

Productivity and energy efficiency indices of diversified maize (*Zea mays*)-based cropping systems for mid hills of Himachal Pradesh

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ABSTRACT

A field experiment was conducted during 2010–2011 to 2013–14 at Palampur, Himachal Pradesh to find out most productive and energy efficient diversified maize (*Zea mays* L.)-based cropping systems. The maximum maize grain equivalent yield was recorded in maize (green cob)+asparagus bean (*Vigna unguiculata* L.)–radish (*Raphanus sativus* L.)–onion (*Allium cepa* L.) (38.8 t/ha) followed by maize (green cob) + french bean (*Phaseolus vulgaris* L.)–pea (*Pisum sativum* L.)–Summer squash (*Cucurbita pepo* L.) (28.1 t/ha) and maize (Green cob)–broccoli (*Brassica oleracea* L.)–potato (*Solanum tuberosum* L.) (25.6 t/ha). The highest total energy input was recorded in maize (green cob)–broccoli–Potato (57.03×10^3 MJ/ha) followed by maize (green cob) + asparagus bean–radish–onion (49.64×10^3 MJ/ha) and maize (Green cob) + asparagus bean–broccoli–radish (43.95×10^3 MJ/ha). The highest energy input was added through fertilizers (46.5% to 60.4%) followed by FYM (16.4–24.9%) and seed (1.4% to 22.9%). The highest energy output was recorded in maize (green cob) + french bean–pea–summer squash (454.0×10^3 MJ/ha) and maize (green cob)–broccoli–potato (376.6×10^3 MJ/ha). The energy productivity was also higher in maize (green cob)+french bean–pea–summer squash (0.8 kg/MJ) and maize+asparagus bean–radish–onion (0.8 kg/MJ). The energy use efficiency was at par in maize + french bean–pea–summer squash (12.2 MJ/ha) and maize–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system (12.9 MJ/ha), however, specific energy was the highest in maize–wheat (3.8 MJ/kg) followed by maize (green cob) + rice bean (*Vigna umbellata*)–cauliflower (*Brassica oleracea* var. botrytis)–buckwheat (*Fagopyrum esculentum*) (2.7 MJ/kg) cropping system.

Key words : Cropping system, Energy input, Energy output, Energy productivity, Energy use-efficiency, Maize equivalent yield

Agricultural productivity cannot hope to increase unless adequate inputs such as power, improved seeds, fertilizers and irrigation water are available in a timely manner and applied judiciously. With the current increase in world population, energy consumption needs effective planning. That is, the input elements need to be identified in order to prescribe the most efficient methods for controlling excess energy use. Crop yields and food supplies to consumers are directly linked to energy, which means sufficient energy is needed in the right form at the right time for adequate crop production. One way to optimize energy consumption in agriculture is to determine the efficiency of

methods and techniques used (Kitani, 1999; Safa and Tabatabaefar, 2002). Crop-yield is directly proportional to the energy input (Srivastava, 1982). Fuel and fertilizers (N and P) account for the largest share (>75%) of all energy expenditures in a different cropping system (Safa and Tabatabaefar, 2002).

The era of low-priced energy is now ending and energy conservation become obligatory because of rising cost of energy. In India, the availability of power on the farm has to be increased if the productivity is to be raised. More power is needed for timely and quality tillage as well as for irrigation, harvesting and threshing. The world-wide energy crisis caused by fuel shortage and high prices of petroleum has adversely affected the Indian economy. In order to mitigate the hardship, it is necessary to conserve non-renewable energy sources and make better use of available conventional energy sources. In India, there is little additional land available for agriculture. Agricultural

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intensification and increase in cropping intensity requires more energy and energy input pattern for crop production depends on economic, technological and social constraints. Commercial and non commercial energy are available in agricultural operations. Commercial energy inputs arrive on farm in many different forms, e.g. fuel, irrigation water, chemical fertilizer, machinery and pesticides (Khan and Hussain, 2007). Among field crops, legumes involve less energy than cereals and oilseeds. Maize production incurs much higher input of energy, mainly due to its high water and fertilizer requirements coupled with other practices like earthing up, weed control, harvesting and threshing. Existing cropping systems may not be efficient energy converters therefore alternative cropping systems need to be designed so that apart from higher productivity and profitability it must be efficient converter of energy (Kachroo *et al.*, 2012). Hence the present study is being carried out to find out the options for replacing the higher input energy requiring conventional maize-wheat cropping system under irrigated conditions of Himachal Pradesh.

