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Effect of Indian mustard to various organic and inorganic sources of nutrient on yield, available soil p balance and p recycling through residues

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Abstract
A study was conducted at agronomy farm Mewar University Gangrar, Chittorgarh, Rajasthan, which are four treatment combinations of 75 and 100% recommended dose of fertilizers (RDF) and their combinations with 5 t farm yard manure ha^{-1} (FYM) were evaluated on medium clay loam soils of chittorgarh during winters of 216 in a Randomized Block Design replicated thrice. Results illustrate that among nutrient treatments, 100% RDF + 5 t FYM registered significantly higher seed and stover yield (3231 and 13604 kg ha^{-1}, respectively), crop phosphorus uptake (52.71 kg ha^{-1}), available soil P at crop harvest (23.35 kg ha^{-1}), gain in available soil P (3.21 kg ha^{-1}) and dry biomass of residues (4649.1 kg ha^{-1}) and P recycled (11.56 kg ha^{-1}).

Keywords: Available soil P, Indian mustard, soil phosphorus balance.

Introduction
India annually imports edible oil worth about >9 million US $ mainly due to poor oilseed productivity that arise out from severe imbalances in NPK use (current NPK removal 34 Mt as against addition of 18 Mt & current N: P: K consumption ratio 8.9: 2.8: 1.0 as against 4:2:1), climatic adversities (unfavourable temperatures, aberrant rains etc.) and physiological and genetic constraints associated with oilseeds (Hegde *et al*., 2012, Babu *et al*., 2014) [26, 3]. Further, Indian agricultural soils have a negative annual P balance (11 kg P_2O_5 ha^{-1}), severely disturbed N: P_2O_5: K_2O: S ratio (14.7:5.1:1.1:1.0), depleting state of soil organic matter and increasing instances of micro-nutrient deficiencies and yield stagnations which needs to be corrected for sustained oilseed productivity (Tandon, 2007, TSI, 2014) [3]. Indian mustard, the 2nd largest oilseed crop in India, Mustard is the main oilseed crop for the Rabi season which is planted on more than 80% area covered under oilseeds. Rajasthan, Uttar Pradesh, Madhya Pradesh, Haryana and Gujarat are the highest sown states of mustard seed accounting The Economics times MAR 27, 2017. Main mustard production constraints but inadequate and imbalanced P fertilization and variable chemical precipitations of applied P are main hurdles in the way of sustained and higher productivity. Use of residues and manures and approach of feeding crop rather than soil, can improve crop P recoveries (Dawson and Hilton, 2011 Edward *et al*., 2015) [12, 15] but Indian agriculture primarily relies on chemical P fertilizers that provide 78% input when P removal by major crops is about 1.3 Mt (Pathak *et al*. 2010) [32]. Residues devoid of any appreciable alleleopathic effect on some other or dominant crops in the region or rotation are suitable for recycling (Babu *et al*., 2014) [3]. Fortunately, alleleopathic effect of mustard residues is rare (Kalinova, 2010) [30]. Organic matter sorb applied P and increases its availability to plants due to competition between decomposition products of organic matter and P for soil sorption sites that increases labile P concentrations (Guppy *et al*., 2005) [18]. Residual P is better than fertilizer P provided a satisfactory critical soil P level (level 2) is maintained. Once this level is achieved, fertilizing each crop becomes not necessary and fertilizers can be applied at any point of rotation, broadcasted after crop is drilled rather than incorporated and 3 years crop P requirement can be supplemented in one application (Defra, 2010) [13]. As such, a serious thought and work on residue or organic matter agronomy is needed for making sustainable the Indian agriculture. Soils release 5-9 kg P_2O_5 ha^{-1} $year^{-1}$ without any use of fertilizer (Edwards *et al*., 2015) [15], therefore, mobilizing large non available P through use of organic manures and bio-fertilizers by devising suitable integrated nutrient management (INM) modules can be a right answer to P related problems in India since P is the most reactive in soil system and it is very difficult to optimise its flows and

fluxes within and off the farm (Dawson and Hilton, 2011) [12]. In this study, P flows and fluxes within a field were grossly be estimated by simple mathematical calculations utilizing data on nutrient additions, crop nutrient removals, soil nutrient status before sowing and at crop harvest and estimation of unaccounted nutrient losses by preparation of nutrient balance sheets.

