high organic matter to the soil by this sequence. The method of rice cultivation did not influence the available zinc status of the soil.

Rice - equivalent yield (kg/ha) and gross return (Rs/ha) : The rice-equivalent yields (kg/ha) of the different rice-based systems were significant only during the first year (1990-91). Among the different methods of rice cultivation, transplanting (7 280 kg/ha) and direct sowing of sprouted seed in puddled soil (7 167 kg/ha) were at par but significantly superior to dry seeding in dry soil (6 375 kg/ha).

Rice-equivalent yield in rice-pigeonpea sequence increased (6 314 kg/ha) during 1992 compared with that of other sequences due to increased N and P availability and increased yield. For rice-equivalent yields of different

systems, rice-safflower recorded significantly higher REY of 8 356 kg/ha compared with rice-redgram and rice-sorghum. The trend was similar during succeeding year. The gross return recorded trend similar to that of rice-equivalent yield. Among the cropping systems, rice-safflower recorded significantly higher gross return of Rs 25 068 /ha in 1991 and Rs 21 285/ha in 1992.

It was concluded that 3 methods of rice cultivation did not influence the available nutrient status of the soil, whereas cropping systems had significant effect on available nutrient status. The availability of N and K was significantly higher after wet-season crop (rice), whereas available P was increased along with N after the harvest of *rabi* crops. The availability of nutrients like P, K and Zn was depleted, whereas available N and organic carbon content increased compared with the initial status of the soil due to continuous cropping system in rice fallows (Fig 1).

In terms of rice-equivalent yield, rice-safflower sequence recorded the best result, probably due to higher price, and safflower crop appeared to be more hardy, requiring less number of irrigations. Hence rice-safflower could be of greater importance to this region.

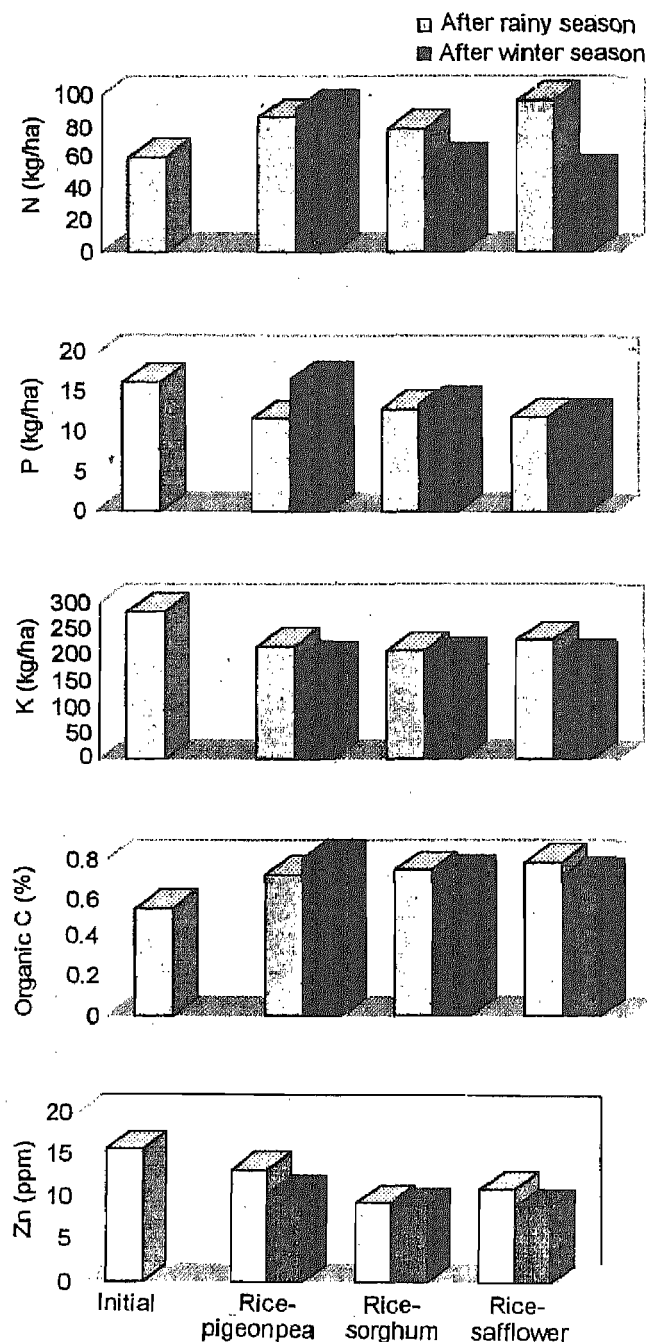


Fig 1 Available nutrient status as influenced by different rice-based cropping systems

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Response of *Rhizobium*-vesicular arbuscular mycorrhizal symbionts on photosynthesis, nitrogen metabolism and sucrose translocation in greengram (*Phaseolus radiatus*)

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ABSTRACT

A field experiment was conducted during rainy season of 1994 to study the response of 'PS 16' and 'Pusa 105' greengram (*Phaseolus radiatus* L.) to *Rhizobium*- and vesicular arbuscular mycorrhizal (VAM) fungi. *Rhizobium*-treated plants had larger leaf area (9.10%), higher chlorophyll content (11.40%) and photosynthesis activity (21.65%), transpiration (15.89%) and stomatal conductance (19.35%) than untreated ones, and thus had higher dry-matter production. Inoculation increased the nodulation, nitrate reductase and nitrogenase activity, but the response was significantly higher in the *Rhizobium*- and VAM-inoculated plants. The translocation pattern (¹⁴C sucrose) was more towards underground portion in dual-inoculated plants compared with single inoculation and the uninoculated control. 'Pusa 105' greengram showed higher activity than 'PS 16' and dual inoculation proved better than single inoculation.

Key words : greengram, *Phaseolus radiatus*, *Rhizobium*, VAM, physiological process

The most important dinitrogen-fixing system in the nodulated legumes is the association with *Rhizobium*, which affects the efficiency of symbiotic nitrogen fixation. The vesicular-arbuscular mycorrhiza (VAM) improves the phosphorus uptake (Clarkson 1985), phosphatase activity in roots (Tarafdar and Marschner 1994) and many other major micro-nutrients (Ho 1993). Application of VAM improves the water relations of many crop plants (Allen 1982, Panwar 1992) owing to extension of hyphae beyond the zone surrounding the absorbing root surface and its root hairs, resulting in improved physiological processes in the symbionts. The present investigation was carried out to study the effect of VAM-*Rhizobium* interaction on physiological processes like photosynthetic activity, N₂ metabolism and translocation under field condition in 2 varieties of greengram (*Phaseolus radiatus* L.).

MATERIALS AND METHODS

Two varieties ('PS 16' and 'Pusa 105') of greengram were raised in field. The seeds were inoculated with *Rhizobium* cowpea miscellaneous group. The VAM (*Glomus fasciculatum* G&T) were applied through layering technique behind the plough in a replicated trial. The seeds were sown on 21 June 1993 in plots (4.0 m x 2.5 m each) for different

treatments. After germination, the plant population was maintained by regulating the row-to-row distance 30 cm and plant-to-plant distance 15 cm. All packages of practices were followed for the treatments, viz uninoculated control, with *Rhizobium* (alone), with VAM (alone) and VAM + *Rhizobium* (dual inoculation), in both the varieties.

For biochemical estimation the fresh, fully expanded third leaves from the top were collected at 30 and 45 days after sowing to estimate the chlorophyll content, following the dimethyl sulphoxide method (Hiscox and Israelstam 1979). The photosynthesis rate was measured at 30 and 45 days after sowing, using LI-6250 portable infra-red gas analyser with LI-6200 CO₂ analyser. The transpiration rate and stomatal conductance were also recorded simultaneously on bright sunny days at 10.00 AM.

Nitrate reductase activity (NRA) and nitrogenase activity of the actively growing nodules were estimated at different stages of growth by acetylene reduction method. To study the translocation pattern, ¹⁴C sucrose feeding was done at 40 days after sowing and 10 µl concentrated ¹⁴C sucrose was fed to fully expanded leaves at its dorsal side near the mid-rib in 2 plants in each replication in both the varieties. After 24 hr, the fed plants were uprooted with nodules intact and divided into fed leaf, leaves other than fed leaf, stem, root and nodules. The plant parts were chopped and after thoroughly mixing were passed through a series of grades of ethanol. The radioactivity of the sample was measured by using liquid scintillation counter (LKB Wallace 1209 Rackbeta).

Based on complete information of MSc thesis of the first author, submitted to Indian Agricultural Research Institute, New Delhi, in 1994 (unpublished)

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Incorporation of ^{14}C and its translocation was expressed as counts per minute and percentage of total volume of ^{14}C sucrose fed to the leaf translocated to the different plant parts of both the varieties under various treatments. The data were statistically analysed by following randomized block design (2-factorial).

RESULTS AND DISCUSSION

The effect of *Rhizobium*-VAM interaction on photosynthesis rate and stomatal conductance showed that 'Pusa 105' had significantly more leaf area than mycorrhizal and uninoculated control plants (Table 1). The dual inoculation led to larger leaf area than single inoculation at both the stages of growth (30 and 45 days after sowing) in both the varieties, and the differences were clear, particularly in later stages of growth. Similarly, the difference due to inoculation with *Rhizobium* or VAM were observed in chlorophyll content, photosynthesis activity and stomatal conductance, which increased with *Rhizobium* (alone) inoculation. But significantly higher activity was observed in the dual-inoculated plants. Our finding confirms the result of Islam *et al.* (1989). The VAM-treated plants in both the varieties showed higher photosynthesis per unit dry matter. It confirms the findings of Smith *et al.* (1986) and Panwar (1991, 1992, 1993). The VAM application improved the stomatal conductance, resulting in increased photosynthesis. The result confirms the findings of Farquhar and Sharkey (1982) and Auge and Duan (1991). The higher degree of mycorrhizal infection is likely to be associated with higher carbohydrate level in the fine roots of the plants treated with higher CO_2 levels (Rygiewicz *et al.* 1994).

The *Rhizobium*-treated plants had significantly highest nodule mass in VAM and *Rhizobium* (dual) inoculation, followed by VAM-treated plants and the uninoculated control plants (Table 2). The nitrate-reductase activity was more at 44 days after sowing, which declined sharply in 'PS 16', but it was maintained up to 51 days after sowing in 'Pusa 105'. The application of *Rhizobium* and VAM increased the nitrate-reductase activity at all the stages of growth and development, particularly in the dual-inoculated plants. Beevers and Hageman (1980) and Panwar (1991) reported increased activity of nitrate-reductase enzyme due to VAM fungi. The improvement in this activity is entirely due to improved P status of the plant, in line with the requirements of this enzyme for phosphorus (Beevers and Hageman (1980).

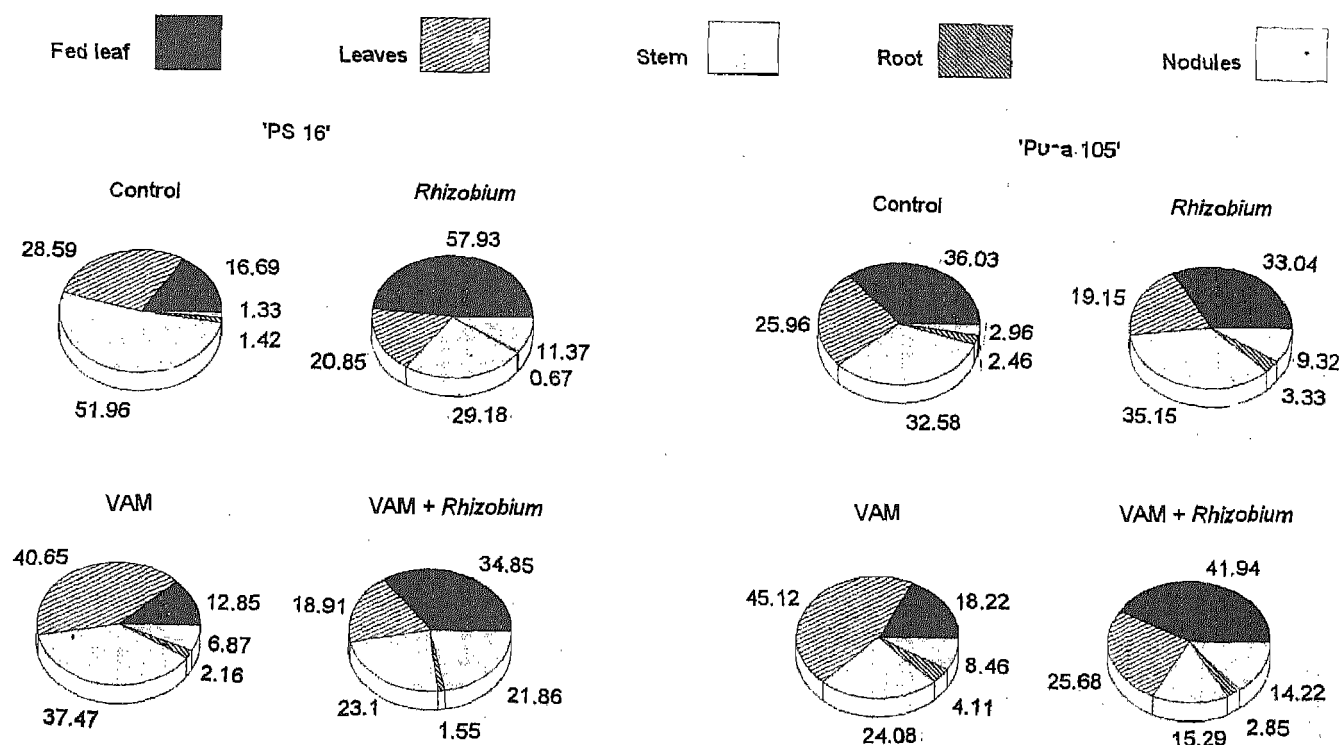
Fixation of N_2 in terms of nitrogenase activity in the nodules at 44 and 51 days after sowing was better in 'Pusa 105' than in 'PS 16'. The *Rhizobium*-treated plants showed higher N_2 -fixation than VAM-treated ones and the uninoculated control, but it was highest in the dual-inoculated plants. This may be owing to the contribution of VAM in increasing the phosphorus uptake from different soil zones due to the presence of hyphae. The phosphatase activity in root was higher in the plants treated with VAM than in those which were non-mycorrhizal (Tarafdar and Marschner 1994). The increase in N_2 -fixation may be attributed to many factors like CO_2 concentration (Thomas *et al.* 1994), hormonal effect (Panwar *et al.* 1988), stem girdling (Panwar *et al.* 1980), and the availability of photosynthates. Hence N_2 -fixation may be better due to the increased photosynthesis rate also.

The translocation of current photosynthates toward

Table 1 Effect of VAM-*Rhizobium* interaction on leaf area, chlorophyll content, photosynthesis rate, stomatal conductance and transpiration rate in 2 varieties of greengram at different stages of growth

Treatment	Leaf area/ plant (cm^2)		Total chlorophyll content (mg/g fresh weight) at		Net photosynthesis rate ($\text{Mmol/m}^2/\text{sec}$) at		Stomatal conductance (cm/sec) at		Transpiration rate ($\text{mol/m}^2/\text{sec}$) at	
	30 days*	45 days*	30 days*	45 days*	30 days*	45 days*	30 days*	45 days*	30 days*	45 days*
'PS 16'										
Control	146.45	500.08	1.235	1.619	4.563	4.856	1.07	1.86	0.0093	0.0101
<i>Rhizobium</i>	160.24	560.43	1.400	1.770	5.551	6.751	1.24	2.83	0.0111	0.0104
VAM	201.50	550.24	1.343	1.699	5.982	5.307	1.17	2.49	0.0100	0.0109
VAM + <i>Rhizobium</i>	259.29	606.90	1.552	1.938	6.993	8.040	1.22	2.94	0.0104	0.0131
Mean	191.87	544.44	1.383	1.757	5.772	6.239	1.18	2.53	0.0102	0.0111
'Pusa 105'										
Control	135.02	627.61	1.430	1.814	5.611	6.984	1.07	2.90	0.0103	0.0110
<i>Rhizobium</i>	222.26	687.89	1.580	1.966	5.975	8.281	1.18	3.09	0.0151	0.0126
VAM	206.12	642.89	1.496	1.890	5.473	7.123	1.12	2.94	0.0101	0.0118
VAM + <i>Rhizobium</i>	228.96	889.53	1.786	2.123	6.645	11.900	1.38	4.29	0.0108	0.0147
Mean	198.09	711.98	1.573	1.948	5.922	8.572	1.19	3.29	0.0116	0.0125
CD ($P = 0.05$).										
Variety	NS	22.27	0.03	0.04	NS	1.07	NS	0.21		
Treatment	18.91	31.49	0.04	0.06	0.55	1.51	NS	0.30		
Interaction	26.74	44.53	NS	NS	0.78	NS	NS	0.43		

*Days after sowing

Fig 1 Translocation of ^{14}C sucrose at preflowering stageTable 2 Effect of *Rhizobium*-VAM interaction on nodulation, nitrate-reductase activity (NRA) and nitrogenase activity in 2 varieties of greengram at different stage of growth

Treatment	Dry weight of nodules (mg/plant) at		NR activity of leaves ($\mu\text{moles NO}_2^-$ formed/g fresh weight/hr)		Nitrogenase activity of nodules (n moles C_2H_4 produced/g/hr)	
	44 days*	51 days*	44 days	51 day	44 days	51 days
'PS 16'						
Control	26.50	37.80	0.806	0.698	4 120.4	4 620.3
<i>Rhizobium</i>	68.20	65.80	0.983	0.732	4 700.1	4 936.2
VAM	39.80	48.70	0.882	0.710	4 210.2	4 686.2
VAM + <i>Rhizobium</i>	77.30	87.50	1.121	0.932	5 100.8	5 826.2
Mean	52.95	57.45	0.948	0.768	4 532.8	5 017.2
'Pusa 105'						
Control	26.60	56.40	0.894	0.932	4 432.2	4 932.7
<i>Rhizobium</i>	40.30	62.70	1.010	1.126	4 898.7	5 426.1
VAM	33.90	89.80	0.932	1.010	4 510.0	4 910.2
VAM + <i>Rhizobium</i>	89.80	105.20	1.200	1.330	5 642.8	5 926.7
Mean	47.65	78.35	1.009	1.099	4 870.9	5 298.9
CD ($P = 0.05$)						
Variety	0.38	0.32	0.05	0.08	150.93	117.82
Treatment	0.54	0.45	0.07	0.11	213.45	166.62
Interaction	0.76	0.63	NS	NS	NS	NS

*Days after sowing

underground portion (root and nodules) was more in the dual-inoculated plants than in single-inoculated ones (Fig 1). In *Rhizobium*-treated plants more ^{14}C sucrose was translocated toward the nodules, whereas in mycorrhiza-treated plants greater translocation of ^{14}C sucrose was toward the root portion. Development of nodules and hyphae depends on the

supply of carbon by the host plant (Ho and Trappe 1973, Cooper 1984). Our result confirms the findings of Pang and Paul (1980) and Harris *et al.* (1985). During the first ontogenic stage of association, VAM fungus was parasitic due to carbohydrate demand on the host plant by the endophyte, whereas at the later stage mycorrhizal fungus and soybean

[*Glycine max* (L.) Merr.] were associated symbiotically (Bethlenfalvay *et al.* 1983). Thus in the early stage of growth the VAM and *Rhizobium* were dependent on current photosynthates for their own establishment and act as parasite, but at later stages of growth had better symbiosis, resulting in increased rate of photosynthesis, stomatal conductance, N_2 metabolism and hence higher dry-matter production (Thakur and Panwar 1995). The net result was significantly better when both the *Rhizobium* and mycorrhizal fungi (dual inoculation) were applied.

