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Suitability of sustainable cropping systems in rainfed tropical islands of India

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Abstract
The climatic data for 40 years from 1978 to 2017 of the rainfed tropical islands of South Andaman district of Andaman and Nicobar group of islands were analyzed to find out effective rainfall and evapotranspiration. These values were used to calculate the monthly climatic index. The 80% dependable monthly climatic index was correlated with crop coefficient. The total cropping period was determined as 246 days commencing from May to end of December. Crops with more water demand having higher $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ values were proposed from May onwards to the end of September, and crops with less water demand having lower $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ values were proposed from October onwards. Based on it a feasible and sustainable set of 54 nos. of cropping sequences were suggested for the study area.

Keywords: Agricultural sustainability, cropping system, cropping period, rainfed tropical islands

Introduction
Coastal agriculture is generally characterized by low productivity due to uncertain weather conditions, traditional agricultural practices, low agricultural inputs and uneconomic size of the land holding. The union territory of Andaman and Nicobar group of islands is one of the coastal state of India with the coastline of 1912 km with the length and average width of Andaman group of islands are 467 km and 24 km respectively. More than 50% of the people of these islands depending on agriculture and allied activities for their livelihood and 50% of the state's economy comes from the agriculture sector. Its importance in these islands has a special bearing because of limitation on alternative livelihood possibilities and because of its dependence on mainland India located at an average distance of 1300 km for almost all essential items (DSHB, 2015-16) [3]. Development of the poor in the area is dependent on development of agriculture and allied activities. Topographically the Andamans are undulating, characterized with hills, hillocks and flat bottomed vallies (Pandey *et al.* 2007) [8]. Agriculture in most of the places of the State is rainfed with low level of production and productivity due to insufficient availability of practical irrigation and is entirely dependent on climatic factors which lead to poverty and malnutrition (Nanda *et al.* 2018a) [6]. In spite of being organic in nature, agriculture in these areas has become more and more risky because of erratic climatic behaviour. Being fed up, in most cases, the farmers of these islands flee away from their native villages in search of alternative methods of livelihood leaving the crop fields fallow, forever. As a result the agriculture lands lead to large scale land degradation. Hence, sustainable cropping systems suitable to the agroclimatic condition of these islands are required so that agricultural activities can be sustainable in long run. The main objectives of the study is to analyze the climatic data of the study area and to find out suitable cropping period and sequences based on monthly water balance.
The area selected for study is the South Andaman district located in the Southern part of the Andaman group of islands in the Union Territory of Andaman and Nicobar group of islands. Among the total 37 inhabited islands in this Union Territory of India, 10 inhabited islands are there in South Andaman group of islands. The district lies between latitude of 6° 45´ to 13° 4´ North and longitude of 92° 15´ to 94° East at an elevation of 13.0 m from mean sea level with 95.3 per cent of the land area covered with dense tropical rain forest. These Islands have a true maritime climate of warm and humid with mean maximum and minimum temperatures of 31 °C and 21 °C, respectively and fall under agro climatic zone XV. The agro-ecoregion (hot perhumid island ecoregion with red loamy soils AESR 21) comprises the group of islands of Andaman and Nicobar has a climate typified by tropical conditions with little difference between mean summer and mean winter temperatures by 1.7 °C.

The soil temperature and moisture regimes are isohyperthermic and udic, respectively. The annual normal rainfall in the district is 3054.2 mm distributed over 131.1 rainy days. The daily rainfall data indicates that these groups of islands receive 72.5% of the total normal annual rainfall due to South-West monsoon recorded in 91 rainy days. May to November is the usual wet period, where 90.4% rainfall is recorded in about 117.3 rainy days. Mean relative humidity varies from 67% to 95% in monsoon and 56% to 84% in off season (DSHB, 2015-16) [3]. Agricultural activity during the monsoon in these islands is largely affected by the heavy rainfall that occurred during the months of May to July and October to December in the calendar year (Nanda *et al*, 2018b) [7].