Materials and methods

A field study was conducted at Gangrar ($24^0$05'N latitude and 75.60'E longitude) in Rajasthan state of India in agro-climatic zone IV a (Sub-Humid Southern Plains) at an elevation of 394 m above mean sea level during winters of 2016. The experimental soil was well drained clay loam (sand: 38.20%, silt: 25.70% and clay: 36.10%) having an alkali pH 8.2, bulk density 138 Mg/m^3, soil organic carbon 0.66%, field capacity 28.6%, permanent wilting point 12.4% and available N, P_2O_5 and S to a tune of 283.2, 20.13 and 33.26 kg ha^{-1}, respectively. four nutrient treatments (N_1: 75% RDF, N_2: 100% RDF or 60:35:40 kg N:P_2O_5:S ha^{-1}, respectively, N_3: N_1 + 5 t FYM ha^{-1} and N_4: N_2 + 5 t FYM ha^{-1} were evaluated in a split plot design replicated thrice. Gross sub plot (5.0 x 3.6 m) were reduced to 4.0 x 2.4 m for estimation of yield and deriving soil samples at crop harvested on turning uniform pale in colour after removal of border rows. Certified seed of Indian mustard (Cv. Laxmi) was drilled in rows at 30 cm on 24.10.2016 in a field under continuous maize crop for previous five rainy seasons. A plant to plant spacing of 10 cm was manually maintained within the each row while carrying out the hoeing and weeding at 20 days crop stage. Full quantity of well rotten FYM, phosphorus and gypsum and half quantity of N were carefully applied as basal dressing in each main and sub plot after weighing on a highly precise digital electronic balance (accuracy: 0.01 g) through a close band placement in the side of seed furrow strictly following the treatment specifications. Remaining half N was topdressed in two equal splits at 38 and 78 days crop stages *i.e.* about three days after 1st and 2nd irrigation (each about 6 cm depth), respectively. P content in oven dried FYM, mustard seed and stover and composite samples of crop and weed roots, litterfall and above ground weed biomass was estimated by ammonium vanadomolybdate yellow colour method (Richards, 1968). Oven dried FYM contained 0.23% P. Soil samples randomly collected by augur from furrow slice (0-15 cm) zone at three random points in each sub plot were thoroughly mixed and finally 100 g soil was carefully derived following repeated half accept and half reject method. Available soil phosphorus before sowing and at crop harvest was determined by Olsen method (Olsen *et al.*, 1954) [31]. Nutrient balance sheets were prepared on the basis of initial nutrient status, nutrients added, soil nutrient status at crop harvest, total crop nutrient uptake and calculation of unaccounted nutrient losses. Data were statistically analysed during each year of study and on pooled basis deploying standard procedure for analysis of variance (ANOVA) of split plot design (Gomez and Gomez, 1984) [17].

