*Indian Journal of Agronomy* **58** (3): 303–308 (September 2013)

**Research Paper**

# Productivity, economics and energetics of pigeonpea (*Cajanus cajan*)-based cropping systems in mid-hills of north–west Himalaya

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Received : August 2012; Revised accepted : July 2013

## ABSTRACT

The study on system productivity, energy-use efficiency and economics of pigeonpea [*Cajanus cajan* (L.) Mill sp.]–based cropping systems, *viz.,* pigeonpea–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol.}, pigeonpea–barley (*Hordeum vulgare* L.), pigeonpea–lentil {*Lens culinaris* (L.) Medicus, pigeonpea–field pea {*Pisum sativum* (L.), sensu lato} and pigeonpea–toria {*Brassica rapa* (L.) var. *toria*} with comparise to rice (*Oryza sativa* L.)–wheat cropping system was carried out at the Hawalbagh experimental farm of Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand during 2007–2009, under rainfed conditions. Results showed that all the pigeonpea–based cropping systems were superior to traditional rice–wheat cropping system in terms of system productivity, net returns, benefit:cost ratio and net energy returns. Pigeonpea–lentil cropping system proved superior in terms of system net returns (₹63,616/ha), benefit:cost ratio (1.64) and energy ratio (1.94) to pigeonpea–wheat, pigeonpea–barley, pigeonpea–field pea and pigeonpea–toria cropping systems. Rice–wheat cropping system recorded the lowest pigeonpea–equivalent yield (1.32 t/ha), net returns (₹2,750/ha) and benefit:cost ratio (0.06). Nutrient status of the soil improved significantly due to pigeonpea–lentil cropping system over other cropping systems. Pigeonpea–lentil cropping system proved to be the best in terms of monetary returns, net energy return and soil productivity and hence, could be adopted in the north-west Himalayas under rainfed conditions.

***Key words* :** Cropping systems, Energetics, North–western Himalaya, Nutrient balance, Pigeonpea equivalent yield



Higher productivity with sustainability remains the major concern of any crop planning. Any system which requires less input and contributes more is considered to be the efficient. In recent years, oilseeds and legumes are receiving more attention owing to limited production and higher prices. Inclusion of these crops in the sequence changes the economics of the cropping system (Chauhan *et al*., 2001; Singh and Sharma, 2001). There is a closer relationship between cropping system productivity, economics, energy and environment. The net energy and monetary return of a cropping system can be quantified for sound planning of sustainable systems (Tuti *et al.*, 2012). About 90% of the cultivated land from north–western Himalayan region is rainfed. In the rice–wheat based rainfed cropping system, hardly 10–15 days time is available between harvesting of rice and timely sowing of wheat. In this short duration, farmers find difficult to complete the timely sowing of wheat crop. Moreover, delayed sowing affects germination adversely owing to moisture depletion, which results in lower yield. Higher production cost restricts the farmers to follow the improved cropping sequences. In the north-west Himalayas, the yield levels are very low due to erratic rainfall, lack of farmers' resources and fragmented land holdings. Most of the previous work focused on specific aspects of the rice–wheat systems with a strong emphasis on yields and nutrient management. The productivity of the rice–wheat system has shown consistently declining trend in most of areas and the income from this system is hardly sufficient for its continuance on sustainable basis. Studies providing an integrated assessment of more diversified cropping systems have remained relatively less in the scientific literature, but they are needed for understanding options for intensification and diversification in the north-western Himalayan region. The advantages of legume-based cropping systems were well proven in this region (Singh *et al*., 2008). Pigeonpea is an important legume crop of rainfed agriculture because of its ability to produce economic yield under limited moisture

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conditions. But the pigeonpea–based cropping system needs to be evaluated agronomically, economically as well as in terms of energy-use efficiency. Hence, the present investigation was undertaken to evaluate the productivity, profitability and energy–use efficiency of pigeonpea–based cropping systems in comparison with the traditional rice–wheat cropping system.

