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ORIGINAL PAPER

Identification of climate-resilient integrated nutrient management practices for rice-rice cropping system—an empirical approach to uphold food security

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Abstract Yield datasets of long-term experiments on integrated nutrient management in rice-rice cropping systems were used to investigate the relationship of variability in rainfall, temperature, and integrated nutrient management (INM) practices in rice-rice cropping system in three different agroecological regions of India. Twelve treatments with different combinations of inorganic (chemical fertilizer) and organic (farmyard manure, green manure, and paddy straw) were compared with farmer's conventional practice. The intraseasonal variations in rice yields are largely driven by rainfall during *kharif* rice and by temperature during *rabi* rice. Half of the standard deviation from the average monthly as well as seasonal rainfall during *kharif* rice and 1 °C increase or decrease from the average maximum and minimum temperature during *rabi* rice has been taken as the classification of yield groups. The trends in the date of effective onset of monsoon indicate a 36-day delay during the 30-year period at Rajendranagar, which is statistically significant at 95 % confidence level. The mean annual maximum temperature shows an increasing trend in all the study sites. The length of monsoon also showed a shrinking trend in the rate of 40 days during the 30-year study period at Rajendranagar representing a semiarid region. At Bhubaneshwar, the application of 50 % recommended NPK through chemical fertilizers and 50 % N through green manure resulted in an overall average higher increase of 5.1 % in system productivity under both excess and deficit rainfall years and also during the years having seasonal mean maximum temperature ≥35 °C. However, at Jorhat, the application of 50 % recommended NPK through chemical fertilizers and 50 % N through straw resulted in an overall average higher increase of 7.4 % in system productivity, while at Rajendranagar, the application of 75 % NPK through chemical fertilizers and 25 % N through green manusre resulted in an overall average higher increase of 8.8 % in system productivity. This study highlights the adaptive capacity of different integrated nutrient management practices to rainfall and temperature variability under a rice-rice cropping system in humid, subhumid, and semiarid ecosystems.

Keywords Extreme climate · Integrated nutrient management · Rice-rice · Climate resilient · Cropping system · Yield deviation

Introduction

Changes in climate will affect the rice production and thus have an impact on food security. Rice-rice production systems make a vital contribution to the reduction of hunger and poverty, and its cultivation extends from drylands to wetlands, cool climates at altitudes to hot deserts, and also areas of below mean sea level. Studies suggest that the temperature increased, rising seas, and changes in rainfall pattern and distribution expected as a result of global climate change could lead to substantial modifications in land and water resources for rice production as well as in the productivity of rice crops grown in different parts of the world. It is estimated that production must increase by 50 % in 2050 to meet global food needs (WWF-ICRISAT 2010). The required increase in production will have to be achieved despite the increasing temperatures, decreasing rainfall effectiveness, increasing frequency of extreme events, degrading soils, declining and polluting water resources, increasing demands on energy,

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and regressive change to more fragile and harsh environments (Lal 2010). It has been estimated that for every 1 °C rise in mean temperature, there is a corresponding 7 % decline in rice yield (IWMI 2007).

Flowering is the most critical stage when the rice crop should not be subjected to any moisture stress. According to Jearakongman et al. (1995), grain yields were severely reduced when standing water disappeared more than 20 days before anthesis, while the presence of standing water 20 days after anthesis resulted in higher yields. According to Peng et al. (2004), rice grain yield declined by 10 % for each 1 °C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant. The linear regression analysis showed that there will be a decline in rice yield with minimum temperature based on experimental data as well as through modeling approach (Sheehy et al. 2006). Lobell and Asner (2003) suggested a larger negative response of yield to temperature using regression analysis. Depending on climate, soils, cultivars, and management practices, the total irrigation water requirement of the rice crop ranges from 450 mm in upland conditions to 1,300 mm in lowland conditions (Yoshida 1975, 1978; Doorenbos and Kassam 1979). Even though the monsoon enters over the main lands of India through Kerala Coast during the last week of May or the first week of June, it can be transplanted in the puddled field after good initial monsoon showers. Hence, as far as *kharif* rice crop is concerned, June–September rainfall is considered as important. However, with the adoption of suitable integrated nutrient management practices, the adverse effects of extreme climatic conditions can be minimized. There is an urgent need to quantify the response of different integrated nutrient management practices to extreme climatic conditions under a rice-rice system. The present study aims at (i) understanding observed trends in climate variables, (ii) how the variability of rainfall and temperature affects the productivity under different management practices, and (iii) identification of site-specific climate-resilient integrated nutrient management practices under a rice-rice system.

