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Residual effect of organic amendments on growth, productivity, economics and agri-energetics of local popcorn (*Zea mays* everta) in toria (*Brassica campestris*) – popcorn cropping system under mid hills of Sikkim Himalayas

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ABSTRACT

Under organic management condition, it is presumed that the nutrients applied to preceding crops exhibits the considerable effect on succeeding crops, hence a fixed plot field experiment was conducted during three years (2011 to 2014) at Research Farm, National Organic Farming Research Institute (NOFRI), Tadong, Gangtok to assess the residual effect of mulching and vermicompost on growth, productivity, profitability and energetics of popcorn (*Zea mays everta*) under toria (*Brassica campestris*)-popcorn cropping system. The results revealed that the mulching materials applied to the preceding crops exhibited significant residual effect on growth, yield attributes and grain yield of succeeding popcorn over non-mulching (bare soil). However, among the mulching materials, rice straw mulch @ 5 t/ha exerted maximum residual effect and resulted in higher cob length (16.0 cm), cob girth (12.0 cm), grain yield (1.93 ha), stover yield (3.07 t/ha), net returns (72.8 × 10^3 ₹/ha), B:C ratio (2.87) and energy use efficiency (20.62%) of popcorn. With regards to the vermicompost levels, residual effect of vermicompost @ 1.5 t/ha recorded the maximum grain yield (1.9 t/ha), net returns (71.3× 10^3 ₹/ha), B:C ratio (2.81) and energy use efficiency (20.34%) of the succeeding popcorn under toria-popcorn cropping system.

Key words: Energy productivity, Energy use efficiency, Maize, Mulching, Toria, Vermicompost

Maize is the third most important cereal after wheat and rice and grown in virtually every agricultural region of the globe. In India, it is cultivated as food and feed crop under varying soils, topography, seasons and management practices throughout the country. In Sikkim, it is an important cereal crop grown in an area of 40000 ha.Generally, the crop is grown in *pre-kharif* season which starts from February to mid-March. Its productivity in Sikkim is 47 % lower than the national average (2.48 t/ha). Farmers of the state grow local popcorn (*Zea mays* everta) with very negligible amount of external inputs, which may be one of the reasons for lower productivity. Being an organic state, it is quite difficult to manage adequate supply of nutrients for proper plant growth and yield.

Nutrient-sufficiency is a desirable characteristic of agronomically sustainable cropping systems. Organic sources of nutrients applied to the preceding crops exhibit residual effects on succeeding crops due to slow decomposition process (Babu *et al.* 2013) particularly in acidic soil, hence fertilization must be done keeping the whole cropping system in view rather than the individual crops. Crop residue mulching is a novel technique for enhancing crop yield and reducing weed pressure besides improving soil health (Yadav *et al.* 2018). Achieving maximum profitability lies not only in reducing the use of input per unit area but also in lowering the cost per unit production through higher yields. Energy is an important valuable input for production in agriculture. Agriculture is also energy user and energy supplier in the form of bio-energy (Alam *et al.* 2005). Energy is an important indicator of crop performance and provides financial savings, fossil resource preservation and air pollution reduction (Uhlin 1998 and Yadav *et al.* 2017). Availability of sufficient energy and its effective and efficient use are prerequisites for improved agricultural production. Energy analysis, therefore, is necessary for efficient management of scarce resources for improved agricultural production. Other benefit of energy analysis is to determine the energy invested at every step of the production process (hence, identifying the steps that require least energy inputs) to provide a basis

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for conservation and aid in making sound management and policy decisions. Keeping the above in view, a fixed plot field experiment was conducted with the objective to assess the residual effect of mulching and vermicompost applied to the preceding toria on growth, productivity, profitability and energetics of local popcorn under toria (*Brassica campestris*)-popcorn cropping system.

