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**Research Paper**

# Efficient cropping systems and their energetics for sustainable irrigated tropical ecosystems

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## ABSTRACT

An experiment was conducted at Bheemarayanagudi, Karnataka, during 2010–11, 2011–12 and 2012–13 to find out efficient cropping systems and to know energetics of different cropping systems. Ten cropping systems, viz. sole *Bt* cotton ( *Gossypium* spp.), *Bt* cotton–greengram [*Vigna radiate* (L.) Wilczek], *Bt* cotton–green-manure crop sun hemp (*Crotalaria juncea* (L.), *Bt* cotton–sesame (*Sesamum indicum* L.), maize (*Zea mays* L.)–chickpea (*Cicer arietinum* L.), sunflower (*Helianthus annuus* L.)–wheat [*Triticum aestivum* (L.) Emend. Fiori & Paol.], sunflower–chickpea, chilli (*Capsicum annuum* L.) + onion (*Allium cepa* L.) (1:2 row proportion), transplanted *Bt* cotton and rice–rice (*Oryza sativa* L.) as check were evaluated under irrigated condition to find out efficient cropping systems. The transplanted *Bt* cotton gave the maximum cotton-equivalent yield (2.73 t/ha ) and was significantly superior to that of rice–rice (2.29 t/ha), while *Bt* cotton–greengram (2.53 t/ha), *Bt* cotton–sesame (2.61 t/ha), maize–chickpea (2.47 t/ha) and chilli + onion (2.41 t/ha ) were at par with transplanted *Bt* cotton as well as rice–rice. All cropping systems gave significantly higher net returns over rice–rice cropping system (₹44,730/ha) except sunflower–wheat or chickpea; highest being with transplanted cotton (₹79,507/ha). All the systems were significantly superior to rice–rice (0.96) in benefit: cost ratio and maize–chickpea recorded the highest benefit: cost ratio (3.31). Energetics revealed different trend, wherein protein yields were higher with maize–chickpea (0.73 t/ha), while carbohydrate yield (6.32 t/ha) was higher with rice-rice. Among all the systems, the highest land-utilization index was observed with *Bt* cotton–sesame cropping system (76.7%).

***Key words*** **:** Cotton equivalent yield, Cropping systems, Economic efficiency, Energetics, Production efficiency, Sustainable yield index, Water use efficiency

Many of the irrigation projects in the country are reported to be less viable and may not run effectively for the entire planned period either due to faulty irrigation practice or adoption of less sustainable cropping system or both. One such irrigation system in the tropical south is Upper Krishna Project (UKP) in Karnataka. Though the ultimate irrigation potential is 10 lakh ha, even 60% of it could not be achieved in spite of completion of the project. In this dry belt during the initial period of water release farmers cultivated crops like hybrid cotton, groundnut, sorghum etc. But the falling prices, failing yields and inundation of land due to improper land levelling and breaching of field canals led to the introduction of paddy in the area by the proficient Andhra farmers who entered the command area and acquired land on lease. Soils being medium to deep black belonging to Vertisols or Vertic inseptisols not suitable to excessive irrigation at parts became less productive and lost from cultivation due to waterlogging and salinity. Mosquito, pig and *Prosofis juliflora* weed menace, health problems of human and livestock in rural areas etc. have also cropped up with time. Besides, the excessive water use in the upper reaches never allowed any water to the tail-end farmers, thereby causing economic disparity among farmers in the command. Now, falling water level in the reservoir due to low rainfall in the river catchment made cultivation of second crop in succession impossible as water was available for just 6 months. With similar water availability and soil situation in the Malaprabha right bank canal in Karnataka state cultivation of 2 arable crops is successful and sustainable. Therefore, an investigation was undertaken to find out efficient cropping systems for ecological security and sustainability and to know the energetics of different cropping systems for the UKP command area.

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## MATERIALS AND METHODS

A field experiment was conducted for 3 years (2010–11, 2011–12 and 2012–13) under irrigated condition at Agricultural College farm, Bheemarayanagudi, Karnataka, situated in the centre of the Upper Krishna Project command in the North Eastern dry zone, with semi-arid climate characterized by short monsoon, mild winter and hot summer. The soil was medium black cotton soil, low in nitrogen (225 kg/ha), medium in phosphorus (40 kg/ha) and high in potassium (320 kg/ha). The experiment was laid out in randomized block design with 3 replications. There were 10 cropping systems, comprising sole *Bt* cotton, *Bt* cotton–greengram, *Bt* cotton–green manure crop (sunnhemp), *Bt* cotton–sesame, maize–chickpea, sunflower–wheat, sunflower–chickpea, chilli + onion (1:2 row proportion), transplanted *Bt* cotton and rice – rice as outside check (on adjacent farmers field).

