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Effect of crop establishment practices on the performance of component cultivars under pigeonpea (*Cajanus cajan*) – wheat (*Triticum aestivum*) cropping system in IGP

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ABSTRACT

Pigeonpea–wheat rotation is emerging as a potential alternative to existing rice–wheat system of Indo–Gangetic plains because of many inherent constraints right from requirements of higher inputs to deterioration in soil health in the latter. Realizing the importance of pigeonpea–wheat cropping system, the present study was conducted to evaluate diverse crop establishment practices [ridge pigeonpea followed by flatbed wheat (RP–FBW); raised–bed pigeonpea followed by raised–bed wheat (RBP–RBW)] in combination with three cultivars of pigeonpea (UPAS 120, ICP 67B, and Pusa 992), and two wheat cultivars (Shatabdi, Unnat Halna). Two–year study revealed that raised–bed practice of crop establishment resulted in 11.7% higher grain yield of pigeonpea as compared to ridge planting. Although the advantage of raised–bed was not apparent in wheat as 13.9% higher grain yield was recorded under flatbed over raised–bed establishment method. Based on pigeonpea equivalent yield and production economics, RP–FBW was found superior over RBP–RBW. However, the performance of component crops suggested that raised–bed for pigeonpea and flatbed for wheat could be the strategic crop establishment under pigeonpea–wheat rotation. Plant nutrient utilization as expressed by nutrient harvest index, physiological efficiency and utilization efficiency differed substantially within the cultivars of pigeonpea and wheat crop; and the preceding pigeonpea cultivars significantly influenced the nutrient acquisition in the successive wheat crop. Among the different cultivars, UPAS 120 pigeonpea followed by Unnat Halna wheat had far better response measured through the highest pigeonpea equivalent yield (2.71 t/ha), net return (₹ 69,331), and benefit: cost ratio (2.02). Thus, the study suggested that strategic cultivar selection and appropriate crop establishment method could be the key to maximize output from the pigeonpea–wheat system in IGP.

Key words: Economics, Nutrient harvest index, Pigeonpea–Wheat, Raised–bed, Ridge–furrow, System productivity

Pigeonpea (*Cajanus cajan* L.)–wheat (*Tritium aestivum* L.) is an important cereal–legume rotation of Indo–Gangetic plain (IGP). The cropping system is evolving over the years as a potential alternative to exhaustive rice–wheat cropping system in IGP region (Singh and Ahlawat 2007, Sepat *et al.* 2015) because of many inherent constraints right from requirements of higher inputs to deterioration in soil health. As a consequence, the inclusion of a soil building crop (pulses) in combination with a staple food crop (cereal) is becoming a necessity on many counts including sustainability and profitability (Hazra *et al.* 2014). Indeed, the declining natural resources and development of secondary salinization in the rice–wheat dominated North Western IGP paved the way to replace the rice crop with short duration pigeonpea crop since it is established as an efficient and sustainable cropping system for northern plains of India (Singh and Ahlawat 2006).

Pigeonpea with its intrinsic characters of a legume (such as biological N fixation, profuse leaf fall, deep roots, rotational effect, low external input requirement) is becoming dominant during rainy season which could be followed by staple cereal, i.e, wheat so that the cropping system (pigeonpea–wheat) as a whole becomes stable and remunerative. Notwithstanding all these, the major constraint of the base crop (pigeonpea) is its dismally low plant stand in field and low crop productivity. Further, pigeonpea being an upland crop usually suffers from water–logging in lowland condition. The high yielding short duration pigeonpea cultivars (around 120 days) is again essential to best fit the component crops in the pigeonpea–wheat rotation. Consequently, absence of suitable short–duration genotypes of pigeonpea and loss of wheat yield (sensitivity to high

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temperature at terminal stages leading to substantial yield reduction) due to its delayed sowing after the preceding pigeonpea crop pose further complexity and vulnerability to adoption of this cropping system. Besides this, the early pigeonpea cultivars suitable for the cropping system are usually susceptible to *Phytophthora* blight, where field drainage is not proper. Therefore, agronomic assessment pertaining to this apparently prevalent cropping system needs scrutiny.