MATERIALS AND METHODS

A fixed plot field experiment was conducted for three consecutive years (2011-12, 2012-13 and 2013-14) at Research Farm, ICAR-NOFRI, Tadong, Gangtok 1350 m above mean sea level situated at 27°32' N latitude and 88°60' E longitude. Soils of experimental field are clay loam in texture withpH 5.6 (1: 2.5 soil and water ratio), 225.5 kg/ha alkaline permanganate oxidizable N, 27.50 kg/ha Brays available P, 198.3 kg/ha 1 *N* ammonium acetate exchangeable K and 1.93% organic carbon.The experiment was laid out in split-plot design, assigning four types of mulching, viz. control (no mulching), tree leaf mulch @ 5 t/ha, maize stover mulch @ 5 t/ha and rice straw mulch @ 5 t/ha to main plots and three levels of vermicompost (control, vermicompost @ 1 t/ha and vermicompost @ 1.5 t/ha) to sub-plots. All the treatments were replicated four times during all the years. All the treatments were applied to the preceding toria. After proper field preparation, succeeding popcorn seed @ 20 kg/ha was sown manually during first week of March in both the years on residual fertility (no fertility treatment was given to popcorn).The seed was sown at 20 × 15 cm distance and 3-4 cm depth on side of the ridge. Recommended practices for weed control and other plant protection measures were adopted to raise the crop.Observation on yield attributes and yields were recorded as per the standard procedures. Cost of cultivation was computed based on the prevailing market prices of the inputs during the respective crop season. Gross returns were computed based on the grain and straw yield and their prevailing market prices during the respective crop season. Net return was computed by subtracting cost of cultivation from gross return.

Net return (₹/ha) = Gross return (₹/ha) – Cost of cultivation (₹/ha)

Benefit: cost (B: C) ratio was computed by using following expression:

B: C = Net return (₹/ha)/Cost of cultivation (₹/ha)

For energetics, the input energy was divided into direct and indirect and renewable and non-renewable forms (Hatirli *et al.* 2006). The direct energy consists of diesel, human power and electricity, while the indirect energy contains seed, farmyard manure and machinery (Singh *et al.* 2007). Total physical output referred to both grain/seed and by-product yields. To calculate the input energy, quantity/numbers of all inputs used in the form of labour, seed and manures used in both crops were taken into consideration and converted to energy equivalents by multiplying their per unit energy equivalents. The farm produce (seed yield+straw yield) was also converted into energy in terms of energy output (MJ) calculation on two years average crop yield multiplied by their energy equivalents per unit. Based on the energy equivalents of the input and output, energy use efficiency, energy productivity (Shahan *et al.* 2008), specific energy (Mohammad *et al.* 2010) was calculated.

Table 1 Energy equivalent used in calculation for computation of energetics

Item	Energy equivalent	References
Input		
Man labour (adult)	1.96 MJ/h	Babu (2012)
Women labour (adult)	1.57 MJ/h	Yadav *et al.* (2013)
Bullock pair (small)	8.07 MJ/h	Yadav *et al.* (2013)
Maize seed	15.2 MJ/kg	Yadav *et al.* (2013)
Biocide	120 MJ/kg	Singh (2000)
Farm machinery	62.7 MJ/h	Yadav *et al.* (2013)
Output		
Maize grain	14.7 MJ/h	Ozkan *et al.* (2004)
Maize stalk	18.0 MJ/kg	Yadav *et al.* (2013)

Energy use efficiency = Gross energy output (MJ/ha)/ Energy input (MJ/ha)

Energy productivity (kg/MJ) = [Total output (grain+stover) (kg/ha)]/Total energy input (MJ/ha)

Net energy output (MJ/ha) = Gross energy output (MJ/ha) – Energy input (MJ/ha)

Specific energy (MJ/kg) = Total energy input (MJ/ha)/Total output (grain+stover) (kg/ha)

All the data obtained from local popcorn for consecutive two years were statistically analysed 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 the treatment means.