## MATERIALS AND METHODS

A fixed plot field study was carried out at the research farm (Hawalbagh) of Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand, India, situated at 29°36' N latitude and 79°40' E longitude at an elevation of 1250 m AMSL during 2007–2009. The soil of the experiment site was slightly alkaline in reaction (pH 7.1), sandy loam in texture having bulk density 1.38 Mg/m$^3$, plant-available water capacity 2.4 cm/15 cm, porosity 50.2%, organic C 0.63% and available N 288 kg/ha, available P 13 kg/ha and available K 175 kg/ha. The total rainfall received during 2007-08 and 2008-09 were 670 and 821 mm, respectively. The treatments comprised of five pigeonpea–based cropping systems along with the rice–wheat cropping system were taken in randomized block design with four replications. The treatments were pigeonpea–wheat, pigeonpea–barley, pigeonpea–lentil, pigeonpea–field pea, pigeonpea–*toria* and rice–wheat in sequential cropping. The pigeonpea crop was sown on 18 and 15 June in 2007 and 2008, respectively and all other *rabi* season crops were sown on 1 November in 2007 and 16 October in 2008. Pigeonpea 'VL Arhar 1', wheat 'VL *Gehun* 804', barley 'VL Barley 85', lentil 'VL *Masoor* 507', field pea 'VL *Matar* 42' and rice 'VL *Dhan* 154' were used for the experimentation. In all the treatments, 10 FYM/ha along with recommended dose of NPK of respective crops was applied. Recommended dose of fertilizers applied to different crops were 20 kg N + 26.4 kg P + 33.3 kg K/ha to pigeonpea, 60 kg N + 13.2 kg P + 16.7 kg K/ha to rice, wheat and barley, 20 kg N + 17.6 kg P + 16.7 kg K/ha to lentil, 20 kg N + 26.4 kg P + 33.3 kg K/ha to field pea and 50 kg N + 13.2 kg P + 16.7 kg K/ha to *toria*. Full amount of N, P and K in pigeonpea, lentil and field pea and half the amount of N and full amount of P and K in rice, wheat, barley and *toria* was applied at the time of sowing. The remaining half of N was top-dressed in rice, wheat, barley and *toria* after the rains in august and February, for *kharif* (rainy) and *rabi* (winter season) crops respectively. Seeds of pigeonpea and rice during *kharif* and wheat, barley, lentil, field pea and *toria* during *rabi* were sown after tilling the fields once in minimum tillage. Before sowing of *kharif* crops, weeds were controlled with the application of glyphosate at 1.0 kg/ha followed by one hand weeding at 45 days after sowing. Similarly, during the *rabi* season, weeds were controlled in all the cropping systems by spraying isoproturon at 1.0 kg/ha at 35 days after sowing in wheat and barley; and pendimethalin at 1.0 kg/ha (as pre-emergence) in plots of lentil, field pea and *toria*, followed by hand weeding as and when required. Production indices like pigeonpea-equivalent yield (PEY), system productivity of the cropping system were worked out to evaluate the system efficiency.

To calculate the input energy, all inputs in the form of labour, seed, chemical fertilizer, herbicides and pesticides used in all crop sequences were taken into consideration with use of energy conversion factors. The energy requirement of the different field operations were calculated by using the energy conversion factors as given in Table 1. The farm produce (grain yield + straw/stalk yield) was also converted into energy in terms of energy output (MJ) by using two year's average yield under different crops of selected sequences. Input energy was worked out in terms of different external sources utilized, i.e. seed, fertilizer, herbicide and plant protection chemicals. The parameters measured or calculated were input energy, output energy, net energy returns and energy ratio (energy efficiency). Energy equivalents for all inputs were summed to provide an estimate for total energy input (Table 1). Output energy from the product (grain) was calculated by multiplying the amount of production and its corresponding energy equivalent. Energy output from the by-product (stalk and straw) was estimated by multiplying the amount of by-