For improving the productivity of pigeonpea–wheat rotation in IGP, strategic interventions involving improved agronomic practices are needed. Appropriate land configuration through tillage while draining excessive water from the soil is important for ensuring optimum plant stand of pigeonpea. Ridge sowing under ridge–furrow system or raised–bed sowing offers alternative crop establishment practice for pigeonpea crop in lowland areas, where crop establishment pose further challenge. Thus, growing of pigeonpea in elevated places (ridges and raised beds) could result in more effective utilization of stored water, improved drainage, reduced crop–weed interaction and lodging, and scaling nutrient use efficiency (Hobbs and Gupta 2003, Fahong *et al.* 2004). Supplementing these, selection of appropriate cultivars is the key considering crop/system productivity and profitability. Similarly, wheat cultivar appropriate for late sown condition could be the right choice in place of regular wheat varieties.

In view of these considerations, the present study was planned to investigate system based crop establishment practices and cultivar combinations of pigeonpea and wheat on productivity, nutrient utilization, and economics and to identify suitable establishment practice and cultivars of pigeonpea and wheat.

MATERIALS AND METHODS

Field experiment was carried out during 2013–2015 at new research campus of ICAR–Indian Institute of Pulses Research, Kanpur, India. The monthly mean annual maximum and minimum temperature of the experimental site were 33 and 20°C, respectively. The average annual rainfall of the region is 722 mm, and ~75% of it is received during July to September through South–West monsoon.

Two crop establishment practices were evaluated in the main plots *i.e.* pigeonpea on ridge followed by wheat on flatbed (RP–FBW), and pigeonpea on raised–bed followed by wheat on raised–bed (RBP–RBW). For pigeonpea, ridges were made 50 cm apart with the help of tractor drawn ridge maker. Whereas, the raised–beds were constructed with the help of multi–crop bed planter maintaining 1.0 m spacing from centre to centre of adjacent furrows. During rainy season (pigeonpea growing season), each main plot was divided into three subplots for inclusion of three pigeonpea cultivars (UPAS 120, ICP 67B and Pusa 992) following the principles of randomization. During winter, after the harvest of pigeonpea, the main plots with ridge were tilled properly and converted to flatbed to accommodate two wheat varieties (Shatabdi and Unnat Halna) which were again randomized in sub–sub plots. Thus, two crop establishment practices [pigeonpea on ridge followed by wheat on flatbed (RP–FBW) and pigeonpea on raised–bed followed by wheat on raised–bed (RBP–RBW)] in combination with three cultivars of pigeonpea (UPAS 120, ICP 67B, and Pusa 992) in rainy season, and two of wheat (Shatabdi, Unnat Halna) in winter season so as to assess and refine their influence on system productivity, plant nutrient acquisition, and farm profitability. The crop of wheat was sown in second week of December following pigeonpea harvest. Shatabdi matured in 120-125 days and Unnat Halna in 105-110 days during both the years of experimentation. Pigeonpea was fertilized with a uniform basal dose of NPKSZn (25:26:33:20:5 kg/ha). The wheat crop was applied with 120:26:33:20 kg/ha NPKS; where full dose of PKS and half–dose of N was applied as basal and remaining 25% N was applied at first irrigation (20–25 days after sowing) and the rest 25% N at boot stage.

Five representative pigeonpea plants were randomly sampled from each plot at physiological maturity to record plant height, above ground dry biomass, root length and weight, yield attributes like pods/plant, grains/pod and 1000–seed weight. Selected plants were uprooted carefully without damaging the roots (~1.0 m deep). In wheat crop, one meter row length of plants were sampled from two locations in each plot to measure total tillers, effective tillers, whereas plant height, spike length, spike weight and grains/spike were recorded from the selected 10 plants. A net plot area of 30 m^2 and 15 m^2 were harvested for estimation of grain yield and straw/stover yields of pigeonpea and wheat. Total biomass was recorded after proper sun drying of harvested plants and threshing was done manually in pigeonpea and thresher was used in wheat. Grain and straw yield was calculated in terms of t/ha after stabilizing moisture content in grains at 14%. The stover yield was obtained after subtracting grain yield from total biomass yield.