Results and discussion

Available P balance

Pooled crop P uptake (C values) registered a significant variation among PGRs (BR + IAA >BR >IAA > water spray). Integration of either 75 or 100% RDF with FYM + bio-fertilizers, FYM and bio-fertilizers also registered significant variations in pooled C values but differences between N_2 and N_6 were at par (Table 1). Pooled C values ranging from 34.46 (N_1) to 52.71 kg ha^{-1} (N_8) and 38.43 (water spray) to 47.12 kg ha^{-1} (BR + IAA) variably exceeded the corresponding B values depicting an additional P mining over and above the applied P to an extent of 5.30 (N_4) to 17.34 kg ha^{-1} (N_8) and 7.68 (water spray) to 16.37 kg ha^{-1} (BR + IAA). Analysis of pooled C values as a fraction of pooled A + B values shows that crop P recovery ranged from 73.93% (N_1) to 89.81% (N_8) and 75.69 (water spray) to 92.52% (BR + IAA) which is exceptionally high against usual crop P recovery (35-50%). This pin points on a cafeteria of possible routes potent to strengthen the available P pool *viz.* P mineralization from recycled residues at harvest of previous maize crop, P release from non-labile pool, P benefits from PSB, crop P mining from beneath the furrow slice etc. or there can be a higher recovery of applied P due to band placement of P fertilizer close to seed furrow along with gypsum. Higher crop P recovery due to presence of S traces (10-12%) in single super phosphate has also been reported by Khaswa *et al*. 2014 [29] in soybean in Udaipur region. Also, a large quantity of weed residues is recycled at maize harvest in Udaipur region (Chalka and Nepalia, 2005) [8]. In this study, simultaneous band placement of both P and S fertilizer can largely reduce the contact surface between reactive mineral and fertilizer P and can increase $H_2PO_4^-$ adsorption on exchange sites and prevent chemical precipitation of $H_2PO_4^-$ ions/applied P as Ca-P complexes. Total soil P is usually low (10-25% of N and 5% of K) and can range between 200 to 2000 kg ha^{-1} in furrow slice (average: about 1000 kg ha^{-1}) (Jones and Eva, 2011) [28]. This is notable that a fairly high quantity of P was contained in total residues (Table 3) recycled at harvest of even a winter season smothering crop like mustard normally beset with a sparse weed infestation and weed biomass per unit area than a highly weedy rainy season maize crop. This indicates a huge residue and large P recycling potent to benefit mustard crop after growing maize. Organic compounds in soil increase P availability to plants due to formation of organophosphate complexes, replacement of $H_2PO_4^-$ ions on adsorption sites by other anions and more mineralized organic P relative to inorganic P (Gyneswar *et al*., 2002) [19]. Available P is normally a resultant of physico-chemical (sorption-desorption) and biological (mineralization-immobilization) processes and a large fraction of fertilizer P can enter into non available pool via chemical reaction with highly reactive Al^+ and Fe^{3+} in acidic soils while with Ca^{2+} in calcareous and normal soils (Hao *et al.*, 2002) [21]. Concentration of bio-available soil P is very low (1 mg kg^{-1} soil) but PSB can potentially enhance P availability to crop plants through mineralization of organic P and dissolution of precipitated P through release of organic acids and assimilation of labile P in microbial biomass which prevents P from being adsorbed/fixed (Richardson, 2001, Chen *et al.*, 2006) [10].

In fact, P adsorption is more in soils having less P adsorbed on mineral micelle in want of full saturation of exchange sites. Clay loam soils of Udaipur have medium state of available P which at the most exhibit an intermediate P adsorption but this too can enable a fairly high recovery of fertilizer P under continuous sorption-desorption process. Organic P can move to a more depth through soil solution in comparison to inorganic P that is why continued manures use leads to soil P build up even up to 60-120 cm depth while use of same quantity of P through fertilizers shows less downward movement of $H_2PO_4^-$ ions, however these ions can be well intercepted by deep rooted mustard plants. Further, microbial organic P mineralization in presence of phosphatase enzyme can constitute about 50% part of available P (range: 15-80%). Available P increases with enhancing soil organic P level but inorganic P immobilized is inversely related to organic P and increases when C: P ratio exceeds 200. Thus, FYM/recycled residues can appreciably influence available P levels in this study. Organic anions (citrate, oxalate, tartrate and malate) can be adsorbed on exchange complex and replace adsorbed $H_2PO_4^-$ in labile pool, thus adsorbed P is reduced and available P is enhanced. However availability of organic anions depends on soil organic matter (SOM) level while Udaipur soils have medium SOM category. It is established that >0.3% P content in residues favours net P mineralization and immobilization dominates if residues contain <0.2% P (Havlin *et al*., 2007) [25]. It is already mentioned in materials and method part that FYM and other residues recycled at mustard harvest contained P in the range of 0.22-0.48% which forms a strong basis for high P mineralization from previous crop/weed residues. Mineralization of organic P can be further supported by bright sunny days and moderate winter temperature during mustard crop period in Udaipur region while high temperature encourages adsorption of $H_2PO_4^-$ ions on mineral micelle. Though P immobilization from applied fertilizer vary widely (25-100%) but as a rule continued P fertilization which is a practice in NW India can increases soil organic P content. There is favourable effect of PGRs on root growth (Bao *et al*., 2004) [5] which appears to be one of the prime reasons behind significant variations in pooled C values among different PGRs. Pooled C values significantly increased with increase in RDF from 75% to 100% which was 39.81 and 45.31 kg ha^{-1} (average of set of four treatments in each RDF level), respectively. Significantly higher pooled C values in N_8 can also be ascribed to a synergistic interaction between FYM and bio-fertilizers (Chand and Ram, 2008) [9]. These dispositions well support the high P recovery by Indian mustard under different nutrient and PGR treatments in this study.