Materials and Methods

Basic relevant information of South Andaman district and primary data related to agriculture i.e. existing area under food crops (cereals, pulses, oilseeds) and vegetable crops, their productivity and production, the level of application of inputs like seeds, manures, fertilizers and labour etc. were collected from published reports (DSHB, 2015-16) [3]. Climate data i.e. rainfall, maximum and minimum temperature, relative humidity, sunshine hours, wind velocity, wind direction etc. were collected from DSHB (2015-16) [3], Division of Natural Resources Management, ICAR-Central Island Agricultural Research Institute (CIARI), Port Blair (ICAR-CIARI, 2017) [4] and Indian Meteorological Department, Kolkata. The data on soil type, texture etc. were collected from ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur. The data on land uses, existing cropping pattern etc. were collected from ICAR-Krishi Vigyan Kendra, Port Blair (ICAR-KVK, Port Blair, 2018) [5].

Effective rainfall and Reference crop evapotranspiration (ET_o)

The monthly rainfall data for 40 years from 1978 to 2007 were analyzed and the USDA Soil Conservation Service method as given in Eqs. (1) and (2) was used to calculate monthly effective rainfall with help of "FAO CROPWAT 8.0 for Windows" software.

$$P_e = (P_t/125) \times (125 - 0.2 \times P_t) \text{ (when } P_t < 250\ mm) \quad (1)$$

$$P_e = 125 + 0.1 \times P_t \text{ (when } P_t > 250 \text{ mm)} \quad (2)$$

Where,
P_e = Monthly effective rainfall, mm and P_t = Total monthly rainfall, mm

The monthly reference crop evapotranspiration was calculated from climatic data such as daily mean maximum and minimum temperature, humidity, wind speed and daily sunshine hours using "FAO Penman-Monteith" method (Allen *et al*., 1998) [1] with the help of "FAO CROPWAT 8.0 Windows" software.

Crop coefficient (K_c)

During the initial period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. The K_c during the initial period ($K_{c\ ini}$), is a function of wetting interval, evaporating power of the atmosphere and magnitude or importance of the wetting event (Allen *et al*., 1998) [1]. The interval between significant rains (calculated by dividing the number of normal rainy days by 30 considering one event per normal rainy day) daily ET_o and the importance of wetting event (calculated by dividing the number of normal rainy days to the total monthly rainfall), were used to estimate the value of $K_{c\ ini}$ from Figs. 1 and 2 as suggested by Allen *et al*. (1998) [1].

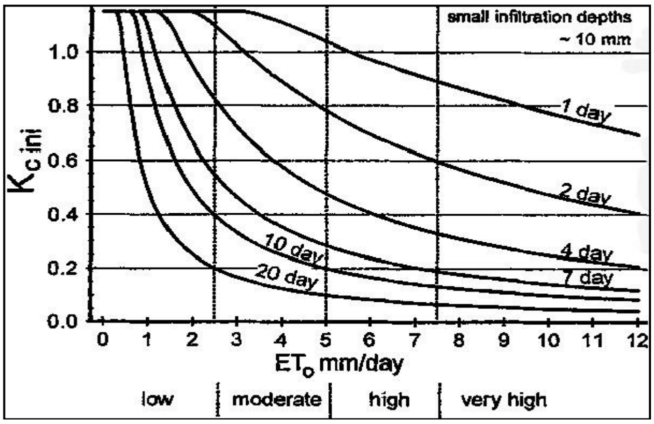

Fig 1: Average $K_{c\ ini}$ as related to the level of ET_o and the interval between significant rain during the initial growth stage for small infiltration depths (Fig. 29, Allen *et al*., 1998) [1].

The range of K_c at the development stage ($K_{c\ dev}$), mid season stage ($K_{c\ mid}$) and late season stage ($K_{c\ end}$) were adopted as 0.6–0.85, 0.9–1.2 and 0.55–1.05, respectively for food crops like maize, green gram, black gram, arhar, groundnut, ginger, turmeric, tapioca, mustard, vegetables, etc., except in case of rice for which higher $K_{c\ dev}$ values of 1.1–1.15 (Doorenbos and Pruitt, 1977; Allen *et al*., 1998) [2, 1]. FAO Irrigation and Drainage paper 56 (Allen *et al*., 1998) [1] have also suggested using these values for calculation of ET_c.