RESULTS AND DISCUSSION

Growth attributes

Mean data of three years analysis showed significant residual effect of mulching on popcorn dry matter accumulation and leaf area index (LAI) at all the growth stages of crop (Table 2). All the mulches showed the significant effect on dry matter accumulation over control (no-mulch) at all the stages. However, among the mulching application of rice straw mulch @ 5 t/ha recorded significantly higher dry matter accumulation over other mulches and control (no-mulch) at all the growth stages. At harvest stage the increase in dry matter accumulation was 37.4, 31.3 and 12.7% higher with rice straw mulch @ 5 t/ha over control (no-mulch), tree leaf mulch @ 5 t/ha and maize stover mulch @ 5 t/ha, respectively. Similarly, LAI was also affected by the residual effect of mulching applied to the preceding toria crop and rice straw mulch @ 5 t/ha recorded significantly higher values at all the stages. The LAI was higher (4.1) at 60 days after sowing with paddy straw mulch @ 5 t/ha. The continuous supply of nutrients might

Table 2 Residual effect of mulching and vermicompost on dry matter accumulation and leaf area index of local popcorn under toria-popcorn cropping system (Mean data of three years)

Treatment	Dry matter accumulation (g/m)				Leaf area index (LAI)		
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS
Residual effect of mulching							
Control	45.03	119.33	313.12	393.42	1.29	2.49	2.40
Tree leaf mulch @ 5 t/ha	50.93	127.22	324.60	411.75	1.47	2.94	2.78
Maize stover mulch @ 5 t/ha	53.64	131.87	389.19	479.94	1.56	3.61	3.37
Rice straw mulch @ 5 t/ha	58.27	135.25	412.15	540.67	2.13	4.10	3.80
SEm±	0.54	0.89	3.64	1.98	0.01	0.02	0.02
LSD (*P*=0.05)	1.72	2.84	11.64	6.33	0.03	0.08	0.08
Residual effect of vermicompost (VC)							
Control	50.08	124.67	347.67	415.14	1.52	3.12	2.94
VC@ 1 t/ha	52.21	127.90	362.12	452.19	1.60	3.31	3.09
VC@ 1.5 t/ha	53.61	132.69	369.51	502.00	1.72	3.43	3.23
SEm±	0.17	0.53	1.95	1.24	0.02	0.02	0.03
LSD (*P*=0.05)	0.49	1.54	5.67	3.62	0.05	0.06	0.08

be the reason for higher growth resulting in the increase in dry matter accumulation and LAI with the application of mulches to the preceding toria crop.

Vermicompost applied to the toria crop produced significant effect on dry matter accumulation and LAI of popcorn at all the stages. Among the mulches, rice straw mulch @ 5 t/ha recorded significantly higher dry matter over control and vermicompost @ 1.0 t/ha at all the stages. The increase in dry matter accumulation was 20.9 and 11.0% higher with same treatment over control and vermicompost @ 1.0 t/ha at harvest stage, respectively. LAI at 30, 60 and 90 DAS recorded significantly higher values with application of vermicompost @ 1.5 t/ha over control and vermicompost @ 1.0 t/ha.

Yield attributes and yield

Mean data of three years revealed that mulching applied to the preceding crop exhibited significant effect on yield attributes and yield of succeeding popcorn (Table 3). Maximum values of cob length (16.0 cm), cob girth (12.0 cm), cob grain (256 nos.) and 1000-grain weight (201.8 g) was recorded with rice straw mulch @ 5 t/ha applied to the previous crop. Similarly, grain yield, stover yield, biological yield and harvest index were also significantly affected with application of mulches to previous crop and maximum values of all these parameters were recorded with application of rice straw mulch @ 5 t/ha to the previous toria crop. In general, rice straw mulch @5 t/ha recorded 38.8, 28.7 and 7.8% higher grain yield over control, tree

Table 3 Residual effect of mulching and vermicompost on yield attributes, yields and harvest index of local popcorn under toria-popcorn cropping system (Mean data of three years)

