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System Productivity and Resource Use Efficiency of Alternative Cropping Systems for Sugarcane in Karnataka

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Abstract

The field experiments were conducted at Agricultural Research Station, Hukkeri, Belagavi, Karnataka, India during 2018–19 and 2019–20 to study the system productivity and resource use efficiency of alternative cropping systems for sugarcane. There were 11 treatments involving different cropping systems viz., soybean–sorghum–ridge gourd, pigeon pea±green gram (1:1)–beans, pigeon pea±soybean (1:1)–cowpea, soybean–wheat–groundnut, groundnut–sorghum–sesame, maize–cabbage–fallow, soybean–wheat–green gram, maize–wheat–sesame, Bt cotton–groundnut, sugarcane±onion (1:2) and sugarcane (sole) replicated thrice and laid out in randomized complete block design. Among the cropping systems, maize-cabbage-fallow system recorded significantly higher total system productivity (58,234 kg ha^{-1}), water use efficiency (199.67 kg ha^{-1}-mm) and energy use efficiency (129.91 MJ ha^{-1}) compared to rest of the cropping systems. However, sugarcane (sole) recorded (1,11,008 kg ha^{-1}, 68.64 kg ha^{-1}-mm and 16.58 MJ ha^{-1}, respectively). Based on alternative cropping systems involving only field crops, maize-wheat-sesame (9633 kg ha^{-1}, 30.65 kg ha^{-1}-mm and 132.20 MJ ha^{-1} respectively), soybean-wheat-groundnut (7602 kg ha^{-1}, 27.40 kg ha^{-1}-mm and 32.35 MJ ha^{-1}, respectively), soybean-wheat-green gram (6424 kg ha^{-1}, 23.05 kg ha^{-1}-mm and 31.91 MJ ha^{-1}, respectively) and Bt cotton-groundnut (4503 kg ha^{-1}, 17.97 kg ha^{-1}-mm and 16.95 MJ ha^{-1}, respectively) were significantly higher. By adopting the alternative cropping systems, there was water saving of approximately 45% compared to sugarcane monocropping and sugarcane±onion (1:2) intercropping.

Keywords: Sugarcane, alternative crops, system productivity, resource use efficiency

1. Introduction

Sugarcane is an important commercial crop of India and holds a prominent position as a cash crop. The crop also contributes to energy demands through co-generation, alcohol production and other high value products besides, providing livelihoods to millions of farmers and industrial workers. Brazil, India, China Thailand, Pakistan, Mexico, Colombia and Australia are the top sugarcane producing countries in the world. In the world, sugarcane occupies an area of 26.54 mha with production of 1861 mt and productivity of 70.13 t ha^{-1}. In India, the area is 4.44 mha with production of 306.07 mt and productivity of 69.11 t ha^{-1}. Uttar

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Pradesh, Maharashtra, Karnataka, Tamil Nadu, Bihar, Gujarat, Haryana, Punjab and Andhra Pradesh are the leading states for sugarcane production in India. In Karnataka, sugarcane is cultivated on an area of 0.40 lakh ha with production of 27.38 m t and productivity of 68.96 t ha^{-1} (Anonymous, 2019).

The productivity of sugarcane has gone down due to continuous monocropping system, being responsible for the deterioration of soil fertility. This clearly indicates that, there is an urgent need for crop diversification to include/ integrate cereals, pulses, millets, oilseeds, fibre crops and vegetables which can arrest the declining trend in productivity of sugarcane monocropping system. Inclusion of these crops in intensive sugarcane- based cropping systems itself is a component of integrated plant nutrient supply system. Therefore, diversified crops have become viable alternative to improve the soil health and conserve the natural resources, agricultural sustainability, stabilize the farm productivity and income and also to reduce the water requirement.