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Effect of soybean (*Glycine max*) intercropping under different nitrogen levels on yield, yield attributes and quality of maize (*Zea mays*)

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ABSTRACT

A field experiment was conducted during rainy season of 1992 and 1993 to study the effect of N application on yield, yield attributes and quality of maize (*Zea mays* L.) in soybean [*Glycine max* (L.) Merr.] + maize intercropping system. The treatment consisted of 4 levels of nitrogen (0, 50, 100, 150 kg N/ha) for soybean + maize intercropping system and 0 and 120 kg N/ha for sole crop of maize. Cob number, cob length, number of grains/cob, 1 000-grain weight, grain yield, stover yield and protein yield of maize increased significantly under intercropping system. Maximum number of cobs were recorded in soybean + maize at 150 kg N/ha during both the years. Maximum cob length was recorded in maize pure at 120 kg N/ha during both the years. The application of 100 kg N/ha in soybean + maize system showed the highest number of grains/cob and 1 000-grain weight of maize among maize pure and maize + soybean systems. The maximum grain yield (2 654 and 3 606 kg/ha) of maize was recorded with 100 kg N/ha to soybean + maize intercropping system, which was significantly higher than soybean + maize at 0 and 50 kg N/ha and maize pure at 0 kg N/ha during both the years. Maize-equivalent grain yield (3 729 and 4 412 kg/ha) was maximum in soybean + maize at 100 kg N/ha. Protein content of maize grain improved with N application in maize + soybean system. Maximum protein yield (303 and 389 kg/ha) of maize grain was recorded in soybean + maize at 100 kg N/ha treatment.

Key words : soybean, *Glycine max*, maize, *Zea mays*, intercropping, nitrogen, yield and its attributes

Maize (*Zea mays* L.) is an important food crop that is generally grown pure as well as mixed with pulses and oilseed crops, especially in rainy season. Intercropping soybean [*Glycine max* (L.) Merr.] and maize reduces the yield of former crop considerably, but has little influence on that of latter (Hiebsch 1981, Chui and Shibles 1984). Maize being an exhaustive crop requires high quantity of fertilizer, particularly nitrogenous, which is one of the problems for marginal farmers in India due to increasing cost. Nair *et al.* (1979) and Singh *et al.* (1986) reported the role of legumes in replacing fertilizer nitrogen and increasing the yield of associated maize crop. Very little work has been done so far to evaluate the fertilizer need of the mixed stand when the crops of dissimilar nutrient requirement are grown together. Keeping this in view, the present experiment was planned to evaluate the optimum dose of nitrogen for maize under soybean + maize intercropping system.

MATERIALS AND METHODS

The field experiment was conducted in rainy season

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(kharif) 1992 and 1993 at the Crop Research Centre of the university at Pantnagar, situated at 29°N, 79°30'E at an altitude of 244 m above mean sea-level in foot-hill (*tarai*) region. The soil was silty clay-loam, with pH 8.16 and 7.34, organic carbon 0.68 and 0.73%, total N 831.0 and 816 kg/ha, available P 65.4 and 59.4 kg/ha and available K 193.3 and 196.6 kg/ha during 1992 and 1993 respectively.

The experiment consisted of 4 levels of nitrogen (0, 50, 100, 150 kg N/ha) for soybean + maize intercropping system, and 0 and 120 kg N/ha for sole crop of maize. Randomized block design was following with 3 replications. Alternate rows of soybean and maize were followed, keeping row-to-row distance of soybean 60 cm and 1 row of maize in between 2 rows of soybean. Each crop was thinned 15 days after sowing to keep the plant-to-plant spacing 5 cm in soybean and 20 cm in maize. 'PK 472' soybean and 'Kanchan' maize were sown on 26 June 1992 and 3 July 1993. Nitrogen as per treatment and a uniform dose of phosphorus @ 17.6 kg P/ha to all the systems were given through urea and single superphosphate respectively. Out of total N, one-third quantity of N along with full dose of P was applied basal. The remaining two-thirds N was top-dressed twice, i.e. 30 and 45 days after sowing. Soybean seeds were inoculated by *Bradyrhizobium japonicum* culture @ 0.5 kg/75 kg seed. Yield attributes and

grain and stover yields were recorded at harvest. The protein yield in the maize grain was calculated with formula:

$$\text{Protein yield (kg/ha)} = \frac{\text{Grain yield (kg/ha)} \times \text{protein content (\%)}}{100}$$

RESULTS AND DISCUSSION

Yield attributes

Nitrogen application significantly affected the cob number, cob length, number of grains/cob and 1 000-grain weight of maize during both the years. The maximum number of cobs of maize recorded in soybean + maize at 150 kg N/ha, which was significantly higher than in soybean + maize at 0 and 50 kg N/ha. In the maize pure system it remained statistically at par with soybean + maize at 100 kg N/ha during both the years (Table 1). Soybean + maize at 100 kg N/ha recorded 1.15 and 2.1 % more cobs/ha during 1992 and 1993 respectively compared with maize pure at 120 kg N/ha. The increase in number of cobs in maize with increase in N level could be attributed to N deficiency in the soil. Therefore application of nitrogen improved the growth and development of maize and better survival of plants (Table 1), which resulted in higher number of cobs/ha under soybean + maize at 100 and 150 kg N/ha compared with the other treatments. The high number of cobs/ha in soybean + maize at 100 and 150 kg N/ha than maize pure at 120 kg N/ha might be due to nitrogen contribution from association of soybean. Kalra and Gangwar (1980) reported that 80 kg N/ha maximizes the number of cobs/ha of maize when it is intercropped with different legumes. Kaushik (1989) and Mohammed (1989) also reported similar findings.

The maximum length of maize cob in the intercropping system was recorded in soybean + maize at 100 kg N/ha in 1992 and 150 kg N/ha in 1993. Soybean + maize at 100 kg N/ha significantly increased the cob length compared with soybean + maize at 0 kg N/ha during 1992 (Table 1). The cob length of maize in all the treatments of intercropping was significantly reduced when compared with maize pure at 120 kg N/ha during both the years. This pattern might have been caused by competition for solar radiation and nutrients among the intercropped maize plants, which recorded more number of cobs. Minimum cob length was recorded in maize pure at 0 kg N/ha and soybean + maize at 0 kg N/ha. Cob width was not significantly affected by the treatments (Table 1).

During 1992 the highest number of grains/cob recorded in maize pure at 120 kg N/ha (340.7), followed by soybean + maize at 100 kg N/ha (337.4), which was significantly greater than maize pure at 0 kg N/ha and soybean + maize at 0 and 150 kg N/ha. But during 1993 the maximum grain number/cob was in soybean + maize at 100 kg N/ha (341.4), followed by soybean + maize at 150 kg N/ha (336.9) (Table 1). The increase in the number of grains/cob of maize in soybean + maize with increase in N level up to 100 kg N/ha was due to combined effect of applied N and nitrogen advantage from the associated soybean. Kalra and Gangwar (1980) and Singh

and Chand (1980) reported significant increase in the number of grains/cob in the maize+legume compared with sole crop of maize with application of 80 kg N/ha.

The highest 1 000-grain weight of maize in soybean + maize at 150 kg N/ha and 100 kg N/ha was significantly greater and 5.2 and 16.5% higher than soybean + maize @ 0 kg N/ha during 1992 and 1993 respectively (Table 1). Soybean + maize at 100 kg N/ha also gave 1.8–2.2% more 1 000-grain weight of maize than maize pure at 120 kg N/ha during both the years. This increase in 1 000-grain weight may be attributed to greater production and diversion of photosynthates for grain formation with increase in nitrogen level. Nair *et al.* (1979) observed significant increase in the 1 000-grain weight of maize up to 120 kg N/ha in maize + soybean compared with pure maize.

Grain and stover yields

The grain and stover yields of maize were significantly affected by N application during both the years. In soybean + maize system the highest grain yield of maize was recorded in soybean + maize at 100 kg N/ha, which was significantly greater than of soybean + maize at 0 and 50 kg N/ha (Table 2), the increase in grain yield of maize with increase in N level up to 100 kg N/ha may be due to increase in the yield attributes of maize with N application. Soybean + maize at 150 kg N/ha did not further increase the grain yield, because additional required nitrogen if any to maize was met by associated soybean and therefore there was no further increase in the yield attributes and the grain yield of maize. Singh *et al.* (1986) reported that 80 kg N/ha gave significantly higher grain yield of the mixed cropping of maize than 40 kg N/ha, but 120 kg N/ha gave no further increase in maize yield. Soybean + maize at 100 kg N/ha gave 7.6 and 6.2% higher grain yield of maize than maize pure at 120 kg N/ha during the 2 years respectively. Soybean + maize without N fertilizer also gave 13.6 and 6.7% higher grain yield of maize than maize pure with no N during 1992 and 1993 respectively. This yield advantage might be due to N contribution from soybean to maize. Wong and Kalpage (1976) reported that with increase in N level the grain yield of intercropped maize increased from 0.58 tonnes/ha at 0 kg N/ha to 1.17 tonnes/ha at 120 kg N/ha. However, Singh and Guleria (1979) and Kalia and Gangwar (1980) observed significant increase in yield with increase in N level from 0 to 80 kg/ha in maize and soybean intercropping system compared with pure maize. Further increase in nitrogen did not prove beneficial.

The maximum stover yield of maize was recorded in soybean + maize at 150 and 100 kg N/ha, which was at par. But minimum yield was obtained by no nitrogen application under both the cropping systems (Table 2). Soybean + maize at 0 kg N/ha also yielded 12.1 and 14.3% higher stover than maize pure with no N during 1992 and 1993 respectively. This increase in stover yield of maize may be due to N advantage from the associated soybean crop to maize. Wong and Kalpage (1976) observed positive response of N up to

Table 1 Effect of nitrogen application on yield attributes and plant stand at harvest of maize pure and intercropped with soybean

Treatment	Cob number (⁰ 000/ha)		Cob length (cm)		Cob width (cm)		Grains/ cob		1 000-grain weight (g)		Plant stand (⁰ 000/ha)	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Maize pure at N ₀	35.8	54.8	13.6	13.6	3.4	3.7	310.8	283.0	177.6	159.8	61.46	58.49
Maize pure at N ₁₂₀	42.2	55.8	15.4	15.4	3.6	3.9	340.7	332.5	202.3	190.0	65.38	60.71
Soybean + maize at N ₀	36.5	55.2	13.8	13.4	3.5	3.6	320.4	288.9	197.3	166.0	61.84	58.14
Soybean + maize at N ₅₀	40.3	55.3	14.5	13.7	3.5	3.7	337.2	330.4	204.1	188.6	63.58	58.95
Soybean + maize at N ₁₀₀	42.8	57.0	14.6	14.2	3.6	3.8	337.4	341.4	206.8	193.5	64.55	59.99
Soybean + maize at N ₁₅₀	43.9	57.5	14.3	14.3	3.6	3.7	300.5	336.9	207.6	190.8	64.91	59.44
CD (<i>P</i> = 0.05)	1.2	1.2	0.7	1.1	NS	NS	6.4	8.9	8.7	12.9	1.60	1.57

Table 2 Effect of nitrogen application on yield, protein content and protein yield of maize

Treatment	Grain yield (kg/ha)		Stover yield (kg/ha)		Maize-equivalent grain yield (kg/ha)		Protein content (%)		Protein yield (kg/ha)	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Maize pure at N ₀	1 720	2 373	3 861	4 246	1 720	2 373	9.3	9.6	161	227
Maize pure at N ₁₂₀	2 465	3 393	4 658	5 341	2 465	3 393	12.0	11.2	297	381
Soybean + maize at N ₀	1 955	2 534	4 330	4 854	2 866	3 353	10.0	9.9	196	252
Soybean + maize at N ₅₀	2 384	3 279	4 763	5 276	3 697	4 224	10.9	10.4	262	342
Soybean + maize at N ₁₀₀	2 654	3 606	5 122	5 728	3 729	4 412	11.4	10.8	303	389
Soybean + maize at N ₁₅₀	2 528	3 564	5 276	5 484	3 533	4 356	11.3	10.7	287	382
CD (<i>P</i> = 0.05)	154	455	313	376	302	411	1.2	0.2	37	48

120 kg N/ha to stover yield of maize monocropped and maize + soybean intercropping systems. However, they also observed the advantage of stover yield from intercropping compared with monocropping.

Maize-equivalent grain yield

Maximum maize-equivalent grain yield (3 729 and 4 412 kg/ha) was recorded in soybean + maize at 100 kg N/ha, which gave 51.2 and 30% higher maize-equivalent grain yield than maize pure at 120 kg N/ha during 1992 and 1993 respectively (Table 2). Such increase in maize-equivalent grain yield was due to highest grain yield of maize, along with higher market selling price of maize seed and with lower grain yield of soybean (890 and 654 kg/ha) for the 2 consecutive years. Soybean + maize at 0 kg N/ha also gave 66.0 and 41.2% higher maize-equivalent grain yield compared with pure maize at 0 kg N/ha during 1992 and 1993 respectively. It indicated that soybean + maize intercropping at all levels of N proved more advantageous than pure maize, but maximum advantage was obtained on application of 100 kg N/ha. Sharma and Choubey (1991) also observed similar result.

Protein content and protein yield

Nitrogen application significantly affected the protein content and protein yield of maize grain during both the years. The protein content in maize grain was lower in intercropped crop than in maize pure at 120 kg N/ha. But significant

reduction in protein content of maize grain was observed in all the intercropped maize treatments than in maize pure at 120 kg N/ha during 1993 only. Increase in the protein content of maize with increase in N rate up to 100 kg N/ha might be attributed to the increased availability of N to the plant on N application. But soybean + maize at 0 kg N/ha treatment showed 6.8 and 3.7 % greater protein content of maize grain than the maize pure with no N, which recorded the lowest protein content during 1992 and 1993 respectively (Table 2). This higher protein content of maize grain was possibly due to nitrogen advantage from soybean to maize. Jagannathan *et al.* (1979) reported that protein content of maize grain increased in the mixed stand with soybean.

Maximum protein yield of maize grain was recorded in soybean + maize at 100 kg N/ha, which showed higher production than maize pure at 120 kg N/ha during both the years (Table 2). Protein yield of maize grain in soybean + maize at 0 kg N/ha recorded 21.6 and 10.9% increase compared with maize pure at 0 kg N/ha during 1992 and 1993 respectively. This increase was caused by higher protein content of maize grain as well as higher grain yield of intercropped maize. Martin (1992) reported significantly higher protein yield of intercropped maize with soybean compared with maize pure.

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Effect of intercropping winter-season forage crops on their yield and nodulation

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ABSTRACT

In an experiment on intercropping of fodder crops, berseem [*Trifolium alexandrinum* (L.) Juslen.] plants in sole and intercropping were taller compared with lucerne (*Medicago sativa* L.). Among the different cropping systems berseem sole crop gave the highest yield of green and dry forage and economic return. A combination of oat (*Avena sativa* L.) either with berseem or lucerne in 2 : 2 or 4 : 4 row arrangements respectively gave more green-fodder yield than oat alone. Berseem in sole and intercropping systems produced more nodules/plant than lucerne. The nodule number started decreasing after second cut (80 days after sowing) both in berseem and lucerne. Hence under medium black-soil conditions berseem as sole and in intercropping gave maximum forage yield and economic return.

Key words: forage crops, intercropping, nodulation, winter season, yield attributes, economics

Livestock feed accounts for 60–70% of the total cost of milk production and the cost of feed concentrate is increasing and is costlier than of green forage (Fitzhugh *et al.* 1978). The area under winter-season (*rabi*) fodder crops like berseem [*Trifolium alexandrinum* (L.) Juslen.], lucerne (*Medicago sativa* L.) and oat (*Avena sativa* L.) needs to be increased to sustain the productivity of high-yielding milch cows. These fodders are not only highly nutritious and succulent but also available up to early summer. India is in short supply of fodders and also there is much pressure on the land for growing food crops; therefore the gap between demand and supply of green fodders could be narrowed down by maximizing the production per unit area per unit time. Intercropping of legume forage crops with non-legumes improves the yield and quality of green forages. An experiment was therefore conducted to find out the effect of intercropping berseem and lucerne with oat on forage yield and nodulation.