Treatment	Cob length (cm)	Cob girth (cm)	Grains/cob (Nos.)	1000 grain weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	HI (%)
Residual effect of mulching								
Control	13.5	11.0	206.2	184.4	1.39	2.28	3.67	36.3
Tree leaf mulch @ 5 t/ha	14.9	11.5	227.0	197.3	1.50	2.45	3.94	37.7
Maize stover mulch @ 5 t/ha	15.0	11.6	236.0	200.5	1.79	2.89	4.68	37.8
Rice straw mulch @ 5 t/ha	16.0	12.0	256.0	201.8	1.93	3.07	5.00	38.0
SEm±	0.3	0.2	3.90	3.8	0.04	0.05	0.09	0.31
LSD (*P*=0.05)	0.9	0.6	11.36	12.1	0.13	0.17	0.28	0.98
Residual effect of vermicompost (VC)								
Control	14.2	10.9	216.0	190.3	1.40	2.29	3.69	36.6
VC@ 1 t/ha	14.9	11.6	236.0	200.8	1.65	2.70	4.35	37.6
VC@ 1.5 t/ha	15.4	12.0	253.0	204.5	1.90	3.03	4.93	38.1
SEm±	0.2	0.2	2.48	3.0	0.04	0.05	0.07	0.36
LSD (*P*=0.05)	0.5	0.5	7.56	8.7	0.11	0.13	0.22	1.05

leaf mulch @ 5 t/ha and maize stover mulch @ 5 t/ha, respectively.The increase in yield was, perhaps, due to adequate amount of mineralized nutrients mainly N being slowly available to the plants from well decomposed rice straw, which induced high photosynthetic activity, vigorous growth and dark green colour of leaves (Tisdale *et al*. 2003). Improvement in growth of succeeding crop due to residual effect of crop residue has also been reported by Singh *et al.* (2005). The incorporation of crop residue to the previous crop influenced the physical condition, increased nutrient availability and crop production. Similarly increased grain yield of sunflower due to incorporation of previous crop stover has also been noticed by Babu *et al.* (2013).

Application of vermicompost to the previous crop also significantly affected the yield attributes and yield of popcorn and the maximum values of cob length, cob girth, cob grain (no.) and 1000-grain weight was recorded with the application of vermicompost @ 1.5 t/ha followed by 1.0 t/ha. Significant improvement of 35.7 and 18.2 % in grain yield of popcorn was found with the application of vermicompost @ 1.5 t/ha and 1.0 t/ha over control. Similarly, application of 1.5 and 1.0 t/ha vermicompost also registered 32.3 and 12.2 % higher stover yield over control. Residual effect of vermicompost increased the availability of nutrients to the crop which might be the reason for higher yield of popcorn.These results are corroborated with the findings of Jat and Ahlawat (2006).

Economics

Mean data of three years revealed that the cost of cultivation was same for all the treatments as vermicompost and mulching material was applied to the preceding crop (Table 4). Gross returns, net returns and B:C ratio were significantly affected by the application of mulches to the previous crop. With regards to gross returns, net returns and B:C ratio, among the mulches rice straw mulch @ 5 t/ha recorded higher values of gross returns (98.1× 10^3 ₹/ha), net returns (72.8× 10^3 ₹/ha) and B:C ratio (2.87) over control and other mulching materials. Similarly, different vermicompost levels was also exhibited significant effect on gross returns, net returns and B:C ratio and the maximum values were recorded with application of vermicompost @ 1.5 t/ha to the preceding toria crop. The higher productivity of popcorn under different mulches and vermicompost could lead the higher values of these parameters. Yield enhancement in wheat due to residual effect of mulching in preceding crop was also reported by Sharma (2010).

Energetics

Mean data on energetics of popcorn production is presented in Table 5. Data revealed that energy input was common to all the treatments as the mulching material and vermicompost were applied to the preceding crop. Application of mulches to the previous crop induced marked variation in gross and net energy output, energy use efficiency, energy productivity and specific energy. Application of rice straw mulch @ 5 t/ha recorded significantly higher gross energy output (83.66 GJ/ha), net energy output (79.60 GJ/ha), energy use efficiency (20.62%) and energy productivity (1.23 kg/MJ). This improvement in gross energy output, net energy output, energy use efficiency and energy productivity was 35.92,38.50, 36.01 and 35.16% thigher over control, respectively. However, the lowest value of energy intensity in physical terms or specific energy (0.82 MJ/kg) was recorded with rice straw mulch, which was 41.46, 26.82 and 8.53 % lower than the control (no mulch), tree leaf mulch @ 5 t/ha and maize straw mulch @ 5 t/ha, respectively.The output energy was determined by the amount and quality of harvestable biomass (Gelfand *et al.* 2010). In the present investigation, the maximum values of growth parameters and yield attributing characters were recorded under rice