Sugarcane is a water-intensive crop due to its long duration and accumulation of the largest biomass among all the agricultural crops. Maintenance of optimum soil moisture during all stages of crop growth is one of the essential pre-requisites for obtaining higher cane yields. Under the field conditions, water requirements are met through effective rainfall, contribution from shallow water table and irrigation. It is estimated that about 80 per cent of the irrigation requirements of sugarcane in India are met through groundwater sources (Sharma et al., 2018). Frequent light irrigations, each of 40 to 50 mm, adjusted to suit growing period of the crop and to the prevalent weather conditions are very useful. Water requirement is least during ripening stage when accumulation of sucrose starts and just before harvest, irrigation is withheld for about a month. It has been estimated that the irrigation water requirement for sugarcane crop in India, ranges between 375 mm (Bihar) and 2970 mm (Tamil Nadu) or about 5-40 irrigations of 75 mm each per hectare during its crop growth (CACP, 2013). However, there are variations between the tropical and sub-tropical regions due to variations in crop duration, growing season, soil type and the targeted yield levels. The production and productivity are directly related with the use in unit operation of agricultural production. The variation in yield of crop in India occurs due to wide variation in energy inputs, agro-climatic conditions and resources used. Most of the research studies concentrated either on a cropping systems or adoptability of specific cropping systems under different climatic situations. Sugarcane is an intensive crop requiring high inputs of natural resources especially fossil energy and irrigation water (Karimi et al., 2008). Major energy inputs on farms were derived through farm machinery, equipments, use of petroleum products, tube well irrigation using electricity as well as animal and man power and plant nutrients like FYM and fertilizers [Fauconnier (1991)] compared to other crops. Effective energy use in agriculture is one of the conditions for sustainable agriculture production, since it provides financial savings, fossil resources preservation and air pollution reduction (Uhlin, 1998). Energy budgets for agricultural production can be used as building blocks for life cycle assessments that include agricultural products and can also serve as a first step towards identifying crop production processes that benefit most them increased frequency [Piringer and Steinberg (2006)]. Many researchers have studied energy analysis to determine the energy efficiency of crops like sugarcane (Mrini et al., 2001), wheat, maize and sunflower (Triolo et al., 1987), soybean (Mandal et al., 2002) and cotton (Sartori et al., 2005), but the studies are lacking in cropping sequences on system bases. Keeping these in view, the study was carried out on system productivity and resource use efficiency of alternative cropping systems for sugarcane.

2. Materials and Methods

The field experiments were conducted during 2018–19 and 2019–20 at Agricultural Research Station, Hukkeri which is situated in the Northern transition zone (Agro-climatic Zone 8) of Karnataka at a latitude of $16^0 13' 48.00''$ North, longitude 74^0 35’ 59.99” East and at an altitude of 631 m above mean sea level (MSL). The soil of the experimental site was medium black clay loam having normal pH of 7.81 and EC of 0.72 dSm^{-1}, medium in organic carbon (0.53%), low in available nitrogen (236.74 kg ha^{-1}), medium in available phosphorus (14.79 kg ha^{-1}) and high in available potassium (317.41 kg ha^{-1}). It was laid out in Randomised Complete Block Design and replicated thrice. There were 11 treatments consisting of soybean soybean–sorghum–ridge gourd (T_1), pigeon pea±green gram (1:1)–beans (T_2), pigeon pea±soybean (1:1)–cowpea (T_3), soybean–wheat–groundnut (T_4), groundnut–sorghum–sesame (T_5), maize–cabbage–fallow (T_6), soybean–wheat–green gram (T_7), maize–wheat–sesame (T_8), Bt cotton–groundnut (T_9), sugarcane±onion (1:2) (T_{10}) and sugarcane (sole) (T_{11}). The intercropping treatments were in additive series. The seed rate, row spacing and other inputs for *kharif* (rainy), *rabi* (post rainy) and summer crops was followed as per the recommended package of practices (RPP) and different crops were sown during respective seasons for both the years. Irrigation was provided regularly for sugarcane and to summer season crops and protective irrigation for *rabi* crops at critical stages. Plant protection and weed management measures were attended and when required. Harvesting was done based on the maturity of individual crops during their respective seasons. Water requirement of crops was calculated based on the quantity of rainfall received. If the rainfall received per day was >50 mm, considered 1/10th of the quantity received, if the rainfall received per day was 25- 50 mm, considered 1/3rd of the quantity received (Richard et al., 1998). Water use efficiency (WUE) was estimated by the following formula suggested by Khan et al. (2004) and the calculation of water use efficiency for the intercropping systems, involving green gram (T_2), soybean (T_3) during *kharif* and onion (T_{10}) during *rabi,* the quantity of water applied to the system/rainfall received was considered only for the main/base crop and the intercrop yield were converted to main/base crop equivalent yield. The depth of irrigation was considered at 75 mm for sugarcane and at 50 mm for rest of the crops.

$$\text{WUE (kg ha}^{-1}\text{-mm)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Total quantity of water applied (mm)}}$$

Production Efficiency was calculated after converting the total produce into sugarcane equivalent yield divided by total duration of crops in a sequence (days), which was expressed as kg ha^{-1} day^{-1}.

$$\text{Production efficiency} = \frac{\text{Sugarcane equivalent yield (kg ha}^{-1}\text{)}}{\text{Total duration of crops in the sequence (days)}}$$

The energy output (MJ ha^{-1}) was calculated using the energy equivalents (MJ) for main and by products and their yields and energy input (MJ ha^{-1}) was calculated by adding all the energy expenditures used for raising the component/sequence crops (Mittal et al., 1985).