**Table 1.** Energy conversion factors used in the study

| Power source | Units | Equivalent energy (MJ) |
|---|---|---|
| Human labour | | |
| Adult man | Man-hour | 1.96 |
| Woman | Woman-hour | 1.57 |
| Farm machinery | kg | 62.7 |
| Chemical fertilizers | | |
| N | kg | 60.60 |
| $P_2O_5$ | kg | 11.10 |
| $K_2O$ | kg | 6.70 |
| Farm yard manure | kg (dry mass) | 0.30 |
| Plant protection chemicals | kg | 120 |
| Crop Produce | | |
| Pigeonpea | kg | 14.7 |
| Rice | kg | 14.7 |
| Wheat | kg | 14.7 |
| Barley | kg | 14.7 |
| Lentil | kg | 14.7 |
| Field pea | kg | 14.7 |
| Toria | kg | 25.0 |
| By-product | | |
| Straw, vines etc. | kg | 12.5 |
| Stalks | kg (dry mass) | 18.0 |

(Devasenapathy *et al.*, 2009)

product and its corresponding equivalent. Net energy returns or net energy production, is the difference between the gross energy output produced and the total energy required to obtain it (energy input). Energy ratio was determined as energy output divided by input.

Different economic indicators were calculated based on the existing market price of the inputs and outputs. Variable cost of cultivation was worked out and the fixed cost was not taken into account. Gross income was calculated out by taking into account the main product and the by-product. The prices of different produce per tonne used for calculation were: ₹35,500 for pigeonpea grains, ₹8,500 for rice grains, ₹10,800 for wheat grains, ₹6,500 for barley grains, ₹23,000 for lentil grains, ₹18,000 for field pea grains, ₹17,350 for *toria* grains, ₹1,600 for rice/wheat/barley straw, and ₹2,750 for field pea/lentil/*toria* straw. The inputs costs used for calculation of net returns were: ₹115/manday, ₹11/kg N, ₹23/kg P, ₹8/kg K and ₹6,000/ha for land preparation. Land–use efficiency (LUE) was obtained by taking total duration of crops in an individual crop rotation divided by 365 days. Production-efficiency values in terms of kg/ha/day were worked out for the total production by means of pigeonpea equivalent yield in a crop rotation divided by total duration of crop in that rotation. The values of production efficiency in terms of ₹/ha/day were calculated by net monetary returns of the rotation divided by total duration of the crop in that rotation. The data collected were subjected to statistical analysis of variance (ANOVA). The least significant difference (LSD) test was carried out for analyzed mean square errors. The procedure provides for a single LSD value at 5% level of significance, which serves as a boundary between significant and non-significant differences between any pair of treatment means.

## RESULTS AND DISCUSSION

### *System productivity and use efficiency*

There was not much variation in yields of pigeonpea in different cropping sequence (Table 2). Significantly higher number of pods/plant in pigeonpea was observed under pigeonpea–lentil cropping system. However, seeds/pod and 1,000-seed weight was found to be non-significant among the treatments. Total system productivity in terms of pigeonpea equivalent yield (PEY) was affected significantly due to different sequential cropping systems. Pooled data on yield showed that pigeonpea–wheat cropping system recorded the highest PEY (2.80 t/ha), which was significantly higher than the rest of the treatments. This was mainly due to fairly good yield of wheat and its good market price. Mukherjee (2010) also reported the productivity and profitability were higher under legume–wheat cropping sequence than the traditional rice–wheat sequence. Similar things also observed in pigeonpea–lentil cropping system. This also corroborates the earlier findings of Rao and Rogers (2006). Rice–wheat sequence recorded the lowest PEY (1.32 t/ha) because of the lower yield of these crops. Similarly, pigeonpea–barley (2.36 t/ha), pigeonpea–field pea (2.53 t/ha) and pigeonpea–*toria* (2.51 t/ha) were found significantly superior to rice–wheat in terms of PEY. It was mainly due to higher price of pigeonpea, field pea as well as *toria* compared with that of rice and wheat. Pigeonpea–wheat (2.80 t/ha) and pigeonpea–lentil (2.74 t/ha) cropping system improved the system productivity in terms of PEY by 112 and 108%, respectively, compared to the traditional rice–wheat sequence (1.32 t/ha). Ghosh *et al.* (2006) also reported that cropping sequence with a high yielding or legume crop in pigeonpea is advantageous. Higher PEY under different cropping systems than rice–wheat sequential cropping indicated higher biomass production resulting in more efficient utilization of land and available resources in pigeonpea based cropping systems. Prakash *et al.* (2004) reported similar findings in soybean–lentil cropping system. The pigeonpea–barley cropping sequence registered the highest land use efficiency (87.7%). This can be attributed mainly to the barley crop in the respective sequence because this sequence occupied the field for 320 days. LUE was lowest in the pigeonpea–*toria* system (78.1%). The pigeonpea–wheat cropping sequence, although the most productive and highest rainfall use efficiency (3.76 kg/ha/mm) could register 85.8% of LUE because it occupied the field for only 313 days. However, the pigeonpea–lentil sequence gave the highest production efficiency (9.29 kg/ha/day). The inclusion of crops like pigeonpea, barley, lentil, fieldpea and *toria* in these sequences was mainly responsible for the higher production and rainfall use efficiencies. In general, besides having higher price in the market, pulses provide acceptable production within a shorter time. Sharma *et al.* (2004) also reported that crop intensification through the inclusion of leguminous crops increased production and land use efficiencies. The lowest production and field water use efficiencies were obtained with the rice–wheat cropping system.