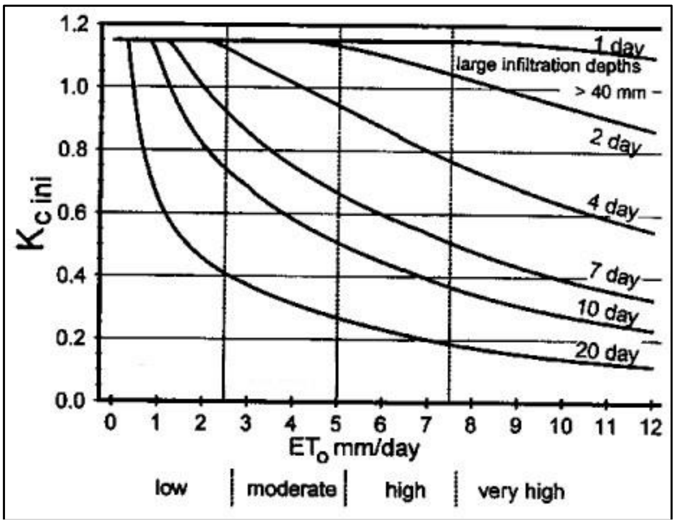

Fig 2: Average $K_{c\ ini}$ as related to the level of ET_o and the mean wetting interval during the initial growth stage for large infiltration depths (Fig. 30b, Allen *et al*., 1998) [1].

Climatic index

The cropping period was selected depending on the water availability and water utilised in the crop field. The amount of effective rain should at least be equal to the water loss through crop evapotranspiration (ET_c) from a crop field in a particular period for successful crop growth. For climatic suitability, the value of crop coefficient (K_c) should, therefore, be less than the ratio of two climatic factors, effective rainfall and ET_o, at each stage of crop growth. The water balance stage is characterised by the ratio of effective rainfall and

ET_o, that evidently equates to K_c and hereinafter be termed as "climatic index (C_i)" to be effectively representing the climatic factors in water balance calculations. Monthly values of C_i were grouped using 0.1 groupings (0–0.1, 0.1–0.2, 0.2–0.3, . . . and 0.9–1.0) and 80% dependable values of C_i for each month was calculated, by dividing the number of times the monthly value of C_i falls within a group by the number of monthly records (Savva and Frenken, 2002) [9]. The values of 80% dependable C_i were correlated with the $K_{c\ ini}$ values to suggest starting of the cropping period and with values of $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ to suggest the total cropping period. Crops that are traditionally grown in the area are planned as per the local affinity and scheduled in the selected cropping period by comparing the values of 80% dependable C_i with the values of $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ (Allen *et al.*, 1998) [1] and as per the land type.

Results and Discussions

Selection of crop sequences and cropping period

The annual value of effective rainfall was found minimum (924.6 mm) during 1979 and maximum (1606.7 mm) during 2011, whereas the annual value of ET_o was found minimum (1196.8 mm) during 1993 and maximum (1444.4 mm) during 2014. The annual value of climatic index (C_i) was found lowest (0.71) during 1979 and highest (1.29) during 1984. The average values of annual effective rainfall (P_e), reference crop evapotranspiration (ET_o) and climatic index (C_i) over the said period of 40 years were found to be 1302.3 mm, 1294.7 mm and 1.01 respectively.

Climatic index

The month wise calculated values of crop coefficient at initial stage ($K_{c\ ini}$) and the values of 80% dependable C_i are given in Table 1 and their graphical representation is given in Fig. 3. The monthly values of 80% dependable climatic index (C_i) becomes equal to the value of $K_{c\ ini}$ after 1st week of May and thereafter it exceeds $K_{c\ ini}$ till 3rd week of September. It indicates that crops can be taken up suitably from 1st week of May onwards and may be sown up to the end of 3rd week of September with sufficient $K_{c\ ini}$ values. The total cropping period was determined as 246 days commencing from May to end of December. Crops with more water demand having higher $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ values were proposed from May onwards to the end of September, and crops with less water demand having lower $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ values were proposed from October onwards.