MATERIALS AND METHODS

The study was conducted during winters of 1993–94 and 1994–95 at Anjora, Madhya Pradesh, on medium black soil, being medium in available N, low in available P and high in available K, with pH 6.7. The treatment consisted of 7 intercropping systems, viz T₁, sole berseem; T₂, sole lucerne; T₃, sole oat; T₄, berseem + oat in 2 : 2 (row ratio);

T₅, berseem + oat 4 : 4; T₆, lucerne + oat 2 : 2; and T₇, lucerne + oat 4 : 4. The treatments were taken with 3 replicates each in randomized block design. Berseem in sole as well as in intercropping was sown by broadcasting, whereas lucerne and oat in sole and intercropping systems were sown in rows 30 cm apart. The crops were sown using 30 kg berseem seed, 30 kg lucerne seed and 80 kg oat seed/ha on 10 November 1993 and 18 November 1994. In all the crops recommended dose of fertilizers were applied, ie NP and K @ 30, 40 and 20 kg/ha respectively at sowing, and 30 kg N/ha after first cut and after the second cut. The forage yields were calculated from the net plot size of 10 m x 5 m. The first cut in all the crops was taken at 50 days after sowing and the subsequent cuts at 30-day intervals. In oat, berseem and lucerne, 3, 4, and 5–6 cuts respectively were obtained both in sole and intercropping systems. The data were analysed statistically, using standard methods as suggested by Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Yield attributes

Number of branches/plant of berseem and lucerne did not differ significantly among the treatments at first and third cut, except at second cut where sole berseem recorded significantly higher number of branches/plant (5.31) compared with sole crop of lucerne (4.08) during both the years. The number of tillers/plant of oat was non-significant during both the years of study.

At different stages of growth plant height of berseem

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and lucerne differed significantly. Berseem in sole as well as intercropping combination with oat attained significantly higher plant height in comparison with that of lucerne, except at fourth cutting. Highest plant height of sole berseem (76.2 cm) was recorded at second cutting, which was significantly different from plant height of lucerne (58.2 cm) in sole cropping. Plant height of oat in sole as well as intercropping systems was non-significant.

Forage yield

Green-forage yields of berseem, lucerne and oat varied at different growth stages (Table 1). Berseem recorded the highest total green-forage yield (74.6 tonnes/ha) than its intercropping and lucerne and oat (52.47 and 44.14 tonnes/ha respectively). Prasad *et al.* (1985) also reported higher green-fodder yield of berseem than of lucerne. Green-fodder yield of oat in intercropping was higher than of any other

Table 1 Mean green and dry forage yields of berseem, lucerne and oat in sole and intercropping

Treatment	I cut	II cut	III cut	IV cut	V cut	VI cut	Total
<i>Mean green-fodder yield (tonnes/ha)</i>							
Berseem sole	14.51	23.33	22.98	13.79			74.60
Lucerne sole	6.93	10.11	9.63	9.94	12.62	6.50	52.47
Oat sole	24.07	10.19	9.88				44.14
Berseem + oat (2 : 2)	21.08 (14.26)	20.07 (7.30)	17.98 (7.08)	6.85			65.99
Berseem + oat (4 : 4)	21.28 (13.55)	18.15 (6.39)	15.78 (5.94)	7.51			62.68
Lucerne + oat (2 : 2)	15.34 (12.36)	12.71 (7.59)	11.72 (6.73)	5.89	6.00	3.66	53.53
Lucerne + oat (4 : 4)	15.95 (12.64)	11.36 (6.63)	10.72 (5.89)	5.36	5.17	3.35	50.23
CD ($P = 0.05$)	7.50	7.34	8.35	6.71	9.22	6.44	14.66
<i>Mean dry-fodder yield (tonnes/ha)</i>							
Berseem sole	2.16	2.79	4.25	3.29			12.39
Lucerne sole	1.30	1.59	1.76	2.22	3.08	1.53	10.71
Oat sole	4.31	1.41	1.52				7.23
Berseem + oat (2 : 2)	3.57 (2.55)	2.54 (1.00)	3.06 (1.09)	1.64			10.79
Berseem + oat (4 : 4)	3.57 (2.42)	2.29 (0.88)	2.67 (0.91)		1.79		10.31
Berseem + oat (2 : 2)	2.77 (2.20)	1.85 (1.05)	1.95 (1.03)	1.31	1.47	0.86	9.78
Berseem + oat (4 : 4)	2.88 (2.26)	1.65 (0.91)	1.78 (0.91)	1.20	1.25	0.78	9.16
CD ($P = 0.05$)	1.37	1.11	1.72	1.53	2.19	1.53	2.68

Figures in parentheses indicate oat yield

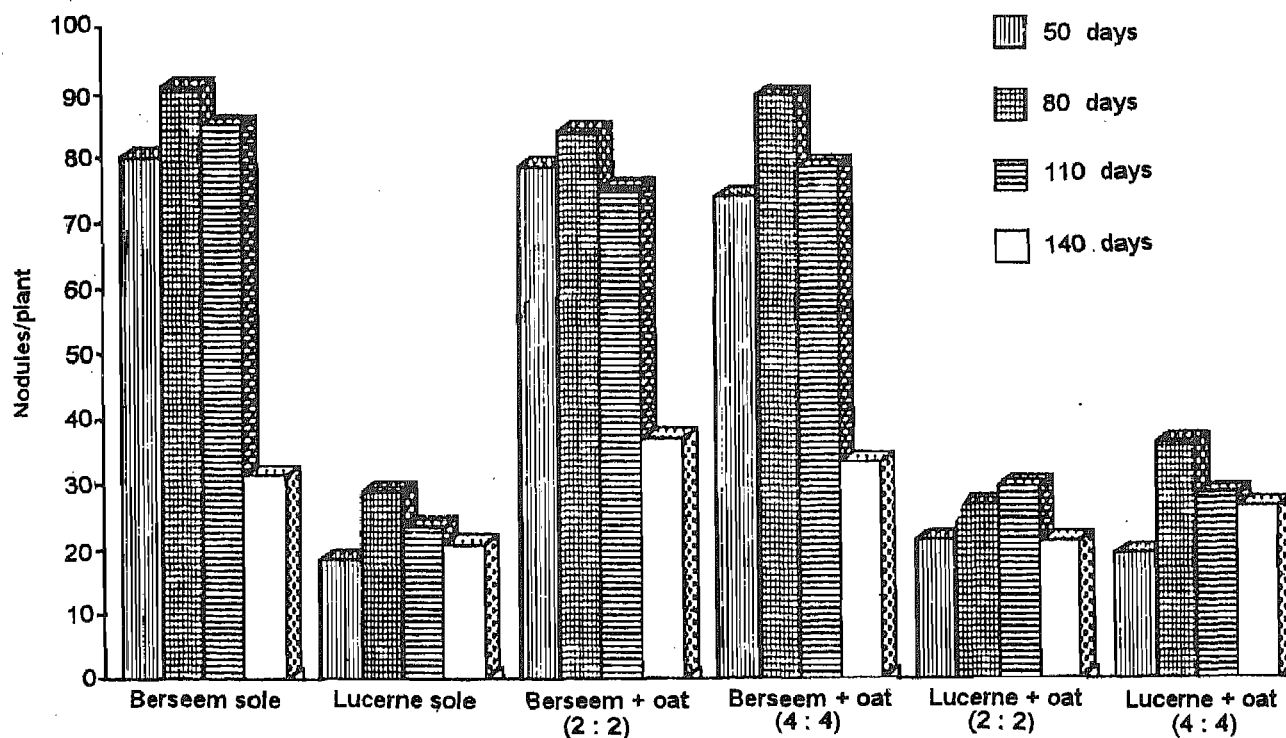


Fig 1 Effect of intercropping on mean nodule number/plant in fodder crops

Table 2 Effect of sole and intercrops on net return, land-equivalent ratio (LER), monetary advantage and benefit : cost (B : C) ratio (mean data of 2 years)

Treatment	Net return (Rs/ha)	LER	Monetary advantage (Rs)	B : C
Berseem sole	13 909			2.64
Lucerne sole	8 186			2.08
Oat sole	5 746			2.09
Berseem + oat (2 : 2)	11 385	1.18 (0.51 + 0.67)	2 808	2.63
Berseem + oat (4 : 4)	10 616	1.10 (0.50 + 0.60)	1 594	2.54
Lucerne + oat (2 : 2)	8 103	1.16 (0.51 + 0.65)	2 011	2.22
Lucerne + oat (4 : 4)	7 280	1.09 (0.49 + 0.60)	1 121	2.11

Price of green forage (Rs/100 kg) : berseem and lucerne, 30; oat 25

intercropping system as well as sole one, due to transfer of nitrogen to the root rhizosphere from the legume to non-legume component. Ledgard *et al.* (1985), Ta *et al.* (1986). Haystead *et al.* (1988), Ledgard and Steele (1992) and Russele *et al.* (1994) also reported similar results. A combination of oat either with berseem or lucerne in 2 : 2 or 4 : 4 planting ratios respectively gave higher green-fodder yield than oat alone, but the total fodder production was less than of sole berseem or lucerne. Similar trend was also observed for dry-forage yields under different cropping systems (Table 1).

Nodulation

Dry weight and number of nodules/plant of berseem and lucerne varied significantly at different stages of growth (Fig 1). The highest number of nodules/plant (90.9) of berseem was observed at second cutting (80 days after sowing) and a decreasing trend was found afterward. This result confirms the finding of Nagre and Keshkar (1990). Lucerne also showed trend similar to that of berseem. Dry weight of nodules/plant of berseem and lucerne decreased after third cutting (110 days after sowing). At fourth cut the number and dry weight of nodules/plant of berseem and lucerne were higher in intercropping with oat than of the respective sole crops.

Net return

Sole crop of berseem recorded the highest net return among the different cropping systems, followed by berseem + oat (2 : 2 planting ratio) (Table 2).

Land-equivalent ratio

All the treatments showed land-equivalent ratio greater than 1, indicating advantage in yield (Table 2). However, the highest value was recorded by berseem + oat (2 : 2) and the lowest value by lucerne + oat (4 : 4). Our result corroborates the finding of Rao *et al.* (1979).

Monetary advantage

Berseem + oat (2 : 2) recorded the highest monetary advantage, whereas lucerne + oat (4 : 4) the lowest (Table 2).

On the basis of benefit : cost ratio, the highest benefit was obtained from sole berseem (2.64), followed by berseem + oat 2 : 2 and berseem + oat 4 : 4 planting ratio (Table 2).

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Suitability of intercropping flue-cured tobacco (*Nicotiana tabacum*) with lentil (*Lens culinaris*)

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ABSTRACT

In a 2-year field experiment, tobacco (*Nicotiana tabacum* L.) was intercropped with lentil (*Lens culinaris* Medikus). Significantly highest yields of cured tobacco leaf (1 970 kg/ha) and lentil (980 kg/ha) were obtained from the pure stand. Among intercropping treatments, tobacco paired row + 50% lentil gave the highest land-equivalent ratio (1.49), tobacco-equivalent yield (2 109 kg/ha), net return (Rs 52 864/ha), monetary advantage (Rs 20 804/ha) and benefit : cost ratio (6 : 08).

Key words: intercropping, tobacco, lentil, yield, *Nicotiana tabacum*, *Lens culinaris*

Tobacco (*Nicotiana tabacum* L.) is an important cash crop of Bangladesh, covering an area of 36 800 ha with an annual production of 34 100 tonnes. Intercropping systems increase the total yield and monetary returns through better utilization of available resources (Sharma 1994). In India tobacco was found to intercrop successfully with sugarcane (*Saccharum officinarum* L.) (Singh and Sinha 1985) and gram or chickpea (*Cicer arietinum* L.) (Veera Raghavaiah *et al.* 1986). In Bangladesh such an information on intercropping flue-cured tobacco with lentil (*Lens culinaris* Medikus) is lacking. Hence the present investigation was undertaken.

MATERIALS AND METHODS

An experiment was conducted for 2 consecutive winter

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seasons of 1993–94 and 1994–95 in calcareous grey flood-plain soil of Ishurdi, Bangladesh. The soil was silty loam, with pH 7.3. The treatments were : T₁, sole tobacco (75 cm x 60 cm); T₂, sole lentil (broadcast); T₃, 100% tobacco + 50% lentil; T₄, 100% tobacco + 33% lentil; T₅, 67% tobacco + 50% lentil; T₆, 67% tobacco + 33% lentil; T₇, tobacco paired row + 50% lentil; and T₈, tobacco paired row + 33% lentil. The treatments were tested in randomized complete block design with 3 replications. Gross plot size was 5 m x 4.5 m. Nitrogen, phosphorus and potassium @ 25, 50 and 45 kg/ha respectively were applied basal in the form of urea, triple superphosphate and potassium sulphate. Another 25 kg N/ha was applied in tobacco through ring method at 30 days after transplanting. 'Utfola' lentil was broadcast and the seedlings of 'Virginia Gold' tobacco were transplanted on 4 November 1993 and 10 November 1994.

Table 1 Yield and yield components of tobacco in tobacco-lentil intercropping (mean data of 1993–94 and 1994–95)

Treatment	Plant population/m ²	Curable leaves/plant	Weight/cured leaf (g)	Cured-leaf yield (kg/ha)
T ₁	2.22	32.1	2.81	1 970
T ₂				
T ₃	2.22	30.4	2.73	1 710
T ₄	2.22	33.0	2.67	1 695
T ₅	1.48	30.7	2.90	1 329
T ₆	1.48	32.1	2.89	1 385
T ₇	2.22	30.9	2.50	1 700
T ₈	2.22	31.0	2.48	1 690
LSD (<i>P</i> = 0.05)	0.36	NS	0.29	292

Details of treatments are given under Materials and Methods

Table 2 Yield and yield components of lentil in tobacco-lentil intercropping (mean data of 1993-94 and 1994-95)

Treatment	Plant population/ m ²	Pods/ plant	Seeds/ pod	1 000- seed weight (g)	Seed yield (kg/ha)
T ₁	86.70	115.0	1.9	12.6	980
T ₂	51.52	98.5	1.7	11.8	495
T ₃	31.71	97.2	1.7	11.8	330
T ₄	58.30	101.9	1.8	12.3	583
T ₅	35.00	108.1	1.8	12.4	378
T ₆	61.70	105.0	1.8	12.5	613
T ₇	38.30	109.5	1.8	12.5	400
LSD (<i>P</i> = 0.05)	12.92	NS	NS	NS	115

Details of treatments are given under Materials and Methods

Table 3 Relative yield, land-equivalent ratio (LER), tobacco-equivalent yield (TEY), cost of cultivation, gross income, net returns, monetary advantage index (MAT) and benefit : cost ratio of tobacco-lentil intercropping

Treat ment	Relative Tobacco	yield Lentil	LER	TEY (kg/ha)			Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	MAI (Rs/ha)	Benefit : cost
				1993-94	1994-95	Mean					
T ₁	1.00		1.00	1 966	1 974	1 970	10 137	59 100	48 963		5.83
T ₂		1.00	1.00	650	656	653	5 795	19 590	13 795		3.38
T ₃	0.87	0.51	1.38	2 037	2 043	2 040	10 425	61 200	50 775	16 852	5.87
T ₄	0.86	0.34	1.20	1 911	1 919	1 915	10 277	57 450	47 173	9 575	5.59
T ₅	0.67	0.59	1.26	1 715	1 721	1 718	10 412	51 540	41 128	10 633	4.95
T ₆	0.70	0.39	1.09	1 633	1 641	1 637	10 274	49 110	38 836	4 055	4.78
T ₇	0.86	0.63	1.49	2 105	2 113	2 109	10 406	63 270	52 864	20 804	6.08
T ₈	0.86	0.41	1.27	1 954	1 960	1 957	10 281	58 710	48 429	10 480	5.71
LSD (<i>P</i> = 0.05)					245	261	251				

Details of treatments are given under Materials and Methods

Selling price (Rs/kg) : Tobacco leaf, 30; lentil, 20

Recommended seed rate of lentil (30 kg/ha) was used. For establishment of tobacco seedlings and after ring application of urea, water was applied in the pit. The harvest (net plot size) area for tobacco excluded 1 line from each side and 2 plants from both the ends of each line, and for lentil 0.5m from the borders. Data on yield and yield components were recorded and analysed statistically. Land-equivalent ratio (LER) and economic analyses were also computed. Tobacco-equivalent yield (TEY) was calculated by the formula given by Anjeneyulu *et al.* (1982) and monetary advantage index (MAI) was computed as per Masood Ali and Mishra (1993).

RESULTS AND DISCUSSION

Tobacco

Significantly similar single-leaf weight was recorded in paired row system (T₇ and T₈), but it was lower compared with that in other treatments. Single-leaf weight in T₁, T₃, T₄, T₅ and T₆ was found statistically identical. Reduction in single-leaf weight in the paired row (T₇ and T₈) may be due to crowding effect of adjacent plants within the pair. The cured-leaf yield (1 970 kg/ha) in sole tobacco (T₁) was numerically highest, but it was statistically at par with that in T₃, T₄, T₅

and T₈, where plant population/m² remained the same. Similarly, T₅ and T₆ (67% tobacco) gave statistically identical leaf yield (Table 1). This is in agreement with the finding of Veera Raghavaiah *et al.* (1986), who reported that cured leaf yield of tobacco was statistically similar in different planting patterns.

Lentil

Plant population/m² of lentil varied significantly on the basis of seeding ratio. Significantly highest seed yield (980 kg/ha) of lentil was obtained from pure stand, contributed by the highest plant population/m² (T₁). In intercropping treatments, seed yield of lentil was statistically reduced from 37 to 40%. This reduction in seed yield was caused by a reduction in plant population/m² and other yield attributes (Table 2). Aktar *et al.* (1993) reported similar result.

Relative yield, land-equivalent ratio, tobacco-equivalent yield and economics

Relative yield showed that lentil yield was proportionately more than the seeding ratios. Lentil yield was 63% in the treatment T₇, where 50% lentil seed was used.

The increase in yield (13%) from the expected yield possibly reflects the complementary effect of tobacco on lentil. But the tobacco yield in the same treatment (T_7) was 86%, a decrease in yield of 14% from the seeding ratio. The decrease in yield may indicate the competition between these 2 crops (Table 3).

Significantly identical tobacco-equivalent yield was obtained from T_1 , T_3 , T_4 , T_7 and T_8 , although the numerically highest TEY was recorded in T_7 (2 105 kg/ha in 1993–94; 2 113 kg/ha in 1994–95, and mean 2 109 kg/ha. The highest land -equivalent ratio (1.49), gross income (Rs 63 270/ha), net return (Rs 52 864/ha), monetary advantage (Rs 20 804/ha) and benefit : cost ratio (6.08) were obtained from T_7 (tobacco paired row + 50% lentil) (Table 3). This result confirms the finding of Islam and Paul (1992).