MATERIALS AND METHODS

The study was conducted at Palampur, Himachal Pradesh during 2010–11, 2011–12, 2012–13 and 2013–14 under All India Co-ordinated Research Project on Integrated Farming Systems. The soil of the experimental site was acidic in reaction and silty clay loam in texture, having pH 5.60, organic C 0.99% and available N, P and K of 293, 63.0 and 113.0 kg/ha, respectively. Eight cropping systems were replicated four times in randomised block design, viz. maize-wheat, maize (green cob) + french bean (pole type)-pea-summer squash, maize + soybean-garlic, maize (green cob)-broccoli-potato, maize (green cob) + asparagus bean-radish-onion, maize (green cob) + urdbean-cauliflower-french bean, maize (green cob) + rice bean-cauliflower-buckwheat and maize (green cob) + asparagus bean-broccoli-radish. All crops were raised with recommended package of practices under irrigated conditions. Fertilizers particularly N, P and K were supplied as per recommended dose of the crops. Full dose of phosphorus and potassium and half dose of nitrogen were applied at the time of ploughing in all crops, except in french bean and buckwheat, where full dose of nitrogen was applied at ploughing. Application of remaining half of nitrogen for each crop was done at appropriate stages i.e. maize at knee-high and tesseling, in wheat at tillering and panicle initiation, in potato at earthing, in pea and summer-squash at 30 days after sowing (DAS), in garlic at 45 DAS, in radish at the time of root formation, in onion at initiation of bulb, in cauliflower and broccoli at 30 DAS and flowering. No additional dose of fertilizer was added

in maize + french bean, maize + asparagus bean, maize+rice bean and maize + urdbean, however, in maize + soybean additional dose of 7.5 kg N, 22.5 kg P and 7.5 kg K was applied in addition to recommended dose of fertilizer to maize. The total rainfall of 2,738 mm, 2,611 mm, 2,606 mm, 2,606 mm, was received during 2010–11, 2011–12, 2012–13 and 2013–14, respectively. Maize 'Early composite', french bean pole type 'Laxmi' as intercrop in maize-soybean 'Harit soya', asparagus bean 'DP ASB 1', urdbean 'P 93' and rice bean 'BRS II', were grown during rainy (*kharif*) season; and wheat 'HPW 155', Pea 'Palam Priya', garlic 'GHC 1', broccolli 'Palam Samridhi', radish (Early menu long white), cauliflower 'Palam Uphar', during winter (*rabi*) season and summer squash 'Australian green', potato 'Kufri jyoti', onion 'Patna Red', frenchbean 'Contender', buck-wheat 'Sangla B1', during summer season were raised under irrigated conditions. Frenchbean, asparagus bean and pea were used for vegetable purpose. Rice bean and urdbean were used for pulse purpose, while, soybean was used both as a pulse and oilseed crop. Buckwheat was used as leafy vegetable. The yield of *rabi*, *kharif* and summer crops were converted into maize grain equivalent yield (MGEY) by multiplying yield with prevailing price of produce and divided by price of maize in different years.

Energy values for various input and output used in the experiment are given in table 1 (Singh and Mittal, 1992). The total energy input for a given cropping system was calculated by adding the energy requirement for human labour, diesel, herbicides, farmyard manure (FYM) and the fertilizers used in that sequence. The energy output was calculated by accumulating the main product and by-product produced from different cropping systems. Subtracting input energy from output energy derived the net return of energy. The output: input ratio was worked out by dividing the total energy generated from main product and by-product by the total energy used for raising the crop in the unit area. The energy input and output were computed as Mega Joule (MJ) by using different formulae. The energy efficiency (EE) and specific energy (SE) were worked out as per Dazhong and Pimental (1984).

$$EE = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}; SE = \frac{\text{Total system output (MJ/ha)}}{\text{Maize equivalent yield (t/ha)}}$$