The grain and straw samples of pigeonpea and wheat were oven dried till constant weight and fine grinded for chemical analysis. The N, P and K content in the grain and straw were analyzed, following modified micro–kjeldahl method, vanadomolybdo–phosphoric acid yellow colour method, and flame emission photometry method, respectively (Jackson 1973). Nutrient uptake was estimated by multiplying the concentration of a particular nutrient (%) in grain or straw/stover with the respective yield (kg/ha), and the nutrient uptake by grain and straw/stover was summed up to obtain total nutrient uptake (kg/ha). Nutrient harvest index (NHI) was computed using the formula given below:

$$\text{NHI} = \frac{U_{grain}}{U_{total}} \times 100 \qquad (1)$$

where, U_{grain} is the uptake (kg/ha) of a particular nutrient by the grain and U_{total} is the total uptake (kg/ha) of that nutrient by total biomass. Likewise, the physiological efficiency (PE) was derived by dividing the total dry matter yield (kg/ha) by total nutrient uptake (kg/ha). Internal utilization efficiency

(IUE) was calculated by dividing the grain yield (kg) by total nutrient uptake (kg).

$$\text{PE (kg/kg)} = \frac{\text{Total dry matter}}{U_{\text{total}}} \qquad (2)$$

$$\text{IUE (kg/kg)} = \frac{\text{Grain yield}}{U_{\text{total}}} \qquad (3)$$

Data obtained from pigeonpea and wheat for consecutive two years was analyzed statistically using the F–test, as per the procedure given by Gomez and Gomez (1984). LSD values at P=0.05 were used to determine the significance of difference between treatment means. The data were analyzed with online statistical software OPSTAT (Sheoran *et al.* 1998).The correlation values were determined using MS Excel 2007. Statistical differences between the treatments were recorded following standard statistical tools as per procedure laid out for split plot and split–split plot design (Cochran and Cox 1957).

RESULTS AND DISCUSSION

Grain yield and growth attributes of component crops

In the present investigation, crop establishment practices significantly influenced the grain yields of both pigeonpea and wheat. The overall performance of pigeonpea was better on raised–bed as it yielded 11.7% higher seed yield over ridge–furrow practice. It may be due to the fact that early pigeonpea cultivars are more sensitive to water logging as compared to long–duration pigeonpea cultivars spanning over the entire rainy and winter season. Raised beds or ridge furrow is helpful to plants to avoid water stagnation in early growth stages and thereby escaping crop from blight (*Phytophthora* spp. *cajani*) disease which is mostly prevalent at present agroecology of IGP (Ahlawat *et al.* 2005, Johansen *et al.* 2000, Praharaj *et al.* 2016, 2017).

The study showed that wheat grain yield was higher (13.4–14.3%) in flatbed than that of raised–bed method of crop establishment. Thus, it is apparent that flatbed system could be advantageous to raised–bed system especially for the late sown wheat. The results clearly indicated that crop establishment treatments (RP–FBW, RBP–RBW) would not be appropriate to realize the potential productivity of pigeonpea–wheat rotation. Rather, the results suggested the fact that the best combination could be sowing of pigeonpea on raised–beds during rainy season and that of wheat on flatbed in winter. This could be the strategic combination for realizing higher yields from component crops in pigeonpea–wheat rotation under IGP.

Table 1 Effect of crop establishment practices on grain yield of component cultivars in pigeonpea–wheat system

Treatment	Grain yield (t/ha)			
	1st Year (2013-14)		2nd Year (2014-15)	
	Pigeonpea	Wheat	Pigeonpea	Wheat
Crop establishment practice				
Ridge (pigeonpea) – flatbed (wheat)	1.10	3.38	1.21	3.68
Raised bed (pigeonpea) – raised bed (wheat)	1.23	2.98	1.35	3.22
LSD (P=0.05)	0.11	0.38	0.13	0.31
Pigeonpea cultivar				
UPAS 120	1.38	3.30	1.51	3.67
ICP 67B	0.91	3.05	1.01	3.26
Pusa 992	1.21	3.19	1.32	3.42
LSD (P=0.05)	0.10	0.18	0.10	0.23
Wheat cultivar				
Shatabdi	–	2.93	–	3.15
Unnat Halna	–	3.43	–	3.75
LSD (P=0.05)		0.21		0.15