Energy output=$(a\times A)+(b\times B)$

Where, a=Energy equivalent per kg of main product (MJ)

A= Yield of main product (kg ha^{-1})

b= Energy equivalent per kg of by-product (MJ)

B= Yield of by-product (kg ha^{-1})

Energy Use Efficiency was estimated using the following formula suggested by Khan and Singh (1996).

$$\text{Energy Use Efficiency (MJ ha}^{-1}\text{)} = \frac{\text{Output energy (MJ ha}^{-1}\text{)}}{\text{Input energy (MJ ha}^{-1}\text{)}}$$

Energy productivity was worked out by dividing respective crop yield by respective input energy of the crops and was expressed in kilogram per mega joule (kg MJ^{-1}) as outlined by Mandal et al. (2002).

$$\text{Energy Productivity} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Total energy input (MJ ha}^{-1}\text{)}}$$

3. Results and Discussion

3.1. Productivity

The pooled data of two seasons for *kharif* resulted in maize recording significantly higher grain yield (T_6, 6123 kg ha^{-1}) which was on par with maize (T_8, 6012 kg ha^{-1}) compared to rest of the crops. The other higher yielding crops were *viz.,* groundnut with higher dry pod yield (T_5, 2355 kg ha^{-1}) followed by soybean (T_4, 2275 kg ha^{-1}), soybean (T_7, 2267 kg ha^{-1}), Bt cotton (T_9, 2201 kg ha^{-1}) and soybean (T_1, 2182 kg ha^{-1}) (Table 1).

The pooled data for *rabi* season showed that, cabbage recorded significantly higher head yield (T_6, 52111 kg ha^{-1}) compared to rest of the crops. Amongst other treatments *viz.,* onion intercropped with sugarcane recorded significantly higher bulb yield (T_{10}, 4626 kg ha^{-1}) followed by wheat (T_7, 3206 kg ha^{-1}), wheat (T_4, 3111 kg ha^{-1}), wheat (T_8, 2948 kg

Table 1: Productivity and production efficiency of alternative cropping systems for sugarcane

Treatment	Productivity (kg ha^{-1})			Production efficiency (kg ha^{-1} day^{-1})			
	Kharif	*Rabi*	Summer	*Kharif*	*Rabi*	Summer	Total
T_1: Soybean–sorghum–ridge gourd	2182	1676	6864	440	184	1094	1717
T_2: Pigeon pea±green gram* (1:1)–beans	596	1460	6117	252	249	1997	2498
T_3: Pigeon pea±soybean* (1:1)–cowpea	698	1512	1355	141	258	297	696
T_4: Soybean–wheat–groundnut	2275	3111	2216	458	336	382	1176
T_5: Groundnut–sorghum–sesame	2355	1799	688	408	198	349	954
T_6: Maize–cabbage–fallow	6123	52111	- - - -	429	6221	- - -	6650
T_7: Soybean–wheat–green gram	2267	3206	951	457	347	377	1181
T_8: Maize–wheat– sesame	6012	2948	673	422	319	340	1080
T_9: Bt cotton–groundnut	2201		2302	387		702	784
T_{10}: Sugarcane±onion* (1:2)		4626	113515		511	311	822
T_{11}: Sugarcane (sole)			111008			304	304
SEm±	151.95	228.53	1316.40	19.22	28.08	28.15	41.58
LSD (p=0.05)	455.54	685.14	3911.23	57.62	84.19	83.62	122.67

Note: Bt cotton, pigeon pea and sugarcane are considered as *kharif*, *rabi* and summer crops, respectively, Individual crops were considered for calculation of sugarcane equivalent yield and respective crop duration, *: Additive series intercropping systems ha^{-1}) and sorghum.

During summer (pooled), sugarcane in intercropping system recorded significantly higher cane yield (T_{10}, 113515 kg ha^{-1}) and it was on par with sugarcane (sole) (T_{10}, 111008 kg ha^{-1}) compared to other treatments. Next in the order, were ridge gourd with higher fruit yield (T_1, 6864 kg ha^{-1}) followed by beans (T_2, 6117 kg ha^{-1}), groundnut (T_9, 2302 kg ha^{-1}), groundnut (T_4, 2216 kg ha^{-1}), cowpea (T_3, 1355 kg ha^{-1}) and green gram (T_7, 951 kg ha^{-1}). Sesame recorded the significantly lower seed yield (T_5, 688 kg ha^{-1} and T_8, 673 kg ha^{-1}).

