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Evaluation of oleiferous brassicas, staggered sowing and fertility level for improvement in potato (*Solanum tubersosum*)-based intercropping systems

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ABSTRACT

In a field experiment conducted during the winter (*rabi*) seasons of 1995–97 at New Delhi, Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson], *karan rai* (*Brassica carinata* A. Braun) and *gobhi sarson* [*Brassica napus* L. ssp *oleifera* DC. var *annua*] were evaluated as intercrop with potato (*Solanum tuberosum* L.) in 3 : 1 replacement series (3 rows of potato + 1 row of *Brassica* spp) under staggered sowing (sowing of *Brassica* spp at the time of potato planting and 20 days after potato planting) and fertility levels (N_0, N_{75}, N_{150}, N_{75}+S_{30} and N_{150}+S_{30}). Intercropped potato received variable quantum of solar radiation at 70 and 90 days after planting of potato owing to differences in intercrop-canopy formation, maximum being in association with *karan rai* (90.3–98.7%). Sole stand of each crop gave significantly higher yield than their respective intercropped stand but the tuber (22.8 tonnes/ha, 81.4%) and seed yields (1.62 tonnes/ha, 60.3%) recovery in intercropped stand in relation to sole stand was the highest in potato + *B. carinata* system. This system also showed its significant superiority to other systems for tuber equivalent (35.90 tonnes/ha), protein (0.75 tonne/ha) and oil (0.65 tonne/ha) yields, land-equivalent ratio (1.42), energy output (122 500 MJ), energy-use efficiency (4.23), net return (Rs 15 800/ha) and net return/rupee investment (0.78). Staggered sowing improved the productivity of potato, but this increase was not enough to compensate for disadvantage to brassicas under delayed sowing. Values of competition function revealed dominance of *Brassica* spp over potato. Tuber yield (15.5–26.9 tonnes/ha), tuber equivalent (20.8–35.8 tonnes/ha), protein (0.36–0.78 tonne/ha) and oil yields (0.31–0.48 tonne/ha) and energy (52 500–97 400 MJ/ha) and economic parameters recorded perceptible increase with successive increase in N level up to 150 kg N/ha. Application of N+S caused marked increase in the productivity and net return/rupee investment over the N alone.

Key words: Intercropping. Potato, *Brassica* spp, Staggered sowing, Nitrogen, Sulphur, Productivity, Energetics, Economics, Competition function

Potato (*Solanum tuberosum* L.) is an important crop of north–west part of India. Its cultivation involves heavy expenditure as well as time high degree of risk and thus depriving off the growers from regular stable returns. Intercropping of Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson], linseed (*Linum usitatissimum* L.), wheat (*Triticum aestivum* L. emend. Fiori & Paol.) and frenchbean (*Phaseolus vulgaris* L.) with potato stabilizes the farmer's income from potato cultivation and increases production per unit area (Ahlawat 1998, Rana and Ganga Saran 1998). Of these recommendations, potato + Indian mustard intercropping system has found favour among the farmers. In addition to Indian mustard, *gobhi sarson* (*Brassica napus* L. ssp. *oleifera* DC. var *annua*) and *karan rai* (*Brassica carinata* A. Braun) also have found place with farmers. These 2 new introductions have not been tested in intercropping with potato. These species exhibit different growth rhythm than Indian mustard and stand a chance for increasing the spatial and temporal complementarity of potato-based intercropping system, which can be manipulated further by opting for staggered sowing of component crops. Nitrogen is the most limiting nutrient for potato and brassicas; and sulphur for the oilseed crops. Keeping these aspects in view, the present investigation was undertaken to evaluate the *Brassica* spp in association with potato under staggered sowing and fertility levels for increasing the production potential of potato-based intercropping systems.

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MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) seasons of 1995–96 and 1996–97 at New Delhi. The soil was sandy loam, with *p*H 7.2. It had low available

Table 1 Canopy development and solar radiation transmittance (%) as influenced by *Brassica* spp and staggered sowing (data pooled over 2 years)

Treatment	Plant height of brassicas (cm)		Horizontal spread of brassicas (cm)		Days taken by *Brassica* spp after sowing for		Solar radiation (%) recorded at the top of potato canopy	
	70 DAP	90 DAP	70 DAP	90 DAP	50% flowering	Maturity	70 DAP	90 DAP
Cropping system								
Potato							100	100
Potato + *B. juncea*	89.5	123.6	40.9	49.4	64	136	80.4	85.4
Potato + *B. carinata*	34.7	77.3	35.7	59.3	108	168	98.7	90.3
Potato + *B. napus*	44.6	97.3	35.8	54.4	80	148	97.2	89.9
CD (*P*=0.05)	3.1	7.8	1.5	24.2			4.7	5.1
Staggered sowing								
Sowing of brassicas at the time of potato planting (D_1)	78.3	121.3	40.8	67.2	86.6	153	91.5	85.7
Sowing of brassicas at the time of potato planting (D_2)	34.2	77.3	34.4	41.9	80.0	148	98.0	90.9
CD (*P*=0.05)	2.5	6.5	1.2	1.9			2.3	3.1