Among the pigeonpea cultivars, the study revealed that the higher grain yield was recorded under UPAS 120 (1.38–1.51 t/ha) followed by Pusa 992 and ICP 67B (Table 1). The yield differences might be due to varietal characteristics. However, the residual impact of the preceding pigeonpea cultivars to wheat was also evident and observed to be statistically significant on wheat grain yield. The cultivar Unnat Halna yielded higher (17.1–19.0%) than Shatabdi. Since the cultivar Unnat Halna was bred for the late sown

Table 2 NHI, PE and IUE of pigeonpea as influenced by different crop establishment practices and cultivars

Treatment	NHI				PE				IUE			
	N	P	K	S	N	P	K	S	N	P	K	S
Crop establishment practice												
Ridge (pigeonpea) – flatbed (wheat)	48.0	47.1	25.6	37.7	13.0	110.9	18.8	145.4	56.4	488.6	81.9	634.3
Raised bed (pigeonpea) – raised bed (wheat)	45.4	44.2	23.5	35.1	11.7	99.5	16.4	128.8	54.7	468.8	76.7	602.0
LSD (P=0.05)	NS	NS	1.3	NS	NS	NS	2.5	15.8	NS	NS	NS	NS
Pigeonpea cultivar												
UPAS 120	45.9	52.1	25.1	39.1	13.5	81.4	17.8	147.0	58.1	350.5	76.5	632.4
ICP 67B	39.7	39.4	28.1	32.9	10.9	125.7	16.8	134.8	53.1	610.6	81.8	655.5
Pusa 992	54.7	45.4	20.4	37.2	12.6	108.4	18.2	129.4	55.4	474.9	79.5	566.7
LSD (P=0.05)	1.0	1.1	1.1	0.8	0.7	5.7	NS	10.3	2.6	25.9	NS	43.8

NHI–Nutrient harvest index; PE–Physiological efficiency; IUE–Internal utilization efficiency

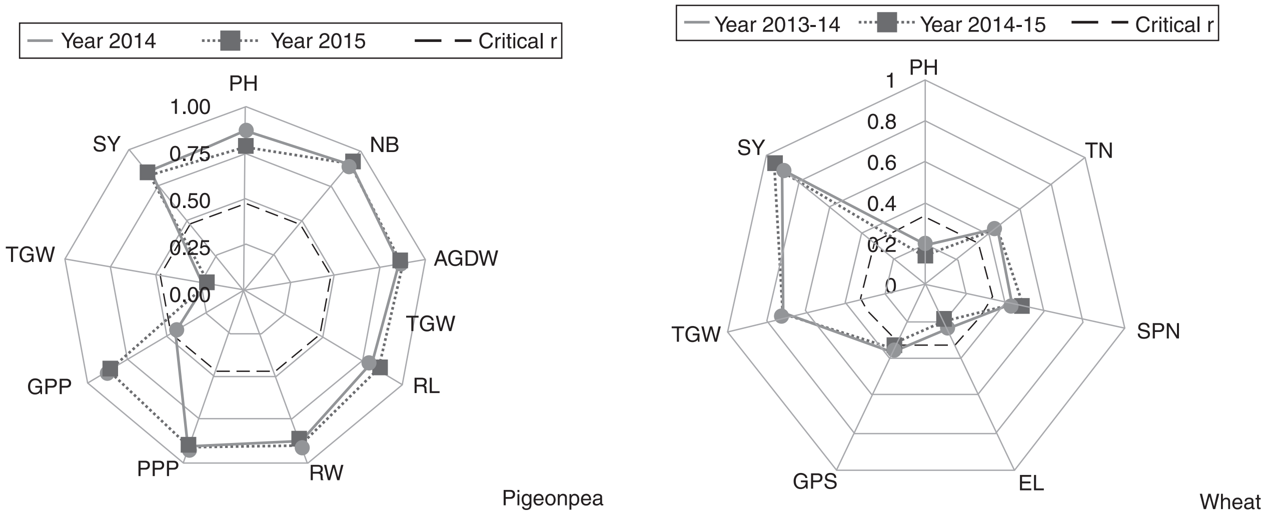

Fig 1 Correlation (r) values of growth and yield attributes with grain yield in pigeonpea and wheat crop. The beak line represents the critical r values, the r values higher than the critical values are significant at P <0.05. PH – plant height, NB – number of branches/plant, AGDW– above ground plant dry matter, RL –root length, RW– root dry weight, PPP – number of pods/plant, GPP – grains/pod GWPP – grain weight/pod, TGW – thousand grain weight, TN – number of tillers, SPN – number of spikes, EL – ear length, GPS – grains per spike, SY – straw yield.

condition which was known for its input intensive (high fertilizer and irrigation) production system, the cultivar performed better over the Shatabdi.