Table 1: Month wise initial crop coefficient, $K_{c\ ini}$ and 80% dependable Ci.

Month	Normal Rainfall (mm)	Normal rainy days	Average infiltration depth (mm)	Mean wetting interval, days	Daily ET_o (mm)	$K_{c\ ini}$ for I = 10 mm	$K_{c\ ini}$ for I = 40 mm	Calculated $K_{c\ ini}$	80% dependable C_i
January	45.1	2.1	21.48	10	3.22	0.308	0.65	0.439	0
February	14.1	0.8	17.63	30	3.73	0.067	0.16	0.091	0
March	44.0	1.8	24.44	15	4.10	0.292	0.45	0.368	0
April	82.0	4.5	18.22	6	4.35	0.392	0.82	0.509	0
May	399.2	16.0	24.95	2	3.91	0.900	1.15	1.025	1.11
June	439.0	17.9	24.53	2	3.36	0.984	1.15	1.064	1.41
July	446.4	18.7	23.87	2	3.31	0.992	1.15	1.065	1.41
August	424.8	18.6	22.84	2	3.31	0.992	1.15	1.060	1.41
September	505.2	19.8	25.52	1	3.39	0.976	1.15	1.066	1.51
October	301.2	15.1	19.95	2	3.47	0.968	1.15	1.028	1.01
November	245.9	11.2	21.96	3	3.25	0.842	1.11	0.949	0.91
December	107.3	4.6	23.33	6	3.05	0.550	0.94	0.723	0.11

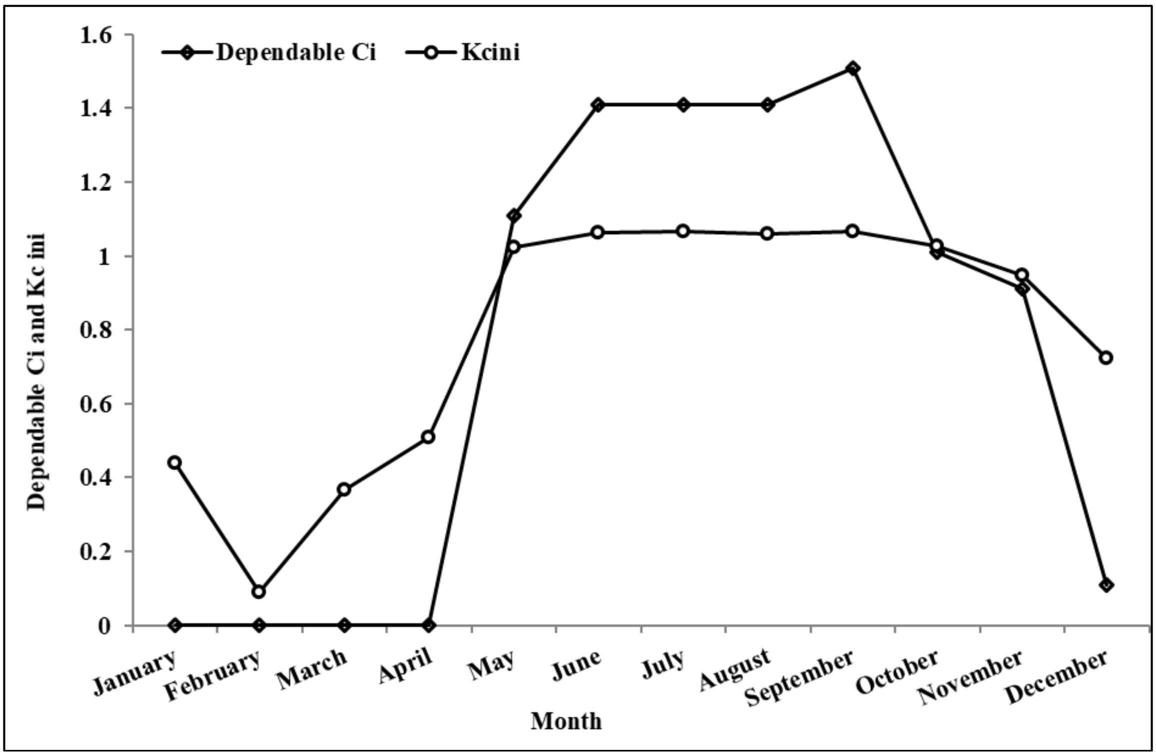

Fig 3: Month wise variation of dependable climatic index (C_i) and initial crop coefficient ($K_{c\ ini}$) for South Andaman district.