Lower pooled E values than corresponding pooled A values indicate over mining of available P in furrow slice, however, higher pooled E values over corresponding expected pooled D values indicate variable P build up in furrow slice under different nutrient and PGR treatments against the depletion that was theoretically expected. Pooled F values ranged from 5.73 (N_1) to 18.74 kg ha^{-1} (N_7) and 8.09 (water spray) to 16.83 kg ha^{-1} (BR + IAA). Analysis of pooled F values also indicate significantly lower crop P mining in nutrient treatments involving 75% (N_1, N_3, N_5, N_7) than their corresponding counter parts having 100% RDF (N_2, N_4, N_6, N_8) together with lesser depletion in available P levels in latter set of treatments. This can be ascribed to significant variations in pooled seed and stover yield between nutrient treatments having 75 and 100% RDF (Table 4). All nutrient and PGR treatments involving 100% RDF recorded a positive pooled G value (range: 0.81 in N_2 to 3.21 kg ha^{-1} in N_8 and 0.41 in water spray to 0.76 kg ha^{-1} in IAA) but variations among PGRs was not significant. Data on pooled actual gain/loss in available P (G values) reveal that 3 out of 4 nutrient treatments involving 75% RDF (N_1, N_3, N_5) recorded negative values while N_7 registered a positive value. Build-up in pooled available P as revealed by positive G values under N_7 and nutrient treatments involving 100% RDF indicate relative sufficiency of available P under these treatments and other dispositions enumerated earlier.

Table 1: Available P balance sheet (kg ha^{-1}) under different nutrient and PGR treatments in Indian mustard

Treatments	Initial available soil P A			Phosphorus added B	Total crop P uptake C			Expected available soil P D= (A+B-C)			Actual available soil P at crop harvest E		Pooled apparent gain/ loss F=E-D		Pooled actual gain/ loss G=E-A
	2015	2016	Pooled		2015	2016	Pooled	2015	2016	Pooled	2015	2016	Pooled		
Nutrient management options															
N_1	19.69	20.53	20.11	26.50	34.24	34.68	34.46	11.95	12.35	12.15	17.83	17.92	17.88	5.73	-2.23
N_2	19.72	20.54	20.13	35.00	41.10	41.49	41.30	13.62	14.05	13.83	20.81	21.08	20.94	7.11	0.81
N_3	19.69	20.54	20.11	30.25	38.97	39.95	39.46	10.97	10.84	10.90	20.01	20.11	20.06	9.16	-0.05
N_4	19.70	20.57	20.13	38.75	43.97	44.13	44.05	14.48	15.19	14.83	21.10	21.95	21.53	6.70	1.40
N_5	19.68	20.58	20.13	26.50	37.56	37.91	37.74	8.62	9.17	8.89	18.91	19.03	18.97	10.08	-1.16
N_6	19.77	20.56	20.17	35.00	43.14	43.24	43.19	11.63	12.32	11.98	21.40	21.52	21.46	9.48	1.29
N_7	19.69	20.54	20.12	30.25	47.31	47.86	47.59	2.63	2.93	2.78	21.37	21.67	21.52	18.74	1.40
N_8	19.72	20.56	20.14	38.75	52.78	52.64	52.71	5.69	6.67	6.18	22.88	23.82	23.35	17.17	3.21
SEm±	0.45	0.58	0.37		1.18	1.12	0.81	1.15	1.10	0.80	0.47	0.56	0.37	1.09	0.41
CD (P=0.05)	NS	NS	NS		3.58	3.39	2.35	3.50	3.35	2.31	1.42	1.71	1.06	3.15	1.20
PGRs															
G_0	19.55	20.50	20.02	30.75	37.99	38.87	38.43	12.31	12.38	12.34	20.37	20.49	20.43	8.09	0.41
G_1	19.77	20.57	20.17	30.75	43.79	43.97	43.88	6.73	7.35	7.04	20.70	21.10	20.90	13.86	0.73
G_2	19.71	20.56	20.13	30.75	40.67	40.97	40.82	9.79	10.34	10.06	20.72	21.05	20.89	10.83	0.76
G_3	19.80	20.57	20.18	30.75	47.08	47.15	47.12	3.47	4.17	3.81	20.38	20.91	20.64	16.83	0.46
SEm±	0.27	0.27	0.18		0.48	0.46	0.46	0.41	0.44	0.30	0.21	0.22	0.15	0.39	0.21
CD (P=0.05)	NS	NS	NS		1.36	1.31	1.31	1.17	1.24	0.84	NS	NS	NS	1.11	NS