DAP, Days after planting of potato

nitrogen (270 kg N/ha) and medium available phosphorus (14.5 kg P/ha), potassium (211.6 kg K/ha) and sulphur (13.3 ppm). The experiment was laid in split-plot design with 3 replications. The main-plot treatments comprised 7 cropping systems, whereas 5 fertility levels were allocated to subplots. Of the 7 cropping systems, sole crop of potato was sown in rows interspaced at 60 cm, whereas the remaining 6 cropping systems were created by replacing every fourth row of potato with 1 row of either 'Pusa Jaikishan' Indian mustard or 'ISN 706' *gobhi sarson* or *Brassica carinata* (Ethiopian mustard or *karan rai* cv. 'DLSC 1') and doing staggered sowing of the brasicas, ie sowing at the time of potato planting (D_1) and 20 days after potato planting (D_2). Five fertility levels were created by adopting 0, 75 and 150 kg N/ha and combining 30 kg S/ha with 75 and 150 kg N/ha. The main plot size was 15 m × 6 m and subplot size was 3 m × 6 m. The planting of sole potato and simultaneous sowing of potato and *Brassica* spp was done on 4 November in 1995 and 22 October in 1996. Staggered sowing of *Brassica* spp as intercrop was done 20 days after planting of potato. Both potato and *Brassica* spp were planted on ridges. In sole potato 60 cm × 20 cm spacing was adopted and same population of potato was maintained in intercropped stand by intra-hill adjustment. In *Brassica* spp, a uniform intra-row spacing of 10 cm was maintained by thinning at app;ropriate stage. Half dose of nitrogen and full dose of sulphur as per treatments and 35.2 kg P and 83 kg K/ha were applied plot-wise before the preparaation of ridges. Remaining nitrogen was top-dressed at the time of earthing up. First irrigation was given just after planting the potato to ensure good germination and later on cropping systems received irrigations as per need of potato crop. The potato crop was harvested on 15 March and 1 March in 1995 and 1996 respectively, whereas *Brassica* spp took different time for 50% flowering and harvesting as per detail in Table 1.

The total rainfall received during the crop season of 1995–96 and 1996–97 was 25.9 and 61.4 mm respectively. The mean evaporation was 3.04 and 3.05 mm/day in the respective season. The January was the coldest month in both seasons with temperature of 6.5°C in 1995-96 and 4.2°C in 1996–97. Mean maximum temperature ranged between 30.0 and 37.3°C during the crop maturity and harvesting time.

The observation on canopy development and interception of radiation by the canopy were recorded at 70 and 90 days after planting of potato. The tuber and seed yields recorded per plot were converted to yield/ha and used to work out other parameters by using standard procedure. The N content in the tuber and seed was used to work out protein content and finally protein yield, whereas oil content in seed was used to compute oil yield. The tuber-equivalent yield was calculated using of prices available to farmers at the time of crop harvesting, ie Rs 1 000/tonne for potato and Rs 8 000/tonne for seed of *Brassica* spp. Energetics was worked out by using energy-equivalent as per Mittal and

Table 2 Effect of cropping systems, staggered sowing and fertility levels on tuber, seed, tuber-equivalent, protein and oil yields of component crops (data pooled over 2 years)

Treatment	Yield (kg/ha)			Protein (kg/ha)			Oil in seed (kg/ha)
	Tuber	Seed	Tuber-equivalent	Tuber	Seed	Total	
Cropping system							
Sole potato	28 000		28 000	540		540	
Potato + *B. juncea*	22 300	931	29 880	385	199	584	354
Potato + *B. carinata*	22 800	1 620	35 990	405	354	759	651
Potato + *B. napus*	21 970	933	29 550	391	210	601	367
CD (*P*=0.05)	725	70	1 050	28	34	40	40
Staggered sowing							
Sowing of brassicas at the time of potato planting (D_1)	21 760	1 314	32 410	378	383	661	519
Sowing of brassicas 20 days after potato planting (D_2)	22 960	1 010	31 210	409	222	631	395
CD (*P*=0.05)	592	58	850	23	27	36	32
Fertility level (kg/ha)							
N_0	15 510	766	20 810	231	130	361	307
N_{75}	22 540	1 128	30 440	284	245	529	391
N_{150}	26 990	1 269	35 860	498	286	784	484
$N_{75}+S_{30}$	23 430	1 238	32 000	405	273	678	496
$N_{150}+S_{30}$	27 710	1 406	37 520	516	329	845	559
CD (*P*=0.05)	910	144	790	35	38	56	48