The study inferred that tobacco paired row + 50% lentil is a profitable system, giving the highest monetary advantage.

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Field evaluation of different economic threshold levels for chemical control of pink bollworm (*Pectinophora gossypiella*), spotted bollworm (*Earias vittella*, *E. insulana*) and cotton bollworm (*Helicoverpa armigera*) on cotton (*Gossypium* species)

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ABSTRACT

An experiment was conducted during 1993–95 for testing the performance of different economic threshold levels for controlling bollworms [*Pectinophora gossypiella* (Saund.), *Earias vittella* (Fabr.), *E. insulana* (Boisd.)] and cotton bollworm [*Helicoverpa armigera* (Hubner)] with insecticides. These economic thresholds included 5% bollworm incidence in intact floral forms on the plants and 5, 10 and 15% bollworm incidence in the shed floral forms, and they were compared with standard spray schedule. Varieties 'LH 900', 'LH 1134' and 'F 846' of upland cotton (*Gossypium hirsutum* L.) and 'LD 327' of tree cotton (*Gossypium arboreum* L.) were used. The comparative performance of these treatments was assessed by observing bollworm incidence in open bolls and recording yield of seed cotton. The pooled analysis of data (1993–94) showed that bollworm incidence in open bolls, both on boll and locule basis, was significantly higher at 5% bollworm incidence in intact floral forms than 5 and 10% bollworm incidence in shed floral forms and standard spray schedule. But the yield of seed cotton in the former, which was on a par with that of standard spray schedule, was significantly higher than 5 and 10% bollworm incidence in shed floral forms. The cost : benefit ratio was also highest (1 : 26.29) in 5% bollworm incidence in intact floral forms. The pooled analysis of data (1995) revealed that the performance of all economic threshold levels including standard spray schedule was on a par with each other regarding boll damage (8.2–10.3%), locule damage (4.3–5.6%) in open bolls and yield of seed cotton (1 490–1 678 kg/ha). The cost : benefit ratio was, however, highest in standard spray schedule (1 : 9.54), followed by 5% bollworm incidence in intact floral forms (1 : 7.20), 15% (1 : 6.28), 10% (1 : 5.79) and 5% (1 : 5.51) bollworm incidence in shed floral forms.

Key words : cotton, economic threshold levels, bollworm incidence, *Gossypium* spp, *Pectinophora gossypiella*, *Earias vittella*, *Earias insulana*, *Helicoverpa armigera*

The indiscriminate and excessive use of insecticides, especially synthetic pyrethroids, on cotton (*Gossypium* spp) has aggravated the pest problem and resulted in poor seed-cotton yield. The need-based use of insecticides on the basis of economic threshold levels of pests is the integral component of integrated pest-management strategy on cotton. A 5% bollworm incidence is the economic threshold level in freshly shed cotton floral forms for controlling bollworms on cotton (PAU, Ludhiana 1991).

As no information was available on the field testing of economic thresholds for controlling bollworms on cotton, the present study was undertaken, wherein different economic threshold levels, ie 5% bollworm incidence in intact floral forms on plants and 5, 10 and 15% bollworm incidence in freshly shed floral forms, were evaluated and compared with standard spray schedule during 1993–95.

MATERIALS AND METHODS

The experiment on evaluation of different economic threshold levels based on bollworm incidence in floral forms (squares, flowers and green bolls) intact on plants and shed on ground was conducted on 'LG 900', 'LH 1134', 'F 846' varieties of upland cotton (*G. hirsutum* L.) and 'LD 327' tree cotton (*G. arboreum* L.) during 1993–95. Randomized block design was followed, with 3 replications with a plot size of 100–315 m². During 1993–94, 4 economic thresholds, 5% bollworm incidence in intact as well as shed floral forms, and 5 and 10% bollworm incidence in shed floral forms were compared with standard spray schedule on 'LH 900' and 'LH 1134' varieties. During 1995 another economic threshold of 15% bollworm incidence in shed floral forms was added in place of 5% bollworm incidence in intact as well as shed floral forms. Bollworm incidence in green floral forms was monitored regularly. All the intact floral forms from 5 plants/ treatment and 25–50 shed floral forms/ treatment were examined for calculating the extent of bollworm incidence in

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intact and shed floral forms respectively. The insecticide spray was given as and when the bollworm incidence in green floral forms exceeded the limit of economic threshold level. In the standard spray schedule, insecticide sprays were given at 10-day intervals during effective boll-formation period of the cotton variety. Cypermethrin (0.05 kg ai/ha) and deltamethrin (0.01 kg/ ai/ha) were used in first 4 trials (1993–95), whereas in last 3 trials (1995) alternate sprays of deltamethrin and quinalphos (0.5 kg/ ai/ha) were given. The insecticide spray was done by manually operated knapsack sprayer using 250–300 litres spray material/ ha. The efficacy of performance of economic threshold levels was assessed on the basis of bollworm incidence in open bolls/10 plants from each repeat both on boll and locule basis. Yield of seed cotton was calculated on whole-plot basis and cost : benefit ratio depended on the cost of insecticide sprays, labour charges and market price of seed cotton/ha.

RESULTS AND DISCUSSION

The pooled analysis of data of 2 trials (1993–94) (Table 1) indicated that economic threshold of 5 and 10% bollworm incidence in shed floral forms and standard spray schedule were significantly more efficient with respect to reduction of bollworm incidence in open bolls than 5% bollworm incidence in intact floral forms, but yield of seed cotton in 5% bollworm incidence in intact floral forms, being at par with standard spray schedule, was significantly higher than 5 and 10% bollworm incidence in shed floral forms. The cost : benefit ratio (1 : 26.29) was also highest in 5% bollworm incidence

in intact floral forms than the rest of the treatments. The pooled analysis of 5 trials (1995) (Table 2) revealed that performance of all economic threshold levels including standard spray schedule was statistically on a par with each other with respect to boll damage (8.2–10.3%), locule damage (4.3–5.6%) and yield of seed cotton (1 490–1 678 kg/ha). The cost : benefit ratio was, however, highest in standard spray schedule (1 : 9.54), followed by that in 5% bollworm incidence in intact floral forms (1 : 7.20) and 15% (1 : 6.28), 10% (1 : 5.79) and 50% (1 : 5.51) bollworm incidence in shed floral forms. The number of sprays on an average in 7 trials was lowest in standard spray schedule (7.85), followed by 5% bollworm incidence in intact floral forms (8.85) and 5, 10 and 15% bollworm incidence in shed floral forms (11.50–12.40), indicating that none of economic threshold levels could help reduce the number of sprays compared with the standard spray schedule, though, 5% bollworm incidence in intact floral forms was nearest to the standard practice.

The study revealed that standard spray schedule was the best, being most economical, followed by economic threshold level of 5% bollworm incidence in intact floral forms, whereas 5% bollworm incidence in shed floral forms was least economical for chemical control of bollworms on cotton. Our finding supports that of Simwat *et al.* (1992), who reported equal efficacy of 5% bollworm incidence in intact fruiting bodies and standard spray schedule for initiating insecticide sprays for controlling bollworms on *G. arboreum* ('LD 230') cotton. Singh and Sandhu (1995) also reported that standard spray schedule was most economical, followed by 5%

Table 1 Comparative performance of different economic threshold levels (ETL) for controlling bollworms with insecticides on upland cotton varieties 'LH 900' and 'LH 1134' in 1993–94

Treatment	ETL (bollworm incidence)	Boll damage (%)			Locule damage (%)			Yield of seed cotton (kg/ha)			Cost : benefit (Rs)		
		'LH 900'	'LH 1134'	Pooled	'LH 900'	'LH 1134'	Pooled	'LH 900'	'LH 1134'	Pooled	'LH 900'	'LH 1134'	Pooled
T ₁	5% in intact floral forms	7.2 (15.59)	12.0 (20.31)	9.5 (17.95)	4.8 (12.60)	6.3 (14.53)	5.5 (13.57)	1 420	1 850	1638	27.58	25.81	26.24
T ₂	5% in shed floral forms	5.9 (14.06)	7.0 (15.37)	6.5 (14.71)	3.2 (10.36)	3.5 (10.58)	3.3 (10.47)	1 504	1 547	1525	19.88	11.22	15.55
T ₃	5% both in intact and shed floral forms	NR	10.6 (18.95)	10.5 (18.95)	NR	4.3 (11.93)	4.3 (11.93)	NR	1 660	1660	NR	19.62	19.62
T ₄	10% in shed floral forms	6.9 (15.22)	NR	6.9 (15.22)	4.0 (11.49)	NR	4.0 (11.49)	1 300	NR	1300	20.66	NR	20.66
T ₅	Standard spray schedule	7.5 (15.93)	8.0 (16.46)	7.8 (16.19)	4.2 (11.82)	3.2 (10.24)	3.7 (11.03)	1 438	1 964	1701	22.96	23.39	23.17
CD (<i>P</i> = 0.05)		NS	(1.49)	(1.73)	NS	(1.95)	(1.54)	86	117	63			

No. of sprays with cypermethrin and deltamethrin in T₁ – T₅ were 4–6, 6–11, 5, 6 and 5–7 respectively

Cost : Cypermethrin 25 EC @ 200 ml/ha/spray, Rs 130; deltamethrin 2.8 EC @ 400 ml/ha/spray, Rs 180; labour charges/ha/spray, Rs 50; market price : Seed cotton/100 kg, Rs 1500 (1993) and Rs 2000 (1994);

figures in parentheses are arc-sin√% transformation

NR, Not recorded

Table 2 Comparative performance of different economic threshold levels (ETL) for controlling bollworms with insecticides* on cotton (*Gossypium* species) in 1995

Treatment	Trial 1 (‘F 846’)	Trial 2 (‘LH 900’)	Trial 3 (‘LH 900’)	Trial 4 (‘LH 900’)	Trial 5 (‘LH 327’)	Pooled
<i>Boll damage (%)</i>						
T ₁	10.4 (18.85)	11.6 (19.96)	6.8 (15.12)	9.7 (18.17)	13.7 (21.66)	10.3 (18.74)
T ₂	5.4 (13.43)	11.2 (19.53)	12.2 (20.45)	11.1 (19.42)	7.1 (15.44)	9.2 (17.65)
T ₃	4.1 (11.70)	11.1 (19.48)	9.8 (18.27)	9.3 (17.71)	8.3 (16.70)	8.3 (16.68)
T ₄	8.7 (17.16)	10.4 (18.83)	4.7 (12.48)	9.9 (18.33)	8.2 (16.63)	8.2 (16.68)
T ₅	6.0 (14.13)	12.2 (20.40)	4.4 (12.06)	9.7 (18.16)	11.2 (19.54)	8.4 (16.25)
CD (<i>P</i> = 0.05)	(3.66)	NS	(3.98)	NS	(1.77)	NS
<i>Locule damage (%)</i>						
T ₁	5.8 (13.88)	5.7 (13.83)	3.6 (10.96)	4.9 (12.79)	8.5 (16.94)	5.6 (13.68)
T ₂	2.7 (9.47)	5.3 (13.29)	5.4 (13.38)	5.1 (13.03)	4.5 (12.20)	4.5 (12.27)
T ₃	2.0 (8.19)	5.9 (14.04)	5.6 (13.71)	4.1 (11.72)	4.4 (12.17)	4.3 (11.96)
T ₄	5.3 (13.30)	4.6 (12.40)	3.3 (10.44)	4.5 (12.24)	4.7 (12.53)	4.5 (12.18)
T ₅	3.5 (10.70)	5.9 (14.09)	2.3 (8.62)	4.2 (11.80)	6.9 (15.20)	4.4 (12.80)
CD (<i>P</i> = 0.05)	(3.02)	NS	(2.95)	NS	(1.47)	NS
<i>Yield of seed cotton (kg/ha)</i>						
T ₁	1 339	1 555	1 487	1 546	1 523	1 490
T ₂	1 523	1 496	1 397	1 529	1 945	1 578
T ₃	1 619	1 411	1 520	1 494	1 933	1 595
T ₄	1 485	1 500	1 756	1 568	2 084	1 678
T ₅	1 557	1 466	1 837	1 533	1 910	1 660
CD (<i>P</i> = 0.05)	154	NS	186	NS	207	NS
<i>Cost : benefit ratio (Rs)</i>						
T ₁	6.77	8.85	5.08	5.72	9.60	7.20
T ₂	6.58	7.01	3.63	4.60	5.76	5.51
T ₃	7.67	6.56	4.56	4.47	5.72	5.79
T ₄	6.96	7.71	5.43	5.06	6.25	6.28
T ₅	12.38	10.35	8.83	7.20	8.97	9.54

T₁, 5% incidence in intact floral forms; T₂, 5% in shed floral forms; T₃, 10% in shed floral forms; T₄, 15% in shed floral forms; T₅, standard spray schedule

* Deltamethrin (0.01 kg ai/ha) used in Trials 1 and 2, whereas in Trials 3–5, alternate sprays of deltamethrin and quinalphos (0.5 kg ai/ha) were given, number of insecticide sprays in Trials 1, 2, 3, 4 and 5 was 6–12, 12–14, 12–13, 12–13 and 8–9 respectively; cost of plant protection includes cost of insecticide sprays and labour charges/ha/spray @ Rs 75; market price of seed cotton/100 kg, Rs 2 000 (upland cotton) and Rs 1 800 (tree cotton)

Figures in parentheses are $\sin^{-1}\sqrt{\%}$ transformation

NS, critical differences were not significant as indicated by non-significant F ratio

bollworm incidence in shed and 5% bollworm incidence in intact fruiting bodies for controlling bollworms on *G. arboreum*.

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Energy input-output relationship of cropping systems

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ABSTRACT

A field experiment was conducted during 1983–90 at Ranchi, to study the energetics of 4 cropping systems, viz maize (*Zea mays* L.) – wheat (*Triticum aestivum* L. emend. Fiori & Paol.), soybean [*Glycine max* (L.) Merr.] – wheat, rice (*Oryza sativa* L.) – wheat and groundnut (*Arachis hypogaea* L.) – wheat. Maize produced significantly higher grain and total biomass energy (34 332 and 130 394 MJ/ha respectively) than the other rainy season (*khari*) crops. Wheat grown in sequence after soybean or groundnut produced higher energy from grain and total biomass than after maize or rice. Among cropping systems, groundnut–wheat sequence was most efficient in energy production through grain (321 MJ/ha/day), followed by maize–wheat (318 MJ/ha/day). But in terms of total biomass, maize–wheat sequence was more efficient (923 MJ/ha/day), followed by groundnut–wheat (609 MJ/ha/day).

Key words : energy input-output, cropping systems, maize, soybean, rice, groundnut, wheat, *Zea mays*, *Glycine max*, *Oryza sativa*, *Arachis hypogaea*, *Triticum aestivum*

Energy is the basic need of our national economy and about 2 billion calories of energy is needed to feed its increasing population of 1 billion, for producing more than 200 million tonnes foodgrain by 2000 AD (Prusty *et al.* 1983). The use of biomass as a source of renewable energy has attracted attention to bring more and more area under biomass-oriented cropping. The scope of increasing cultivable land horizontally is not feasible. Hence the sequential cropping systems need to be quantitatively evaluated for their intrinsic potential to produce food, feed and fuel energy. The research knowledge on energy utilization and efficiency is scarce and scanty. This experiment was therefore undertaken to study the relationship between energy input and output of crops in 4 cropping systems.

MATERIALS AND METHODS

A field experiment was conducted at the university farm, Ranchi, to study the energetics of 4 rainy season crops, viz 'Suwan 1' maize (*Zea mays* L.), 'Brownchora 23-19' rice (*Oryza sativa* L.), 'Birsa Soybean 1' soybean [*Glycine max* (L.) Merr.], and 'AK 12-24' groundnut (*Arachis hypogaea* L.), followed by winter-season 'Sonalka' wheat (*Triticum aestivum* L. emend. Fiori & Paol.). Randomized block design was followed, replicated 6 times for 7 consecutive years (1983–90). The soil was sandy loam (8.4% silt and 29.2% clay), containing available N, P and K @ 175, 9.7 and 180 kg/ha respectively. All the crops were grown with

recommended level of management. Energy input and output were calculated from the recorded data for each item of operations (expressed in MJ/ha), taking standard values suggested by Panesar and Bhatnagar (1994). Energy-use efficiency (EUE) based on output : input energy ratio and cereal- or pulse- energy- equivalent yield were calculated to know the efficacy of crops and cropping systems. Energy productivity (g grain/MJ) was calculated by dividing the mean grain yield of 7 years by the corresponding energy input. The total plant yield refers to the grain + by-product yield.