Higher productivity of respective crops was due to genetic characteristics of individual crops *viz.,* faster growth (cereals), slow growth (pulses), nutrient uptake of individual crops, nutrient exhaustiveness (cereals), yield potentiality, different ideotypes, early maturity/duration with high yielding ability, photosynthesis and translocation of photosynthates to reproductive organs *i.e.,* from source of sink. These results are in conformity with the findings of Rao and Rogers (2006), Mukherjee (2010) in rice–cauliflower, Kaur and Bhullar (2014) in autumn sugarcane and *brassica* based intercropping systems, Kumar et al. (2014) in sugarcane intercropping with onion, Prajapat et al. (2014) in soybean based cropping systems, Bhat et al. (2013) in maize, Mukherjee (2016) in cropping sequence and Pacharne (2017) in different cropping system.

3.2. *Production efficiency*

Among the cropping systems, maize–cabbage–fallow system recorded significantly higher (pooled) total production efficiency (T_6, 6650 kg ha^{-1} day^{-1}) compared to rest of the cropping systems. However, pigeon pea±green gram (1:1)–beans (T_2, 2498 kg ha^{-1} day^{-1}) was significantly higher over rest of the cropping systems (Table 1).

The next best cropping systems with total higher production efficiency were soybean-sorghum-ridge gourd (T_1, 1717 kg ha^{-1} day^{-1}), soybean–wheat–green gram (T_7, 1181 kg ha^{-1} day^{-1}), soybean–wheat–groundnut (T_4, 1176 kg ha^{-1} day^{-1}) and maize–wheat–sesame (T_8, 1080 kg ha^{-1} day^{-1}). This was due to the higher sugarcane equivalent yield, individual crop duration and inclusion of vegetables in the system, normally result in higher production efficiency owing to better price for the produce which lead to harness the production resources efficiently. Similar findings have also been reported by Kapil *et al.* (2005) in rice based cropping system and Prajapat *et al.* (2014) in soybean–chickpea– fodder sorghum.

The sugarcane (sole) recorded significantly lower total production efficiency (T_{11}, 304 kg ha^{-1} day^{-1}).

3.3. *Quantity of water applied*

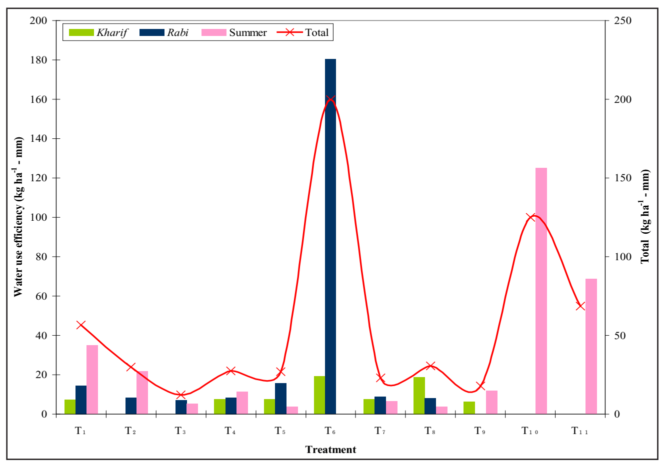
During 2018, among the cropping systems, the higher quantity of water applied was with sugarcane ±onion (1:2) and sugarcane (sole) (T_{10} and T_{11}, 1612.39 mm) compared to rest of the treatments (Table 2).

The cropping systems which recorded the lower requirement of water were Bt cotton–groundnut (T_9, 489.76 mm), pigeon pea±green gram (1:1)–beans and pigeon pea±soybean (1:1)–cowpea (T_2 and T_3, 538.16 mm), maize–cabbage–fallow (T_6, 573.82 mm), groundnut–sorghum–sesame (T_5, 586.62 mm), soybean–sorghum–ridge gourd (T_1, 636.62 mm), soybean–wheat–green gram (T_7, 786.62 mm), soybean–wheat–groundnut (T_4, 836.62 mm) and maize–wheat–sesame (T_8, 836.62 mm) compared to sugarcane sole and sugarcane intercropping system.

During 2019, among the cropping systems, the higher quantity of water applied was with sugarcane±onion (1:2) and sugarcane (sole) (T_{10} and T_{11}, 1622.71 mm) compared to rest of the cropping systems. The cropping systems which recorded lower water requirement were soybean–sorghum–ridge gourd (T_1, 633.21 mm), groundnut–sorghum–sesame (T_5, 650.71 mm), maize–cabbage–fallow (T_6, 674.41 mm), Bt cotton–groundnut (T_9, 696.71 mm), pigeon pea±soybean(1:1)–cowpea (T_3, 770.51 mm), pigeon pea±green gram(1:1)–beans (T_2, 820.51 mm), soybean–wheat–green gram (T_7, 849.71 mm), soybean–wheat–groundnut (T_4, 906.91 mm) and maize–wheat–sesame (T_8, 933.21 mm) compared to sugarcane intercropping and sugarcane (sole) systems.

