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Integrated analysis of energy and resource use indicators in rose production systems in open-field and protected condition in India

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ABSTRACT

Comprehensive studies assessed the role of inputs on efficiency parameters in rose production systems in open-field and protected conditions at Bengaluru, India during 2017–2020. Results highlight that precision application of critical inputs based on assessment of crop demand contribute to 4-fold increase in flower yields and substantial accumulation of above-ground biomass in open-grown roses. The net return per each unit investment can be trebled in loose flower rose and doubled in cut flower rose. Critical inputs such as nutrients and water account for maximum energy consumption (93.5–94.7%). Loose flower rose registers better energy efficiency indices than cut flower rose. In protected condition, variations in flower yields, carbon stocks and energy efficiency indices are significant among rose genotypes. Arka Swadesh genotype is efficient in resource use accruing maximum net benefit per rupee investment. Nutrients are the maximum consumers of energy (41.2%) followed by irrigation (20.9%). In protected condition, the productivity levels are similar among nutrient levels implying lesser nutrient application is sufficient for rose due to higher efficiency indices and optimum soil fertility. The results imply that rose production systems are highly productive and sustainable at optimum input levels and would reduce environmental pollution due to higher resource use efficiencies.

1. Introduction

Crop production systems can be made sustainable and profitable by improving the efficiency of resources, energy and ecosystem services (Esengün et al., 2007; Pretty, 2008; Gyamfi et al., 2018; Wang et al., 2019). The present-day agriculture experiences recurring problems of stagnant productivity, soil fertility imbalances, biotic stresses and diminishing returns due to climate change. There are pressing demands for improving the crop productivity, quality and income through cleaner developmental mechanisms. Crop production practices influence the energy use and bio-energy generation (Mandal et al., 2002; Parihar et al., 2017). Energy consumption increases considerably due to regular use of fertilizers, pesticides, electricity, machinery and fossil fuels (Zhang et al., 2015; Saad et al., 2016). Scientific crop management combined with precision input application improves energy use and ecosystem indicators (Gyamfi et al., 2018; Paramesh et al., 2019; Kaab et al., 2019). (see Fig. 1)

Globally, flower crops are cultivated in 2 million hectares (ha) in several countries. Maximum area under flower crops is concentrated in China and India. India's share of floricultural exports in the global market is negligible (~0.61%). The export-oriented status is accorded to floriculture industry in India due to it's potential to grow @ 8–10% per annum. Roses (*Rosa* spp.) in the family *Rosaseae* are grown for variety of purposes and contribute to 60–70% of the cut flower trade in global market. As per estimates of National Horticultural Board (NHB, 2021), roses are cultivated in 30,000 ha in open-fields and in 650 ha in polyhouses in India. Rose production has to be increased at compound growth rate of 7.25% annually to meet the projected demand. Precision input management influences productivity and quality of flowers in *Rosa* spp (Raviv and Blom, 2001). The existing recommendations are divergent and are mostly pertinent to soilless culture in greenhouses.

Biomass and nutrient removal through harvesting and pruning is huge in perennial rose (Sujatha et al., 2020). Fertilizer applications are blanket and do not match crop nutrient demand resulting in nutrient imbalances and environmental pollution (He et al., 2009; Chuan et al., 2013). It is appropriate to consider nutrient removal pattern and soil fertility status for assessing nutrient demand and for achieving target yields (Wang et al., 2007). Energy use is quantified in vegetable and fruit crop systems (Gezer et al., 2003; Ozkan et al., 2004b, 2007; Canakci and Akinci, 2006). In rose, the status of energy use is indicated in survey report (Akbolat, 2006), but there is a need for systematic quantification of energy efficiency indices. Roses are intensive crops and the recommendations need to be optimized

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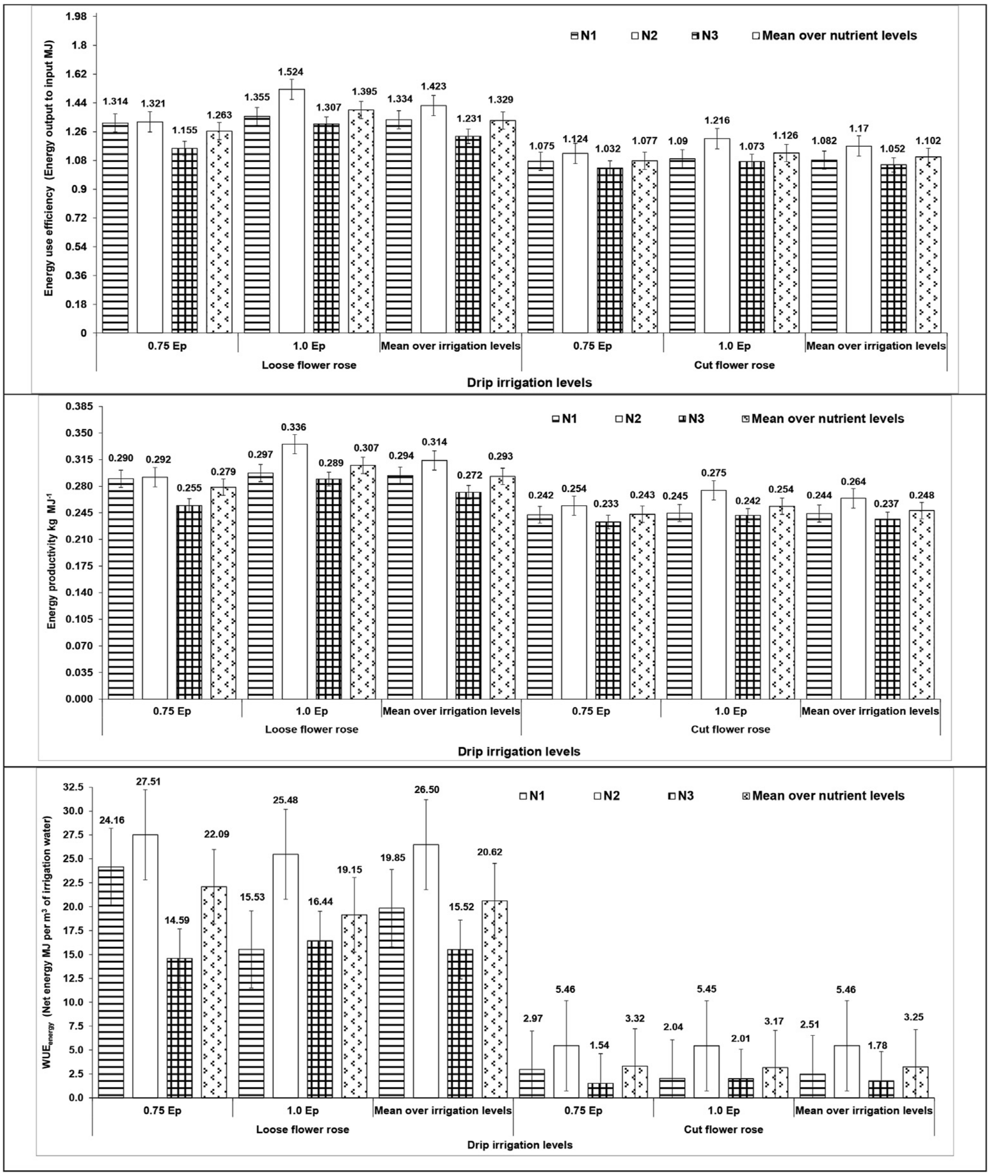

Fig. 1. Energy efficiency indicators in open grown roses during 2017–2020.

Table 1
Technical details of three experiments in open-field and protected conditions.