RESULTS AND DISCUSSION

Energetics of rainy-season crops

Cultivation of *khari* crops required more indirect sources of energy (186, 143, 104 and 65% for maize, groundnut, soybean and rice respectively) than direct sources (Table 1). Maize produced significantly higher grain and total biomass energy than soybean, rice and groundnut (Table 2). Maize, a C₄ crop with negligible photo-respiration, has ability to utilize the solar energy more efficiently, which reflected in grain and total biomass production compared with C₃ crops (Table 3). Consequently, its total plant yield resulted in maximum EUE of 12.37. Groundnut, with least economic and biological yield, ranked second in energy output, because energy density within a unit mass of its kernel is much higher than in cereals and pulses. This finding is in agreement with that of Verma *et al.* (1994). Subsequently, it showed an edge over rice and soybean in energy output through grain and total biomass. Groundnut with maximum grain EUE (3.73) also proved superior to soybean, maize and rice. Further, the efficiency

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Table 1 Relationship between direct and indirect energy input (MJ/ha) of crops and cropping system

Crop sequence	Direct energy input				Indirect energy input				Grand : indirect	
	Human	Animal	Diesel	Total	Seed	Fertilizer	Chemicals	Total	Total	Direct
Maize	1 717	1 017		2 734	2 333	6 783	790	7 806	10 540	2.86
Wheat	1 507	1 162	5 631	8 300	1 617	6 783	251	8 651	16 951	1.04
Maize-wheat	3 224	2 179	5 631	11 034	3 950	13 566	1 041	16 457	27 491	1.49
Soybean	1 112	1 114		2 226	740	2 146	790	3 676	5 902	1.65
Wheat	1 507	1 162	5 631	8 300	1 617	6 783	251	8 651	16 951	1.04
Soybean-wheat	2 619	2 276	5 631	10 526	2 357	8 929	1 041	12 327	22 853	1.17
Rice	1 004	1 162		2 166	1 035	2 891	490	4 416	6 582	2.04
Wheat	1 507	1 162	5 631	8 300	1 617	6 783	251	8 651	16 951	1.04
Rice-wheat	2 511	2 324	5 631	10 466	2 652	9 674	741	13 067	23 533	1.25
Groundnut	1 082	1 114		2 196	2 250	2 238	850	5 338	7 534	2.43
Wheat	1 507	1 162	5 631	8 300	1 617	6 783	251	8 651	16 951	1.04
Groundnut-wheat	2 589	2 276	5 631	10 496	3 867	9 021	1 101	13 989	24 485	1.37

Table 2 Energy output, energy-use efficiency and grain-energy productivity of crops and cropping systems (mean data of 1983-90)

Crop sequence	Energy output (MJ/ha)		Energy-use efficiency		Energy productivity (g/MJ)
	Grain	Total biomass	Grain	Total biomass	
Maize	34 332	130 394	3.26	12.37	252
Wheat	35 548	72 639	2.10	4.29	162
Maize-wheat	69 880	203 033	2.54	7.38	197
Soybean	19 541	44 414	3.31	7.53	250
Wheat	37 928	80 150	2.24	4.73	173
Soybean-wheat	57 469	124 564	2.51	5.45	193
Rice	19 896	43 251	3.02	6.57	234
Wheat	31 857	65 444	1.85	3.86	143
Rice-wheat	51 252	108 695	2.18	4.61	168
Groundnut	28 103	49 084	3.73	6.52	166
Wheat	39 390	78 788	2.32	4.65	180
Groundnut-wheat	67 493	127 871	2.76	5.22	175
CD ($P = 0.05$)					(211)
Kharif crops	1 569	1 894	0.12	0.92	17
Wheat	1 484	1 539	0.08	0.32	8
Cropping system	2 963	4 568	0.14	0.59	16

Figures in parentheses indicate energy productivity based on cereal- or pulse-energy-equivalent yield

of grain-energy utilization of soybean was superior to maize, which in turn was superior to rice. The productivity of grain energy of soybean and maize was almost similar. Though groundnut gave the lowest grain-energy productivity owing to poor production (1 249 kg/ha), it was maximum (282 g/MJ) in terms of cereal- or pulse-energy-equivalent yield owing to its high energy content. Maize with high energy input

(10 540 MJ/ha) gave grain-energy productivity (252 g grain/MJ) similar to soybean (250 g grain/MJ) because of high grain productivity of maize (2 654 kg/ha) as well as low energy input (5 902 MJ/ha) in soybean.

Energetics of succeeding wheat crop

Wheat required 122% more energy than the average

Table 3 Economic yield, by-product and total biomass production of crops and cropping systems (mean data of 1983–90)

Crop sequence	Economic yield (kg/ha)	By-product (kg/ha)	Total biomass (kg/ha)
Maize	2 654	6 671	9 325
Wheat	2 748	3 297	6 045
Maize–wheat	5 402	9 968	15 370
Soybean	1 477	2 211	3 688
Wheat	2 932	3 753	6 685
Soybean–wheat	4 409	5 964	10 373
Rice	1 538	2 076	3 614
Wheat	2 424	3 030	5 454
Rice–wheat	3 962	5 106	9 068
Groundnut	1 249 (2 124)	1 865	3 114
Wheat	3 045	3 502	6 547
Groundnut–wheat	4 294 (5 169)	5 367	9 661

Figures in parentheses indicate cereal- or pulse- energy- equivalent yield

energy need of *kharif* crops (7 460 MJ/ha), mainly because of additional energy expenditure of 6 000 MJ/ha for irrigation. Further, wheat cultivation needed almost equal amount of direct and indirect sources of input energy. Wheat following groundnut and soybean produced higher energy from grain and total biomass than maize and rice crops. Grain and total biomass EUE along with grain-energy productivity also followed the similar trend. This may be attributed to favourable residual fertility of the preceding legumes on the succeeding wheat crop.

Energetics of cropping system

The cropping systems varied in energy requirement from 22 853 MJ/ha under soybean–wheat to 27 491 MJ/ha under maize–wheat system owing to differential energy need of *kharif* crops (Table 1). Maize–wheat recorded maximum energy output from grain (69 880 MJ/ha) and total biomass (203 033 MJ/ha) owing to inclusion of maize in the system. Groundnut–wheat system also showed grain-energy output (67 493 MJ/ha) similar to maize–wheat and was superior to soybean–wheat and rice–wheat systems. High grain-energy production from groundnut–wheat system was partly due to groundnut, which is an energy-rich crop and has some beneficial residual effect on the productivity of succeeding wheat crop. Pal and Patil (1988) also observed beneficial residual effect of legumes on the succeeding cereal crop.

Groundnut–wheat system also recorded higher EUE than the rest of the cropping systems. In spite of similar grain-energy output from maize–wheat and groundnut–wheat, the latter system gave higher grain EUE (5.7%) mainly because of 11% lower energy requirement. Total biomass EUE of

different cropping systems followed the path of their total biomass-energy production. Grain-energy productivity of groundnut–wheat, maize–wheat and soybean–wheat systems, being similar to each other, proved superior to that of rice–wheat system. Considering the energy productivity per unit area per unit time, groundnut–wheat and maize–wheat systems were almost equally efficient in terms of grain (321 and 318 MJ/ha/day respectively), whereas in terms of total biomass maize–wheat sequence (923 MJ/ha/day) was more efficient than groundnut–wheat (609 MJ/ha/day). Rice–wheat sequence was the least efficient both in terms of grain and total biomass-energy productivity per unit area per unit time (214 and 453 MJ/ha/day respectively).

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Agro-climatic indices for predicting phenology of wheat (*Triticum aestivum*) in Punjab

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ABSTRACT

The study of phenology of wheat (*Triticum aestivum* L. emend. Fiori & Paol.) crop in relation to various energy-summation indices, viz accumulated growing degree-days, accumulated helio-thermal units, cumulative solar radiation and cumulative pan evaporation, for 8 crop seasons of 1986–87 to 1993–94 was conducted at Ludhiana. A comparison of various agro-climatic indices revealed that accumulated growing degree-days can be used as the best index to predict various phenophases under Punjab conditions, as it gave the lowest coefficient of variation under early-, normal- as well as late-sown conditions. From sowing to complete emergence and also during intermediate phenophases representing reproductive phase, the delay in sowing reduced the cumulative energy attained, but no such trend was observed during the vegetative phase.

Key words : wheat, *Triticum aestivum*, agro-climatic indices, energy-summation indices, phenology

Wheat (*Triticum aestivum* L. emend. Fiori & Paol.) is a thermo-sensitive, long-day crop, grown extensively throughout the world. The duration, growth and yield are decided by the thermal and photoperiod conditions experienced by the crop during its life-cycle (Ghadekar *et al.* 1992). Accurate prediction of crop phenology is often required for crop modelling and crop management. The primary focus for estimating phenology has been the approach of growing degree-days (Nuttonson 1955, Ritchie and Otter 1985). For simplicity, many workers have used a single-threshold temperature or photoperiod, but Angus *et al.* (1981) reported that different threshold temperatures and photoperiods could be used for predicting different growth stages. Even a particular growth stage may be best predicted by one model or other using the growing degree-days and photo-thermal models (McMaster and Smika 1988).

The application of agro-climatic indices provides a scientific basis for determining the effect of temperature, radiation or photoperiod on phenological behaviour of the crop. Although these techniques are yet to be tried in India on a regional scale, a few studies have been conducted at local level (Sastry and Chakaravarty 1982). Considerable research has been conducted on various aspects of increasing wheat yield but there is still some scope to optimize it by exploiting meteorological conditions to enable it to express its best performance. Sufficient work has not been reported on energy-summation indices for wheat under Punjab

conditions. Keeping this in view, an attempt was made to study the phenology of wheat crop in relation to various energy-summation indices such as growing degree-days, helio-thermal units, cumulative solar radiation and cumulative pan evaporation.

MATERIALS AND METHODS

'HD 2329' wheat was grown for winter season (*rabi*) 1986–87 to 1993–94 in randomized block design at the research farm of the university at Ludhiana (30°54'N latitude, 75°48'E longitude, 247m above mean sea-level). The crop was sown on 3 dates, ie during the first week of November, third week of November and second week of December, to be called early-, normal- and late-sowing respectively, for the 8 years. The recommended agronomic and plant-protection measures were adopted to raise the crop. The various phenological stages of the crop, viz sowing, complete emergence, crown-root initiation, 50% jointing, 50% heading, 50% flowering, 50% milking, 50% dough and maturity, were identified visually on randomly selected plants. Weather parameters were recorded at the agro-meteorological observatory located within 200 m of the experimental field. The following agro-climatic indices were computed to be related with different phenological stages.

Growing degree-days (GDD or heat units) were determined as per Nuttonson (1955):

$$GDD = \frac{T_{max} + T_{min}}{2} - T_b$$

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where $T_{\max}$, maximum temperature ($^{\circ}\text{C}$) during a day; $T_{\min}$, minimum temperature ($^{\circ}\text{C}$) during a day; and T_b , base temperature of 3.5°C . Growing degree-days were accumulated from the date of sowing up to each individual phenological event to give accumulated growing degree-days.

For helio-thermal units (HTU) the product of the growing degree-days and the corresponding actual sunshine hours for that day were computed on daily basis.

$$\text{HTU} = (\text{GDD}) \times (\text{actual sunshine hours})$$

The helio-thermal units were also accumulated from sowing to each phenological event to yield accumulated helio-thermal units.

For cumulative solar radiation, the values of daily solar radiation (MJ/m^2) were accumulated from sowing to different phenological stages; and the daily values of pan evaporation (mm) were accumulated from sowing to different phenophasic events.

RESULTS AND DISCUSSION

The various phenophases of wheat crop are divided into 3 groups for simplicity, viz emergence, vegetative (from emergence to heading) and reproductive (from flowering to maturity).

Sowing to complete emergence

The early and normal sowing experienced nearly equal number of growing degree-days (141.7 and 144.3) from sowing to complete emergence, but a decrease was noticed with further delay in sowing (Table 1). The maximum helio-thermal units (Table 2) were availed by early sowing, and successive delay in sowing decreased the requirement of

helio-thermal units. The maximum amount of solar radiation ($140.3 \text{ MJ}/\text{m}^2$) for sowing to emergence was experienced by the normal sowing date (Table 3). Cumulative pan evaporation was also similar (23.9 mm and 22.7 mm) for early and normal sowing (Table 4).

From sowing to complete emergence, the coefficient of variation (CV) was lower for accumulated growing degree-days, ie 10.1, 12.2 and 6.2% for early, normal and late sowing respectively (Table 1). The corresponding values of CV for accumulated helio-thermal units were 13.9, 20.3 and 22.4% (Table 2) respectively. Similarly, for cumulative solar radiation the CV was 13.2, 12.6 and 17.8% (Table 3), and for cumulative pan evaporation 16.6, 16.6 and 27.5% (Table 4) for early, normal and late sowing respectively.

Vegetative phase

The growing degree-days (Table 1) and helio-thermal units (Table 2) accumulated by the crop decreased with delay in sowing from early to late sowing of wheat. The early sowing accumulated the maximum amount of solar radiation ($287.0 \text{ MJ}/\text{m}^2$) up to crown-root initiation (Table 3) and also up to jointing stage ($586.7 \text{ MJ}/\text{m}^2$); however, up to the heading stage the normal sowing experienced the maximum amount of radiation ($978.9 \text{ MJ}/\text{m}^2$). Similarly, the early sowing experienced maximum pan evaporation of 55.4 mm up to crown-root initiation and 94.1 mm up to jointing stage (Table 4). But up to the heading stage late sowing accumulated the maximum amount of pan evaporation (145.5 mm).

The CV for vegetative phase including early, normal and late sowings was 5.2–14.5% for accumulated growing degree-days, 10.3–30.9% for accumulated helio-thermal units, 9.9–25.0 for cumulative solar radiation, and 11.9–24.4% for

Table 1 Mean, standard deviation (SD) and coefficient of variation (CV) in accumulated growing degree-days for various phenological stages of wheat under different sowing environments

Phenological stage	Early sowing			Normal sowing			Late sowing		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
<i>Emergence</i>									
S-CE	141.7	14.3	10.1	144.3	17.6	12.2	128.9	8.1	6.2
<i>Vegetative phase</i>									
S-CRI	331.6	26.1	7.9	298.5	17.6	5.9	241.4	13.6	5.6
S-50%	592.8	49.9	8.4	487.7	70.7	14.5	445.7	75.6	7.0
<i>Jointing</i>									
S-50%	965.5	49.8	5.2	867.7	66.1	7.6	797.4	57.3	7.2
<i>Heading</i>									
<i>Reproductive phase</i>									
S-50%	1 054.3	53.7	5.1	979.1	70.5	7.2	916.1	57.7	6.3
<i>Flowering</i>									
S-50%	1 251.7	56.2	4.5	1 179.8	81.9	6.9	1 090.7	76.4	7.0
<i>Milking</i>									
S-50%	1 424.1	73.5	5.2	1 384.0	97.7	7.0	1 282.8	77.0	6.0
<i>Dough</i>									
S-M	1 860.2	103.1	5.5	1 774.6	101.9	5.7	1 649.5	84.8	5.1

S, Sowing; CE, complete emergence; CRI, crown-root initiation; M, maturity

Table 2 Mean, standard deviation (SD) and coefficient of variation (CV) in accumulated helio-thermal units for various phenological stages of wheat under different sowing environments

Phenological stage	Early sowing			Normal sowing			Late sowing		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
<i>Emergence</i>									
S-CE	1 291.8	180.0	13.9	1 158.9	234.9	20.3	815.7	183.3	22.4
<i>Vegetative phase</i>									
S-CRI	2 280.6	315.0	10.9	2 195.9	361.6	16.5	1 502.5	297.7	19.8
S-50%	4 763.0	707.8	14.9	3 397.5	749.4	22.0	2 848.2	880.0	30.9
<i>Jointing</i>									
S-50%	7 162.5	738.6	10.3	6 196.8	966.1	15.6	5 788.9	755.1	13.0
<i>Heading</i>									
<i>Reproductive phase</i>									
S-50%	7 874.0	776.6	9.9	7 205.9	1 074.5	14.9	6 710.1	793.0	11.8
<i>Flowering</i>									
S-50%	9 520.2	888.9	9.3	8 916.5	1 136.0	12.7	8 137.9	1 096.9	13.5
<i>Milking</i>									
S-50%	11 015.6	1 105.6	10.0	10 580.5	1 460.6	13.8	9 853.2	1 092.7	11.1
<i>Dough</i>									
S-M	14 843.4	1 721.7	11.6	14 420.4	1 631.2	11.3	13 578.1	1 191.4	8.8

S, Sowing; CE, complete emergence; CRI, crown-root initiation; M, maturity

Table 3 Mean, standard deviation (SD) and coefficient of variation (CV) in cumulative solar radiation for various phenological stages of wheat under different sowing environments

Phenological stage	Early sowing			Normal sowing			Late sowing		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
<i>Emergence</i>									
S-CE	120.3	15.9	13.2	140.3	17.7	12.6	134.2	23.9	17.8
<i>Vegetative phase</i>									
S-CRI	287.2	37.2	13.0	280.8	31.7	11.3	271.7	40.8	15.0
S-50%	586.7	149.2	25.0	504.5	83.2	16.5	518.9	97.4	18.8
<i>Jointing</i>									
S-50%	894.7	200.5	22.4	978.9	95.7	9.9	974.6	133.5	13.7
<i>Heading</i>									
<i>Reproductive phase</i>									
S-50%	1 103.3	87.4	7.9	1 107.7	128.2	11.6	1 110.7	141.1	12.7
<i>Flowering</i>									
S-50%	1 346.6	129.6	9.6	1 347.0	149.1	11.1	1 293.9	150.1	11.6
<i>Milking</i>									
S-50%	1 558.5	151.4	9.7	1 522.5	192.0	12.6	1 501.9	167.0	11.1
<i>Dough</i>									
S-M	2 031.0	188.9	9.3	1 956.7	209.7	10.7	1 861.9	188.9	10.1

S, Sowing; CE, complete emergence; CRI, crown-root initiation; M, maturity

cumulative pan evaporation. Taking into consideration the 3 groups of phenophases, the CV was usually the highest for all agro-climatic indices during the vegetative phase.

Reproductive phase

From flowering to maturity the early sowing availed the highest number of accumulated growing degree-days (1 860.2, Table 1) as well as accumulated helio-thermal units (14 843.4, Table 2) during the reproductive phase. Angiras

(1974) and Ashwini Kumar (1982) also reported similar findings.

The early-sown crop accumulated maximum number of growing degree-days, helio-thermal units and solar radiation compared with normal- and late-sown crop from sowing to physiological maturity. This is largely due to longer duration of the reproductive phase for the early-sown crop. The reduction in duration of reproductive phase for late-sown condition occurred because of higher temperatures coinciding

Table 4 Mean, standard deviation (SD) and coefficient of variation (CV) in cumulative pan evaporation for various phenological stages of wheat under different sowing environments

Phenological stage	Early sowing			Normal sowing			Late sowing		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
<i>Emergence</i>									
S-CE	23.9	4.0	16.6	22.7	3.8	16.6	18.5	5.1	27.5
<i>Vegetative phase</i>									
S-CRI	55.4	6.6	11.9	43.9	7.9	18.0	35.9	8.1	22.4
S-50%	94.1	12.4	13.1	71.5	14.5	20.2	70.4	17.2	24.4
<i>Jointing</i>									
S-50%	142.5	29.9	21.0	141.2	26.8	18.9	145.5	22.6	15.5
<i>Heading</i>									
<i>Reproductive phase</i>									
S-50%	172.3	19.8	11.5	162.8	31.1	19.1	171.6	25.8	15.0
<i>Flowering</i>									
S-50%	210.7	21.3	10.1	208.1	35.6	17.1	211.3	28.7	13.5
<i>Milking</i>									
S-50%	252.9	25.4	10.1	258.1	24.6	9.5	262.0	32.4	12.4
<i>Dough</i>									
S-M	363.1	41.1	11.3	345.4	65.2	18.9	360.5	41.9	11.6

S, Sowing; CE, complete emergence; CRI, crown-root initiation; M, maturity

with grain development and resulting in enforced maturity of the late-sown crop. Sekhon (1987) also reported that rapid attainment of phenological stages with delayed sowing was associated with significant decrease in heat-unit requirement for maturity.