Recycling of residues and P

Among nutrient and PGR treatments, N_8 and BR + IAA recorded significantly higher pooled residues and P contained in root biomass, litter fall and total residues (Table 2 and 3) which can be ascribed to significantly higher growth which is otherwise indirectly endorsed by significantly higher seed and stover yield (Table 4). More senescence of plant organs under more growth that leads to more mutual shading are established facts. N_1 recorded significantly higher pooled residues and P recycled through weed biomass but variations were at par among N_1, N_5 and N_7. This can be ascribed to significantly lower growth under these treatments as also indirectly indicated by seed and stover yield (Table 4) and lower smothering effect of crop plants on weed growth. Different PGRs registered significant variations in pooled quantities of dry residues and P recycled through root biomass, litter fall and weed biomass (Table 2). Variations in pooled dry root biomass and P recycled followed an order BR + IAA> BR> IAA> water spray while variations in pooled litter fall and P recycled registered a reverse trend (water spray> IAA> BR> BR + IAA) on account of variations in growth, smothering effect on weeds and delay in senescence of plant organs under PGRs.

Yield performance

Significantly higher pooled seed and stover yield under N_8 over other nutrient treatments (Table 4) can be ascribed to not only significantly higher pooled crop P uptake but also to more availability and uptake of other nutrients on account of P benefits from FYM, bio-fertilizers, synergistic interaction between FYM and bio-fertilizers etc. (Aulakh, 2010) [2]. Variations in pooled yield levels was identical to pooled crop P uptake but a response exceeding 100% RDF (60:35:40 kg N: P: S ha^{-1}) was noticed which is also well reported in other/. new mustard cultivars/agro-climatic zones in India. Role of P in significantly improving growth and yield of crops up to an optimum fertilizer level is well established but P is also involved in energy transformations, bio-chemical reactions apart from being a constituent of genetic material (Havlin *et al*., 2007) [25].

Table 2: Dry biomass of litter fall, weeds, roots and total residues (kg ha^{-1}) recycled under different nutrient and PGR treatments at mustard harvest

Treatments	Litter fall			Weed biomass			Dry roots			Total residues		
	2015	2016	Pooled	2015	2016	Pooled	2015	2016	Pooled	2015	2016	Pooled
Nutrient management options												
N_1	926.1	920.2	923.1	142.7	142.9	142.8	2387.0	2413.0	2400.0	3455.8	3476.1	3465.9
N_2	969.3	969.5	969.4	127.4	126.9	127.2	2686.1	2709.2	2697.7	3782.8	3805.6	3794.2
N_3	1083.1	1077.9	1080.5	132.9	133.0	132.9	2624.8	2665.0	2644.9	3840.9	3875.9	3858.4
N_4	1120.6	1113.6	1117.1	121.7	121.7	121.7	2900.8	2926.6	2913.7	4143.1	4161.9	4152.5
N_5	1121.8	1119.5	1120.7	138.6	138.4	138.5	2569.0	2591.4	2580.2	3829.3	3849.3	3839.3
N_6	1178.1	1174.0	1176.0	126.5	126.4	126.4	2843.3	2862.7	2853.0	4147.9	4163.1	4155.5
N_7	1384.7	1411.5	1398.1	124.7	124.8	124.7	2778.3	2800.9	2789.6	4287.6	4337.2	4312.4
N_8	1426.2	1467.9	1447.0	115.0	114.4	114.7	3006.1	3108.5	3057.3	4547.3	4690.9	4619.1
SEm±	12.6	19.9	11.8	5.3	5.1	3.7	65.9	73.1	49.2	67.2	85.7	54.4
CD (P=0.05)	38.3	60.2	34.1	16.2	15.4	10.7	200.0	221.9	142.6	203.7	260.0	157.7
PGRs												
G_0	1343.5	1347.0	1345.2	137.4	137.6	137.5	2423.0	2467.2	2445.1	3903.8	3951.8	3927.8
G_1	1073.4	1072.3	1072.8	126.9	126.7	126.8	2741.4	2771.5	2756.5	3941.7	3970.6	3956.1
G_2	1265.9	1258.6	1262.2	129.1	128.7	128.9	2622.5	2650.9	2636.7	4017.5	4038.2	4027.9
G_3	922.1	949.2	935.7	121.3	121.2	121.3	3110.9	3149.0	3129.9	4154.3	4219.5	4186.9
SEm±	8.4	10.4	6.7	3.7	2.8	2.3	35.6	37.5	25.9	37.3	40.9	27.7
CD (P=0.05)	24.0	29.6	18.8	10.4	7.9	6.4	101.2	106.7	72.6	106.2	116.3	77.8