This increase in grain yield of pigeonpea was further attributed to higher growth and yield attributes.The pooled ANOVA table showed that both crop establishment practices and pigeonpea cultivar significantly influenced the growth and yield attributes of pigeonpea such as number of branches/plant, above ground plant dry matter, root length, root dry weight, number of pods/plant, grains/pod and straw yield (Table 4). Significant differences within experimental years were also detected for these parameters. Likewise, Table 5 demonstrated that crop establishment practices significantly influenced the growth and yield attributes of wheat such as tillers and spikes density, ear length, grains/spike, and straw yield. However, preceding pigeonpea cultivar only had effect on wheat straw yield. The study also showed that except thousand grains weight, all others growth and yield attributes had higher and significant (P<0.05) correlation with pigeonpea grain yield (Fig 1). Similarly, for the wheat crop, all the growth and yield attributes except plant height and ear length, had significant

Table 3 NHI, PE and IUE of wheat as influenced by different crop establishment practices and cultivars

Treatment	NHI				PE				IUE			
	N	P	K	S	N	P	K	S	N	P	K	S
Crop establishment practice												
Ridge (pigeonpea) – flatbed (wheat)	68.5	47.9	37.3	19.2	116.3	485.3	131.4	389.8	40.9	170.0	46.3	137.7
Raised bed (pigeonpea) – raised bed (wheat)	67.6	46.7	36.9	18.6	110.3	457.4	121.8	359.6	38.5	160.8	43.6	128.6
LSD (*P*=0.05)	0.43	0.55	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Preceding pigeonpea cultivar												
UPAS 120	67.3	46.4	36.3	18.4	99.9	414.4	108.4	320.0	34.4	144.3	37.9	112.0
ICP 67B	69.7	47.0	39.1	19.5	126.1	532.6	142.5	420.1	44.9	190.1	51.7	152.4
Pusa 992	67.2	48.5	35.8	18.7	113.9	467.0	128.9	384.1	39.9	161.7	45.3	135.1
LSD (*P*=0.05)	1.52	1.18	1.8	0.7	11.6	49.6	14.6	46.2	4.6	19.0	5.4	17.2
Wheat cultivar												
Shatabdi	67.9	44.8	36.4	18.5	112.4	509.8	133.6	393.5	39.0	179.8	46.6	137.1
Unnat Halna	68.2	49.8	37.7	19.3	114.2	432.9	119.6	356.0	40.5	151.0	43.4	129.3
LSD (*P*=0.05)	0.50	0.49	0.37	0.24	NS	18.4	4.8	14.1	NS	6.2	1.7	5.8

NHI – Nutrient harvest index; PE – Physiological efficiency; IUE – Internal utilization efficiency

Table 4 Analysis of variance of crop establishment, and cultivar effects on growth and yield attributes of pigeonpea

Source	DF	PH	NB	AGDW	RL	RW	PPP	GPP	TGW	SY
Replication	2	1,641.2	10.7	3,661.3	633.2	71.5	271.9	0.7	619.6	89.1
Year (Y)	1	338.3**	16.0**	1,005.4*	72.4	125.4**	295.8*	3.1**	213.2*	18.0
Error (a)	2	0.7	0.2	52.9	8.5	1.8	7.2	0.0	7.1	2.4
Crop establishment	1	33.0	48.3**	12,671.4**	2,175.6**	233.7**	1,039.3**	2.0**	44.4	640.9**
Y×TCE	1	64.2	0.0	61.9	7.8	0.9	0.9	0.2	1.1	0.4
Error (b)	4	838.7	4.3	1,210.1	203.3	25.6	110.3	0.3	146.4	63.2
Pigeonpea cultivar (P)	2	19,829.6**	149.5**	21,811.2**	3,200.1**	629.2**	9,796.4**	1.6**	776.7**	688.3**
Y × P	2	5.8	4.2	9.2	3.3	8.1	21.1	1.6**	2.6	1.5
TCE × P	2	40.3	3.6	755.3	128.4	18.6	34.8	0.0	1.8	13.7
Y × TCE × P	2	17.0	2.5	652.9	116.3	9.8	69.4	0.0	3.6	2.4
Error (c)	16	2,517.0	10.2	3,525.0	608.2	68.7	300.6	0.7	634.4	129.6
Total	35	25,325.9	249.6	45,416.4	7,157.0	71.5	11,947.7	10.1	2,451.0	1,649.3