### *Energetics*

The energy budget revealed that the maximum input energy of the system was recorded under rice–wheat (1,57,370 MJ/ha) followed by pigeonpea–wheat (1,55,540 MJ/ha) cropping system (Table 3). The lowest input energy was noted with pigeonpea–lentil (1,00,270 MJ/ha) cropping sequence. The input energy increased with the increase in inputs (seed, fertilizer, pesticide and human labours). The maximum system output energy (194040 MJ/ha), net energy return (93770 MJ/ha) and energy ratio

(1.94) were obtained with pigeonpea–lentil cropping system followed by pigeonpea–*toria* cropping system because of higher system productivity. The lowest values were noted with rice–wheat, mainly because of high input energy and too low system productivity. Singh *et al.* (2008) also reported more net energy returns and energy ratio due to less input energy and more output energy in different cropping systems studied in the north–western Himalaya. Therefore, pigeonpea–lentil was recommended for rainfed farming in this region.

### *Soil properties, nutrient uptake and balance*

In *kharif* season significant improvement in N uptake by pigeonpea than rice was observed (Table 4). The maximum uptake of N (185.3 kg/ha) in pigeonpea was recorded under pigeonpea–lentil cropping system which was at par with other pigeonpea–based cropping systems. Similar trend of P and K uptake by pigeonpea also highest under pigeonpea–lentil cropping system. In *rabi* season higher variability N, P and K uptake recorded due to different crops grown in this season. The highest N (277.5 kg/ha) and K (246.5 kg/ha) uptake of cropping system was recorded with pigeonpea–wheat cropping system. However, P uptake was highest (28.2 kg/ha) in the rice–wheat cropping system. Similar variability in nutrient uptake due to different cropping system in mid-hill conditions was

**Table 2.** Productivity, production efficiency, land–use efficiency and economics (× $10^3$ ₹/ha) of pigeonpea–based cropping systems (Data pooled over two years)