Open field	Polyhouse
Exp. 1. Loose flower rose (genotype Arka Parimala)	Exp. 3 Design: Strip-split plot
Design: Split- plot; Replications: 7	Replications: 3; No. of plants per treatment: 6
No. of plants per treatment: 4	
Exp. 2. Cut flower rose (genotype Arka Swadesh)	Main plots: Spacing (S) S_1: 40 cm × 20 cm
Design: Split- plot; Replications: 5	S_2: 45 cm × 15 cm
No. of plants per treatment: 6	
Main plots: Drip irrigation levels (I)	Sub plots: Genotypes (G)
I_1: 0.75 Ep	G_1: Arka Swadesh
I_2: 1.0 Ep	G_2: Arka Ivory
	G_3: Arka Pride
Sub-plots: Nutrient level + 2 kg FYM plant^{-1} or m^{-2} yr^{-1} (N)	Sub-sub plots: Nutrient level + 2 kg FYM m^{-2} yr^{-1} (N)
N_1: 50:6.5:50 g NPK	N_1: 40:4.3:42 g NPK
N_2: 60:8.7:58 g NPK	N_2: 50:6.5:50 g NPK
N_3: 70:10.9:66 g NPK	N_3: 60:8.7:58 g NPK
	N_4: 50:6.5:50 g NPK (1st yr) + soil-test based P application in 2nd yr

based on biomass/yield levels for precision input management. The possibility of cut flower cultivation in open-field is to be explored to meet the domestic demand. Further, there is a need to develop cost-effective module for cultivation of cut flowers in soil-based protected cultivation for export purposes. With this background, comprehensive studies were planned to assess the effects of input levels on productivity, economic and energy use indices in rose production systems.

2. Materials and methods

2.1. Description of study site

The present study was carried out in the experimental farm of ICAR-Indian Institute of Horticultural Research (ICAR-IIHR), Bengaluru, India (13^{o}7'N latitude, 77^{o} 29'E longitude, 890 m (m) above sea level) during 2017–2020. The climate at the study site is semi-arid. Mean temperature ranges between 15.9 and 33.9 °C. The soil is red sandy loam. Pre-experimental soil-test status indicated that the soil pH is near to neutral (6.7–6.8). The soil organic carbon (SOC) was 0.82% in open-field and 1.02% in protected condition. Total annual rainfall varied from 761 to 1061 mm (mm) during 2017–2020. The effective rainfall was 577 mm

Table 2
Input consumption pattern in different rose production systems as per treatment.

Field operation/input	Input consumption		
	Loose flower rose in open-field per ha yr^{-1}	Cut flower rose in open-field per ha yr^{-1}	Cut flower rose in protected condition per acre yr^{-1}
Establishment: Number of man days (one man day = 8 h) for preparation of beds, manure application, planting and laying out of drip system	40	40	62
Annual maintenance: Number of man days for field operations such as basin loosening, weeding, spraying, irrigation, fertigation, manure application, training, pruning, harvesting and post- harvest operations	140	150	142
FYM (t)	16	16	7.4
Micronutrients (kg)	8	8	3.7
Insecticides (kg)	0.6	0.6	4.8
Fungicides (kg)	0.3	0.3	2.4
Irrigation water (m^3 yr^{-1}) in different years 0.75 Ep 1.00 Ep	1062–1187 1180–2097	2123-3774 2359-4194	1272
Nutrient consumption (kg) at different nutrient levels applied on plant or m^2 basis per yr			
1. 40:4.3:42 g NPK (40:10:50 g $N:P_2O_5:K_2O$)	–		148 (N) 37 (P_2O_5) 185 (K_2O)
2. 50:6.5:50 g NPK (50:15:60 g $N:P_2O_5:K_2O$)	400 (N) 120 (P_2O_5) 480 (K_2O)		185 (N) 55.5 (P_2O_5) 222 (K_2O)
3. 60:8.7:58 g NPK (60:20:70 g $N:P_2O_5:K_2O$)	480 (N) 160 (P_2O_5) 560 (K_2O)		222 (N) 74 (P_2O_5) 259 (K_2O)
4. 70:10.9:66 g NPK (70:25:80 g $N:P_2O_5:K_2O$)	560 (N) 200 (P_2O_5) 640 (K_2O)		–

Table 3
Energy equivalents of different inputs and outputs used energy analysis.

Inputs	Unit	Energy equivalent (MJ U^{-1})	Reference
Labour	hr	1.96	Singh et al. (2002)
Tractor	hr	27.6	Fluck (1992)
Knapsack Sprayer	hr	1.4	Fluck (1992)
Plough	hr	10.8	Fluck (1992)
Disc Harrow	hr	17.8	Fluck (1992)
Nitrogen (N)	kg	60.6	Singh et al. (2002)
Phosphorus (P_2O_5)	kg	11.1	Singh et al. (2002)
Potassium (K_2O)	kg	6.7	Singh et al. (2002)
FYM	kg	0.3	Singh (2002)
Micronutrient	kg	120	Mandal et al. (2002)
Insecticides	kg	363.6	Pimental (1980)
Fungicides	kg	99	Fluck and Biard (1982)
Diesel	l	56.3	Singh et al. (2002)
Irrigation water	m^3	0.6	Akbolat et al. (2006)
Electricity	kWh	11.93	Esengün et al. (2007)
Rose flower	kg	4.2	Akbolat et al. (2006)
Crop residues/ wastes	kg	0.3	Navarro-Miró et al. (2019)
Plastics (in general)	kg	90	Canakci and Akinci (2006)

in 2018 and 923 mm in 2019. The average monthly pan evaporation (E_p) varied between 3.08 and 7.48 mm.

Table 4
Cumulative flower yield and biomass on fresh weight basis in open-grown roses (2017–2020).

Nutrient level (N) (g NPK $plant^{-1}$ or m^{-2} yr^{-1})	Drip irrigation levels (I)					
	Flower yield (t ha^{-1})					
	Loose flower rose			Cut flower rose		
	0.75 E_p	1.0 E_p	Mean	0.75 E_p	1.0 E_p	Mean
50:6.5:50	30.0	31.1	30.6	25.8	26.6	26.2
60:8.7:58	33.6	39.0	36.3	30.0	33.0	31.5
70:10.9:66	32.3	37.0	34.6	30.2	31.9	31.1
Mean	31.9	35.7	33.8	28.7	30.5	29.6
CD (p=0.05)	I: 3.62	N: 2.61	I x N: NS	I: NS	N: 2.39	I x N: 3.06
	Leaf and stalk biomass (t ha^{-1})					
50:6.5:50	97	108	103	67	75	71
60:8.7:58	107	130	119	74	85	79
70:10.9:66	105	121	113	77	86	81
Mean	104	120	112	73	82	77
CD (p=0.05)	I: 5.1	N: 3.7	I x N: NS	I: NS	N: 4.3	I x N: 5.9

2.2. *Treatment details*

Three experiments were conducted in open-field and protected conditions to optimize resource use for roses and the technical details are given in Table 1. In open-field, two experiments were initiated in loose flower genotype Arka Parimala (Experiment1) and cut flower genotype Arka Swadesh (Experiment 2) in September 2017. Arka Parimala (IC-574579) is a fragrant genotype with red flowers. Arka Swadesh (IC-0617933) is a cut flower cultivar with shiny foliage and flowers of attractive red colour. The experiment on cut flower roses (Experiment 3) was initiated in July 2017 in East-West oriented and naturally ventilated polyhouse with a ground area of 240 square meter (m^2). Three cut flower genotypes *viz.*, Arka Swadesh, Arka Ivory (IC-0617930) and Arka Pride (IC-0617937) identified at ICAR-IIHR were included as exotic rose cultivars are costly and less adaptable to diverse Indian conditions. During March–April, the internal temperature was maintained by placing 35% shade net at 2.5 m (m) height from the ground.