Taking into consideration the cumulative solar radiation and cumulative pan evaporation, there were variations under different sowing conditions, but at maturity early sowing experienced the maximum solar radiation (2 031 MJ/m²), followed in decreasing order by normal sowing (1 957 MJ/m²) and late sowing (1 862 MJ/m²) respectively (Table 3). Similarly, cumulative pan evaporation was also maximum (363 mm) in early sowing and minimum (345.4 mm) in normal sowing (Table 4).

The CV for reproductive phase including all sowing dates was 4.5–7.2% for accumulated growing degree-days, 8.8–14.9% for accumulated helio-thermal units, 7.9–12.7% for cumulative solar radiation and 9.5–19.1% for cumulative pan evaporation. The CV for various agro-climatic indices was usually the lowest during reproductive phase compared with other stages.

A comparison of the 4 agro-climatic indices used revealed that the accumulated growing-degree-days yielded the lowest CV for all the phenological stages under early-, normal- as well as late-sowing conditions. The evaporation and radiation indices gave relatively higher coefficients of variation. This may be due to the indirect influence of these energy-summation indices on various phenological growth stages.

It was concluded that the accumulated growing degree-days can be used as the best index to predict any phenological stage in wheat under Punjab conditions.

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Evaluation of reference-crop evapo-transpiration by empirical method for predicting consumptive water use of a crop in a tropical wet-and-dry climate

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ABSTRACT

Reference-crop evapo-transpiration (ET_o) was determined according to 4 empirical methods using climatic data for the different phenological stages of maize (*Zea mays* L.) grown during the rainy seasons of 1992–95. Evaluation of the empirical methods for the prediction of crop-consumptive water use (ET_{crop}) was based on the variability of derived ET_o estimates and the capability of each estimate to reliably predict the ET_{crop} during the different phenological stages of growth. The modified Penman method offered the best result with significant ($P = 0.01$) coefficient of determination of ET_{crop}. Next to Penman is the modified pan-evaporation method. The modified radiation method was graded next and lastly the modified Blaney-Criddle approach. The relative reliability of each method in terms of accuracy of both measured and extrapolated meteorological data utilized is also discussed.

Key words : reference-crop evapo-transpiration, maize, water use, phenological stage, *Zea mays*

Tropical wet-and-dry climate is characterized by an unpredictable distribution and variability of seasonal rainfall. Thus moisture remains the most critical agro-meteorological factor for crop production in the region. Hence precise quantitative characterization of the plant environment based on moisture requirement (consumptive water use) of cultivated crops is essential for an objective project planning in agriculture, particularly in the tropical wet-and-dry climate. However, accurate measurement of consumptive water use (ET_{crop}) of a crop in field is difficult. Hence empirical formulae have been developed to predict ET_{crop} using climatic data. A prediction method by Doorenbos and Pruitt (1977) is expressed as:

$$ET_{crop} = K_c \times ET_o$$

where ET_{crop}, crop consumptive water use of the crop; K_c, crop coefficient; and ET_o, reference-crop evapo-transpiration.

Thus given the crop coefficient at a specified phenological stage of a crop, the reliability of the predicted ET_{crop} for planning will depend on the accuracy of the method of estimating ET_o. This study was therefore taken up to evaluate the ET_o determined by different empirical methods for predicting ET_{crop}.

MATERIALS AND METHODS

The ET_o estimates were derived from 4 empirical methods, viz energy budget and aerodynamic approach of Penman (1948), temperature method of Blaney and Criddle (1950), radiation method of Makkink (1957) and Pan-

evaporation method of Pruitt (1966), following the modifications and guidelines of Doorenbos and Pruitt (1977).

Meteorological data used in the process are air temperature (°C), psychrometric reading (T °C of dry- and wet-bulb thermometer), relative humidity (%), duration of bright sunshine (hr), pan evaporation (mm) and wind speed (km/day) at 2 m height. Other required variables of which measured values were not available but estimated with the use of meteorological table (List 1966, Hounam 1973, Doorenbos and Pruitt 1977) are radiation received at the top of the atmosphere (R_a), solar radiation in equivalent evaporation in mm/day (R_s), daily maximum possible sunshine duration (N), reflectivity of crop surface (OC), mean saturation water vapour pressure (e_a), net radiation (R_n) in equivalent evaporation in mm/day, mean actual water-vapour pressure (e_d), adjustment factor (c), pan coefficient (K_p), weighing factor for the effect of temperature and altitude (W), and weighing factor for the effect of wind and relative humidity on ET_o (I–W).

The relative reliability of the methods considered in this study for the prediction of ET_{crop} was assessed with respect to 4 phenological stages (establishment, vegetative, flowering and grain-filling periods) of maize (*Zea mays* L.). Variety 'TZER-Y' belonging to parental population '31 Amerillo Cristalino 2' was grown during each year of early and late rains (March–June and July–October respectively) in 1992–95 at the university farm at Abeokuta (7°15'N, 3°25'E) in Nigeria. The soil was well drained, tropical ferruginous type with a sandy-loam surface horizon underlain by a weakly developed clayey, mottled and occasionally concrete sub soil.

It had 83.3% sand, 4.6% silt and 12.1% clay in the A-horizon (Adetunji 1991).

The crop coefficient (K_c) during the growing season was determined following the guidelines of Doorenbos and Pruitt (1977). The measured weather data were recorded at an agrometeorological station adjacent to the university farm in Nigeria.

There is no base-line type of climate for testing the accuracy of methods of estimating ET_o (Doorenbos and Pruitt 1977, Sudhakara Rao and Subramanian 1991). Doorenbos and Pruitt (1977) suggested an evaluation based on the average of the absolute difference between the measured and computed values. But since measured values of both ET_o and ET_{crop} are not available, the evaluation done in this study was based on: (i) relative variability (R_v) of ET_o estimates derived from each of the empirical methods, and (ii) the extent to which ET_o estimates derived by each method could significantly predict ET_{crop} . R_v was determined following the method of Ojo (1977) as:

$$RV = \frac{AV}{\bar{r}} \times 100$$

$$\text{where } AV \text{ (average variability)} = \frac{1}{n} \sum_{i=1}^n r_i - \bar{r}$$

$\bar{r}_i$, ET_o during a given phenological stage; $\bar{r}_i$, mean ET_o for the entire phenological stages studied; and n , period under investigation.

Using the simple linear regression model the procedure of Steel and Torrie (1960) was followed to calculate the correlation coefficient and coefficient of determination. Based on these analyses, the extent to which each set of ET_o estimates could significantly predict ET_{crop} was assessed. The procedure of simple linear regression model was that each set of ET_o derived by each method during each phenological stage was taken as the independent variable, whereas the mean ET_{crop} resulting from the application of all the methods during the corresponding phenological stage stood as the dependent variable.

RESULTS AND DISCUSSION

Seasonal ET_o (Fig 1) varies with the method of estimation and phenological stage. For all the methods, ET_o is highest during the flowering stage, indicating that consumptive water use by maize (ET_{maize}) will be the highest during the flowering stage. This agrees with the observation of Denmead and Shaw (1959) and Chang (1968). The modified Penman method is associated with the highest relative and coefficient of variability (Table 1), indicating that this method best reflects the variable nature of the evaporative demand of the plant

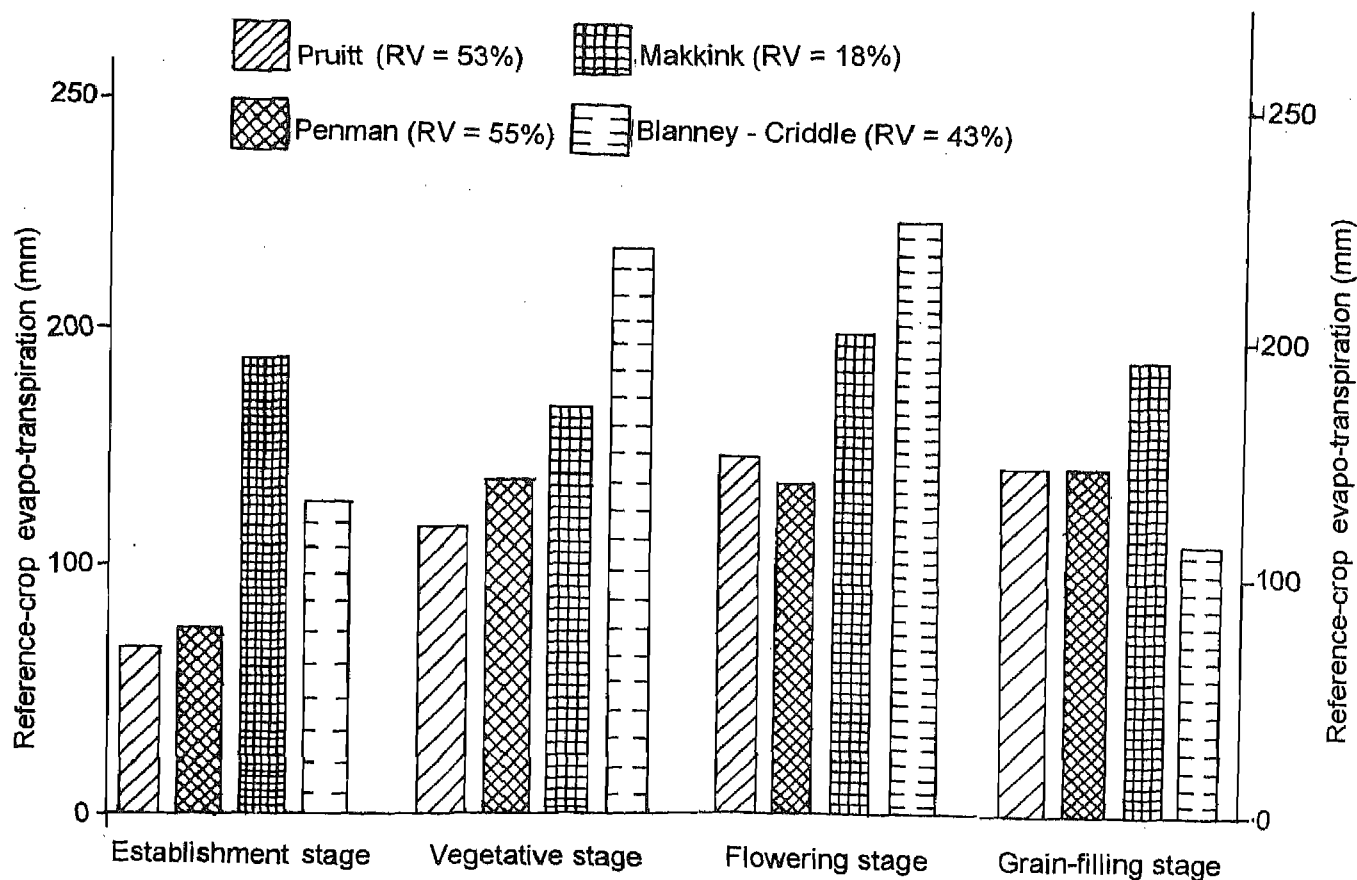


Fig 1 Seasonal reference-crop evapotranspiration (ET_o) determined according to 4 empirical methods for different phenological stages of maize

environment during the different phenological stages of the growing season. Thus the modified Penman method appeared most suitable for an area characterized by an irregular sequence of wet and dry spells.

The simple linear regression model (Table 1) shows further that the Penman method has the highest significant positive correlation as well as the highest coefficient of determination of ET_{crop} for each phenological stage. This can be interpreted to mean that ET estimate determined by the modified Penman method has the highest coefficient (capability) of prediction of reliable ET_{crop} . Therefore the modified Penman method appeared most suitable in the study area.

Next to Penman is the modified pan-evaporation method of Pruitt. This is followed by the method of Makkink and Blaney-Criddle.

Although different statistical methods of evaluation were adopted, the outcome of evaluation done here corresponds with the finding by Doorenbos and Pruitt (1977).

One major issue in the application of the modified Penman's formula is that important parameters such as wind-related function and net radiation data are not easy to come by. Thus where the measured data are insufficient to permit estimation of radiation and wind-related function from the

meteorological table, the modified pan-evaporation method of Pruitt offers an easier and next-best alternative to Penman's method. In fact, because of its relatively lower level of empiricism, pan-evaporation method appears easy to adopt for application in a wide geographical area.

However, the major problem associated with the application of pan-evaporation method is that, since it is based on evaporation from a specific open water surface, such a measurement may not entirely apply to plants, since water loss from the plant surfaces may differ from that of open water due to differences in albedo, heat-storage capacity, turbulence, air temperature and humidity above the surfaces.

Doorenbos and Pruitt (1977) and Sudhakara Rao and Subramanian (1991) however noted that the use of appropriate pan coefficient and adjustment factor could reduce the effects of the observed problems.

Finally, the modified radiation and temperature methods of Makkink and Blaney-Criddle respectively appear very simple. But a major shortcoming of the method of Makkink is that it is based solely on local estimates of radiation, which had to be extrapolated because of non-availability of direct measurement of radiation. Thus the method is not as reliable as either Penman or pan-evaporation method of Pruitt. Also, because ET_{crop} could vary even between the climates having

Table 1 Simple linear regression between reference-crop evapo-transpiration determined according to different empirical methods and consumptive water use by maize during phenological stage of crop

Method	Sd	Mean	CV	Regression equation	correlation coefficient (r)	Coefficient of determination (r^2) (%)	Significant
<i>Establishment stage</i>							
Pruitt	0.50	1.28	39	$Y = 1.08 + 0.45 x$	0.77	59	$P = 0.01$
Penman	0.73	1.49	49	$Y = 1.07 + 0.39 x$	0.96	92	$P = 0.01$
Makkink	0.48	3.72	13	$Y = 0.10 + 0.42 x$	0.68	46	$P = 0.05$
Blaney-Criddle	0.47	2.45	19	$Y = 1.06 + 0.24 x$	0.39	15	NS
<i>Vegetative stage</i>							
Pruitt	0.79	2.25	38	$Y = 0.79 + 0.72 x$	0.92	85	$P = 0.01$
Penman	1.14	2.77	41	$Y = 1.00 + 0.50 x$	0.94	88	$P = 0.01$
Makkink	1.25	3.30	16	$Y = 0.93 + 0.44 x$	0.90	81	$P = 0.01$
Blaney-Criddle	0.74	4.64	35	$Y = 0.30 + 0.45 x$	0.54	29	$P = 0.05$
<i>Flowering stage</i>							
Pruitt	1.22	2.88	37	$Y = 1.41 + 0.42 x$	0.92	85	$P = 0.01$
Penman	0.98	2.65	42	$Y = 1.14 + 0.56 x$	0.98	96	$P = 0.01$
Makkink	0.88	3.94	19	$Y = 0.78 + 0.47 x$	0.73	53	$P = 0.02$
Blaney-Criddle	0.88	4.75	22	$Y = 1.37 + 0.26 x$	0.41	17	NS
<i>Grain-filling stage</i>							
Pruitt	0.92	1.84	42	$Y = 1.11 + 0.36 x$	0.78	61	$P = 0.01$
Penman	0.75	1.80	50	$Y = 0.87 + 0.51 x$	0.88	77	$P = 0.01$
Makkink	0.69	3.74	18	$Y = 0.07 + 0.46 x$	0.73	53	$P = 0.02$
Blaney-Criddle	0.82	2.23	37	$Y = 1.14 + 0.28 x$	0.54	29	$P = 0.05$

similar values of temperature and daylength, the method of Blaney-Criddle might not be applicable to a wide geographical area. Thus according to Doorenbos and Pruitt (1977) it should be used with skepticism in regions with little temperature variation during the growing season.

In the present study area, rainfall distribution is seasonal and variable (Olaniran 1983), whereas air temperature is high but does not vary much during the growing season (Ojo 1977). Thus the methods based on the processes of moisture loss from the plant environment (modified Penman and pan-evaporation method of Pruitt) offer comparatively more desirable results than the rest of the methods considered.

In conclusion, the reliability of results obtained from the method adopted depends on the availability of accurate measured climatic data. Where the bulk of data are obtained by extrapolation from nearby station and general description of climate, a less reliable result can be expected. Thus a well-equipped weather station is necessary to derive accurate meteorological data required for the estimation of ET_{crop} , which are pertinent for a reliable prediction of ET_{crop} .

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Effect of fruit pedicel on storage behaviour of 'Santa Rosa' plum (*Prunus salicina*)*

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Key words : plum, pedicellate fruit, non-pedicellate fruit, ripening index, decay loss, fruit firmness, storage behaviour, shelf-life, *Prunus salicina*

In India plum (*Prunus salicina* Lindl.) fruits are mostly harvested by hand and sometimes plucked with a manual harvester (Mitra *et al.* 1991). Hand-picking has proved superior in terms of quality and for controlling decay than traditional harvesting by shaking the branches (Yagi *et al.* 1978). Fuchs and Barki-Golan (1979) and Singh *et al.* (1993) recorded longer shelf-life of tomato (*Lycopersicon esculentum* Mill. nom. cons.) and mango (*Mangifera indica* L.) fruits when plucked along with small pedicels. La Rue and Gerdtz (1976) advocated harvesting plum with peduncle intact; however, research data are not available on the effect of fruit pedicel on storage behaviour of plum, a highly perishable and delicate fruit (Childers 1983). Hence an experiment was conducted to find out the effect of method of harvesting on post-harvest behaviour of pedicellate and non-pedicellate fruit of 'Santa Rosa' plum, which is an important commercial cultivar of central Himalayas.