3.4. *Water use efficiency*

The significantly higher total water use efficiency (WUE) with maize–cabbage–fallow system (T_6, 199.67 kg ha^{-1} -mm) compared to rest of the cropping systems was because of higher sugarcane equivalent yield, application of individual water requirement of crops and other inputs in the cropping system (Table 3 and Figure 1). A proper water supply and nitrogen application rate are also major contributors to higher economic yield and water use efficiency (Zhang et al., 1998 in wheat). However, the sugarcane±onion (1:2) intercropping



T_1 : Soybean–sorghum–ridge gourd; T_2 Z:Pigeon pea±green gram* (1:1)–beans; T_3 : Pigeon pea±soybean* (1:1–cowpea); T_4 : Soybean–wheat–groundnut; T_5 : Groundnut–sorghum–sesame; T_6 : Maize–cabbage–fallow; T_7 : Soybean–wheat–green gram; T_8 : Maize–wheat– sesame; T_9 : Bt cotton–groundnut; T_{10} : Sugarcane±onion* (1:2); T_{11} : Sugarcane (sole)

Figure 1: Water use efficiency of alternative cropping systems for sugarcane

Table 2: Quantity of water applied to alternative cropping systems for sugarcane

Treatment	Quantity of water applied (mm)									
	2018–19					2019–20				
	Kharif	*Rabi*	Summer	Total	Water saving (%) compared to sugarcane	*Kharif*	*Rabi*	Summer	Total	Water saving (%) compared to sugarcane
T_1	264.22	109.60	262.80	636.62	39.48	353.41	121.90	157.90	633.21	39.02
T_2		276.96	261.20	538.16	33.37		515.11	305.40	820.51	50.56
T_3		276.96	261.20	538.16	33.37		515.11	255.40	770.51	47.48
T_4	264.22	359.60	212.80	836.62	51.88	353.41	371.90	181.60	906.91	55.88
T_5	264.22	109.60	212.80	586.62	36.38	370.81	121.90	158.00	650.71	40.10
T_6	264.22	309.60	- - -	573.82	35.58	402.51	271.90	- - -	674.41	41.56
T_7	264.22	359.60	162.80	786.62	48.78	353.41	371.90	124.40	849.71	52.36
T_8	264.22	359.60	212.80	836.62	51.88	402.51	371.90	158.80	933.21	57.50
T_9	276.96		212.80	489.76	30.37	515.11		181.60	696.71	42.93
T_{10}				1612.39					1622.71	
		1612.39					1622.71			
T_{11}				1612.39					1622.71	
		1612.39					1622.71			

T_1 : Soybean–sorghum–ridge gourd; T_2 Z:Pigeon pea±green gram* (1:1)–beans; T_3 : Pigeon pea±soybean* (1:1–cowpea); T_4 : Soybean–wheat–groundnut; T_5 : Groundnut–sorghum–sesame; T_6 : Maize–cabbage–fallow; T_7 : Soybean–wheat–green gram; T_8 : Maize–wheat– sesame; T_9 : Bt cotton–groundnut; T_{10} : Sugarcane±onion* (1:2); T_{11} : Sugarcane (sole); Note: For T_2, T_3 and T_{10}, quantity of water applied only to the base crop/main crop and base crop equivalent yield of intercrop was considered for calculation of WUE of intercropping system; *: Additive series intercropping system

Table 3: Water use efficiency of alternative cropping systems for sugarcane

Treatment	Water use efficiency (kg ha^{-1} - mm)			
	Kharif	*Rabi*	Summer	Total
T_1: Soybean–sorghum–ridge gourd	7.25	14.51	34.88	56.64
T_2: Pigeon pea±green gram* (1:1)–beans		8.20	21.69	29.89
T_3: Pigeon pea±soybean* (1:1)–cowpea		7.00	5.25	12.25
T_4: Soybean–wheat–groundnut	7.55	8.51	11.34	27.40
T_5: Groundnut–sorghum–sesame	7.68	15.59	3.79	27.06
T_6: Maize–cabbage–fallow	19.23	180.44	- - -	199.67
T_7: Soybean–wheat–green gram	7.53	8.77	6.75	23.05
T_8: Maize–wheat– sesame	18.88	8.06	3.71	30.65
T_9: Bt cotton–groundnut	6.19		11.78	17.97
T_{10}: Sugarcane±onion* (1:2)			125.08	125.08
T_{11}: Sugarcane (sole)			68.64	68.64
SEm±	0.51	1.01	1.11	1.42
LSD (p=0.05)	1.53	3.07	3.30	4.19