In open-field, budded plants were planted at 1.0 m × 1.0 m spacing in Arka Parimala and 0.5 m × 0.5 m in Arka Swadesh. The planting was done after leaving sufficient area for paths and drip lines for facilitating easy field operations. The flower buds were allowed only after four months. Straight fertilizers were used as sources of Nitrogen (N), Phosphorus (P) and Potassium (K). The water-soluble complex fertilizer (19:19:19 NPK) was also used in protected condition along with straight fertilizers. Farmyard manure (FYM) was used as source of organic manure. Standard management practices were followed. The North-South (NS) and East-West (EW) plant spread was measured in rose germplasm block at the Institute and the spacing for each genotype was fixed based on the spread.

Drip irrigation was scheduled based on pan evaporation and the data was collected from USWB Class A open pan evaporimeter of meteorological observatory in ICAR-IIHR. Total water use was estimated considering effective rainfall (20 mm and above). In 2018, irrigation water requirement was quantified at 884 mm for 0.75 E_p and 1179 mm for 1.0 E_p drip level. Similarly, it was 1401 mm for 0.75 E_p and 1868 mm for 1.0 E_p levels in 2019. Daily irrigation requirement was estimated by multiplying E_p with plant spacing, pan coefficient, wetted area and crop coefficient values. The crop coefficient values of 0.9 to 1.0 were considered (Baille et al., 1996; Karlik et al., 2003). Drip lateral was provided with a valve to control application of water and nutrients. Emitters with discharge rate of 4 L (L) per hour (hr) were placed at 20–25 cm (cm) distance from the base. Nutrient doses were fixed as gram (g) per plant or m^2 per year (yr) by assessing the crop demand based on biomass partitioning and nutrient removal pattern (ICAR-IIHR, 2018). It

Table 5
Economic analysis for open-grown roses at different nutrient levels.

Nutrient level (N) (g NPK yr^{-1} $plant^{-1}$ or m^{-2})	Economic indicators (USD ha^{-1} yr^{-1})					
	Annual maintenance cost (AMC)	Annuity value (AV) + drip fixed cost (DFC)	Total cost of cultivation (AMC + AV + DC)	Gross returns	Net returns	Net return per each USD investment (USD)
Loose flower rose						
50:6.5:50	1866	659	2524	10338	7813	3.10
60:8.7:58	1928	659	2587	12230	9643	3.73
70:10.9:66	1991	659	2650	11689	9039	3.41
Cut flower rose						
50:6.5:50	2002	1308	3310	9863	6553	1.98
60:8.7:58	2065	1308	3373	12080	8707	2.58
70:10.9:66	2128	1308	3436	12337	8902	2.59

Table 6
Cumulative energy flows and energy balance in open-grown roses during 2017–2020.

Nutrient level (N) (g NPK $plant^{-1}$ or m^{-2} yr^{-1})	Drip Irrigation level (I)					
	Loose flower rose			Cut flower rose		
	0.75 E_p	1.00 E_p	Mean	0.75 E_p	1.00 E_p	Mean
Energy input (MJ ha^{-1})						
50:6.5:50	103489	104582	104036	106513	108652	107583
60:8.7:58	115145	116238	115692	118169	120308	119239
70:10.9:66	126801	127894	127348	129825	131964	130895
Mean	115145	116238	115692	118169	120308	119239
CD ($p=0.05$)	I: NS	N: 3391	I x N: 4672	I: NS	N: 3885	I x N: 4999
Energy output (MJ ha^{-1})						
50:6.5:50	135979	141701	138840	114499	118427	116463
60:8.7:58	152136	177149	164642	132853	146342	139598
70:10.9:66	146417	167194	156805	133957	141582	137770
Mean	144844	162014	153429	127103	135450	131277
CD ($p=0.05$)	I: 5210	N: 4803	I x N: 6672	I: 3930	N: 3855	I x N: 4967
Net energy (MJ ha^{-1})						
50:6.5:50	32490	37119	34805	7986	9774	8880
60:8.7:58	36991	60911	48951	14684	26034	20359
70:10.9:66	19616	39299	29458	4132	9618	6875
Mean	29699	45776	37738	8934	15142	12038
CD ($p=0.05$)	I: NS	N: 3391	I x N: 4672	I: NS	N: 3391	I x N: 4672

ensures wider applicability of nutrient recommendations as that can be given per tonne (t) of flower yields. The major nutrients were fertigated in 12 equal splits in open-field and 24 equal splits per year in protected condition.

2.3. *Flower yield and biomass*

Number and weight of flowers/flower stalks were recorded in all plants at each harvest from 4th month after planting to March 2020. The flower yields of all harvests were added to arrive at total flower yields and were expressed in terms of kilogram (kg) or t per unit area. The flower diameter and stalk length were recorded at different periods. Biomass removed through pruning and harvesting was quantified in each treatment for arriving at total biomass produced from the system. Root:shoot ratio was computed by estimating root and shoot biomass through destructive sampling of two plants per treatment. Growth parameters were measured at regular intervals and utilized for discussion.

2.4. *Economic analysis*

All input and output data were recorded systematically for each experiment for computing economic benefits and energy flows. The annuity value was estimated on establishment cost considering 12% interest rate and economic yielding period as 10 years (Gattinger, 1981). For economic analysis, market rates for inputs and farm gate prices for planting material/economic produce were considered. The annual maintenance cost included cost of all inputs and man days for different field operations. The details of field operations and consumption pattern of production factors are given in Table 2. Total cost of cultivation was computed as sum of annuity value and annual maintenance cost. The farm gate price for flowers and single flower stalk was considered for estimating gross returns. The net returns in terms of United States Dollar (USD) ha^{-1} were computed by deducting the total cost of cultivation from gross returns. The net profit per each USD investment was worked out as the quotient of total cost of cultivation to net returns.

2.5. *Computation of energy inputs and outputs*

For estimation of energy inputs, all inputs *viz.*, tractor, diesel, electricity, human labor, irrigation water, plastics, manures, fertilizers, insecticides, fungicides, sprayer etc., were considered. The flower yields and biomass removed through pruning and harvests were considered for calculation of energy output. For computation of energy flows in Mega Joules (MJ), energy coefficients from published reports were applied to convert inputs and outputs to their energy equivalents (Table 3). The energy use indicators were computed using following formulas (Mittal and Dhawan, 1989; Demircan et al., 2006).

$$\text{Net energy }(\text{NE},\cdot\text{MJ ha}^{-1}\cdot\text{or}\cdot\text{acre}^{-1}) = \frac{\text{Energy output }(\text{MJ ha}^{-1}\text{ or acre}^{-1})}{-\text{Energy input }(\text{MJ ha}^{-1}\text{ or acre}^{-1})} \tag{1}$$

$$\text{Energy use efficiency (EUE)} = \frac{\text{Energy output }(\text{MJ ha}^{-1}\text{ or acre}^{-1})}{\text{Energy input }(\text{MJ ha}^{-1}\text{ or acre}^{-1})} \tag{2}$$