The *Bt* cotton seedlings were raised in black polythene bags of 15 cm × 10 cm size. The poly bags were filled with red earth and vermicompost in 3:1 ratio. Soil was moistened to field capacity and seeds were dibbled with 1 seed/poly bag at a depth of 5 cm in the centre. Soil moisture in the poly bag was maintained by watering regularly. Seedlings were exposed to direct sunlight for a week before transplanting. Seedlings of 25 days age were transplanted in the main field as per treatment. And 30-days old seedling of chilli and dibbling of seeds of different crops in the field was also done on the same day after the release of water, i.e. after July 15 every year. Recommended cultivars, spacing and fertilizer levels were used and production practices of nutrition, weed, irrigation and pest management were followed (Table 1). The yield of each crop was recorded and economics using prevailing market price was worked out. Protein, carbohydrates and fat were estimate using the nutritive values (Gopalan *et al*., 1978, Gangwar *et al*., 2003; Renuka *et al*., 2005) and were expressed in tonnes/ha taking into consideration component crops of the systems. Water requirement of different crops were used to calculate the water-use efficiency in terms of kg/ha-mm. Further, production efficiency (kg/ha/day) is worked out by dividing the seed-cotton yield with the number of days crop/s in each system remains/remain on the land. Economic efficiency (₹/ha/day) was calculated by dividing the returns with the number of days of crops/cropping systems remain on the land as per the procedure (Tomar and Tiwari, 1990; Patil *et al*., 1995). Land-utilization index (LUI) was calculated by dividing the total duration of respective crops with 365 days (Tomar and Tiwari, 1990). The data were subjected to statistical analysis and interpretation. Sustainable yield index (SYI) was also worked out using the formula as suggested by Wanjari *et al.* (2004).

The input and output energies were calculated by energy conversion factors (Table 2) for inputs like labour, fuel, fertilizers, seeds, machineries, pesticides and irrigation etc., used in the respective crop sequence (Mittal and Dhawan, 1988; Devasenapathy *et al.,* 2009). Energy-use efficiency was calculated by energy output: energy input ratio and energy productivity was worked out by dividing the cotton-equivalent yield by input energy. System net energy return was calculated by deducting input energy from output energy. Energy intensiveness was worked out by dividing energy output from cost of cultivation incurred in crop production.

## RESULTS AND DISCUSSION

### *Yield and water-use efficiency*

Crop yields and cotton-equivalent yield (CEY) varied significantly amongst different cropping systems (Table 3). The transplanted *Bt* cotton recorded the maximum

**Table 1.** Agronomic practices followed for the different crops and values of energetics per 100 g of edible portion of the crop

| Crops | Variety | Spacing (cm × cm) | NPK (kg/ha) | Number of Irrigations* | Protein (g) | Carbohydrate (g) | Fat (g) |
|---|---|---|---|---|---|---|---|
| Bt Cotton | 'ACH 33-2' | 90 × 60 | 150:75:75 | 6–8 | 19.22 | 36.9 | 14.2 |
| Greengram | 'Pusa Bhaisaki' | 30 × 7.5 | 12.5:25:0 | 1–2 | 24.5 | 59.9 | 1.2 |
| Sunhemp | 'Local' | 30 cm row | - | 2 | - | - | - |
| Sesame | 'E 8' | 30 × 7.5 | 40:25:25 | 2–3 | 17.73 | 23.45 | 49.67 |
| Maize | 'All rounder' | 60 × 20 | 150:75:37.5 | 5–6 | 11.1 | 66.2 | 3.6 |
| Chickpea | 'A 1' | 30 × 10 | 25:50:0 | 2–3 | 17.1 | 60.9 | 5.3 |
| Sunflower | 'GK 202' | 60 × 20 | 90:90:60 | 3-4 | 19.8 | 17.9 | 52.1 |
| Wheat | 'DWR 162' | 23 cm row | 100:75:50 | 5–6 | 11.8 | 71.20 | 1.5 |
| Chilli | 'HPH 1900' | 75 × 45 | 150:75:75 | 5–6 | 2.9 | 3.0 | 0.6 |
| Onion | 'Light red' | 15 × 15 | 125:50:125 | 5–6 | 1.2 | 11.0 | 0.08 |
| Rice | 'GGV 05-01' | 20 × 10 | 150:75:75 | ** | 7.0 | 77 | 3.2 |