Table 4 Residual effect of mulching and vermicompost on cost of cultivation, gross returns, net returns, B:C ratio, and energy input of local popcorn under toria-popcorn cropping system (Mean data of three years)

Treatment	COC (× 10^3 ₹/ha)	Gross returns (× 10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	B:C ratio	Energy input (GJ/ha)
Residual effect of mulching					
Control	25.34	70.5	45.2	1.78	4.06
Tree leaf mulch @ 5 t/ha	25.34	76.0	50.7	2.00	4.06
Maize stover mulch @ 5 t/ha	25.34	90.8	65.5	2.58	4.06
Rice straw mulch @ 5 t/ha	25.34	98.1	72.8	2.87	4.06
SEm±		2.0	2.0	0.08	
LSD (*P*=0.05)		6.5	6.5	0.26	
Residual effect of vermicompost (VC)					
Control	25.34	71.0	45.7	1.80	4.06
VC@ 1 t/ha	25.34	84.0	58.6	2.31	4.06
VC@ 1.5 t/ha	25.34	96.6	71.3	2.81	4.06
SEm±		1.8	1.8	0.07	
LSD (*P*=0.05)		5.3	4.3	0.21	

Table 5 Residual effect of mulching and vermicompost on gross and net energy output, energy use efficiency (EUE), energy productivity (EP) and specific energy of local popcorn under toria-popcorn cropping system (Mean data of three years)

Treatment	Gross energy output (GJ/ha)	Net energy output (GJ/ha)	EUE (%)	EP (kg/MJ)	Specific energy (MJ/kg)
Residual effect of mulching					
Control	61.52	57.47	15.16	0.91	1.16
Tree leaf mulch @ 5 t/ha	66.08	62.02	16.28	0.97	1.04
Maize stover mulch @ 5 t/ha	78.37	74.31	19.31	1.15	0.89
Rice straw mulch @ 5 t/ha	83.66	79.60	20.62	1.23	0.82
SEm±	1.49	1.49	0.37	0.02	0.02
LSD (*P*=0.05)	4.75	4.75	1.17	0.07	0.06
Residual effect of vermicompost (VC)					
Control	61.82	57.76	15.23	0.91	1.14
VC@ 1 t/ha	72.86	68.80	17.96	1.07	0.95
VC@ 1.5 t/ha	82.54	78.48	20.34	1.22	0.83
SEm±	1.24	1.24	0.31	0.02	0.02
LSD (*P*=0.05)	3.63	3.63	0.89	0.05	0.06

straw mulch, which ultimately produced higher grain and stover yields.

Vermicompost application to the preceding crop also significantly influenced the energetics of popcorn (Table 5). Among the different levels of application of vermicompost @ 1.5 t/ha recorded significantly higher values of gross energy output (82.54 GJ/ha), net energy output (78.48 GJ/ha), energy use efficiency (20.34%) and energy productivity (1.22 kg/MJ) over control and application of vermicompost @ 1.0 t/ha. Increase in energy use efficienciesis directly related to the harvestable biomass in any production system. Increased energy output and net energy due to application of vermicompost was also reported by Babu *et al.* (2016) and Deike *et al.* (2008).

Based on the three-year study, it may be concluded that application of rice straw mulch @ 5 t/ha and vermicompost @ 1.5 t/ha to the toria crop in toria-popcorn cropping system may result in higher productivity, profitability and energy productivity for popcorn in mid hills of Sikkim. Hence, it can be recommended for fetching higher yield of popcorn in toria-popcorn system under organic management condition.

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REFERENCES

Alam M S, Alam M R and Islam K K. 2005. Energy flow in agriculture: Bangladesh. *American Journal of Environmental Sciences* **1**(3): 213–20.

Babu Subhash, Rana D S Prasad D and Pal S.2013. Effect of sunflower stover and nutrients management on productivity, nutrient economy and phosphorus use efficiencies of pigeonpea (*Cajanus cajan*)-sunflower (*Helianthus annuus*) cropping system. *Indian Journal of Agricultural Sciences* **83**(2): 203–9.