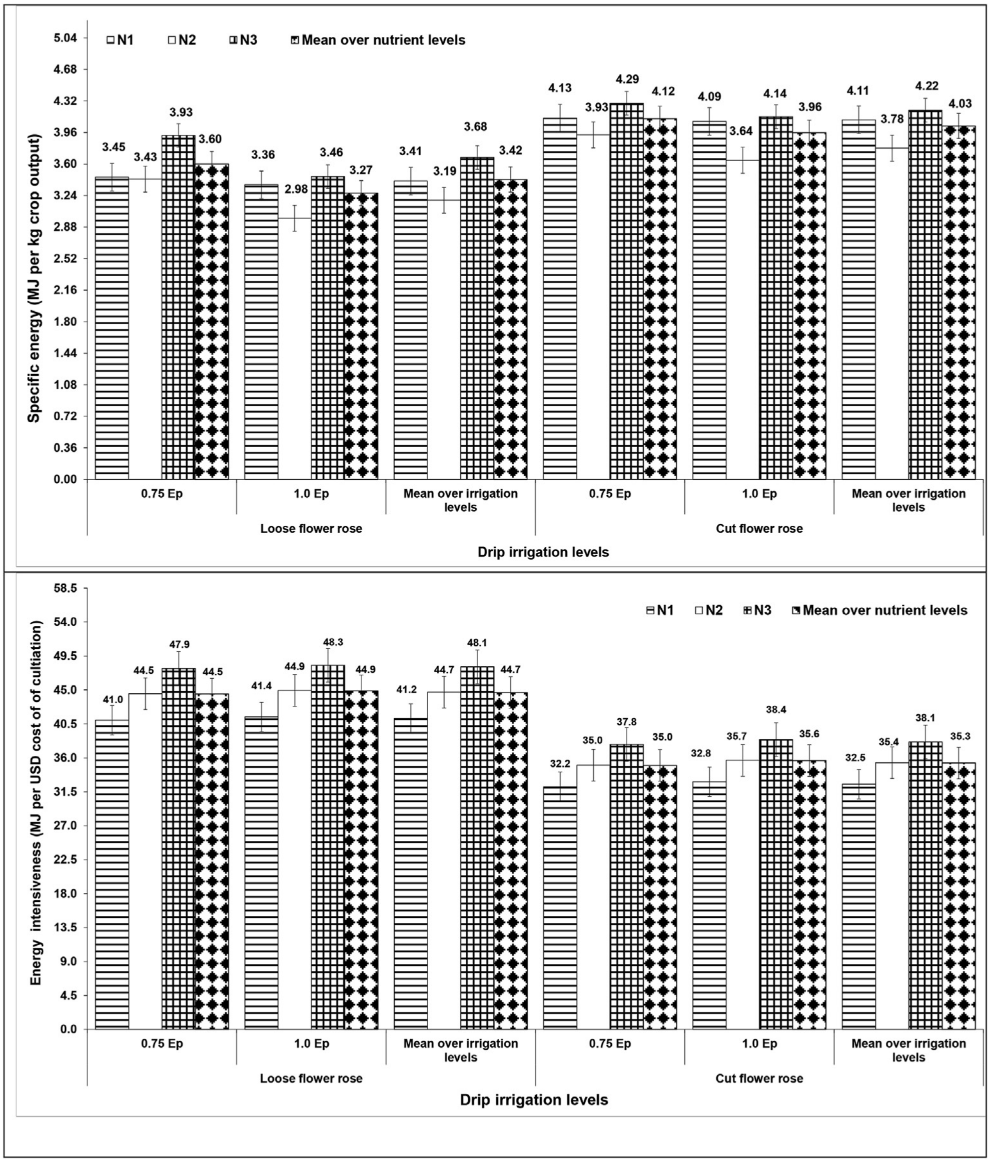

Fig. 2. Energy efficiency indicators in open grown roses at different input levels.

$$\text{Energy productivity (EP, kg MJ}^{-1}) = \frac{\text{Crop output (kg ha}^{-1}\text{ or acre}^{-1})}{\text{Energy input (MJ ha}^{-1}\text{ or acre}^{-1})} \tag{3}$$

$$\text{Energy water use efficiency (WUE}_{\text{energy}}\text{, MJ m}^{-3}\text{ of water}) = \frac{\text{Net energy (MJ ha}^{-1}\text{ or acre}^{-1})}{\text{Water applied (m}^{3})} \tag{4}$$

$$\text{Specific energy (SE, MJ kg}^{-1}) = \frac{\text{Energy input (MJ ha}^{-1}\text{ or acre}^{-1})}{\text{Crop output (kg ha}^{-1}\text{ or acre}^{-1})} \tag{5}$$

$$\text{Energy intensiveness (EI, MJ USD}^{-1}) = \frac{\text{Energy input (MJ ha}^{-1}\text{ or acre}^{-1})}{\text{Cost of cultivation (USD ha}^{-1}\text{ or acre}^{-1})} \tag{6}$$

2.6. Estimation of soil fertility parameters

Soil samples were collected at 0–30 cm depth and at 15 cm distance from the base of the plant. The air-dried soil samples were ground and passed through 2.0-mm sieve and kept in labelled plastic bags for further analysis. Soil pH, organic carbon and available nutrients such as P, K, calcium (Ca), Magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were analyzed as per Jackson (1973). Leaf nutrient analysis was also done for all components of above ground biomass for computing nutrient absorption efficiencies.

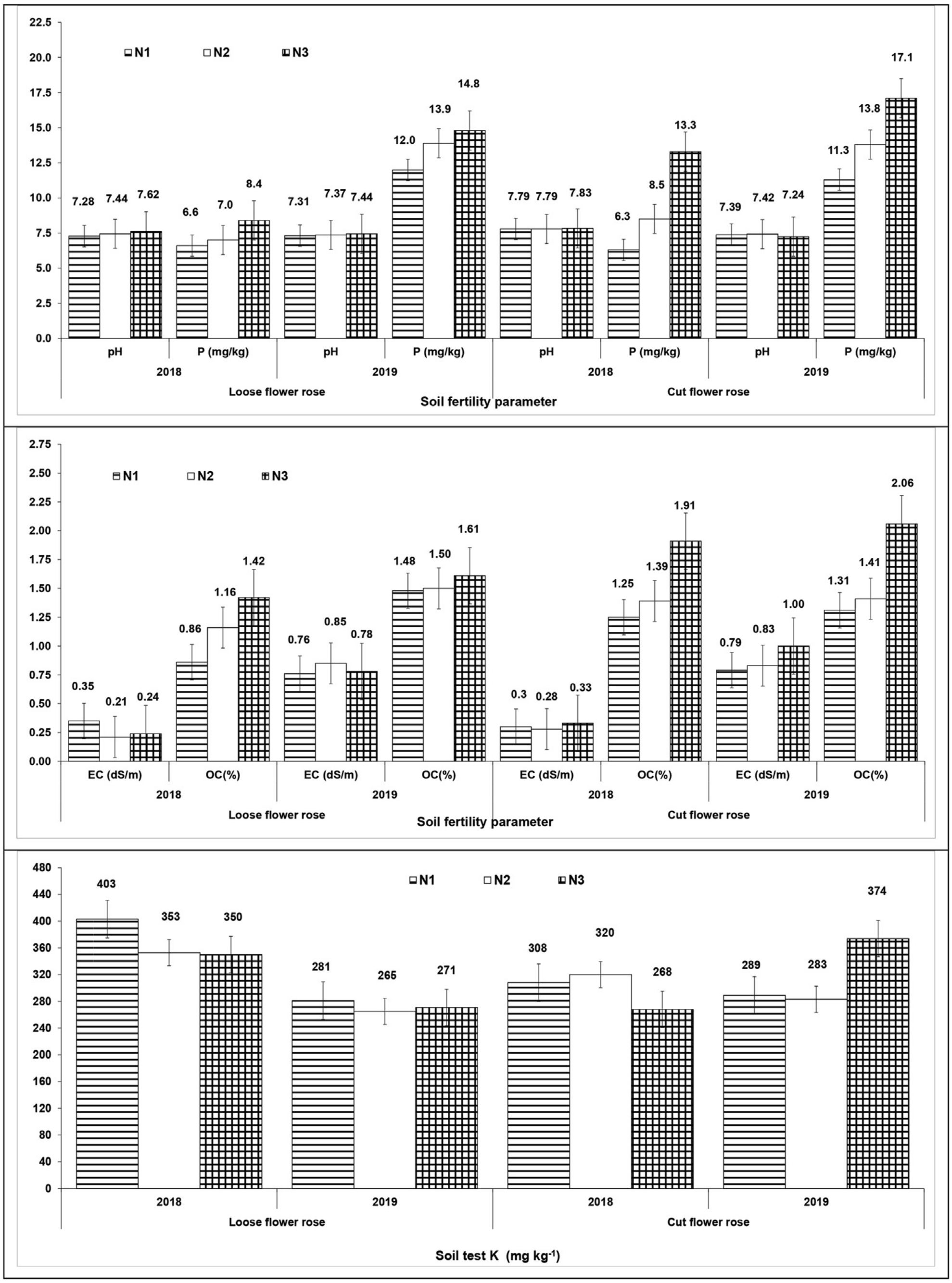

Fig. 3. Soil fertility variations in loose and cut flower roses in open-field.