| Cropping system | Yield (t/ha) | | Pigeonpea | | | PEY* (t/ha) | Production efficiency (kg/ha/day) | Land-use efficiency (%) | Cost of cultivation (×$10^3$ ₹/ha) | Production efficiency (₹/ha/day) | Net returns (×$10^3$ ₹/ha) | B:C ratio** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Rabi* | Pods/ plant | Seeds/ pod | Test weight (g) | | | | | | | |
| Pigeonpea–wheat | 1.58 | 2.20 | 118.7 | 3.2 | 77.3 | 2.80 | 8.95 | 85.8 | 49.2 | 55.9 | 1.14 | 178 |
| Pigeonpea–barley | 1.53 | 1.54 | 107.3 | 3.2 | 75.5 | 2.36 | 7.38 | 87.7 | 42.9 | 45.5 | 1.06 | 142 |
| Pigeonpea–lentil | 1.61 | 0.65 | 129.3 | 3.1 | 77.5 | 2.74 | 9.29 | 80.8 | 38.9 | 63.6 | 1.64 | 215 |
| Pigeonpea–field pea | 1.52 | 0.65 | 104.7 | 3.1 | 76.7 | 2.53 | 8.72 | 79.5 | 39.9 | 54.7 | 1.37 | 188 |
| Pigeonpea–*toria* | 1.49 | 0.75 | 110.3 | 3.2 | 76.1 | 2.51 | 8.81 | 78.1 | 37.6 | 56.5 | 1.50 | 198 |
| Rice–wheat | 1.80 | 2.14 | | | | 1.32 | 4.22 | 85.8 | 46.8 | 2.8 | 0.06 | 8.8 |
| SEm± | | | 3.2 | 0.15 | 1.0 | 0.06 | 0.34 | 3.6 | | | | |
| CD (P=0.05) | | | 9.3 | NS | NS | 0.18 | 1.0 | NS | | | | |

*PEY: Pigeonpea equivalent yield; ** B: C ratio: benefit:cost ratio



**Table 3.** Energy–use efficiency as influenced by different cropping systems (Data pooled over two years)

| Cropping system | System input energy (× $10^3$ MJ/ha) | System output energy (×$10^3$ MJ/ha) | System net energy returns (× $10^3$ MJ/ha) | Energy ratio |
|---|---|---|---|---|
| Pigeonpea–wheat | 155.5 | 213.7 | 58.2 | 1.37 |
| Pigeonpea–barley | 145.6 | 186.7 | 41.1 | 1.28 |
| Pigeonpea–lentil | 100.3 | 194.0 | 93.7 | 1.93 |
| Pigeonpea–field pea | 131.1 | 185.4 | 54.3 | 1.41 |
| Pigeonpea–*toria* | 120.3 | 206.0 | 85.7 | 1.71 |
| Rice–wheat | 157.4 | 141.5 | -15.9 | 0.90 |

**Table 4.** Major nutrient uptake (kg/ha) by different crops, cropping systems, rainfall use efficiency and mandays/ha/year generated under various pigeonpea-based cropping system (Data pooled over two years)

| Cropping system | *Kharif* | | | *Rabi* | | | System | | | RUE* (kg/ha/mm) | Mandays/ ha/year |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | | |
| Pigeonpea–wheat | 176.5 | 11.4 | 98.5 | 101.0 | 13.7 | 148.0 | 277.5 | 25.1 | 246.5 | 3.76 | 206 |
| Pigeonpea–barley | 181.4 | 12.0 | 101.6 | 64.2 | 12.0 | 71.9 | 245.6 | 24.0 | 173.5 | 3.17 | 203 |
| Pigeonpea–lentil | 185.3 | 12.2 | 103.6 | 25.0 | 8.2 | 55.3 | 210.3 | 20.4 | 158.9 | 3.68 | 183 |
| Pigeonpea–field pea | 171.9 | 11.0 | 96.2 | 34.9 | 9.0 | 52.1 | 206.8 | 20.0 | 148.3 | 3.39 | 196 |
| Pigeonpea–*toria* | 175.0 | 11.9 | 98.0 | 35.9 | 6.8 | 27.0 | 210.9 | 18.7 | 125.0 | 3.37 | 193 |
| Rice–wheat | 87.0 | 14.0 | 80.0 | 110.0 | 14.2 | 155.0 | 197.0 | 28.2 | 235.0 | 1.77 | 231 |
| SEm± | 6.0 | 0.7 | 3.2 | 3.9 | 0.6 | 5.6 | 10.9 | 0.9 | 8.8 | | |
| CD (P=0.05) | 17.3 | 2.0 | 9.3 | 11.4 | 1.8 | 16.1 | 31.6 | 2.6 | 25.5 | | |