PH – Plant height, NB – number of branches/plant, AGDW – above ground plant dry matter, RL – root length, RW – root dry weight, PPP – number of pods/plant, GPP – grains/pod, TGW – thousand grain weight, SY – straw yield. $*P \le 0.05$, $**P \le 0.01$, $***P \le 0.001$.

Table 5 Analysis of variance of crop establishment, pigeonpea and wheat cultivar effects on growth and yield attributes of wheat

Source	df	PH	TN	SPN	EL	GPS	TGW	SY
Replication	2	1327.0	2662.1	2326.4	17.3	412.9	416.9	756.4
Tillage cum crop establishment (TCE)	1	61.5	1793.4*	1184.8*	17.2*	424.1*	4.1	536.4*
Error (a)	2	121.5	179.0	122.3	1.8	41.2	19.0	35.8
Pigeonpea cultivar (P)	2	9.3	23.0	4.0	0.2	21.4	4.8	877.9*
TCE × P	2	2.4	4.3	6.9	0.1	0.1	0.2	12.6
Error (b)	8	306.8	429.9	335.5	3.1	78.2	65.4	156.6
Wheat cultivar (W)	1	580.7**	1387.0**	925.9**	19.5**	210.7**	174.8**	426.4**
TCE × W	1	24.0	13.3	9.9	0.0	1.3	0.0	4.8
P × W	2	2.4	17.0	9.2	0.0	10.2	6.5	18.7
TCE × P × W	2	1.6	105.7	20.2	0.0	19.8	12.7	40.2
Error (c)	12	284.7	417.0	342.0	3.0	68.6	66.1	143.8
Total	35	2721.8	7031.7	5287.0	62.0	1288.6	770.5	3009.7

PH – plant height, TN – number of tillers, SPN – number of spikes, EL – ear length, GPS – grains/spike^{-1}, TGW – thousand grain weight, SY – straw yield. $*P \le 0.05$, $**P \le 0.01$, $***P \le 0.001$.

correlation with wheat grain yield.

Intra–plant nutrient utilization

The parameters NHI, PE and IUE were computed to examine the intra–plant utilization of plant nutrients (N, P, K, and S) and their efficiency of utilization. The results indicated that crop establishment practices did not influence the plant nutrient utilization in pigeonpea (Table 2). However, the effects of cultivars (both pigeonpea and wheat) were found prominent in influencing NHI, PE and IUE. Quite apparently, the preceding pigeonpea cultivar affects the productivity of wheat significantly (Singh and Ahlawat 2006). This might be due to the changes in wheat sowing windows as influenced by preceding pigeonpea cultivars of varying duration. Moreover, on the other hand, the variable biomass production and leaf fall of pigeonpea cultivars might be the other important aspects determining the apparent differences in intra–plant nutrient utilization in wheat crop. Similarly, the wheat cultivar Unnat Halna had higher intra–plant nutrient utilization as compared to the cultivar Shatabdi (Table 3).

System productivity and economics

The system productivity as estimated in terms of pigeonpea equivalent yield (PEY) was comparable for both RP–FBW and RBP–RBW with minor differences. On the other hand, the different cultivar combinations largely differed for the PEY. The maximum pigeonpea equivalent yield was recorded with UPAS 120 –Unnat Halna) followed by UPAS 120 –Shatabdi, Pusa 992–Unnat Halna, Pusa 992 –Shatabdi, ICP 67B –Unnat Halna, and ICP 67B –Shatabdi, respectively. Thus, the selection of appropriate cultivars is fundamental to realize the optimum system productivity from pigeonpea-wheat rotation in IGP. In the present study,