Note: For T_2, T_3 and T_{10}, quantity of water applied only to the base crop/main crop and base crop equivalent yield of intercrop was considered for calculation of WUE of intercropping system, *: Additive series intercropping systems system recorded significantly higher total WUE (T_{10}, 125.08 kg ha^{-1}-mm) compared to rest of the cropping systems including sugarcane (sole) (T_{11}, 68.64 kg ha^{-1}-mm).This was mainly because of higher yield potentiality and SEY with the benefit of inclusion of onion as an intercrop with sugarcane and nutrient application as per the requirement of the individual crops. The higher water use efficiency with sugarcane (sole) was due to higher tonnage, water requirement and nutrient requirement compared to other cropping systems. These results are in conformity with the findings of Samui et al. (2008) in sorghum, Rathore et al. (2014) in ridge gourd, Singh *et al.* (2015) in cotton–peanut and Rahman et al. (2017) in maize–soybean.

The next best cropping systems for higher WUE were soybean–sorghum–ridge gourd (T_1, 56.64 kg ha^{-1}-mm) followed by maize–wheat–sesame (T_8, 30.65 kg ha^{-1}-mm), pigeon pea±green gram(1:1)–beans (T_2, 29.89 kg ha^{-1}-mm), soybean–wheat–groundnut (T_4, 27.40 kg ha^{-1}-mm), groundnut–sorghum–sesame (T_5, 27.06 kg ha^{-1}-mm), soybean–wheat–green gram (T_7, 23.05 kg ha^{-1}-mm) and Bt cotton–groundnut (T_9, 17.97 kg ha^{-1}-mm). This was due to the lower SEY, individual crop yielding ability and relationship between economic yield and nutrient application and requirement of water based on the need of individual crops.

3.5. Input and output energy

The pooled data of two seasons for *kharif* resulted in intercropping of green gram with pigeon pea recorded lower requirement of input energy (780.53 MJ ha^{-1}) followed by soybean intercropping with pigeon pea (1519.90 MJ ha^{-1}) compared to rest of the crops due to lower requirement of some of the inputs in intercropping systems compared to base crop (Table 4). The higher requirement of input energy was recorded with groundnut (5618.27 MJ ha^{-1}) followed by sole soybean (4206.04 MJ ha^{-1}). The pooled data of two seasons for *rabi* resulted in pigeon pea recorded lower requirement of input energy (2472.69 MJ ha^{-1}) and wheat recorded higher input energy (15541.09 MJ ha^{-1}) compared to the rest of the crops. The pooled data of summer season indicated that, sugarcane resulted higher requirement of input energy (35468.15 MJ ha^{-1}) and sesame recorded lower input energy (7131.16 MJ ha^{-1}) compared to the other crops.

Table 4: Energetics of alternative cropping systems for sugarcane

Treatment	Input energy (MJ ha^{-1})			Output energy (MJ ha^{-1})		
	Kharif	*Rabi*	Summer	*Kharif*	*Rabi*	Summer
T_1: Soybean–sorghum–ridge gourd	4206.04	7250.37	8295.49	75077	115159	12630
T_2: Pigeon pea±green gram* (1:1)–beans	780.53	2472.69	13764.44	27493	79375	11623
T_3: Pigeon pea±soybean* (1:1)–cowpea	1519.90	2472.69	10656.14	27773	80769	69527
T_4: Soybean–wheat–groundnut	4206.04	15541.09	10632.10	78339	93920	78721
T_5: Groundnut–sorghum–sesame	5618.27	7250.37	7131.16	82525	121267	51351
T_6: Maize–cabbage–fallow	3109.70	13844.69	-----	384198	60333	-----
T_7: Soybean–wheat–green gram	4206.04	15541.09	6309.63	77119	96062	44703
T_8: Maize–wheat–sesame	3109.70	15541.09	7131.16	369046	88468	51672
T_9: Bt cotton–groundnut	2861.48		10632.10	55015		82434
T_{10}: Sugarcane±onion* (1:2)		9714.79	35468.15		8558	601631
T_{11}: Sugarcane (sole)			35468.15			589891

Note: Bt cotton, pigeon pea and sugarcane are considered as *kharif, rabi* and summer crops, respectively, Output energy includes both economic yield and byproducts (except Bt cotton, cabbage, onion, ridge gourd, beans and sugarcane); *: Additive series intercropping systems