2.7. Statistical analysis

All data were analyzed using SPSS for ANOVA tables and Microsoft Excel for correlations. The significant differences between the two means are indicated by LSD (5%) values in the tables. Correlations were done for substantiating the relations between important parameters.

3. Results and discussion

3.1. Rose production systems in open-field

3.1.1. Flower yields and quality

There was differential response to drip irrigation in loose and cut flower roses in terms of flower yields (Table 4). In loose flower rose, drip irrigation at 1.0 E_p registered significantly higher cumulative yields (35.7 t ha^{-1}) than at 0.75 E_p (31.9 t ha^{-1}). Flower yields (t ha^{-1}) were similar in NPK levels of 60:8.7:58 (36.3) and 70:10.9:66 g $plant^{-1}$ (34.6), which were significantly superior to lower NPK level of 50:6.5:50 (30.6). On an average, loose flower rose registered flower yield of 16.9 t ha^{-1} yr^{-1} that was four times higher than average productivity in India (3.85 t ha^{-1}). Loose flower rose registered 10–30% long flower stalks and flower diameter of 6.5–10.1 cm in different seasons.

In cut flower rose, drip levels of 0.75 E_p (28.7 t ha^{-1}) and 1.0 E_p (30.5 t ha^{-1}) recorded similar flower yields (Table 4). The nutrient levels of 60:8.7:58 and 70:10.9:66 g NPK registered similar yields (31.1–31.5 t ha^{-1}), but were significantly superior to 50:6.5:50 g NPK (26.2 t ha^{-1}). Stalk length is an important quality parameter in cut flower rose and long flower stalks (> 50 cm) accounted for 52% of total yields in open-field. The stalk length varied from 47.8 to 77.9 cm and flower diameter from 6.3 to 7.9 cm. Application of 60:8.7:58 g NPK would be

Table 7
Cumulative flower and biomass yields in cut flower rose in protected condition during 2017–2019.

Nutrient level (N) (g NPK m^{-2} yr^{-1})	Spacing (S) and genotypes (G)								Overall mean
	45 cm × 15 cm				40 cm × 20 cm				
	Arka Swadesh	Arka Ivory	Arka Pride	Mean	Arka Swadesh	Arka Ivory	Arka Pride	Mean	
Cumulative flower yields (t $acre^{-1}$)									
40:4.3:42	21.8	20.2	16.7	19.6	23.7	19.5	18.1	20.4	20.0
50:6.5:50	26.0	20.0	16.5	20.8	26.0	20.7	14.6	20.4	20.6
60:8.7:58	22.3	19.1	14.2	18.5	24.6	21.6	14.4	20.2	19.4
50:6.5:50 (1st yr) + soil test-based P appl. (2nd yr)	26.0	20.3	16.5	20.9	25.9	23.0	14.5	21.1	21.0
Mean	24.0	19.9	16.0	20.0	25.1	21.2	15.4	20.5	20.2
Mean for genotypes	24.5	20.5	15.7						
CD (*p=0.05*) for S: NS G: 2.71 N: NS S x N: NS G x N: 3.33									
Leaf and stalk biomass (t $acre^{-1}$)									
40:4.3:42	36.7	37.3	40.4	38.1	46.8	36.0	34.4	39.1	38.6
50:6.5:50	39.5	31.4	36.0	35.6	42.4	38.3	34.2	38.3	37.0
60:8.7:58	45.0	28.0	24.5	32.5	46.0	26.6	31.8	34.8	33.7
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	42.2	32.4	36.9	37.2	42.5	43.8	30.2	38.8	38.0
Mean	40.9	32.3	34.5	35.9	44.4	36.2	32.6	37.7	36.8
Mean for genotypes	42.6	34.2	33.5						
CD (*p=0.05*) for S: NS G: 3.49 N: 2.57 S x N: NS G x N: 4.45									

Table 8
Economic analysis (USD acre-1 yr-1) of cut flower rose in protected condition.

Nutrient level (N) (g NPK m^{-2} yr^{-1})	Spacing and cut flower genotypes					
	Annual Maintenance cost (AMC) USD $acre^{-1}$ yr^{-1}	Total cost of cultivation (AV + AMC) USD $acre^{-1}$ yr^{-1}	Net return per each USD investment (USD)			
			Arka Swadesh	Arka Ivory	Arka Pride	Mean
	45 cm × 15 cm spacing					
40:4.3:42	1779	10456	1.49	1.33	1.69	1.50
50:6.5:50	1861	10538	2.18	1.18	1.31	1.56
60:8.7:58	1943	10620	1.82	1.14	0.97	1.31
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	1848	10525	2.14	1.26	1.38	1.59
Mean	–	–	1.91	1.23	1.34	1.49
Annuity value (AV)	8677	–				
	40 cm × 20 cm spacing					
40:4.3:42	1765	10076	1.77	1.15	1.58	1.50
50:6.5:50	1848	10158	2.20	1.36	1.26	1.60
60:8.7:58	1930	10240	1.90	1.43	1.35	1.56
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	1834	10144	2.15	1.42	1.42	1.66
Mean			2.00	1.34	1.40	1.58
Annuity value (AV)	8311					

optimum for both loose and cut flower roses in open-field condition as substantiated by higher agronomic nutrient use efficiency (ANUE) in loose flower (15.4 kg flowers produced per kg nutrient applied) and cut flower roses (2238 flower stalks per kg nutrient). Earlier reports emphasized the significance of precision input management based on crop nutrient demand (Cabrera et al., 1995a; Pal and Singh, 2013; Rene et al., 2017).

3.1.2. *Leaf and stalk biomass*

The leaf and stalk biomass in loose flower rose was quantified at 112 t ha^{-1} during experimental period (Table 4). The cumulative leaf and stalk biomass was significantly higher at 1.0 E_p drip irrigation (120 t ha^{-1}) than at 0.75 E_p (104 t ha^{-1}). The NPK levels of 60:8.7:58 and 70:10.9:66 g (113–119 t ha^{-1}) were significantly superior to 50:6.5:50 g NPK in terms of cumulative leaf + stalk biomass (103 t ha^{-1}).

In cut flower rose, cumulative leaf and stalk biomass accounted for 77 t ha^{-1} (Table 4). Drip irrigation had significant effect on cumulative leaf and stalk biomass (73 t ha^{-1} at 0.75 E_p and 82 t ha^{-1} at 1.0 E_p). Increased NPK application contributed to significant increase in production of leaf and stalk biomass at higher nutrient levels of 60:8.7:58 (79 t ha^{-1}) and 70:10.9:66 g NPK (81 t ha^{-1}) over 50:6.5:50 g NPK (71 t ha^{-1}).

Overall, there were huge differences in total biomass production in loose flower rose (145.8 t ha^{-1}) and cut flower rose (106.6 t ha^{-1}) that can be attributed to variations in planting density, growth habit, canopy spread (0.85–0.89 m in Arka Parimala and 0.48–0.50 m in Arka Swadesh), root:shoot ratio and yield levels. The differences in nutrient absorption efficiencies in loose (74% for N, 63% for P and 48% for K) and cut flower roses (52% for N, 50% for P and 43% for K) substantiate these results.