N, Nitrogen; S, sulphur

Dhawan (1988), and land-equivalent ratio, aggressivity, relative crowding coefficient and competitive ratio were computed as per the formula of Willey (1979), McGilchrist (1965), Hall (1974) and Willey and Rao (1980) respectively. The data were pooled over 2 years.

RESULTS AND DISCUSSION

Growth rhythm of brassicas

Plant height and horizontal spread of *Brassica* spp recorded at 70 and 90 days after planting potato indicated that *Brassica juncea* recorded the highest values at 70-day stage with significant difference from *B. carinata* and *B. napus* (Table 1). Plant height of all the species and horizontal spread of *B. carinata* and *B. napus* showed marked improvement thereafter, as a result ofwhich, the species maintained their ranking similar to that of 70-days stage for plant height, but in case of horizontal spread *B. carinata* and *B. napus* surpassed *B. juncea*. Plant height and horizontal spread of simultaneous sowing was found significantly higher than staggered sowing at both the stages. The *B.carinata* showed prolonged rosette stage and attained 50% flowering at 108 days after sowing. The *B. juncea* and *B. napus* flowered 44 and 28 days early than *B. carinata*, but after 90-day stage, which coincides with the rising temperature and day-length, *B. carinata* grew faster. This differential growth rhythm of species ensured differential growth condition to potato crop. This differential plant growth behaviour of *Brassica* spp in terms of plant height, horizontal spread and days to 50% flowering and maturity may be ascribed to their genomic constitution and thermo-photoperiodic adaptivity. In contrast to flowering, *karan rai* took only 32 and 20 days more to attain maturity than Indian mustard and *gobhi sarson*.

Light transmittance

The intercropped potato received less amount of solar radiation on the top of its canopy than the sole stand at 70 and 90 days after planting (Table 1). Among the intercropping systems, potato intercropped with *B. carinata* received maximum radiation at both the growth stages. This was because of variation in plant height and horizontal spread of *brassica* spp (98.70% at 70 daysafter planting and

Table 3 Energetics and economics of potato+*Brassica* spp intercropping system as influenced by staggered sowing and fertility levels (data pooled over 2 years)

Treatment	Energetics					Returns		
	Energy output (MJ × 10^3)			Net energy return (MJ×10^3)	Energy-use efficiency	Gross (Rs×10^3)	Net (Rs×10^3)	Net return/ rupee investment (Re)
	Potato	Intercrop	Total					
Cropping system								
Sole	100.7		100.7	72.3	3.53	28.0	8.4	0.43
Potato + *B. juncea*	80.3	23.3	103.6	74.8	3.56	29.9	9.7	0.48
Potato + *B. carinata*	82.2	40.3	122.5	94.1	4.23	35.9	15.8	0.78
Potato + *B. napus*	79.4	23.2	102.6	73.9	3.54	29.6	9.4	0.46
CD (P=0.05)	5.2	3.8	4.5	4.2				
Staggered sowing								
Sowing of brassicas at the time of potato planting (D_1)	74.4	32.8	107.2	82.4	3.83	32.4	12.2	0.60
Sowing of brassicas 20 days after potato planting (D_2)	82.8	25.3	108.1	79.4	3.72	31.2	11.0	0.55
CD (P=0.05)	4.0	3.4	NS	2.4				
Fertility level (kg/ha)								
N_0	55.9	19.2	75.1	52.5	3.32	20.9	1.5	0.08
N_{75}	81.1	28.3	109.4	82.3	4.04	30.4	10.5	0.53
N_{150}	97.4	31.6	129.0	97.4	4.08	35.8	15.4	0.75
$N_{75}+S_{30}$	84.3	30.8	115.1	85.8	3.92	32.0	11.8	0.59
$N_{150}+S_{30}$	99.8	35.2	135.0	101.2	3.98	37.5	16.8	0.82
CD (P=0.05)	8.1	4.6	6.4	4.5				

MJ, Mega Joule; N, nitrogen; S, sulphur

90.3% at 90 days after planting). In contrast to this, *B. juncea* permitted less (89.4% at 70 days after planting and 85.4% at 90 days after planting) radiation to fall on the top of potato canopy. Staggered sowing of brassicas also ensured more radiation to the intercropped potato due to variation in plant height and horizontal spread.