Materials and methods

Study sites and experimental details

This study is based on data collected under the egis of All India Coordinated Project on Farming Systems Research of Indian Council of Agricultural Research located at different agroecological zones of India (Table 1). The ecosystem ranges from humid high rainfall (Bhubaneshwar) to semiarid low rainfall (Rajendranagar) region. The grain yield datasets of these sites under long-term experiments during the period 1988–2008 (21 years) on integrated nutrient management in rice-rice cropping systems were used. Experiments were conducted in all the three study sites with 12 treatments in three replications with different combinations of inorganic and organic sources of nutrients to a rice-rice system. Normally, rice season (June–July to October–November) refers to "*Kharif*" while rice season (November–December to March) refers to "*Rabi*." In *kharif* rice, the full recommended levels of N, P, and K were supplied through inorganic fertilizers or in combination with N through farmyard manure (FYM), crop residue, or green manure so that the 100 % recommended N dose was available to the crop. The *rabi* rice did not receive any organic sources of nutrients and applied NPK through inorganic recommended dose. During the 21 years of long period of experimentation, the varieties were changed/replaced as per the availability; however, the varieties were selected in such a way to match with the yielding and duration to maintain the commonalities and treatments were not changed during the period.

Weather data and its trends and variability

The daily rainfall and maximum and minimum temperature data recorded at these study sites during the period 1980 to 2009 were collected. Mann-Kendall (Mann 1945; Kendall 1975) nonparametric trend test was used for trend analysis, and this basically involves the ranks obtained by each data in the data series and is a statistical yes/no type hypothesis testing procedure for the existence of trends and does not estimate the slope of trends. The magnitude of the trends was estimated using Sen slope (Sen 1968), and according to Hirsch et al. (1982), Sen's method was robust against extreme outliers. The Mann-Kendall test has been used by several researchers to detect trends in hydrometeorological time series data (Kundzewicz and Robson 2000; Chiew and Sirivardena 2005; Sneyers 1990; Serrano et al. 1999; Brunetti et al. 2000a, b; Subash and Ram Mohan 2010a, b; 2012).

Onset of effective monsoon and length of monsoon season

The normal dates of onset of the monsoon, as determined by the India Meteorological Department (IMD), are based on the sudden increase of 5-day pentad average of rainfall for all the rain gauge observatories. The middle date of pentad, in which an increase of rainfall occurs from the preceding pentad, is taken as the date of onset of monsoon. Since to start agricultural field operations, sufficient moisture is required, and rainfall based is not considered the building up of moisture reserve in the soil, which is vital for commencement of field preparations. Moreover, rice is considered as a water-loving crop and requires plenty of water for field preparation and transplanting. A rainfall-potential evapotranspiration-based concept, suggested by Ashok Raj (1979), is employed, with slight modification for defining the normal effective onset date of rainfall as suggested by Subash et al. (2011). The potential evapotranspiration (PET) has been calculated using a FAO-recommended Penman-