3.1.3. *Economic indicators*

The economic indicators in open-grown roses are presented in Table 5. The total cost of cultivation varied from 2524 to 2650 USD ha^{-1} yr^{-1} among different nutrient levels. The net returns varied from 7813 to 9643 USD ha^{-1} yr^{-1}. The net return per rupee investment varied from 3.10 at 50:6.5:50 g NPK to 3.73 at 60:8.7:58 g NPK level. The cost of cultivation per year for cut flower rose ranged between 3310 and 3436 USD ha^{-1} (Table 5). The net returns varied from 6553 to 8902 USD ha^{-1} yr^{-1}. The net return per each USD investment increased from 1.98 to 2.59 with increase in NPK application. Overall, the loose flower rose accrued higher net return of 3.73 per each USD investment at 60:8.7:58 g NPK level than cut flower rose (2.58). This is due to lower establishment cost, higher yields, better response to critical inputs and higher net returns in loose flower rose.

Table 9
Energy use indicators in cut flower rose at different input levels.

Nutrient level (N) (g NPK m^{-2} yr^{-1})	Energy input (MJ acre^{-1})	Spacing (S) and genotypes (G)							
		45 cm × 15 cm				40 cm × 20 cm			
		Arka Swadesh	Arka Ivory	Arka Pride	Mean	Arka Swadesh	Arka Ivory	Arka Pride	Mean
		Energy output (MJ acre^{-1})							
40:4.3:42	71607^{c}	102398	95971	85266	94545	113459	92504	86499	97487
50:6.5:50	76638^{b}	121016	93305	79874	98065	121902	98226	71391	97173
60:8.7:58	82389^{a}	107136	88778	66964	87626	117238	98560	69824	95207
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	76382^{b}	121692	94895	80496	99028	121507	109536	69793	100279
Mean	76754	113060	93237	78150	94816	118526	99706	74377	97537
Mean for genotypes	–	115793	96472	76263					
		CD ($p=0.05$) for S: 2123 G: 1987 N: 1572 S x N: NS G x N: 2415							
	Energy intensiveness (MJ USD^{-1})	Net energy (MJ acre^{-1})							
40:4.3:42	6.98^{a}	30791	24364	13659	22938	41852	20897	14892	25880
50:6.5:50	7.41^{a}	44378	16667	3236	21427	45264	21588	−5247	20535
60:8.7:58	7.90^{a}	24747	6389	−15425	5237	34849	16171	−12565	12818
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	7.39^{a}	45310	18513	4114	22646	45125	33154	−6589	23897
Mean	7.42	36306	16483	1396	18062	41772	22952	−2377	20783
Mean for genotypes	–	39039	19718	−491					
		CD ($p=0.05$) for S: 929 G: 802 N: 782 S x N: 1255 G x N: 1129							

3.1.4. *Energy flows*

The energy flows in open-grown roses were significantly influenced by nutrient levels and their interaction with irrigation levels (Table 6). Drip irrigation had significant effect on energy output. The average energy input and output in loose flower rose were estimated at 115692 and 153429 MJ ha^{-1}, respectively. The net energy accounted for 33% and 25% of total energy input and output, respectively. Application of 60:8.7:58 g NPK resulted in 41% increase in net energy over 50:6.5:50 g NPK. Higher NPK application of 70:10.9:66 g significantly reduced the NE by 5347–19493 MJ ha^{-1}. These results highlight the need for optimizing input use due to considerable energy wastage at higher nutrient level. In cut flower rose, average energy input and outputs were 119239 and 131277 MJ ha^{-1}, respectively. The net energy accounted for 10% and 9% of total energy input and output, respectively. The increase in NE by 129% in 60:8.7:58 g NPK over 50:6.5:50 g NPK indicates definite role of inputs in improving energy efficiency.

The critical inputs contributed to maximum energy consumption in loose (94.7%) and cut flower roses (93.5%). Drip irrigation accounted for 26.4% of total energy input in open-grown roses. Nutrient inputs contributed to energy consumption of 65.5–71.8% in loose flower rose and 63.3–69.9% in cut flower rose. Similar results are reported by earlier workers on energy use in crops (Mandal et al., 2002; Gyamfi et al., 2018).

3.1.5. *Energy efficiency indices*

3.1.5.1. Loose flower rose. The indices of energy efficiency for open-grown roses are depicted in Figures (Fig.) 1 and 2. Drip irrigation and nutrition levels, and their interactions had significant effects on EUE (2) and EP (3) in loose flower rose. Drip irrigation at 1.0 E_p registered higher EUE of 1.395 than 0.75 E_p (1.263). The NPK levels of 60:8.7:58 (1.423) and 70:10.9:66 (1.334) were more efficient in energy use than 50:6.5:50 g NPK (1.231). The energy productivity (kg flowers MJ^{-1}) was higher at 60:8.7:58 (0.314) than other nutrient levels (0.272–0.294). The EP levels are higher in this study compared to published reports on rose and other crops (Akbolat et al., 2006; Ozkan et al., 2004a; Canakci and Akinci, 2006).

The energy WUE (MJ m^{-3} of water) was unaffected by drip irrigation (19.15–22.09), but varied significantly among nutrient levels. The NPK level of 60:8.7:58 (26.5) was more efficient in energy water use than 50:6.5:50 (19.85) and 70:10.9:66 NPK levels (15.52). The specific energy (MJ per kg yield) was similar at 0.75 Ep (3.60) and 1.0 E_p drip levels (3.27). Similar trend was noticed in energy intensiveness (44.5–44.9 MJ USD^{-1} cost of cultivation). Higher energy input along with lower crop output resulted in significantly higher SE of 3.68 (3) and EI (48.1 MJ USD^{-1}) in NPK level of 70:10.9:66.

3.1.5.2. Cut flower rose. In cut flower rose, drip irrigation levels had similar effects on EUE (1.077–1.126) and EP (0.243–0.254 kg flowers MJ^{-1}). The EUE was significantly higher at NPK level of 60:8.7:58 g (1.170) than at other levels (1.052–1.082). Similarly, energy productivity was significantly higher in NPK level of 60:8.7:58 g (0.264 kg flowers MJ^{-1}) over other levels (0.237–0.244 kg flowers MJ^{-1}). The WUE_{energy} (4) was similar at two drip irrigation levels (3.17–3.32), but varied significantly among nutrient levels (1.78–5.46). The SE (MJ per kg yield) was unaffected by drip irrigation levels (3.96–4.12), but significant among nutrient levels with higher value at 70:10.9:66 g NPK (4.22). Higher NPK application resulted in significant increase in EI (38.1 MJ USD^{-1}) due to increased energy input and reduced crop output.

Overall, nutrition had more impact on energy use indices than drip irrigation. However, the synergistic effects of drip irrigation and nutrition on energy parameters were discernible. Loose flower rose is more efficient in energy use than cut flower rose. This can be further substantiated by higher correlations between energy indices and economic output in loose flower rose (r = 0.736 to 0.939** for biomass and r = 0.573–0.744** for flower yields) than in cut flower rose (r = 0.472–0.804** for biomass and r = 0.459–0.756** for flower yields). However, the SE was higher in cut flower rose (4.04 MJ per kg flower yield) than in loose flower rose (3.43 MJ per kg yield). Sustainable yield index of 0.66–0.82 in open-grown roses emphasize that rose production systems are not only productive but also sustainable. These findings are in agreement with earlier reports (Zhang et al., 2015; Gyamfi et al., 2018) (see Fig. 2).