Productivity

The tuber and protein yields of potato were markedly influenced due to *Brassica* spp variation as intercrop. The yields were the highest in sole stand owing to less competition for space, light, moisture and nutrients. Among the intercropping systems, potato grown in association with *B. carinata* recorded higher values of these parameters, which might be attributed to the variation in the growth rhythm of intercrop. The *B. juncea* and *B. napus* caused early shading of potato crop, resulting in reduction of tuber yield and thereby protein yield. Among the intercrops, seed, protein and oil yields of *B. carinata* was significantly higher because of its profused branching habit and the maximum siliquae/plant. All the intercropping systems led to significantly higher total productivity in terms of tuber-equivalent and protein yields than the sole potato, mainly owing to higher yield recovery than expected from component crops as well as higher economic value of the produce of intercrop. Among the intercropping treatments, potato + *B. carinata* recorded significantly the highest value of tuber-equivalent and protein yields. This may be attributed to higher yield recovery than expected which was 81.4% for tuber yield from 75% area and 60.3% for seed yield from 25% area in this system (Table 2).

The staggered sowing of component crops improved the tuber and protein yields of potato over their simultaneous sowing owing to shift in competition for the resources. But this increase in tuber and protein yields was not enough to compensate for the reduction in seed yield of brassicas under delayed sowing. Thus, total productivity in tuber-equivalent, protein and oil yields recorded appreciable decrease under

Table 4 Competition function of potato+*Brassica* spp intercropping systems as influenced by staggered sowing and fertility level (data pooled over 2 years)

Treatment	LER	Aggressivity (A)		Competitive ratio (CR)		Relative crowding coefficient	
		Potato	Brassicas	Potato	Brassicas	Potato	Brassicas
Cropping system							
Potato	1.00						
Potato+*B. juncea*	1.22	0.63	+0.63	0.61	1.68	1.39	2.28
Potato+*B. carinata*	1.42	1.29	+1.29	0.43	2.30	1.64	4.76
Potato+*B. napus*	1.29	1.01	+1.01	0.49	2.03	1.36	3.32
CD (P=0.05)	0.034						
Staggered sowing							
Sowing of brassicas at the time of potato planting (D_1)	1.32	−1.14	+1.14	0.46	2.16	1.20	3.95
Sowing of brassicas 20 days after potato planting (D_2)	1.29	−0.82	+0.82	0.39	1.84	1.72	2.95
CD (P=0.05)	0.028						
Fertility level (kg/ha)							
N_0	1.27	−1.05	+1.05	0.50	1.97	1.61	3.51
N_{75}	1.25	−0.94	+0.94	0.52	1.90	1.55	3.08
N_{150}	1.26	−0.96	+0.96	0.53	1.89	1.64	3.14
$N_{75}+S_{30}$	1.26	−0.99	+0.99	0.52	1.92	1.50	3.24
$N_{150}+S_{30}$	1.28	−1.05	+1.05	0.51	1.94	1.64	3.47
CD (P=0.05)	NS						

N, Nitrogen; S, sulphur; LER, land-equivalent ratio

staggered sowing compared with simultaneous sowing.

With enhanced rate of N application, tuber yield, tuber-equivalent yield, protein yield of component crops and oil yield of *Brassica* spp increased significantly. Contrary to this, seed yield of *Brassica* spp recorded significant increase only up to 75 kg N/ha. This may be attributed to better nourishment of the component crops at higher levels of nitrogen. Addition of 30 kg S/ha along with N caused perceptible improvement in tuber-equivalent yield, seed and oil yields of *Brassica* spp and protein yield of component crops. This could be ascribed to the role of S as constituent of protein, coenzyme A, glutathion, vitamins and oils, synthesis of protein and oil, energy transfer similar to P and activation of enzyme.

Energy budget

Cropping systems and staggered sowing caused significant variations in all the energy parameters (Table 3). Sole potato and *B. carinata* gave significantly higher energy output than the intercropped potato and other *Brassica* spp. Among the cropping systems, potato + *B. carinata* recorded significantly higher values of gross energy output, net energy return and energy-use efficiency being 21.6, 30.1 and 19.8 % higher than the sole potato. Staggered sowing caused perceptible increase in the energy output of potato than simultaneous sowing of component crops and reverse was true with *Brassica* spp. On the contrary, net energy return and energy-use efficiency showed marked decrease under staggered sowing compared with the simultaneous sowing. Gross energy output, net energy return and energy-use efficiency recorded significant change with successive increase in N levels.