Energy output efficiency (MJ/ha/day) and energy productivity were calculated by:

$$\text{Energy output efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Duration of the system (days)}}$$

$$\text{Energy productivity} = \frac{\text{Maize-equivalent yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

RESULTS AND DISCUSSION

Energy input in cropping patterns

Energy inputs for different cropping systems were computed on the basis of mean for 4 years (Table 2). Out of total energy input, fertilizer accounted for a major share of energy input (46.5–60.4%) followed by FYM (16.4–24.9%), seed (1.4–22.9%), diesel (7.1–16.3%), human labour (1.6–2.2%) and herbicide/fungicides (0.9–2.4%). The energy input was minimum through herbicide/fungicides 0.9 to 2.4% followed by human labour (1.6 to 2.2%). The highest energy input was required for fertilizers for different cropping systems (22 to 42.7%). The highest energy input was recorded in maize (green cob)–broccoli–

potato (57.03×10^3 MJ/ha) followed by maize + asparagus bean–radish–onion (49.64×10^3 MJ/ha) and maize (green cob) + asparagus bean–broccoli–radish, (43.95×10^3 MJ/ha), whereas in existing maize–wheat cropping system the lowest energy input was required (28.68×10^3 MJ/ha). The highest energy inputs required for potato-based cropping system might be because it is labour intensive crop and the use of costly inputs like seed, fertilizer, pesticides and irrigation. Similarly the second highest energy input was used in maize+asparagus bean–radish–onion; this sequence also requires heavy doses of fertilizers, seedlings cost and labour intensive. The three-crop pattern with onion required energy inputs next to potato-based cropping

Table 1. Equivalents for various sources of energy

Particulars	Units	Equivalent energy (MJ)	
<i>Inputs</i>			
Human labour	Man-hour	1.96	
Diesel	Litre	56.31	
<i>Chemical fertilizers</i>			
N	kg	60.60	
P ₂ O ₅	kg	11.10	
K ₂ O	kg	6.70	
Farmyard manure	kg	0.3	
Chemicals	(i) Superior chemicals (chemicals requiring dilution at the time of application)	kg 120	
	(ii) Inferior chemicals (chemicals not requiring dilution at the time of application)	kg 10	
Seed	(i) Output of crop production system and not processed	kg -Same as that of output of crop production system	
	(ii) Output of crop production system and is processed before using it for seed	kg - add 1.5 and 0.5 MJ/kg for potato and other seeds respectively to the equivalent energy of the product of crop production system	
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Output	Units	Main product at harvest (MJ/kg)	By-product (dry mass) (MJ/kg)
Maize	kg	14.7	18.0
Wheat	kg	14.7	12.5
Buckwheat	kg	14.7	12.5
French bean	kg	14.7	10.0
Soybean	kg	14.7	10.0
Urdbean	kg	14.7	10.0
Rice bean	kg	14.7	10.0
Asparagus bean	kg	1.9	10.0
Pea	kg	1.6	10.0
Potato	kg	3.6	10.0
Garlic	kg	3.6	10.0
Onion	kg	1.6	10.0
Broccoli	kg	1.2	10.0
Cauliflower	kg	1.2	10.0
Radish	kg	1.6	10.0
Summer squash	kg	0.8	10.0

Source: Singh and Mittal (1992)

system. Same findings are reported by Walia *et al.* (2014) and Channabasavanna *et al.* (2007).

Energy output of different cropping patterns

Total energy output was computed from main product and by-product of different cropping systems and it ranged from 263.3 to 454.0 × 10³ MJ/ha (Table 3). The mean of 4 years revealed that the significantly the highest total energy output was obtained from maize (green cob) + french bean–pea–summer squash followed by maize (green cob)–broccoli–potato and maize (green cob) + rice bean–cauliflower–buckwheat. Maize–wheat cropping system resulted in 4th highest energy output (370.61 × 10³ MJ/ha), this might be due to higher by-product of energy of wheat compared to other winter (*rabi*) crops. Significantly the lowest energy output was obtained from maize + soybean–garlic over rest of cropping systems. This might be due to garlic being a condiment crop and not a energy yielding crop. Though the energy input used was also higher in maize (green cob) + asparagus bean–pea–summer squash, however, this cropping systems and other cropping systems are also efficient converter of energy and resulted in higher output compared to traditional maize–wheat cropping system. Walia *et al.* (2014) also reported similar findings.