3.1.6. *Soil fertility variations*

Soil fertility parameters were unaffected by drip irrigation, but were significant among nutrient levels without any definite trend (Fig. 3). In 2019, nutrient levels registered similar soil pH (7.31–7.44), electrical conductivity (EC, 0.76–0.85 dS m^{-1}), SOC (1.48–1.61%), and soil available P (12.0–14.8 mg kg^{-1}) and K (265–281 mg kg^{-1}). The soil-test values (mg kg^{-1}) of Ca (2112–2145), Mg (903–961), Cu (3.7–5.3), Zn (6.6–10.1), Fe (21.7–26.3) and Mn (17.8–25.2) were optimum. Enrichment in SOC by 0.73% and root:shoot ratio of 0.22 were noticed in loose

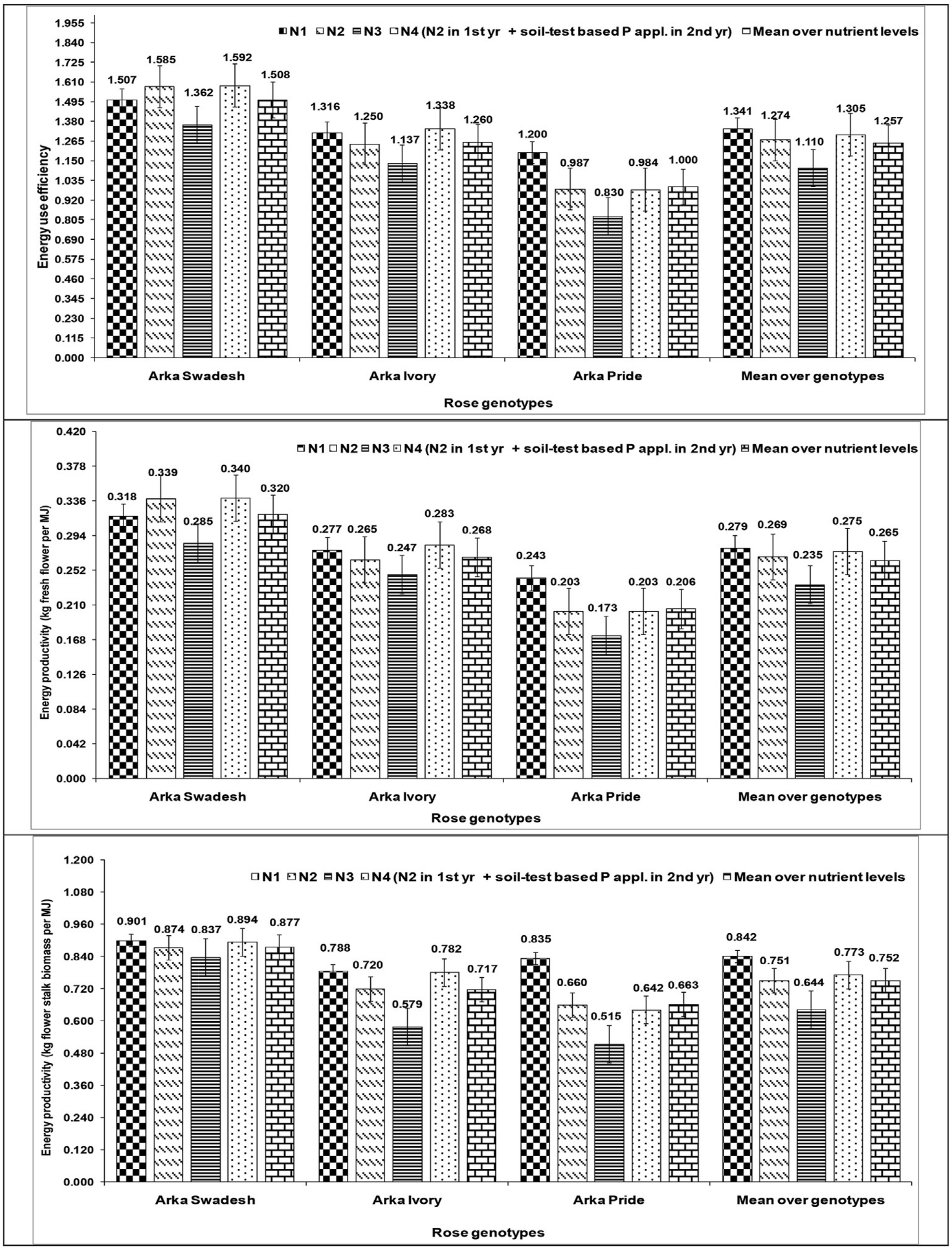

Fig. 4. Energy efficiency indicators in cut flower rose in protected cultivation.

flower rose indicating it's carbon sink capacity.

In cut flower rose, nutrient levels maintained similar soil pH (7.24–7.39), and soil available P (14.0–14.2 mg kg^{-1}) and K (267–364 mg kg^{-1}) levels except in case of SOC (1.31–2.06%). The increased nutrient application resulted in enrichment of SOC from 1.25 to 1.91% in 2018 and 1.31 to 2.06% in 2019. The soil availability (mg kg^{-1}) of Ca, Mg, Cu, Zn, Fe and Mn ranged between 2065 and 2317, 873–1013, 3.9–6.1, 6.8–8.5, 29.0–27.3 and 24.4–28.4, respectively. The SOC enrichment was more in cut flower rose than in loose flower rose. This can be attributed to higher plant density, higher root/shoot ratio (0.24), less soil disturbance and *in situ* root decay (Bhat et al., 2007).

3.2. Rose production systems in protected condition

3.2.1. Flower yields and quality

In protected condition, cumulative flower yields were similar in planting densities of 12 and 15 plants per m^2 (19.95–20.53 t acre^{-1}) as yields per plant were lower at higher planting density (Table 7). Among genotypes, the flower yields (t acre^{-1}) were significantly higher in Arka Swadesh (24.53) than Arka Ivory (20.53) and Arka Pride (15.68). The flower yields (t acre^{-1}) were higher at 50:6.5:50 g NPK (20.60) than at 60:8.7:58 g NPK level (19.36). The interaction of genotypes and nutrient levels was significant. The nutrient level of 40:4.3:42 g NPK (17.42–22.72 t acre^{-1}) registered yield levels either higher or similar to 50:6.5:50 g NPK (15.5–25.99 t acre^{-1}) in all genotypes. The stalk length was more in Arka Swadesh (71.0 cm) followed by Arka Pride (68.2 cm) and Arka Ivory (67.8 cm). Overall, about 51.4% of total flower stalks were long (> 60 cm) and the flower diameter (cm) ranged between 7.5 and 8.2 in Arka Swadesh, 7.9–9.1in Arka Ivory and 7.5–7.8 in Arka Pride.

3.2.2. Leaf and stalk biomass

In polyhouse, the biomass of leaves and stalk (36.8 t acre^{-1}) accounted

Table 10
Energy use indicators in cut flower rose at different input levels during experimental period.

Nutrient level (N) (g NPK m^{-2} yr^{-1})	Spacing (S) and genotypes (G)								
	45 cm × 15 cm				40 cm × 20 cm				Overall mean
	Arka Swadesh	Arka Ivory	Arka Pride	Mean	Arka Swadesh	Arka Ivory	Arka Pride	Mean	
	Specific energy (MJ kg^{-1})								
40:4.3:42	3.29	3.55	4.29	3.66	3.03	3.68	3.95	3.51	3.63
50:6.5:50	2.95	3.84	4.66	3.68	2.95	3.71	5.27	3.76	3.90
60:8.7:58	3.70	4.31	5.81	4.44	3.35	3.82	5.74	4.08	4.46
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	2.94	3.77	4.62	3.65	2.95	3.33	5.28	3.62	3.82
Mean	3.22	3.86	4.84	3.86	3.07	3.63	5.06	3.74	3.95
Mean for genotypes	3.15	3.75	4.95						
	CD ($p=0.05$) for S: NS G: 0.48 N: 0.29 S x N: NS G x N: 0.65								
	WUE$_{energy}$ (MJ m^{-3} of water)								
40:4.3:42	16.22	13.63	9.29	13.05	20.64	12.24	9.83	14.24	16.22
50:6.5:50	21.72	10.60	5.19	12.50	22.07	12.56	1.78	12.14	21.72
60:8.7:58	13.87	6.53	−2.23	6.06	17.93	10.47	−1.10	9.10	13.87
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	22.09	11.34	5.54	12.99	22.01	17.19	1.25	13.48	22.09
Mean	18.47	10.53	4.45	11.15	20.66	13.12	2.94	12.24	18.47
Mean for genotypes	19.57	11.82	3.69						
	CD ($p=0.05$) for S: NS G: 3.29 N: 2.66 S x N: NS G x N: 4.95								

Table 11
Soil fertility parameters as influenced by nutrient levels in rose at 0–30 cm depth in protected condition.