*No. of irrigation during different cropping seasons; ** continuous flooding to 10–12 cm height

**Table 2**. Energy conversion factors used in the study

| Power source | Unit | Equivalent energy (MJ) |
|---|---|---|
| Crop produce | | |
| Bt cotton | kg | 14.8 |
| Greengram | kg | 14.6 |
| Sesame | kg | 24.0 |
| Maize | kg | 14.3 |
| Chickpea | kg | 15.1 |
| Sunflower | kg | 26.0 |
| Wheat | kg | 14.5 |
| Chilli | kg | 1.20 |
| Onion | kg | 0.06 |
| Paddy | kg | 15.5 |
| *Power source* | | |
| Farmard manure | kg (dry mass) | 0.30 |
| Chemical fertilizers | | |
| N | kg | 60.60 |
| $P_2O_5$ | kg | 11.1 |
| $K_2O$ | kg | 6.70 |
| Plant-protection measures | kg | 120 |
| Farm machinery | kg | 62.7 |
| Human labour | | |
| Adult man | Man hour | 1.96 |
| Woman | Woman hour | 1.57 |
| Bullock | Pair hr | 10.10 |
| Diesel | Litre | 56.31 |
| Electricity | KWh | 11.93 |

CEY and was significantly superior to rice–rice, while *Bt* cotton–greengram, *Bt* cotton–sesame, maize–chickpea and chilli + onion remained comparable to transplanted *Bt* cotton as well as rice– rice. This was due to variation in production potential of individual crops constituting the system and the prevailing market prices of the commodities. Similar findings were reported by Ram *et.al.* (1991).

Further, water-use efficiency (WUE) under different cropping system also varied significantly (Table 3). The highest water-use efficiency was observed with maize–checkpea system, which is quite acceptable because both were arable crops with low water requirement; besides maize being C4 plant with higher yield also resulted in very high WUE value amongst all the systems. It was followed by chilli–onion, while the other systems showed lower and comparable values of water-use efficiency. In all, the water-use efficiency values were mainly determined by the component crops making the system.

### *Economics*

The maximum gross returns were observed in transplanted *Bt* Cotton followed by Bt cotton–sesame and *Bt* cotton–greengram, being significantly superior to rice–rice (Table 4). Again, maize–chickpea and chilli + onion were at par. Further, the net returns with all the systems were significantly higher than with rice–rice except sunflower–wheat or chickpea; highest being with transplanted cotton followed by *Bt* cotton–greengram/sesame. Benefit: cost ratio also varied significantly, all the systems were significantly superior to rice–rice because of lower yield, prevailing price; moreover cost of cultivation was high with the latter system. Interestingly transplanted Bt cotton recorded the highest benefit: cost ratio followed by maize–chickpea owing to lower cost of cultivation in comparison to the other systems. The next best systems were *Bt* cotton–sesame, chilli + onion and sunflower–chickpea. Our results are in agreement with Rammohan *et al*. (1999).

**Table 3.** Yield and cotton-equivalent yield, water requirement, water-use efficiency and protein, carbohydrate, fat yields of different cropping systems (pooled data of 3 years)