The experiment was conducted at Ranichauri (2 000 m above mean sea-level) during 1993–94. A representative sample comprising a total of 960 randomly selected physiologically matured (firm ripe) healthy fruits with uniform size and specific gravity (1.01) were harvested with pedicel (15 mm) and without pedicel separately on 19–21 June. The harvested fruits of each category were divided into 4 lots consisting of 120 fruits per lot. The experimental design was completely randomized with 2 treatments, 15 replications and 8 fruits per replication. Just after harvesting, 1 lot was analysed and the remaining 3 lots were packed in ventilated wooden boxes lined with newspaper and stored at ambient condition ($24 \pm 2^\circ\text{C}$ with relative humidity 70–75%). These boxes were opened 6, 8 and 10 days after storage to assess the ripening behaviour and post-harvest changes in physico-chemical traits of the fruits. Marketability of stored fruits are assessed as suggested by Ranganna (1977) by 10 judges on a scale : excellent, > 90–100%; good, > 75–90%; marketable, 65–75%; and unmarketable, 0–65%. A 4-point scale (scoring technique)

suggested by Ranganna (1977) was used to calculate the fruit-ripening index: 4, very attractive, bright purplish crimson and fully ripe fruit with excellent taste and aroma; 3, purplish crimson and ripe fruit with good aroma; 2, light purplish crimson and moderately ripe with light aroma; 1, greenish purple and unripe fruit without aroma.

Fruit with or without pedicel attained ripening after 6 days of storage. Non-pedicellate fruit had a ripening index of 3.80, whereas a ripening index of 4.00 was recorded in pedicellate fruit 6 days after storage. The reduction in marketability (%) and ripening index of non-pedicellate fruit was faster than of pedicellate fruit (Table 1). No loss due to fruit decay was recorded in any treatment up to 6 days of storage. However, decay was significantly higher (0.62 and 19.36%) in fruit without pedicel compared with that with pedicel (0.2–6.1%) 8 and 10 days after storage respectively (Table 1). During storage the rotting in plum was due to brown-rot caused by the fungus *Monilinia fructicola* (Wint.) Honey (La Rue and Gerdtz 1976). The physiological loss in weight was significantly higher in fruit without pedicel (3.24–5.33%) compared with pedicellate fruit (2.91–4.97%) during storage (Table 1). The firmness of the fruit flesh was more (1.95 and 0.43 kg/cm²) in the pedicellate fruit than in the non-pedicellate one (1.87 and 0.30 kg/cm²) 6 and 10 days after storage respectively (Table 1). The fruit pedicel did not significantly influence the chemical composition of fruit in terms of soluble solids, acidity and total sugars. However, higher soluble solids (11.52–12.22° brix) were recorded in non-pedicellate fruit than in pedicellate fruit (11.40–12.15° brix) during storage. The level of acidity was slightly higher (0.17–0.41%) and total sugars were lower (8.00–8.02%) in the fruit harvested with pedicel during storage.

Pedicellate fruit of 'Santa Rosa' plum had better ripening index, storage quality and fruit marketability. This observation supports the findings of Fuchs and Barki-Golan (1979), Singh *et al.* (1993) and Desai (1994). The physiological loss in weight and loss in decay were higher in the non-pedicellate fruit. The result confirms that of Pathak and Srivastava (1969) and Desai (1994). The possible reason for maximum loss in physiological weight in non-pedicellate fruit might be

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Table 1 Effect of cycocel on performance of 'Rose' cassava (mean data, with 95% confidence limits of 10 replicates)

Parameter	Cycocel (ppm)			F-value
	0	1 000	2 000	
Plant height (cm)	15.92 $\pm$ 4.90	13.38 $\pm$ 4.93	10.33 $\pm$ 2.12	3.19*
Diameter of cells (mm)	0.54 $\pm$ 0.01	0.048 $\pm$ 0.02	0.043 $\pm$ 0.01	0.069 ^{NS}
Root biomass (g)	2.55 $\pm$ 0.01	2.76 $\pm$ 0.11	5.69 $\pm$ 0.12	6.85**
Stem biomass (g)	9.61 $\pm$ 0.64	10.69 $\pm$ 0.24	18.72 $\pm$ 0.47	4.95**
Length of root (cm)	22.85 $\pm$ 12.78	28.68 $\pm$ 2.54	29.85 $\pm$ 7.35	1.43 ^{NS}
Diameter of stem (cm)	1.03 $\pm$ 0.02	1.30 $\pm$ 0.37	1.55 $\pm$ 0.43	5.96**
Disease index (DI)	75.17 $\pm$ 0.86	10.51 $\pm$ 0.24	5.53 $\pm$ 0.06	15.13***

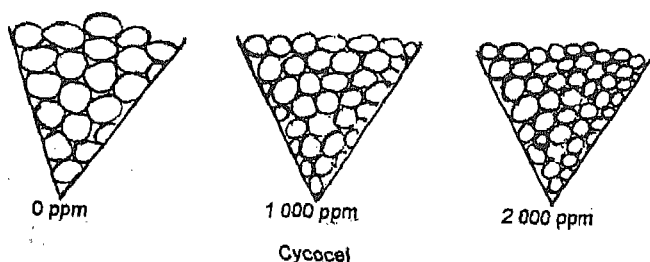
* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$ 

Fig 1 Cortical parenchyma cells of cassava roots at various concentrations of cycocel. Left, 0 ppm; middle, 1 000 ppm; right, 2 000 ppm

the use of resistant cultivars, which are not only inaccessible to the poor rural farmers but are losing their resistance value to plant pathogens.

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Growth and yield of indian mustard (*Brassica juncea*) as influenced by foliar application of potassium on saline black soils*

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Key words : indian mustard; saline black soils, foliar application, potassium, growth, yield, *Brassica juncea*

Soil salinity is an important environmental constraint in crop production. Salts in the root medium generally alter a wide array of metabolic processes, culminating in stunted plant growth. Salinity-induced nutritional imbalance often produces specific nutrient-deficiency symptoms (Mass and Hoffman 1977), and tolerance of plants might be improving by improving nutritional status. Foliar application of nutrients increases the plant growth and yield under normal conditions (Altman *et al.* 1983). Foliar application of major elements (single salts) such as nitrogen as urea (Barel and Black 1979), phosphorus as orthophosphate (Malakondaiah and Rajeswara Rao 1979) and potassium as K_2SO_4 (Garcia and Hanway 1976) or KCl (Doman and Geiger 1979) leads to better growth and yield.

The salt-affected soils are quite prevalent in Bhal region of Gujarat state. These soils covering parts of Ahmedabad, Bhavnagar, Bharuch and Kheda districts possess very low infiltration characteristics, high water-table and very highly saline ground water, that affect growth and productivity due to inherent salinity problems. Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson] is an important crop grown during winter season (*rabi*) in this region. Since potassium uptake is significantly lowered compared with sodium in these soils, an attempt was made to determine the effect of external application of potassium through foliar spray on its growth and yield attributes.

The experiment was conducted during 1993–94 and 1994–95 on saline black soils (Vertic Ustochrepts) on research farm of the institute at Khanpur village (21°45' and 22°53'N and 71°15'E). The climate is tropical and semi-arid. The soils are deep, moderately to poorly drained with saline ground water, and are Vertic Ustochrepts.

Seed of 'Pusa Bold' indian mustard was sown in plots of 2 m x 2 m. Randomized block design was followed. Foliar application of potassium (20 ppm and 40 ppm) as K_2SO_4 was given at 2 stages, ie vegetative (with 75% physiologically

mature leaves) and flower-initiation stage, twice, on alternate days. A distilled-water control was also maintained. The treatment combinations were: T_1 , the control; T_2 , 20 ppm K at vegetative stage; T_3 , 40 ppm K at vegetative stage; T_4 , 20 ppm K at flower-initiation stage; T_5 , 40 ppm K at flower-initiation stage; T_6 , 20 ppm K at vegetative stage followed by 20 ppm K at flower-initiation stage; T_7 , 40 ppm K at vegetative stage followed by 40 ppm K at flower-initiation stage; T_8 , 20 ppm K at vegetative stage followed by 40 ppm K at flower-initiation stage; and T_9 , 40 ppm K at vegetative stage followed by 20 ppm K at flower-initiation stage (50 000 ppm K/ha/spray at 20 ppm and 100 000 ppm K/ha spray at 40 ppm level).

The parameters recorded during the crop growth were: growth parameters like plant height, number of primary branches, specific leaf weight (mg/cm^2) and specific leaf area (cm^2/mg); seed yield/plant, biomass and harvest index, and physiological parameters like leaf sugars and epicuticular waxes. Leaf sugars were extracted and estimated according to Scott (1960) and leaf-epicuticular waxes were extracted and analysed according to Ebercon *et al.* (1977). The salinity status of the soil samples was measured using conductivity-meter.

The foliar application of K gave significantly high plant growth, particularly in the plants treated with 40 ppm K (T_5). In addition to growth, K application gave better canopy spread by increasing the number of primary branches, thereby enabling the plants with more foliage and better light interception. Specific leaf weight and specific leaf area also showed marginal increment in K-treated plants compared with the control (T_1).

Seed yield and productivity increased significantly in the plants treated with potassium compared with the control plants. K at 40 ppm given at flower-initiation stage (T_5), though had higher number of pods/plant showing lower productivity than at 20 ppm given at vegetative stage, followed by 40 ppm at flower-initiation stage (T_7). Productivity was more in the treatment T_8 , followed by T_5 , T_7 , T_6 and the least in the control (T_1), indicating that K given at flower-initiation stage favoured seed production through its role in

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Table 1 Effect of foliar application of potassium on growth and yield of indian mustard on saline black soils

Treatment	Height (cm)	Branches/plant	Seed yield (g/plant)	Productivity (tonnes/ha)	Biomass (tonnes/ha)	Harvest index
T ₁	83.4	5.2	2.4	0.284	1.127	0.252
T ₂	104.6	7.4	3.4	0.459	1.607	0.285
T ₃	105.3	6.4	3.6	0.811	2.393	0.339
T ₄	109.3	8.0	3.6	0.856	2.636	0.325
T ₅	114.9	10.4	3.0	0.931	2.507	0.371
T ₆	103.7	6.0	3.4	0.882	2.095	0.421
T ₇	105.6	7.0	7.1	0.907	2.505	0.362
T ₈	107.5	9.9	5.5	1.265	2.490	0.508
T ₉	100.4	9.6	3.9	0.793	2.167	0.366
CD ($P = 0.05$)	12.4	1.7		0.136	0.298	NS

Details of treatment are given in the text

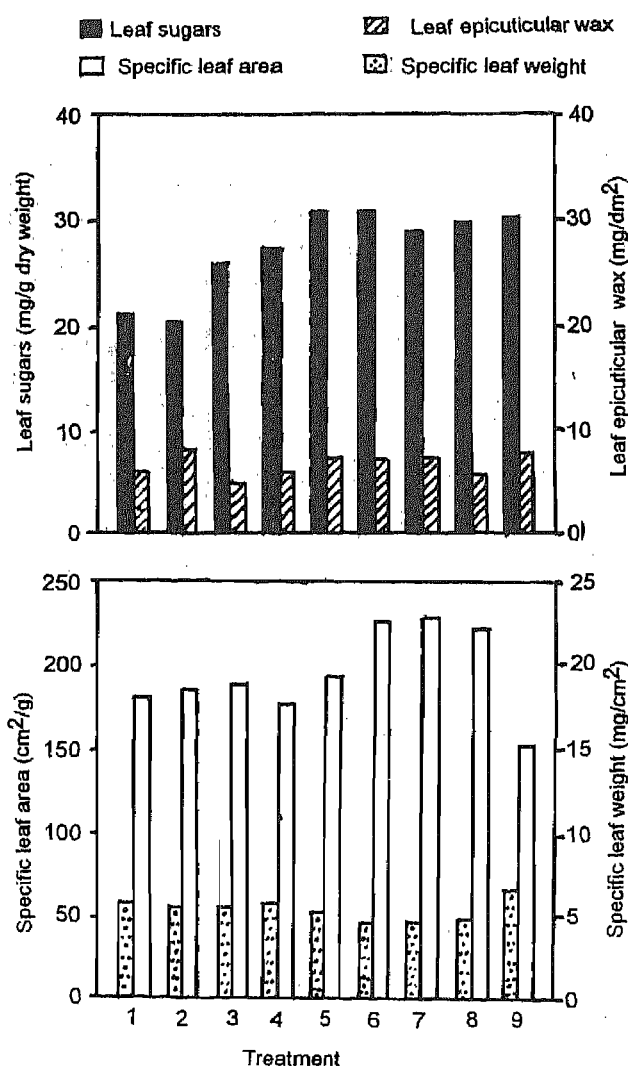


Fig 1 Effect of foliar application of potassium on leaf sugars, epicuticular wax, specific leaf weight and specific leaf area in indian mustard on saline black soils (details of treatments are given in text)

physiological processes like stomatal regulation, water relations and photosynthesis (Table 1). The biomass production and harvest index also increased in K-treated plants.

Foliar application increased the specific leaf weight, indicating higher net assimilation rate (NAR). This was reflected in leaf-sugar content (Fig 1). The increase in leaf sugars might have contributed to better growth of plants and seed yield. Thus potassium plays a pivotal role in reversing the salt-stress effect. Analysis of epicuticular wax in K-treated plants, which might play an important role in minimizing cuticular transpiration and thereby enabling the plants to maintain normal physiological activity.

The soil salinity (EC_e) of 8.1–9.0 dS/m during the crop-growth period in 0–30 cm layer reduced the plant growth and yield in the control plants. Garcia and Hanway (1976) indicated that foliar application of K in combination with other nutrients given at seed-filling stage increased the yield components. Foliar application restored the salinity-lowered growth, specific leaf area and specific leaf weight, since K stimulates shoot growth (Steineck and Haeder 1978). We also noticed similar result in the present study.

Higher K fertilization increased the plant's capacity to osmotic adjustment (Weimberg *et al.* 1982) and thus turgour-dependent processes like stomatal opening, photosynthesis and osmotic adjustment were maintained, resulting in higher biomass and seed yield. Higher leaf-epicuticular wax might play an important role in minimizing the cuticular transpiration, thereby enabling the plants to maintain better plant-water status. It conforms the observation of Gururaja Rao (1983). Thus foliar application of K by increasing sugar accumulation helped the plants in maintaining turgour, better growth and yield. The treatment of 20 ppm K given at vegetative stage followed by 40 ppm K at flower-initiation stage (T₈) was found more effective for higher seed yield.

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Effect of intercrop and row ratio on growth parameters, yield and economics of direct-sown upland rice (*Oryza sativa*)*

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Key words : upland rice, *Oryza sativa*, intercrop, row ratio, performance

An investigation was carried out during rainy season of 1992 and 1993 at Vamban to study the effect of intercrop and row ratio on growth and performance of upland direct-sown 'Adt 36' rice (*Oryza sativa* L.). The soil was acidic, red lateritic (pH 6.4), with available N, P and K contents 204, 9.56 and 226 kg/ha respectively. There were 13 treatments comprising 3 intercrops, viz blackgram (*Phaseolus mungo* L.), greengram (*Phaseolus radiatus* L.) and soybean [*Glycine max* (L.) Merr.], and 3 ratios (2 : 1, 3 : 1 and 4 : 1 in replacement series) with sole rice and sole intercropped pulses. These were : T₁, rice + blackgram (2 : 1); T₂, rice + blackgram (3 : 1); T₃, rice + blackgram (4 : 1); T₄, rice + greengram (2 : 1); T₅, rice + greengram (3 : 1); T₆, rice + greengram (4 : 1); T₇, rice + soybean (2 : 1); T₈, rice + soybean (3 : 1); T₉, rice + soybean (4 : 1); T₁₀, sole rice; T₁₁, sole blackgram; T₁₂, sole greengram; and T₁₃, sole soybean.

The experiment was conducted in randomized block design with 3 replications. Each plot received a uniform dose of 100, 50 and 50 kg/ha N, P₂O₅ and K₂O respectively. The entire dose of P and K was applied basal. Half the N was applied basal and the remaining half N was added in 3 equal splits at 15, 45 and 75 days after sowing only to the rice rows. The intercrops received only the basal application of fertilizers applied to rice.

The crops were sown on 30 June 1992 and 7 July 1993 with an inter-row spacing of 15 cm in solid line. Other recommended agronomic practices were followed in raising the crops. Observations on growth parameters like leaf-area index, crop-growth rate, net assimilation rate and relative growth rate were taken for rice crop only. Yield, land-equivalent ratio and economics were also calculated.

At all the growth stages, leaf-area index of rice was recorded highest under sole rice, whereas the lowest in 2 : 1 ratio of rice + greengram due to greater population. Among the intercrops, higher leaf-area index was recorded with blackgram as intercrop with rice than greengram and soybean.

Rice + blackgram (4 : 1) intercropping system recorded higher leaf-area index of rice than other intercropping systems and ratios. High leaf-area index indicates high mobilizable protein at the beginning of the reproductive stage, which helps the crop to put forth higher production.

Crop-growth rate showed an increasing trend with advancement in the age of rice plant. Increased values of crop-growth rate were obtained from 4 : 1 ratio under blackgram intercropping system than under greengram and soybean.

In general, net assimilation rate was decreased with advancement in age. Increase in the value of net assimilation rate was registered initially in sole rice at all growth stages. Its lowest values were obtained under 2 : 1 ratios. Among the intercrops, blackgram at 4 : 1 ratio recorded higher net assimilation rate, followed by soybean and greengram. Relative growth rate showed similar trend as that of crop growth rate in rice. Increase in leaf-area index, crop-growth rate, net assimilation rate and relative growth rate of rice were noted in blackgram intercropping system at 4 : 1 ratio.

The highest grain yield of rice (4 570 kg/ha) was obtained with sole rice, followed by rice + blackgram at 4 : 1 ratio (4 209 kg/ha), whereas the lowest under 2 : 1 of rice + greengram. These differences in grain yield could be attributed to significant difference in growth parameters observed during the growth cycle. Rao *et al.* (1982) reported similar result in intercropping of greengram and groundnut (*Arachis hypogaea* L.) in upland rice. Among the intercrops, soybean yielded more (1 114 kg/ha) at 2 : 1 ratio than other intercrops. The grain-equivalent yield and land-equivalent ratio were higher under rice + blackgram intercropping system at 4 : 1 ratio compared with sole rice. This might be due to extra grain yield obtained from rice, which made the treatment combination highly productive. It confirms the finding of Rao *et al.* (1983).

In conclusion, rice + blackgram (4 : 1) system gave the highest net return than the rest of the combinations. The increase in net return obtained in this system was 32% in comparison with that of sole rice. Sahu *et al.* (1988) reported similar result.