The pooled data for *kharif* season showed that, maize recorded higher output energy (T_6, 384198 MJ ha^{-1}) followed by maize (T_8, 369046 MJ ha^{-1}) and groundnut (T_5, 82525 MJ ha^{-1}) compared to rest of the crops. This increase in economic yield and byproduct of individual crops of respective seasons was due to genetic potential of the individual crops and significantly higher performance of growth and yield parameters. For *rabi* (pooled), sorghum recorded higher output energy (T_5, 121267 MJ ha^{-1}) followed by sorghum (T_1, 115159 MJ ha^{-1}) and wheat (T_7, 96062 MJ ha^{-1}) compared to rest of the crops. For summer (pooled), sugarcane intercropping with onion produced higher output energy (T_{10}, 601631 MJ ha^{-1}) followed by sugarcane (sole) [T_{10}, 589891 MJ ha^{-1}] and groundnut (T_9, 82434 MJ ha^{-1}) compared to rest of the crops.

3.6. Energy use efficiency

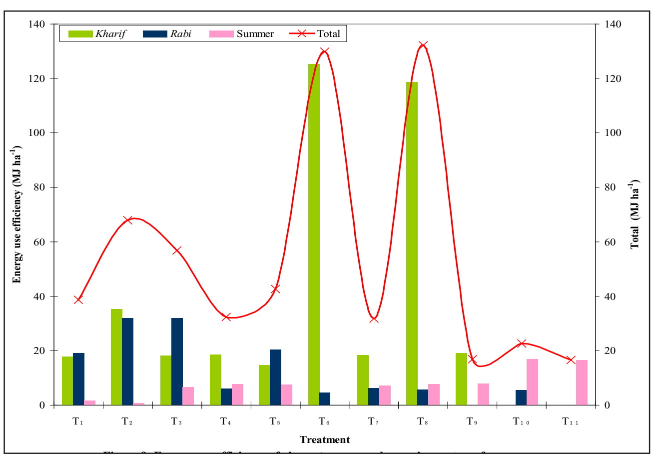
The significantly higher total energy use efficiency (EUE) was recorded with maize–wheat–sesame system (T_8, 132.20 MJ ha^{-1}) and it was on par with maize–cabbage–fallow system (T_6, 129.91 MJ ha^{-1}) compared to rest of the cropping systems (Table 5 and Figure 2). This was mainly because of variations in EUE for different seasons and different crops involved in cropping systems as the inputs viz., seeds, fertilizer, plant protection chemicals, irrigation water, cultivation practices, harvesting and threshing and output energy values in the form of biological yield were different for individual crops. Average Energy input was generally higher in triple cropping systems as they produced more energy output through both economic and biological products (Biswas et al., 2006 in rice and jute based cropping system). These results are also in line with the findings of Subbian *et al.* (1995), Cicek et al. (2011) in wheat, Singh and Kumar (2014) in rice–wheat, Parihar et al. (2018), Canakci et al. (2005) in field and vegetable crops and Saha and Patra (2017) in green gram.

The next best cropping systems for higher total EUE were pigeon pea±green gram(1:1)–beans (T_2, 68.00 MJ ha^{-1}), pigeon pea±soybean (1:1)–cowpea (T_3, 56.79 MJ ha^{-1}), groundnut–sorghum–sesame (T_5, 42.71 MJ ha^{-1}), soybean–sorghum–ridge gourd (T_1, 38.69 MJ ha^{-1}) and soybean–wheat–groundnut (T_4, 32.35 MJ ha^{-1}). This was due to the differences in the input and output energy equivalents with respective individual crops. However, the significantly lower total EUE was recorded with sugarcane±onion (1:2) intercropping (T_{10}, 22.62 MJ ha^{-1}) and sugarcane (sole) (T_{11}, 16.58 MJ ha^{-1}).

Table 5: Energy use efficiency of alternative cropping systems for sugarcane

Treatment	Energy use efficiency (MJ ha^{-1})			
	Kharif	*Rabi*	Summer	Total
T_1: Soybean–sorghum–ridge gourd	17.85	19.16	1.68	38.69
T_2: Pigeon pea±green gram* (1:1)–beans	35.22	31.93	0.85	68.00
T_3: Pigeon pea±soybean* (1:1)–cowpea	18.27	31.99	6.52	56.79
T_4: Soybean–wheat–groundnut	18.63	6.08	7.64	32.35
T_5: Groundnut–sorghum–sesame	14.69	20.45	7.57	42.71
T_6: Maize–cabbage–fallow	125.30	4.61	- - -	129.91
T_7: Soybean–wheat–green gram	18.41	6.26	7.24	31.91
T_8: Maize–wheat–sesame	118.79	5.74	7.67	132.20
T_9: Bt cotton–groundnut	19.23		7.99	27.22
T_{10}: Sugarcane±onion* (1:2)		5.67	16.95	22.62
T_{11}: Sugarcane (sole)			16.58	16.58
SEm±	1.33	0.60	0.32	1.46
LSD (p=0.05)	3.97	1.79	0.94	4.31