| Treatments | Yield (t/ha) | | Seed-cotton equivalent (kg/ha) | Water requirement (mm) | | Water-use efficiency (kg/ha mm) | Protein (t/ha) | Carbohydrate (t/ha) | Fat (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| *Bt* cotton | 2.10 | - | 2.10 | 800 | - | 2.63 | 0.40 | 0.78 | 0.30 |
| *Bt* cotton–green gram | 2.19 | 0.44 | 2.53 | 800 | 300 | 4.18 | 0.53 | 1.07 | 0.32 |
| *Bt* cotton–green manure crop | 2.26 | - | 2.26 | 800 | - | 2.79 | 0.43 | 0.83 | 0.32 |
| *Bt* cotton–sesame | 2.21 | 0.31 | 2.61 | 800 | 450 | 3.47 | 0.48 | 0.89 | 0.47 |
| Maize–chickpea | 4.16 | 1.47 | 2.47 | 600 | 450 | 10.39 | 0.73 | 3.76 | 0.23 |
| Sunflower–wheat | 1.24 | 1.28 | 1.51 | 500 | 600 | 4.69 | 0.51 | 1.14 | 0.68 |
| Sunflower–chickpea | 1.15 | 1.21 | 1.94 | 500 | 450 | 5.48 | 0.58 | 0.97 | 0.75 |
| Chilli + onion | 0.91 | 4.23 | 2.41 | 750 | 400 | 9.96 | 0.08 | 0.47 | 0.01 |
| Transplanted cotton | 2.73 | - | 2.73 | 700 | - | 3.85 | 0.52 | 1.01 | 0.39 |
| Rice–rice | 4.00 | 4.20 | 2.29 | 1,250 | 1,250 | 3.31 | 0.57 | 6.32 | 0.26 |
| SEm ± | - | - | 0.11 | - | - | 0.23 | 0.05 | 0.07 | 0.03 |
| CD (P=0.05) | - | - | 0.33 | - | - | 0.70 | 0.16 | 0.22 | 0.08 |

Market prices (₹/kg): Seed cotton, 42.6; greengram 32.1; sesamum, 55; Maize, 12.3; chickpea, 35; sunflower, 29.3; chiili, 76.6; wheat, 19.6; onion, 9.5; Rice 11.6

### *Energetics*

Evaluation of different cropping systems through energetics is appreciated these days as it is more stable and meaningful and it indicates the energy yield from the system which does not fluctuate with the market prices since it is based on the nutritional value of the system. Unlike cotton-equivalent yields, energetics revealed different pattern, wherein protein yields were higher with maize–chickpea because of higher protein content in maize and chickpea grains compared to other crops under study, while carbohydrate and energy yields (127069 MJ) were significantly higher with rice–rice, rice being cereal rich in carbohydrate, compared to all the other systems (Table 5). However, sunflower being an oilseed crop fat yield was the highest in sunflower-based cropping systems viz., sunflower–wheat and sunflower–chickpea. Similar findings were reported by Ganajaxi (2008) from Zone 8 rainfed ecosystem of Karnataka.

### *Land-utilization index, efficiencies and sustainable yield index*

The highest land-utilization index (Table 4) was observed with *Bt* cotton–sesame cropping system (76.7 %), since these crops occupied the land for the longest duration (280 days). The least land-utilization index was recorded in transplanted *Bt* cotton, which occupied the land for 155 days; however, the latter system registered the highest production efficiency than others. Economic efficiency also varied significantly among different cropping systems; highest being with transplanted *Bt* cotton, which was significantly superior to the other systems. The transplanted cotton has the highest sustainable yield index followed by *Bt* cotton–sesame and the lowest was recorded in sunflower–wheat.

### *Energy analysis*

The highest energy input was recorded in rice–rice cropping system among the systems and the lowest energy input was in *B*t cotton alone because the double cropping systems of rice utilized the maximum input and hence required more cultural practices (Table 5). Energy output was the highest with rice–rice followed by maize–chickpea and the lowest energy output was in chilli+onion. However, energy–use efficiency was the highest for maize–chickpea followed by transplanted Bt cotton, while the lowest in chilli+onion because of the fact that chilli and onion had lowest energy conversion values among all.

Nevertheless, energy productivity was the highest with transplanted Bt cotton because of higher productivity and low energy input compared to all cropping systems. Systems net energy returns were the highest with maize–chickpea followed by transplanted *B*t cotton because of more output energy and low input energy associated with these systems. Energy intensiveness was the highest in maize–chickpea followed by rice–rice again due to higher output energy and lower cost of cultivation. Similar results were obtained by Mishra *et al.* (2013).