Basing on all the factors and with respect to water balance and climate suitability, a standard crop schedule (Fig. 4) was prepared and centering it as many as 54 possible cropping sequences (Table 2) including an option of a perennial grass cover were proposed for the district with following considerations.

1. Crops like ginger, sweet potato, turmeric and tapioca are to be taken in uplands.
2. Crops like rice, maize, arhar, green gram, black gram, sweet potato and ground nut are to be taken in uplands as well as medium lands.
3. Mustard is to be taken up in uplands and medium lands as well as in areas with some assured irrigation.
4. Vegetables are to be taken up in *kharif* in uplands and medium lands and second and third vegetables are to be taken up in *rabi* and *summer* in areas with some assured irrigation.
5. The option of having a perennial grass cover is limited to the upland areas

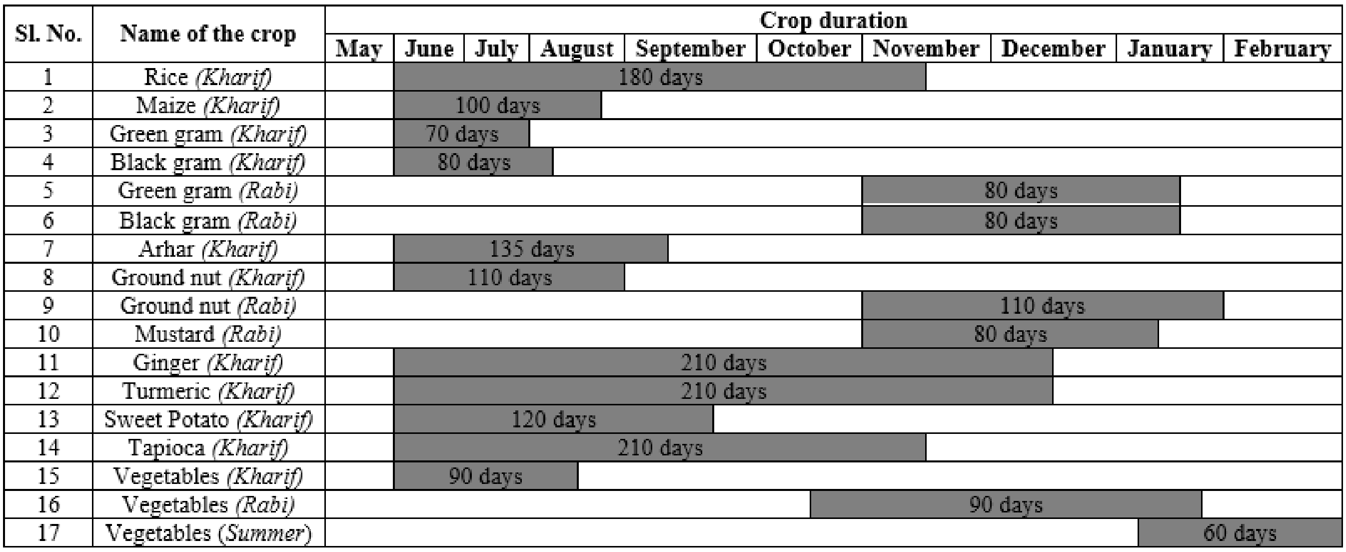

Fig 4: Suggested crop sequences for the study area

Table 2: Crop sequences for South Andaman district.