Productivity of different cropping patterns

Maize (green cob) + asparagus bean–radish–onion, Maize (green cob) + french bean–pea–summer squash, Maize (green cob)–broccoli–potato gave 38.8, 28.1 and 25.6 t/ha of maize grain equivalent yield respectively, which was significantly superior to the most predominant maize–wheat (7.7 t/ha) cropping system, clearly indicating the superiority of these systems over maize–wheat cropping system. The higher productivity of these cropping systems might be due to higher yield of potato, radish, onion and summer squash. The addition of short duration crops like radish, summer squash, potato and onion between the two crops resulted in increased productivity of the system. These results are in conformity with the findings of Walia *et al.* (2014). Maize + asparagus bean–radish–onion gave 21.1 t/ha more maize grain equivalent yield as compared to traditional maize–wheat system. The maize grain equivalent yield of maize (green cob) + asparagus bean–broccoli–radish (23.4 t/ha), maize + soybean–garlic (20.4 t/ha), maize (green cob) + rice bean–cauliflower–buckwheat (17.7t/ha) was also significantly higher as compared to maize–wheat system. The results reveal that several options are available to diversify the existing maize–wheat cropping system, along with higher productivity/unit area/unit time and higher profitability with the inclusion of cash crops like vegetable and condi-

Table 2. Energy values (×10³ MJ/ha) in various inputs in system based crop diversification

Cropping systems	Human labour	Diesel	Seed	Herbicides/ Fungicides	FYM	Fertilizers	Total input
T ₁ Maize-wheat	0.45 (1.6)	4.05 (14.1)	1.76 (6.2)	0.56 (2.0)	6.00 (20.9)	15.85 (55.3)	28.68
T ₂ Maize (green cob) + french bean–pea–summer squash	0.82 (2.2)	6.08 (16.3)	1.69 (4.5)	0.90 (2.4)	9.00 (24.1)	18.79 (50.4)	37.28
T ₃ Maize + soybean–garlic	0.59 (1.6)	4.05 (11.1)	8.20 (22.4)	0.36 (1.0)	6.00 (16.4)	17.38 (47.5)	36.58
T ₄ Maize (green cob)–broccoli–potato	0.88 (1.5)	4.05 (7.1)	13.05 (22.9)	0.54 (0.9)	12.00 (21.0)	26.50 (46.5)	57.03
T ₅ Maize + asparagus bean–radish–onion	0.87 (1.7)	4.05 (8.2)	10.16 (20.5)	0.72 (1.5)	9.00 (18.1)	24.84 (50.0)	49.64
T ₆ Maize (green cob) + urdbean–cauliflower–french bean	0.78 (2.0)	6.08 (15.4)	1.70 (4.3)	0.90 (2.3)	9.00 (22.9)	20.92 (53.1)	39.38
T ₇ Maize (green cob) + rice bean – cauliflower–buckwheat	0.62 (1.7)	4.05 (11.2)	1.77 (4.9)	0.54 (1.5)	9.00 (24.9)	20.22 (55.8)	36.20
T ₈ Maize (green cob) + asparagus bean–broccoli–radish	0.83 (1.9)	6.08 (13.8)	0.61 (1.4)	0.90 (2.0)	9.00 (20.5)	26.53 (60.4)	43.95

*In parenthesis percent share in total input

ments in the cropping systems. Similarly results have been reported by Thakur *et al.* (2009).

Specific energy, energy output efficiency and energy productivity

The mean of 4 year shows that maize–wheat had significantly highest specific energy 3.8 MJ/kg over the other alternative cropping systems. Maize (green cobs) + rice bean – cauliflower–buckwheat cropping system has the second highest specific energy of (2.7 MJ/kg). This indicates that these cropping systems require higher inputs to produce a unit of produce. Channabasavanna *et al.* (2007) recorded the similar results. Maize (green cob) + asparagus bean–radish–onion and maize (green cob) + french bean–pea–summer squash consumed very low input to produce a unit of produce (1.3 MJ/kg) than the existing maize-wheat cropping system. Kachroo *et al.* (2012) also reported similar findings where inclusion of vegetables resulted in low input use/kg of produce. In case of energy output efficiency, maize (GC) + french bean–pea–summer squash has the highest energy output efficiency (1,500 MJ/ha) followed by maize–wheat and maize (green cob)+asparagus bean–broccoli–radish both being the second highest with energy output efficiency value of 1,300 MJ/ha among all cropping systems. Similar results were recorded by Nanda *et al.* (2008).