Nutrient level (N) (g NPK m^{-2} yr^{-1})	pH	EC (dS m^{-1})	SOC (%)	P (mg kg^{-1})	K (mg kg^{-1})
2019					
40:4.3:42	7.43	0.97	1.68	31.6	345
50:6.5:50	7.54	0.92	1.65	34.2	308
60:8.7:58	7.47	0.96	1.38	34.4	311
50:6.5:50 (1st yr) + soil-test based P appl. (2nd yr)	7.55	0.89	1.60	32.6	297
Mean	**7.49**	**0.92**	**1.58**	**33.3**	**315**
CD ($p=0.05$)	NS	NS	0.113	NS	23.4
Initial status in 2017	6.76	1.06	1.02	6.90	143

for 65% of total biomass production in cut flower roses (Table 7). The leaf and stalk biomass was similar at planting densities of 12 per m^2 (35.9 t acre^{-1}) and 15 per m^2 (37.7 t acre^{-1}). Among genotypes, Arka Swadesh (42.6 t acre^{-1}) accumulated significantly higher leaf + stalk than Arka Ivory (34.2 t acre^{-1}) and Arka Pride (33.5 t acre^{-1}). The nutrient levels of 40:4.3:42 g NPK (38.6 t acre^{-1}) and 50:6.5:50 g NPK (37.0 t acre^{-1}) were superior to 60:8.7:58 g NPK (33.7 t acre^{-1}) in terms of leaf + stalk biomass. Further, biomass accumulation pattern in different treatments can be substantiated by ANUE (g flower stalk biomass per g nutrient applied) estimations among genotypes (10.78 in Arka Swadesh, 8.72 in Arka Ivory and 8.56 in Arka Pride) and nutrient levels (6.91–11.25). Rose production system in protected condition is also an important carbon sink as noticed from higher biomass accumulation.

3.2.3. Economic indicators

Economic indicators were computed for cut flower roses considering the establishment cost on polyhouse and other inputs (Table 8). The annuity value was higher at 45 cm × 15 cm spacing (8677 USD acre^{-1}) than at 40 cm × 20 cm (8311 USD acre^{-1}). The total cost of cultivation per acre^{-1} yr^{-1} was higher at planting density of 15 per m^2 (10456 to 10620 USD acre^{-1} yr^{-1}) than at lower planting density of 12 per m^2 (10076 to 10240 USD acre^{-1} yr^{-1}). The net return per USD investment was more than one in all treatments. From economic point of view, growing of Arka Swadesh genotype at planting density of 12 per m^2 (2.00) along with NPK application @ 50:6.5:50 g m^{-2} yr^{-1} (2.20) was better due to accrual of higher return per each USD investment.

3.2.4. Energy flows

The energy accounting for polyhouse grown roses indicated significant variations in energy flow parameters and net energy among treatments (Table 9). The average energy input was estimated at 76754 MJ acre^{-1}. Energy input (MJ acre^{-1}) increased from 71607 in 40:4.3:42 g NPK level to 82389 in 60:8.7:58 g NPK. Nutrients and irrigation contributed to 41.2 and 20.9% of total energy consumption. Energy output (121902 MJ) and net energy (45264 MJ) per acre were higher in Arka Swadesh at planting density of 12 per m^2 and 50:6.5:50 g NPK level. The net energy accrual reduced with increase in nutrient dose. Net energy was negative in Arka Pride (-491 MJ acre^{-1}) implying energy loss in this genotype due to lower yield levels and biomass accumulation in flower stalks. Overall, the net energy was 25% of total energy output in protected condition.

3.2.5. Energy efficiency indices

The energy efficiency indices varied significantly among genotypes and nutrition levels in polyhouse grown roses (Fig. 4). Plant spacing had no significant effect on EUE (1.24–1.27) indicating that the less plant density of 12 per m^2 is optimum. Arka Swadesh was efficient in energy use (1.51) compared to Arka Ivory (1.26) and Arka Pride (1.00). The nutrient level of 40:4.3:42 g NPK m^{-2} (1.341) registered higher EUE than 50:6.5:50 and 60:8.7:58 levels (1.110–1.274). Arka Swadesh registered higher EP (0.32 kg flower yield MJ^{-1}) and 0.88 kg flower stalk yield MJ^{-1}). The EP levels (kg flower yield MJ^{-1}) were 0.268 in Arka Ivory and 0.206 in Arka Pride. Differences in biomass partitioning pattern contributed to differences in energy efficiency indices. Among nutrient levels, the EP ranged between 0.235 and 0.279 kg flower yield and 0.664–0.842 kg flower stalk yield per MJ. The average energy intensiveness was estimated at 7.42 MJ USD^{-1} in protected condition (Table 9). The EI was unaffected by genotypes as well as nutrition levels (6.98 to 7.90 MJ USD^{-1}) due to negligible variations in energy input and cost of cultivation.

The specific energy (3.74–3.86 MJ per kg yield) was similar at planting densities of 15 and 12 per m^2 (Table 10). Among genotypes, the SE (MJ per kg yield) was significantly lower in Arka Swadesh (3.15) than Arka Ivory (3.75) and Arka Pride (4.95). This is due to higher yield levels in Arka Swadesh and similar energy input levels in all genotypes. The SE was significantly higher at 60:8.7:58 g NPK level (4.46) due to increased energy input and reduced yield levels. Despite higher crop output, the SE was 3.80 MJ per kg yield due to higher energy consumption. The WUE$_{energy}$ decreased with increase in planting density and nutrient dose (Table 10). Arka Swadesh registered significantly higher WUE$_{energy}$ of 19.57 MJ per m^3 of water.

On unit area basis, the energy consumption was 61% higher in protected condition over open grown roses (Table 5). However, increased energy input resulted in increased productivity and energy output in protected condition. In comparison to open grown roses, the EI was very low in protected condition due to higher levels of both energy input and cost of cultivation. In protected condition, the strong relations between energy efficiency indices and flower yields ($r = 0.954–0.995^{**}$)/flower stalk biomass yields ($r = 0.857–0.963^{**}$) imply that rose production system is highly efficient in energy use. Protected cultivation of cut flower roses is sustainable in 3-yr period as indicated by sustainable yield index of 0.66, but it's long-term sustainability needs to be assessed.

3.2.6. Soil fertility

Irrespective of treatments, the soil pH was increased by 0.73 to 0.78 units at the end of experiment over initial level of 6.76 (Table 11). The EC was reduced (0.97 dSm^{-1}) compared to initial level of 1.06 dSm^{-1}. The SOC was increased by 0.36–0.66% among nutrient levels over initial status (1.02%). The nutrient availability was above optimum in all treatments in 2019 indicating build-up of soil fertility. Soil-test P level (33.3 mg kg^{-1}) increased 5-fold despite reducing the present recommended P dose by 37 to 68%. It can be attributed to reduced nutrient losses and nutrient addition through irrigation water.

4. Conclusions and the way forward

The 3-yr study indicated that there were variations in productivity levels, energy use and economic indicators in different rose production systems indicating the need for input recommendations based on precision approaches. The positive effects of critical inputs on yield and efficiency indicators were discernible in open-grown roses. The loose flower rose was more efficient in terms of productivity, energy use and net benefit than cut flower rose in open-field. Rose production systems are beneficial from environmental point of view due to huge biomass accumulation, SOC enrichment and EUE of more than one. The critical inputs contributed to 93.5–94.7% of energy consumption in open grown roses and 60% in protected condition. External nutrient inputs accounted for maximum energy consumption in rose production systems (41–65%). Future studies are required on biomass recycling in rose as vermicompost/compost to reduce energy consumption and dependence on external inputs.

Declaration of competing interest

The authors declare no conflict of interest.

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