Combined application of N+S induced upward increase in energy output and net energy return but reverse was true with respect to energy-use efficiency. The trend and changes in these energy parameters with respect to treatments can be traced to their effect on yield of component crops. Similar changes in the energy parameter owing to system and fertility levels were also reported by Rana and Ganga Saran (1998) and Verma *et al.* (1997).

Table 5 Interaction effect between cropping system and staggered sowing on seed yield, tuber yield, tuber-equivalent yield and land-equivalent ratio (data pooled over 2 years)

Cropping system	Staggered sowing			
	D_1	D_2	D_1	D_2
	Seed yield (kg/ha)		*Tuber yield (kg/ha)*	
Potato + *B. juncea*	1 160	712	21 680	22 930
Potato + *B. carinata*	1 808	1 437	22 140	23 460
Potato + *B. napus*	971	885	21 450	22 480
CD (P=0.05)	104		510	
	Tuber-equivalent yield (kg/ha)		*Land-equivalent ratio*	
Potato + *B. juncea*	31 040	28 710	1.25	1.18
Potato + *B. carinata*	36 830	35 150	1.43	1.40
Potato + *B. napus*	29 350	29 750	1.28	1.30
CD (P=0.05)	1 485		0.047	

D_1, Sowing of brassicas at the time of potato planting; D_2, sowing of brassicas 20 days after planting of potato

Economics

Based on pooled data, potato + *B. carinata* was found most remunerative (Table 3). In comparison to sole potato, this system recorded 28.2, 88.8 and 81.3% higher gross returns, net returns and returns/rupee investment respectively. On an average, simultaneous sowing showed its superiority to staggered sowing. Nitrogen fertilization induced marked increase in these economic parameters. Application of 75 and 150 kg N/ha recorded 60% and 47% higher net returns over their successive N level. Application of N+S caused appreciable improvement in the economic parameters than alone treatment of N. With 75 kg N+30 kg S/ha and 150 kg N+30 kg S/ha, net returns increased by Rs 1 300 and 1 400 over respective alone treatment of N. The increase in economic parameters in relation to treatments is by virtue of yield advantage accrued to the component crops.

Competition function

The species variation as intercrop and their staggered sowing caused perceptible effect on the competitive ability of the both the crops (Table 4). Among the cropping systems, system involving *B. carinata* did well than *B. juncea* and *B. napus* in terms of land-equivalent ratio, aggressivity, competitive ratio and relative crowding coefficient. This could be explained on the basis of higher yield potential of *B. carinata* and wide differences in growth rhythm, canopy development and growth period, which ensured higher yield recovery than the expected in this system. Relative crowding coefficient values indicated that brassicas are dominant component, while potato is a dominant component of the sysrtem. The value of competitive ratios showed that *Brassica* spp performed better in intercrop stand and reverse was true for potato. The highest numerical value of competition ratio of potato + *B. carinata* indicated the superiority of this system in term of less competition between the components for the resources. This system also recorded the highest values of aggressivity and product of relative crowding coefficient owing to the greatest gap between the actual and expected yields, resulting in comparative advantage over other systems. The relative crowding coefficient of each component crop was greater than 1, which indicated that each crop gave more yield than the expected. The competition functions indicated that potato got benefited in terms of competition under staggered sowing of the component crops than their simultaneous sowing.

Competition function showed inconsistent behaviour in relation to fertility levels. The values of the competition functions revealed benefit to potato in terms of competitiveness with increasing level of N and reverse was true with *Brassica* spp. Addition of S along with N caused appreciable improvement in the competition values of *Brassica* spp, which was the result of rise in gap between actual and expected yields due to S application.

Interaction effect

A significant interaction of seed yield, tuber yield, tuber-equivalent yield and land-equivalent ratio were recorded with relative sowing time of intercrop (Table 5). Irrespective of sowing time, *B. carinata* recorded the highest seed yield. With the delay in sowing, seed yield declined but the magnitude of reduction was maximum in *B. juncea*, followed by *B. carinata* and *B. napus*. This might be ascribed to different degree of stability among the species across the sowing time. The margin in tuber yield and tuber-equivalent yield, due to staggered sowing, was significant in the systems with *B. juncea* and *B. carinata*, whereas with *B. napus* the gap was insignificant. Potato + *B. carinata* recorded statistically similar land-equivalent ratio with simultaneous (1.43) and staggered sowing (1.40), but the values so recorded were significantly superior to values of land-equivalent ratio recorded with *B. juncea* and *B. napus*. These interactive effect of cropping systems and relative time of sowing of intercrop could be explained on the basis of variation in growth rhythm, sensitivity to sowing time and variation in yield potential of *Brassica* spp.

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