Table 3: P contained in dry roots, litter fall, weed biomass and various residues (kg ha^{-1}) under different nutrient and PGR treatments at mustard harvest

Treatments	Roots			Litter fall			Weeds			Total residues		
	2015	2016	Pooled	2015	2016	Pooled	2015	2016	Pooled	2015	2016	Pooled
Nutrient management options												
N_1	5.73	5.67	5.70	2.41	2.39	2.40	0.68	0.66	0.67	8.82	8.72	8.77
N_2	6.45	6.37	6.41	2.52	2.52	2.52	0.61	0.58	0.60	9.58	9.47	9.52
N_3	6.30	6.26	6.28	2.82	2.80	2.81	0.64	0.61	0.62	9.75	9.68	9.72
N_4	6.96	6.88	6.92	2.91	2.90	2.90	0.58	0.56	0.57	10.46	10.33	10.40
N_5	6.17	6.09	6.13	2.92	2.91	2.91	0.67	0.64	0.65	9.75	9.64	9.69
N_6	6.82	6.73	6.78	3.06	3.05	3.06	0.61	0.58	0.59	10.49	10.36	10.43
N_7	6.67	6.58	6.62	3.60	3.67	3.64	0.60	0.57	0.59	10.87	10.83	10.85
N_8	7.21	7.30	7.26	3.71	3.82	3.76	0.55	0.53	0.54	11.47	11.65	11.56
SEm±	0.16	0.17	0.12	0.03	0.05	0.03	0.03	0.02	0.02	0.17	0.21	0.14
CD (P=0.05)	0.48	0.52	0.34	0.10	0.16	0.09	0.08	0.06	0.05	0.52	0.64	0.39
PGRs												
G_0	5.82	5.80	5.81	3.49	3.50	3.50	0.66	0.63	0.65	9.97	9.93	9.95
G_1	6.58	6.51	6.55	2.79	2.79	2.79	0.61	0.58	0.60	9.98	9.88	9.93
G_2	6.29	6.23	6.26	3.29	3.27	3.28	0.62	0.59	0.61	10.21	10.09	10.15
G_3	7.47	7.40	7.43	2.40	2.47	2.43	0.58	0.56	0.57	10.45	10.43	10.44
SEm±	0.09	0.09	0.06	0.02	0.03	0.02	0.02	0.01	0.01	0.09	0.10	0.07
CD (P=0.05)	0.24	0.25	0.17	0.06	0.08	0.05	0.05	0.04	0.03	0.27	0.28	0.19

Table 4: Seed and stover yield (kg ha^{-1}) of Indian mustard under different nutrient and PGR treatments

Treatments	Seed yield			Stover yield		
	2015	2016	Pooled	2015	2016	Pooled
Nutrient management options						
N_1	2236	2270	2253	9650	9801	9726
N_2	2601	2640	2621	11054	11198	11126
N_3	2500	2541	2521	10764	10909	10836
N_4	2762	2787	2774	11668	11750	11709
N_5	2384	2438	2411	10406	10486	10446
N_6	2707	2733	2720	11492	11540	11516
N_7	2930	2977	2953	12505	12690	12598
N_8	3228	3235	3231	13606	13602	13604
SEm±	065	063	045	287	274	198
CD (P=0.05)	198	190	131	869	831	574
PGRs						
G_0	2452	2503	2478	10509	10705	10607
G_1	2733	2763	2748	11647	11750	11698
G_2	2582	2607	2595	11091	11102	11097
G_3	2907	2937	2922	12326	12432	12379
SEm±	026	028	019	122	129	089
CD (P=0.05)	075	081	054	346	366	249

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