Sl. No.	Kharif	Rabi	Summer	Limitations
1	Rice	Fallow	Fallow	Medium and low land
2	Rice	Green gram	Fallow	Up and medium land
3	Rice	Black gram	Fallow	Up and medium land
4	Rice	Groundnut	Fallow	Medium and irrigated land
5	Rice	Mustard	Fallow	Medium and irrigated land
6	Rice	Vegetable	Fallow	Medium and irrigated land
7	Rice	Fallow	Vegetable	Medium and irrigated land
8	Rice	Vegetable	Vegetable	Medium and irrigated land
9	Maize	Fallow	Fallow	Up and medium land
10	Maize	Black gram	Fallow	Up and medium land
11	Maize	Green gram	Fallow	Up and medium land
12	Maize	Ground nut	Fallow	Medium and irrigated land
13	Maize	Mustard	Fallow	Medium and irrigated land
14	Maize	Fallow	Vegetable	Medium and irrigated land
15	Maize	Vegetable	Fallow	Medium and irrigated land
16	Maize	Vegetable	Vegetable	Medium and irrigated land
17	Green gram	Fallow	Fallow	Up and medium land
18	Green gram	Groundnut	Fallow	Medium and irrigated land
19	Green gram	Mustard	Fallow	Up and medium land
20	Green gram	Vegetable	Fallow	Medium and irrigated land
21	Green gram	Vegetable	Vegetable	Medium and irrigated land
22	Black gram	Fallow	Fallow	Up and medium land
23	Black gram	Ground nut	Fallow	Medium and irrigated land
24	Black gram	Mustard	Fallow	Up and medium land
25	Black gram	Vegetable	Fallow	Medium and irrigated land
26	Black gram	Vegetable	Vegetable	Medium and irrigated land
27	Arhar	Fallow	Fallow	Up and medium land
28	Arhar	Ground nut	Fallow	Medium and irrigated land
29	Arhar	Mustard	Fallow	Medium and irrigated Land
30	Arhar	Veghetable	Fallow	Medium and irrigated Land
31	Arhar	Vegetable	Vegetable	Medium and irrigated Land
32	Ground nut	Fallow	Fallow	Up and medium land

33	Ground nut	Mustard	Fallow	Medium and irrigated Land
34	Ground nut	Vegetable	Fallow	Medium and irrigated Land
35	Ground nut	Vegetable	Vegetable	Medium and irrigated Land
36	Ginger		Fallow	Upland
37	Ginger		Vegetable	Medium and irrigated land
38	Turmeric		Fallow	Upland
39	Turmeric		Vegetable	Medium and irrigated Land
40	Sweet potato	Fallow	Fallow	Upland
41	Sweet potato	Ground nut	Fallow	Medium and irrigated land
42	Sweet potato	Mustard	Fallow	Medium and irrigated land
43	Sweet potato	Vegetable	Fallow	Medium and irrigated Land
44	Sweet potato	Vegetable	Vegetable	Medium and irrigated Land
45	Tapioca		Fallow	Upland
46	Tapioca		Vegetables	Medium and irrigated Land
47	Vegetable	Fallow	Fallow	Up and medium land
48	Vegetable	Black gram	Fallow	Medium and irrigated Land
49	Vegetable	Green gram	Fallow	Medium and irrigated Land
50	Vegetable	Ground nut	Fallow	Medium and irrigated Land
51	Vegetable	Mustard	Fallow	Medium and irrigated Land
52	Vegetable	Vegetable	Fallow	Medium and irrigated land
53	Vegetable	Vegetable	Vegetable	Medium and irrigated land
54	Grass cover (Perennial hybrid napier)		Upland	

Conclusion

Agriculture in rainfed islands of South Andaman district of the Union Territory of Andaman and Nicobar group of islands is extremely dependent on the climatic factors in absence of sufficient irrigation facilities. With erratic nature of the climatic factors, agriculture in these islands is extremely risky. Out of the total annual rainfall of 3054.2 mm, 72.5% occurs during monsoon months from May to September. Climatic analysis suggests suitable cropping period for 246 days from May to January with sowing limitations until end of September. A total nos. of 54 cropping systems can be adopted in these islands considering the crop coefficients of $K_{c\ ini}$, $K_{c\ dev}$, $K_{c\ mid}$ and $K_{c\ end}$ values of different crops and prevailing land use conditions. These cropping systems are sustainable considering the crop water availability in the region.

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