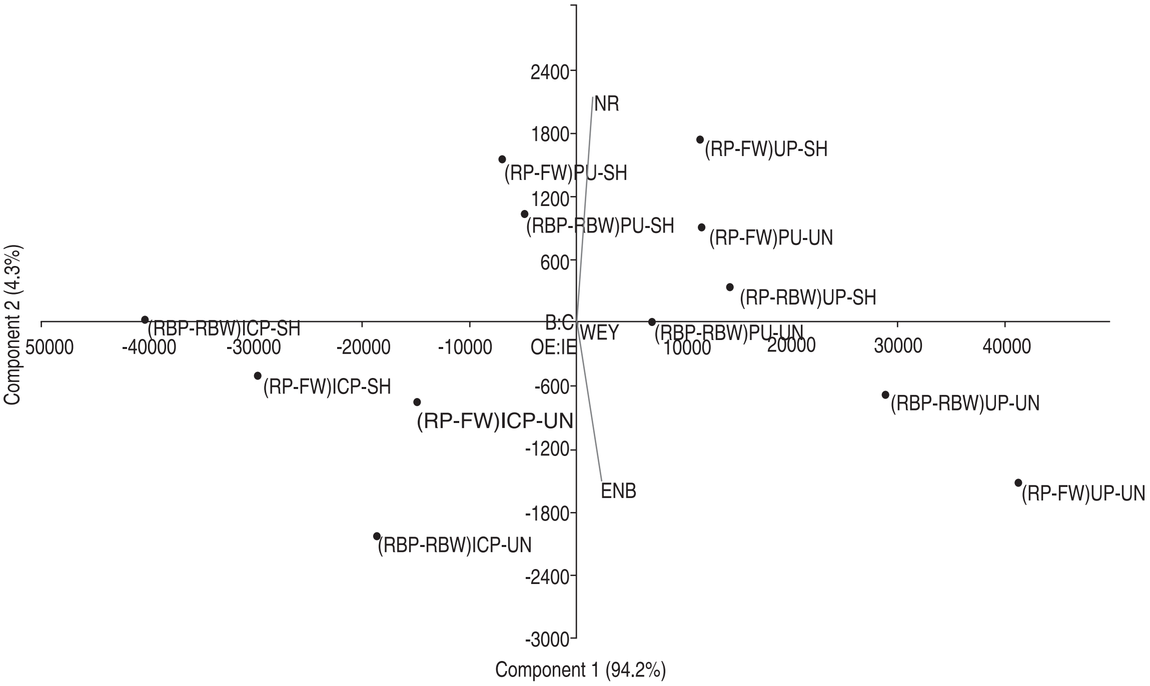

Fig 2 The scatter plot of different treatments in PCA coordinates. RP–FW– pigeonpea on ridge followed by wheat on flatbed, RBP–RBW– pigeonpea on raised bed followed by wheat on raised bed. U–S: UPAS 120–Shatabdi, U–U: UPAS 120–Unnat Halna, I–S: ICP 67B–Shatabdi, I–U: ICP 67B–Unnat Halna, P–S: Pusa 992–Shatabdi, P–U: Pusa 992–Unnat Halna.

pigeonpea 'UPAS120' followed by 'Unnat Halna' could be the right choice so as to upscale the productivity of pigeonpea–wheat system as a whole unless further breeding efforts are made to raise the yield levels vertically. On the same line, the PCA analysis also distinguished the most productive treatment combination (i.e. ridge planted UPAS 120 – flatbed sown Unnat Halna), which is situated in the extreme right of the PCA graph (Fig 2).

Economic analysis also revealed that RP–FBW had a higher net return and BCR over that in RBP–RBW. On the basis of system as a whole, higher net return was realized in UPAS120–Unnat Halna (₹ 69331/ha) whereas the least was measured for ICP 67B –Shatabdi (₹ 29638 ha^{-1}). A similar trend was also evident for the BCR. Since higher productivity with sustainability remains the major concern for any land use /crop planning, any crop/cropping system that requires less input and contributes more (or having higher edge) towards yield, soil health and economics is considered to be the efficient. The results on system productivity and economics clearly illustrated that growing of UPAS 120 (pigeonpea) on a raised–bed followed by Unnat Halna (wheat) on flatbed could be the most productive and remunerative crop establishment practice and varietal intervention for establishing pigeonpea–wheat rotation in IGP.