Babu Subhash, Singh Raghavendra, Avasthe R K, Yadav G S, Chettri T K and Rajkhowa D J. 2016. Productivity, profitability and energetic of buckwheat (*Fagopyrum* spp.) cultivars as influenced by varying levels of vermicompost in acidic soils of Sikkim Himalayas, India. *Indian Journal of Agricultural Sciences* **86** (7): 844–8.

Deike S, Pallutt B and Christen O. 2008. Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. *European Journal of Agronomy* **8**: 461–70.

Gelfand I, Snapp SS and Robertson G P. 2010.Energy efficiency of conventional, organic and alternative cropping systems for food and fuel at a site in the U.S. Midwest. *Environmental Science and Technology* **44**(10): 4006–11.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research.* John Wiley & Sons, Singapore.

Hatirli S A, Ozkan B and Fert C. 2006. Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy* **31**: 427–38.

Jat R S and Ahlawat I P S.2006. Direct and residual effect of vermicompost, biofertilizers and phosphorus on soil nutrient dynamics and productivity of chickpea-fodder maize sequence. *Journal of Sustainable Agriculture* **28**: 41–54.

Mohammad A, Rafiee S, Mohtasebi S S and Rafiee H. 2010. Energy inputs – yield relationship and cost analysis of kiwifruit production in Iran. *Renewable Energy* **35**: 1071–5.

Ozkan B, Akcaoz H and Fert C.2004. Energy input–output analysis in Turkish agriculture. *Renew Energy* **29**: 39–51.

Shahan S, Jafari A, Mobli H, Rafiee and Karimi M. 2008. Energy use and economical analysis of wheat production in Iran: A case study from Ardabil Province. *Journal of Agricultural Technology* **4** (1): 77–88.

Sharma A R, Singh Ratan, Dhyani S K and Dubey R K. 2010.Effect of live mulching with annual legumes on performance of maize (*Zea mays*) and residual effect on following wheat (*Triticum aestivum*). *Indian Journal of Agronomy* 55 (3): 177–84.

Singh H, Singh A K, Kushwaha H L and Singh A. 2007. Energy consumption pattern of wheat production in India. *Energy* **32**: 1848–54.

Singh Y, Singh B and Timsina J. 2005. Crop residue management for nutrient cycling and improving oil productivity in rice based cropping system in tropics. *Advances in Agronomy* **85**: 269–407.

Tisdale S L, Nelson W L, Beaton J D and Havlin J L. 2003. *Soil Fertility and Fertilizers,* 5th Edn. Prentice-Hall of India, New Delhi.

Uhlin H E. 1998. Why energy productivity is increasing: an I-O analysis of Swedish agriculture. *Agricultural Systems* **56** (4): 443–65.

Yadav Gulab Singh, Das Anup, Lal R, Babu Subhash, Meena R S, Patil S B, Saha P and Datta M. 2018. Conservation tillage and mulching effects on the adaptive capacity of direct-seeded upland rice (*Oryza sativa* L.) to alleviate weed and moisture stresses in the North Eastern Himalayan Region of India. *Archives of Agronomy and Soil Science* https://doi.org/10.1080/03650340.2018.1423555

Yadav Gulab Singh, Lal R, Meena R S, Datta M, Babu Subhash, Das Anup, Layek J and Saha P. 2017. Energy budgeting for designing sustainable and environmentallyclean/safer cropping systems for rainfed rice fallow lands in India. *Journal of Cleaner Production* **158**: 29–37.

Yadav S K, Babu Subhash, Singh Y, Yadav G S, Singh K, Singh R and Singh H. 2013. Effect of organic nitrogen sources and biofertilizers on production potential and energy budgeting of rice (*Oryza sativa*)-based cropping systems. *Indian Journal of Agronomy* **58**(4): 9–14.

Yadav S N, Chandra R, Khura T K and Chauhan N S. 2013.Energy input–output analysis and mechanization status for cultivation of rice and maize crops in Sikkim. *Agricultural Engineering International CIGR Journal* **15**(3): 108–16. Open access at http://www.cigrjournal.org