Note: For T_2, T_3 and T_{10} crops were considered individually for accounting input and output energy values; *: Additive series intercropping systems



T_1 : Soybean–sorghum–ridge gourd; T_2 Z: Pigeon pea±green gram* (1:1)–beans; T_3 : Pigeon pea±soybean* (1:1–cowpea); T_4 : Soybean–wheat–groundnut; T_5 : Groundnut–sorghum–sesame; T_6 : Maize–cabbage–fallow; T_7 : Soybean–wheat–green gram; T_8 : Maize–wheat– sesame; T_9 : Bt cotton–groundnut; T_{10} : Sugarcane±onion* (1:2); T_{11} : Sugarcane (sole)

Figure 2: Energy use efficiency of alternative cropping systems for sugarcane

3.7. *Energy productivity*

Among the cropping systems, sugarcane±onion (1:2) recorded significantly higher energy productivity (EP) (T_{10}, 6.26 kg MJ^{-1}) compared to rest of the cropping systems. Amongst rest of the cropping systems, maize–cabbage–fallow system (T_6, 5.81 kg MJ^{-1}) was significantly higher compared to others and sugarcane (sole) (T_{11}, 3.12 kg MJ^{-1}) (Table 6). The next best cropping systems with higher EP were pigeon pea ± green gram(1:1)–beans (T_2, 2.31 kg MJ^{-1}), maize–wheat–sesame (T_8, 2.23 kg MJ^{-1}), soybean–sorghum–ridge gourd (T_1, 1.67 kg MJ^{-1}), pigeon pea ± soybean (1:1)–cowpea (T_3, 1.20 kg MJ^{-1}), Bt cotton–groundnut (T_9, 0.99 kg MJ^{-1}), soybean–wheat–groundnut (T_4, 0.96 kg MJ^{-1}) and soybean–wheat–green gram (T_7, 0.90 kg MJ^{-1}). This was due to differences in yield potentiality of individual crops and also differences in input

Table 6: Energy productivity of alternative cropping systems for sugarcane

Treatment	Energy productivity (kg MJ^{-1})			
	Kharif	*Rabi*	Summer	Total
T_1: Soybean–sorghum–ridge gourd	0.52	0.23	0.91	1.67
T_2: Pigeon pea±green gram* (1:1)–beans	0.76	0.59	0.45	1.80
T_3: Pigeon pea±soybean* (1:1)–cowpea	0.46	0.61	0.13	1.20
T_4: Soybean–wheat–groundnut	0.54	0.20	0.21	0.96
T_5: Groundnut–sorghum–sesame	0.42	0.25	0.10	0.77
T_6: Maize–cabbage–fallow	1.97	3.84	- - -	5.81
T_7: Soybean–wheat–green gram	0.53	0.21	0.15	0.90
T_8: Maize–wheat–sesame	1.93	0.19	0.10	2.23
T_9: Bt cotton–groundnut	0.77		0.22	0.99
T_{10}: Sugarcane±onion* (1:2)		3.06	3.20	6.26
T_{11}: Sugarcane (sole)			3.13	3.13
SEm±	0.05	0.04	0.04	0.07
LSD (p=0.05)	0.14	0.11	0.12	0.20

Note: For T_2, T_3 and T_{10} crops were considered individually for accounting input and output energy values; *: Additive series intercropping systems

energy equivalents for the individual crop cultivation. The energy productivity ratio can be increased by increasing crop yield and/or by decreasing energy equivalent of the crops (input management) (Fadavi et al., 2011 in apple). The similar results were also reported by Chaudhary *et al.* (2006) in rice–vegetable system and Parihar et al. (2018) in maize.

4. Conclusion

Considering field crop+vegetable alternative cropping system for sugarcane, maize–cabbage–fallow system recorded significantly higher total system productivity (58,234 kg ha^{-1}), water use efficiency (199.67 kg ha^{-1}-mm) and energy use efficiency (129.91 MJ ha^{-1}) compared to rest of the cropping systems. Based on alternative cropping systems involving only field crops, maize–wheat–sesame, soybean–wheat–groundnut, soybean–wheat–green gram and Bt cotton–groundnut were significantly higher. By adopting the alternative cropping systems, there was water saving of approximately 45% compared to sugarcane monocropping and sugarcane±onion (1:2) intercropping.

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