Therefore, it is inferred from the above findings that agronomic manipulation of pigeonpea–wheat rotation of IGP through appropriate land configuration and suitable system based component cultivar selection is the key in realizing higher productivity from the cropping system. The results confirmed that raised–bed method of crop establishment is advantageous for pigeonpea while flat sowing for the late sown wheat crop. The UPAS 120 –Unnat Halna cultivar combination was found promising over other cultivar combination. However, a relatively more number of region specific cultivar combinations need to be evaluated so as to identify the potential cultivar combination. In this context, further breeding work is necessary to develop extra early duration pigeonpea cultivar(s) for greater adoption of the rotation in IGP.

REFERENCES

Ahlawat I P S, Gangaiah B and Singh I P. 2005. Pigeonpea (*Cajanus cajan*) research in India: an overview. *Indian Journal of Agricultural Sciences* **75**(6): 309–20.

Cochran W G and Cox G M. 1957. *Experimental Designs*, 2nd ed. JohnWiley and Sons, Singapore.

Fahong W, Xuqing W and Sayre K. 2004. Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. *Field Crops Research* **87**(1): 35–42.

Gomez K A and Gomez A A. 1984. Statistical Procedures for Agricultural Research, 2nd ed, John Wiley and Sons, Singapore:

Hazra K K, Venkatesh M S, Ghosh P K, Ganeshamurthy A N, Kumar N, Nadarajan N and Singh A B. 2014. Long-term effect of pulse crops inclusion on soil–plant nutrient dynamics in puddled rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system on an Inceptisol of Indo-Gangetic plain zone of India. *Nutrient Cycling in Agroecosystems* **100**(1): 95–110.

Hobbs P R and Gupta R K. 2003. Resource conservation technologies for wheat in the rice–wheat system. (*In*) Ladha J K, Duxbury J E, Gupta R K and Buresh R J (Eds), *Improving the Productivity and Sustainability of Rice–Wheat System: Issues and Impacts*, pp 149–171. ASA Special Publication 65.

ASA, CSSA, SSSA, Madison, WI.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt Ltd, New Delhi.

Johansen C, Ali M, Gowada C L L, Ramakrishna A, Nigam S N and Chauhan Y S. 2000. Regional opportunities for warm season grain legumes in the Indo–Gangetic Plain. (*In*) *Legumes in Rice and Wheat Cropping Systems of the Indo–Gangetic Plain–Constraints and Opportunities*. pp 185–99. Johansen C, Duxbury J M, Virmani S M, GowdaC L L, Pande S and Joshi P K (Eds). International Crops Research Institute for the Semi Arid Tropics/Cornell University, Patancheru, India/ Ithaca, New York, USA.

Praharaj C S, Singh U, Singh S S, Singh N P and Shivay Y S. 2016. Supplementary and life–saving irrigation for enhancing pulses production, productivity and water use efficiency in India. *Indian Journal of Agronomy* **61**: S249–S261.

Praharaj C S, Singh U, Singh S S and Kumar N. 2017. Micro–irrigation in rainfed pigeonpea–Upscaling productivity under Eastern Gangetic Plains with suitable land configuration, population management and supplementary fertigation at critical stages. *Current Science* **112**(1): 95–107.

Sepat S, Sharma A R, Kumar D and Das T K. 2015. Effect of conservation agriculture practices on productivity and sustainability of pigeonpea (*Cajanus cajan*)–wheat (*Triticum aestivum*) cropping system in Indo–Gangetic plains of India. *Indian Journal of Agricultural Sciences* **85**(2): 212–6.

Sheoran O P, Tonk D S, Kaushik L S, Hasija R C and Pannu R S. 1998. Statistical software package for agricultural research workers. (*In*) Recent Advances in Information Theory, Statistics and Computer Applications, pp139–143. Department of Mathematics Statistics, CCS HAU, Hisar.

Singh U and Ahlawat I P S. 2006. Productivity, nutrient uptake and soil fertility as influenced by phosphorus management in pigeon pea – wheat cropping system. *Indian Journal of Agricultural Sciences* **76**(9): 538–43.

Singh U and Ahlawat I P S. 2007. Phosphorus management in pigeonpea – wheat cropping system. *Indian Journal of Agronomy* **52**(1): 21–6.