* RUE: Rainfall use efficiency

**Table 5.** Effect of pigeonpea–based cropping systems on chemical properties and nutrient balance sheet (kg/ha) of surface soil (Data pooled over two years)

| Cropping system | Soil pH | SOC (%) | Available N (kg/ha) | Available P (kg/ha) | Available K (kg/ha) | Actual gain/loss over initial status (kg/ha) | | | Nutrient balance (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | N | P | K | N | P | K |
| Pigeonpea–wheat | 7.10 | 0.64 | 284.5 | 13.8 | 176.8 | -3.5 | 0.8 | 1.8 | -84 | 58.7 | -130.3 |
| Pigeonpea–barley | 7.11 | 0.64 | 293.4 | 13.2 | 174.8 | 5.4 | 0.2 | -0.2 | -61 | 60.4 | -55.3 |
| Pigeonpea–lentil | 7.08 | 0.68 | 310.8 | 13.7 | 196.5 | 22.8 | 0.7 | 21.5 | -83.1 | 67.9 | -62.4 |
| Pigeonpea–field pea | 7.09 | 0.67 | 305.6 | 13.4 | 188.3 | 17.6 | 0.4 | 13.3 | -74.4 | 77.4 | -27.0 |
| Pigeonpea–*toria* | 7.11 | 0.66 | 290.5 | 13.0 | 179.4 | 2.5 | 0 | 4.4 | -33.4 | 65.9 | -11.4 |
| Rice–wheat | 7.12 | 0.63 | 260.4 | 12.9 | 166.6 | -27.6 | -0.1 | -8.4 | 60.6 | 43.3 | -125.2 |
| SEm± | 0.23 | 0.02 | 7.2 | 0.2 | 5.9 | | | | | | |
| CD (P=0.05) | NS | NS | 21.3 | 0.6 | 17.4 | | | | | | |

observed by Mukherjee (2010). No significant changes in pH and soil organic carbon were observed among the different cropping systems. There was significant improvement in the available N, P and K of surface soil under all pigeonpea–based cropping systems compared to that in the plots under the rice–wheat sequence. The highest available N, P and K of surface soil were observed under the pigeonpea–lentil cropping system (Table 5). A net gain of 22.8, 0.7 and 21.5 kg/ha of available N, P and K, respectively were recorded under pigeonpea–lentil cropping system. However, soils of rice–wheat system showed loss of 27.6, 0.1 and 8.4 kg/ha available N, P and K over initial status of surface soil. The computed N and K balance was negative under all the cropping systems except N under rice–wheat system, where it showed a gain of 60.6 kg available N/ha. The P balance showed a positive gain under all the cropping system. It shows that lentil crop not only utilized the growth resources more efficiently but also improved the nutrient status of the soil due to symbiotic nitrogen fixation. Thus, it can be inferred that pigeonpea–lentil is a more viable option to improve the concentration of major plant nutrients (N, P and K) in soils in this region.



### *Economics*

The pigeonpea–lentil proved significantly superior based on net returns (Table 2). The mean net returns were more in pigeonpea–lentil (‘63,616) and pigeonpea–*toria* (₹56,484) than rice–wheat (₹2,750/ha) cropping system. Production efficiency was also highest (215.7 ₹/ha/day) under pigeonpea–lentil cropping system. These results corroborate the findings of Gangwar *et al.* (2006). The lower cost of cultivation and higher net returns under sequential cropping resulted in higher benefit: cost ratio under pigeonpea – lentil (1.64) cropping system, followed by pigeonpea–*toria* (1.50) cropping system. Lentil–based cropping system was reported to be a remunerative cropping system in mid-hills of north-west Himalaya (Tripathi and Sah, 2001). The lowest benefit: cost ratio under rice–wheat cropping system was mainly due to higher cost of cultivation and lowest gross return owing to low yield of rice and wheat. Employment generation was highest with rice–wheat (231 man days/ha/year) cropping system compared to pigeonpea–based cropping system because rice–wheat sequence occupies through out the year and it needs more irrigation and weeding which is labour intensive.

Thus, it can be inferred that pigeonpea–lentil cropping system is a more viable option to improve the system productivity, profitability per unit area and time and energy productivity in north-west Himalayan region and can be adopted in future for remunerative agriculture.

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