Average maximum energy productivity of 0.8 was obtained in maize (green cob) + french bean–pea–summer squash and maize (green cob) + asparagus bean–radish–onion cropping sequence, which might be due to higher energy output obtained in these cropping sequences. Inclusion of vegetables in the cropping systems increases the energy productivity from 30 to 60% as compared to maize–wheat cropping system. The energy use efficiency was significantly at par with maize (green cob) + French bean–pea–summer squash (12.2 MJ/ha) and maize–wheat cropping system (12.9 MJ/ha), thus suggesting that alternative cropping systems can replace the existing cropping system without any loss in economic yield. The findings of Walia *et al.* (2011) support the present results.

The maize (green cob) + asparagus bean–radish–onion gave the highest productivity (38.8 t/ha) and 1705×10^4 Kcal energy compared to maize–wheat system with a productivity margin of 31.1 t/ha. Maize + french bean–pea–summer squash cropping system was the second highest in productivity (28.1 t/ha) and 702×10^4 Kcal energy and having a increase of 20.4 t/ha over traditional maize–wheat cropping system. Maize (green cob)–broccoli–potato was the third highest yielder with a productivity of 25.6 t/ha and 1300×10^4 Kcal energy value.

Based upon four years study, it can be concluded that existing maize–wheat cropping system can be diversified

Table 3. Maize grain equivalent yield (t/ha) and energy pattern of different maize-based diversified cropping systems (4 years mean)

Cropping systems	MGEY (t/ha)	Duration (days)	Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Net return of energy ($\times 10^3$ MJ/ha)	Energy efficiency	Specific energy (MJ/kg)	Energy output efficiency ($\times 10^3$ MJ/ha/day)	Energy productivity (Kg/MJ)
T ₁ Maize–wheat	7.7	285	28.7	370.6	342.0	12.9	3.8	1.3	0.3
T ₂ Maize (green cob) + french bean–pea–summer squash	28.1	306	37.3	454.0	416.7	12.2	1.3	1.5	0.8
T ₃ Maize + soybean–garlic	20.4	337	36.6	263.3	226.7	7.2	1.7	0.8	0.6
T ₄ Maize (green cob)–broccoli–potato	25.6	309.3	57.0	376.6	319.6	6.6	2.4	1.2	0.4
T ₅ Maize + asparagus bean–radish–onion	38.8	327.8	49.6	345.7	296.1	7.0	1.3	1.1	0.8
T ₆ Maize (green cob) + mash–cauliflower–French bean	18.5	338.0	39.4	363.2	323.9	9.2	2.4	1.2	0.5
T ₇ Maize (green cob) + rice bean–cauliflower–buckwheat	17.7	326.0	36.2	374.9	338.7	10.4	2.7	1.2	0.5
T ₈ Maize (green cob) + asparagus bean–broccoli–radish	23.4	289.5	43.9	368.2	324.2	8.4	1.8	1.3	0.5
SEm \pm	4.1	11.8	-	29.0	28.9	0.8	0.1	0.1	0.1
CD (P=0.05)	8.4	24.4	-	59.7	59.7	1.6	0.3	0.2	0.2

with highest productivity (38.8 t/ha) and energy (1705×10^4 Kcal) producing maize (green cob) + asparagus bean–radish–onion cropping systems followed by maize (green cob) + french bean–pea–summer squash (28.1 t/ha productivity and 702×10^4 Kcal energy) and maize (green cob)–broccoli–potato (25.6 t/ha and $1,300 \times 10^4$ Kcal energy) cropping systems. These cropping systems are able to realize maximum net returns/unit area/unit time under mid-hill conditions of Himachal Pradesh and farmers can also easily market their produce because of diversity of produce including cereals, vegetables, pulses and oilseeds.

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