* Short note

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Table 1 Effect of intercropping and row ratios on growth parameters and yield of upland rice

Treatment	LAI		CGR		NAR		RGR		Yield (kg/ha)		Rice-grain equivalent yield (kg/ha)	LER	Net return (Rs/ha)
	50 days*	75 days*	25-50 days*	50-75 days*	25-50 days*	50-75 days*	25-50 days*	50-75 days*	Rice	Sole or inter-crop			
T ₁	2.96	4.11	2.51	6.81	0.45	0.36	0.37	0.48	2 869	682	4 687	1.20	6 174
T ₂	3.08	4.28	2.82	6.97	0.49	0.39	0.39	0.50	3 303	625	4 970	1.25	7 039
T ₃	3.23	4.43	3.18	7.36	0.51	0.41	0.41	0.54	4 209	500	5 542	1.34	9 042
T ₄	2.45	3.84	1.80	5.01	0.40	0.33	0.32	0.40	2 251	830	4 741	1.10	6 171
T ₅	2.71	3.92	1.92	5.35	0.41	0.34	0.36	0.41	2 428	703	4 537	1.04	5 456
T ₆	2.89	4.06	2.06	5.60	0.43	0.36	0.36	0.42	3 006	653	4 965	1.05	7 191
T ₇	2.54	3.95	2.13	6.59	0.42	0.35	0.37	0.43	2 346	1 114	4 573	1.08	6 144
T ₈	2.80	4.17	2.40	6.67	0.44	0.37	0.38	0.45	2 472	810	4 092	0.92	4 655
T ₉	3.06	4.22	2.50	6.78	0.48	0.39	0.39	0.48	3 276	610	4 496	1.04	6 148
T ₁₀	3.30	4.58	3.31	7.47	0.50	0.42	0.45	0.61	4 570		4 570	1.00	6 862
T ₁₁										1 199			4 032
T ₁₂										1 404			6 964
T ₁₃										2 015			6 364
CD	0.15	0.10	0.11	0.18	0.02	0.01	0.009	0.018	154.9		234.0		

(P = 0.05)

LAI, Leaf-area index; CGR, crop-growth rate; NAR, net area assimilation; RGR, relative growth rate; LER, land-equivalent ratio

*Days after sowing

Details of treatments are given in text

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Seasonal abundance of insect-pests and mite of groundnut (*Arachis hypogaea*) under irrigated condition*

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Key words : seasonal abundance, groundnut, correlation coefficient, standard week, insect pests, *Arachis hypogaea*

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop. A large number of insect pests have been found depredating the yield potential of this crop (Amin and Mohammad 1980). No concerted efforts have been made in the past in Haryana to establish the sequential appearance and population dynamics of various insect pests on groundnut crop as influenced by abiotic factors and crop phenology. Hence a study was taken up to identify the key pests and their population build-up on groundnut in relation to abiotic factors under irrigated condition.

'MH 4' groundnut (spanish bunch) was grown on an area of 80 m x 20 m during the second week of July 1993 and irrigated twice at 45 and 90 days after sowing. The whole area was divided into 3 subequal sectors. From each subsector, 10 plants were selected at random and marked for recording the population of various insect pests from a week after germination till the maturity of the crop. Absolute population of various insect pests and mite was recorded from 6 sets of compound leaves, representing the lower, middle and upper canopies of the plant. Meteorological data prevailing during the crop season were recorded. Simple correlation coefficients were established between abiotic factors and pest populations and interpretations were made.

One species of mite and 15 species of insects appeared on 'MH 4' under irrigated condition, out of which sesbania thrip (*Caliothrips indicus* Bagnallith), flower thrip [*Frankliniella schultzei* (Trybom)], chilli thrip [*Scirtothrips dorsalis* (Hood)], onion thrip (*Thrips tabaci* Lind.) and tobacco caterpillar [*Spodoptera litura* (Fab.)] appeared as major pests. Leaf webber [*Anarsia ephippias* (Mayrick)] was observed as a potential pest and bihar hairy caterpillar [*Spilosoma obliqua* (Wlk.)] was assessed as a sporadic pest. Green jassid (*Empoasca kerri* Pruthi), gram podborer [*Helicoverpa armigera* (Hub.)], cabbage semilooper [*Plusia orichalcea* (Fab.)], whitefly [*Bemisia tabaci* (Genn.)], groundnut aphid [*Aphis craccivora* (Koch.)], cotton ash

weevil (*Myloccerus maculosus* Dersh), earwig [*Anisolabis annulipes* (Luc.)] and surface grasshopper (*Chrotogonus* sp) appeared as minor pests. Our studies confirm that of Rai (1976), Vora *et al.* (1985) and Singh *et al.* (1990). Thrips remained active during standard weeks 31-40 (seedling to podding stage). Singh *et al.* (1990) observed 6 species of thrips attacking groundnut near Delhi. The average collective population of thrips was more during standard weeks 34-36 (flowering initiation to peg formation) (Table 1). This observation is in agreement with that of Amin and Mohammad (1980). The average temperature of 29.9°C along with 76% relative humidity were found suitable for development of thrips. Al-Faisal and Kardou (1986) pointed out that temperature more than 35°C and high relative humidity favoured thrip development on groundnut. Temperature (minimum) and relative humidity (evening) were positively and significantly correlated with thrip population. The abiotic factors contributed 62.91% on the fluctuation in thrip population on this crop (Table 2).

Population of tobacco caterpillar appeared during standard week 36 and remained active till standard week 43 (Table 1). Temperature (minimum and maximum) and relative humidity of 18.6°C, 33.8°C and 61% respectively were conducive for its development. None of the abiotic factors had significant correlation with its population. This finding confirms that of Bilapate *et al.* (1980), who observed its faster development at 30°C, which slowed down considerably at 20°C. The combined influence of abiotic factors was 30.8% on its population build-up. Singh *et al.* (1978) reported *S. litura* as a potential pest on groundnut under irrigated condition.

Bihar hairy caterpillar appeared late, i.e. in standard week 41, and remained active till standard week 46 (Table 1). Temperature (minimum) and relative humidity (evening) showed significant negative correlation with its population (Table 2). Leaf webber remained active during standard weeks 34-43, coinciding with the flowering to maturity stages of the crop. A maximum of 3.5 larvae/10 plants were recorded during standard week 39 (Table 1). Average temperature (maximum and minimum) 33.0° and 22.0°C respectively and

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Table 1 Weekly build-up of various insect pests and mite on 'MH 4' groundnut

Standard week	Average number of insect pests/10 plants									
	1	2	3	4	5	6	7	8	9	10
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
31	6.4	0	0	0	1.1	0	0	35.3	0	0
32	17.5	0	0	0	2.7	0	0	29.3	0	0
33	8.9	0	0	0	1.5	0.4	0	12.7	0	0
34	44.0	0	0	0.4	5.1	0.7	0.8	26.7	0	0
35	94.9	0	0	0.7	0.8	0.4	0.0	40.0	39.5	0
36	62.8	0.4	0	0.9	3.3	0.2	0.2	20.0	29.1	0
37	11.7	0.7	0	1.7	3.3	0.0	0.0	33.7	17.5	0
38	27.3	3.0	0	2.7	3.1	0.2	0.0	31.1	10.0	0
39	27.5	2.0	0	3.5	4.2	0.2	0.2	78.4	40.6	0
40	14.9	2.6	0	2.0	4.8	0.2	0.4	56.0	0	0
41	0	3.1	0.4	2.4	5.1	0	0	41.5	0	0
42	0	2.2	0.8	2.2	9.5	0	0	13.5	0	0.2
43	0	1.7	0.4	0.2	7.0	0	0	21.5	0	0.4
44	0	0	0.4	0	11.3	0	0	5.7	0	0.8
45	0	0	1.3	0	14.0	0	0	0	0	0.4
46	0	0	0.2	0	2.0	0	0	0	0	1.5

1, Thrips; 2, tobacco caterpillar; 3, hairy caterpillar; 4, leaf webber; 5, jassid; 6, gram podborer; 7, semilooper; 8, white fly; 9, groundnut aphid; 10, red spider mite

Crop stage (standard weeks): seedling (29–41); bunching (32–33), flowering and pegging (34–41); pod development (42–46)

Table 2 Simple correlation coefficients between the various insect pests and mite and the abiotic factors on 'MH 4' groundnut

Variable	Simple correlation(r) value									
	1	2	3	4	5	6	7	8	9	10
Temperature maximum (°C)	0.4633	0.0086	-0.3270	0.2081	-0.1935	0.5370*	0.3542	0.4804*	0.2792	-0.4561
Temperature minimum (°C)	0.5106*	-0.0603	-0.6067*	0.1897	-0.5476*	0.4993*	0.2729	0.4395	0.3569	-0.6853*
Relative humidity at morning (%)	0.3322	-0.0643	-0.4070	-0.0301	-0.4948*	0.0601	0.1204	0.1190	0.1980	-0.3039
Relative humidity at evening (%)	0.5087*	-0.2210	-0.7374*	0.0510	-0.7478*	0.3731	0.1858	0.3085	0.4277	-0.6451*
Rainfall (mm/week)	-0.0757	-0.0764	-0.1857	0.1198	-0.1273	0.0456	-0.1105	0.0780	-1.1240	0.0000
Sunshine (hr/day)	0.1974	0.2379	0.2992	0.1700	0.4000	0.1823	0.1358	0.1534	0.0839	0.2621
R ²	0.6291	0.3076	0.5654	0.1969	0.6451	0.5309	0.2439	0.3923	0.3968	0.6222

1, Thrips; 2, tobacco caterpillar; 3, hairy caterpillar; 4, leaf webber; 5, jassid; 6, gram podborer; 7, semilooper; 8, white fly; 9, groundnut aphid; 10, red spider mite

and relative humidity 70% favoured the pest multiplication; however, none of the abiotic factors had significant impact on the pest population.

Green jassid appeared in the standard week 31 and remained active throughout the crop season. Its population increased to 14.0 individuals/10 plants during standard week 45 (Table 1). Temperature (maximum and minimum) 31.4 and 11.2°C respectively along with relative humidity 52% favoured its development. The abiotic factors contributed 64.5% to the population build up of this pest (Table 2).

The population of gram podborer, cabbage semilooper and spider mite [*Tetranychus telarius* (L.)] were observed in quite low numbers during standard weeks 33–40, 34–40 and 42–46 respectively (Table 1). No significant correlation was observed between the population of *P. orichalcea* and abiotic factors. However, temperature (minimum and maximum)

showed significant positive correlation with *H. armigera* population. The average temperature (minimum) and relative humidity (evening) were inversely and significantly correlated with *T. telarius* population. The abiotic parameters had 53.1, 24.4 and 62.2% influence on the population build up of *H. armigera*, *P. orichalcea* and *T. telarius* respectively (Table 2).

Whitefly remained active during standard weeks 31–44. The highest population of 78.4 adults/10 plants was observed during standard week 39 (Table 1). The average temperature (minimum and maximum) 33.9 and 20.0°C respectively and relative humidity 70% favoured its multiplication. Dhuri *et al.* (1984) and Singh and Butter (1985) observed its maximum development on cotton (*Gossypium* spp) at 27.2°C and 71.2% relative humidity. Temperature (maximum) had significant positive correlation with its population (Table 2).

which confirms the finding of Singh and Butter (1985).

Groundnut aphid remained active during standard weeks 35–39 but in low numbers and none of the abiotic factors showed any significant impact on its population.

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Book Reviews

Indian Journal of Agricultural Sciences 67 (6) : 285, June 1997

Efficient Use of Fertilizers (with Special Reference to Salt, Acid and Drylands). 1996. Somani L L. Agrotech Publishing Co., 1-G-24, Sector 5 (Gayatri Nagar), Hiran Magri, Udaipur (Rajasthan) 313 001. xii + 288 pp. 22.5 cm x 14.5 cm. Rs 500. ISBN 81-85680-19-1.

The book under review explores ways and means of making efficient use of fertilizers in salt-affected, acid and dryland soils, in the Indian context. It begins with a long preamble (11 pages), followed by chapters on drylands, salt-affected soils and acid soils.

The book seems to have been written in a hurry and gives the impression that the 3 main chapters were mostly taken or adopted from the author's recent books on each of these areas. While considerable volume of research information has been included, individual pieces of data have neither been discussed in relation to the specific agro-ecological conditions under which these were obtained nor have they been synthesized or utilized to elucidate the factors affecting fertilizer efficiency under a given set of conditions. Hundreds of pieces of research data are lying around in print at random with no clear direction. It seems as if the first draft was sent to the press. Had the available information been properly organized, processed and presented, a much better book would have resulted.

In a book on efficient use of fertilizers, a table listing commonly available fertilizers and their major characteristics should have come in the beginning. Two tables listing fertilizers do appear (pp 173, 175) but in a different context, however, they do not reflect the present product pattern or nutrient composition because these have been taken from very old publications not relevant to Indian conditions.

The chapter on dryland agriculture touches most of the points of interest but again not in relation to specific dryland environment. The reader's query about what should be done to improve fertilizer efficiency under a given set of conditions remains unanswered and merely stating what was observed at Arjia, Varanasi or Kovilpatti does not help. There is very little discussion on interactions between different inputs, alternative strategies or comparison of different practices in economic terms. There is no mention of numerous on-farm fertilizer trials conducted by the agronomy project of the Indian Council of Agricultural Research under dryland conditions.

The chapter on salt-affected soils is much longer than either the proportion of area under such soils or the quantum of fertilizer that is used there. Fertilizer use can be efficient

only on the soils which have been reclaimed, fully or partially. The unreclaimed soils must first be amended and then fertilized. The author has unnecessarily pitted a saline soil against a sodic soil to show contradiction in research findings (pp 187, 188). While reporting that crops in alkaline soils invariably respond to higher doses of N (p 184), the reader should have been told that this is due to lower N-use efficiency in sodic than in non-sodic soils.

The chapter on acid soils, in a book written in the Indian context, is a disaster. Out of 98 references, only 2 or 3 are from India. What can one get from a chapter in which no mention is made of the writing of Goswami or Mandal or Panda? A chapter on acid soils without mention of Bihar, West Bengal, Orissa, Karnataka or Kerala is spineless. There is no mention of the valuable on-farm data on fertilizer responses generated by the ICAR's agronomy project or the long-term experiments at Bangalore, Palampur and Ranchi.

On the production side, one is time and again faced with lack of standardization, a casual approach and hardly a page without printing mistakes. A very large number of tables and diagrammes do not mention the sources, several column headings do not have units and acronyms are not explained. Spelling mistakes are too many to be listed. Division of information into various sections is also not logical. For example, in the chapter on acid soils, the section on N starts with forms of fertilizers, that of P with methods of application and that of K with weathering of K. Terms rice and paddy are used interchangeably. (They are not the same.) At some places the ions are charged, at other places they are neutral. The list of acronyms is missing and the subject index is sketchy (only 2 entries under dryland soils).

Finally, the book presents a case study for serious authors about the hazards of rushing to the press with a casually assembled rough draft. Most librarians in India will buy at least 1 copy of anything with a catchy title. The production level is mediocre and at Rs 500 a copy is overpriced 200% for what it provides. The need for a good book as efficient use of fertilizers still remains.

H L S TANDON

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Indian Journal of Agricultural Sciences 67 (6) : 286, June 1997

Citrus in South Asia. 1995. Ghosh S P and Singh R B. First Indian edn, Oxford & IBH Publishing Co. Pvt. Ltd, 66 Janpath, New Delhi 110 001; in arrangement with Regional Office, Food and Agriculture Organization, Bangkok. iii + 70 pp. 21.5 cm x 28 cm. Rs 250. ISBN 81-204-1001-7.

Six South Asian countries (India, Pakistan, Bangladesh, Bhutan, Nepal and Sri Lanka) contribute one-third the total citrus fruits produced in Asia-Pacific region. The main focus is on sweet group (mandarin and sweet orange), followed by sour group (acid lime and lemon), though pummelo (in Bangladesh) and all other citrus fruits are grown. The citrus cultivation can be grouped under 3 categories, based on the current status of production, constraints, management, research and trade in South Asia: (i) Bhutan and Nepal, having traditional but expanding citrus industry; (ii) India and Pakistan, having traditional as well as commercial industry, with prospect of good growth on research back-up; (iii) Sri Lanka and Bangladesh, where it is not in good shape, due to severe malady of citrus decline and the lack of development and research support. India and Pakistan share 95% of the total citrus-fruit production in this region.

Based on the data provided by the constituent countries, the book presents good information on Area, production and productivity; Species, varieties and cultural practices; Marketing and trade situation and prospects; and Constraints to production and planned research and development. Prospects of improved citrus production are highlighted,

suggesting the need of greater co-ordination among these countries. A list of selected references is also included as the last chapter.

Mandarin orange has specific agro-climatic requirement and cannot be grown every where. Bhutan, having favourable agro-climate, produces excellent-quality mandarin. Its production and transportation deserves special attention. Pakistan with monoculture of kinnow should diversify to other varieties as well. The citrus production in India increased 3 times during 1961–88. But as per an FAO estimate its growth rate in India and Pakistan is likely to lag behind the world average. The demand for fresh fruit in the world market is expected to be 79 million tonnes by 2000 AD compared with 5–7 million tonnes in 1987. The citrus industry therefore needs to be energized to meet this target.

Absence of photographs of each species is a serious lacuna of the book. The information however would prove highly useful to all the students, scientists and farmers engaged in citrus cultivation.

R S GUPTA
(Editor)

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THE INDIAN JOURNAL OF AGRICULTURAL SCIENCES
(Proforma for Readers' response)

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THE INDIAN JOURNAL OF AGRICULTURAL SCIENCES

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4.1 INTRODUCTION part should be brief and limited to the statement of the problem or the aim and scope of the experiment. The review of recent literature should be pertinent to the problem. Key words of the article should be given in the beginning.

4.2 Relevant details should be given of the MATERIALS AND METHODS including experimental design and the techniques used. Where the methods are well known, citation of the standard work is sufficient. Mean results with the relevant standard errors should be presented rather than detailed data. The statistical methods used should be clearly indicated.

4.3 RESULTS AND DISCUSSION should be combined, to avoid repetition.

4.4 The results should be supported by brief but adequate tables or graphic or pictorial materials wherever necessary. Self-explanatory tables should be typed on separate sheets, with appropriate titles.

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