Thus, the investigation emphasizes the superiority of arable systems such as sole transplanted *Bt* cotton, *Bt* cotton–greengram, *Bt* cotton–sesame, chilli + onion and maize – chickpea which can easily replace rice–rice with least negative environmental impacts. Such a wide array of options also opens possibility for many rotational systems. For farmers with pre-monsoon water availability for nursery, transplanted cotton may be appreciated while for others *Bt* cotton (dibbled)–sesame or greengram is advanta-

**Table 4.** Land-utilization index, production efficiency, economic efficiency and sustainable yield index (SYI), and economics of different cropping systems (pooled data of 3 years)

| Treatment | Land-utilization index (%) | Production efficiency (kg/ha/day) | Economic efficiency (₹/ha/day) | SYI (%) | Gross returns (× $10^3$₹/ha) | Net returns (×$10^3$₹/ha) | Benefit: cost ratio |
|---|---|---|---|---|---|---|---|
| *Bt* cotton | 49.3 (180)* | 11.7 | 328 | 52.71 | 84.1 | 59.1 | 2.36 |
| *Bt* cotton–green gram | 69.9 (255) | 9.9 | 262 | 67.48 | 101.2 | 66.7 | 1.93 |
| *Bt* cotton–green manure crop | 65.8 (240) | 9.4 | 243 | 58.13 | 90.3 | 58.3 | 1.82 |
| *Bt* cotton– sesame | 76.7 (280) | 9.3 | 251 | 70.11 | 104.2 | 70.2 | 2.06 |
| Maize–chickpea | 58.9 (215) | 11.5 | 324 | 65.58 | 98.9 | 69.7 | 2.39 |
| Sunflower–wheat | 60.3 (220) | 6.8 | 146 | 32.12 | 60.2 | 32.1 | 1.14 |
| Sunflower–chickpea | 56.2 (205) | 9.5 | 250 | 47.23 | 77.7 | 51.3 | 1.94 |
| Chilli + onion | 65.8 (240) | 10.0 | 268 | 63.35 | 96.4 | 64.4 | 2.01 |
| Transplanted cotton | 42.8 (155) | 17.6 | 512 | 74.23 | 108.9 | 79.5 | 2.71 |
| Rice–rice | 68.5 (250) | 9.1 | 178 | 59.04 | 91.4 | 44.7 | 0.96 |
| SEm± | - | 0.5 | 17 | 3.63 | 4.2 | 4.2 | 0.15 |
| CD (P=0.05) | - | 1.4 | 52 | 10.78 | 12.5 | 12.5 | 0.46 |

*Figures in parentheses are total duration of the cropping sequences

**Table 5.** Input and output energies and energy use efficiency of different cropping systems (pooled data of 3 years)

| Treatment | Total input energy ($10^3$ MJ/ha) | Total output energy ($10^3$ MJ/ha) | Energy use efficiency (%) | Energy productivity (kg/MJ) | System net energy returns ($10^3$ MJ/ha) | Energy intensiveness (MJ/₹) |
|---|---|---|---|---|---|---|
| *Bt* cotton | 14.0 | 31.1 | 222 | 0.15 | 17.1 | 1.30 |
| *Bt* cotton–green gram | 22.2 | 38.8 | 175 | 0.11 | 16.6 | 1.13 |
| *Bt* cotton–green manure crop | 20.2 | 33.4 | 165 | 0.11 | 13.2 | 1.04 |
| *Bt* cotton– sesame | 20.3 | 40.1 | 197 | 0.13 | 19.8 | 1.18 |
| Maize–chickpea | 28.4 | 81.7 | 288 | 0.09 | 53.3 | 3.53 |
| Sunflower–wheat | 38.4 | 50.8 | 132 | 0.04 | 12.4 | 2.18 |
| Sunflower–chickpea | 27.3 | 48.2 | 176 | 0.07 | 20.8 | 2.29 |
| Chilli + onion | 32.2 | 1.34 | 4 | 0.07 | -30.8 | 0.05 |
| Transplanted cotton | 16.2 | 40.4 | 250 | 0.17 | 24.3 | 1.41 |
| Rice–rice | 105.7 | 127.1 | 130 | 0.02 | 21.4 | 2.69 |

geous, and if financial resources are a constraint then maize–chickpea has the scope. Rice–rice can be relegated to upper reaches and waterlogging/saline areas, where cultivation of arable crops is impossible, and also when production of carbohydrates is the priority. However, with dwindling water resources it would be better to do away with rice–rice as the single crop of rice consumes 2,500–3,000 mm water per crop against 300–600 mm (greengram, chickpea, sunflower, maize, wheat etc.) to 700–800 mm (cotton and chilli) by other crops, and such an alternate system would increase total irrigable area, ensure water to tail- end farmers besides higher water productivity of the command.

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