Table 1 General characteristics of the study sites and experimental details

Characteristics	Study sites		
	Bhubaneshwar	Jorhat	Rajendranagar
Latitude (N)	20°15′	26°47′	18°59′
Longitude (E)	85°52′	94°12′	78°55′
Ecosystem	Sub-humid	Humid	Semiarid
Agroclimatic region/subregion of planning	East coast plains and hills region/ Orissa coastal subregion	Eastern Himalayan region/upper Brahmaputra valley subregion	Southern plateau and hills region/ south Telangana subregion
Soil type	Haplustalfs, very deep, medium textured lateritic soils	Fluaquents/Udicaquents association very deep, alluvial sandy lay loam soils	Udiv Ustochrepts black soils
Annual rainfall (mm)	1,549	1,856	789
Monsoon (June–September)	1,149	1,167	567
rainfall % contribution to annual	74	63	72
Year of start	1983	1987	1988
Crop variety—*kharif*	Pratiksha	Ranjit	RNR-23064
Crop variety—*Rabi*	MTU 1001	Dishang	RNR-23064
RDF—*kharif* (N:P:K—kg/ha)	80:40:40	45:30:40	120:60:60
RDF—*rabi* N:P:K—kg/ha)	100:50:50	45:30:40	120:60:60
Farmers' practice—*kharif*	20:0:0+FYM(2 t/ha)	12.5:0:0	80:50:20
Farmers' practice- *rabi*	20:0:0+FYM(2 t/ha)	12.5:0:0+FYM (1 t/ha)	120:60:40
Treatments	Experimental details		
	Kharif rice		*Rabi*- rice
T1	No fertilizer, no organic manure(control)		No fertilizer, no organic manure(control)
T2	50 % NPK RDF		50 % NPK RDF
T3	50 % NPK RDF		100 % NPK RDF
T4	75 % NPK RDF		75 % NPK RDF
T5	100 % NPK RDF		100 % NPK RDF
T6	50 % NPK RDF+50 % N−FYM		100 % NPK RDF
T7	75 % NPK RDF+25 % N−FYM		75 % NPK RDF
T8	50 % NPK RDF+50 % N−straw		100 % NPK RDF
T9	75 % NPK RDF+25 % N−straw		75 % NPK RDF
T10	50 % NPK RDF+50 % N−GM		100 % NPK RDF
T11	75 % NPK RDF+25 % N−GM		75 % NPK RDF
T12	Farmer's conventional practice		Farmer's conventional practice

RDF recommended dose of fertilizer, *FYM* farmyard manure, *GM* green manure (Azolla caroliniana—2.5–3.5 % nitrogen availability on a dry weight basis used at Bhubaneshwar and Jorhat and Gliricidia—2.93 % nitrogen availability on a dry weight basis used at Rajendranagar), *Straw* crop residue

Monteith equation (FAO 1998). The following crieteria are used for defining the effective onset date:

- The first day's rain in the 7-day spell should be more than the normal daily PET on that day,
- The total rain during the 7-day spell should be more than the total normal PET of that 7-day spell, and
- At least 4 of these 7 days should have more than 2.5 mm of rainfall.

The withdrawal of effective monsoon that is the last rainy day of the season as defined by Ashok Raj (1979) is used in this study. The variability as well as the trends of effective onset and length of monsoon period were also worked out using the Mann-Kendall test. Based on climatic features, IMD, which is India's nodal agency of WMO, defined four seasons, viz. winter (January–February), pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–December). The averages of monthly, seasonal, and annual rainfall as well as rainy days and its standard deviation (SD) and coefficient of variation (CV) (CV=(SD/mean)×100) were calculated in order to find out the variability during the study period.

Empirical relationship

Statistical correlations were working out between rice yields and monthly rainfall during kharif rice for all the treatments for all the study sites to know which month's rainfall is more influenced to yield. Similarly, correlations were done between rice yield and monthly maximum and minimum temperature during rabi rice. Tests of significance at 0.01 and 0.05 levels were also performed. Year-to-year variability in rice yields is largely driven by rainfall during *kharif* and temperature during *rabi*. To quantify the influence of rainfall on rice productivity during *kharif*, the productivity was grouped into three categories based on half of the SD from the average seasonal rainfall during the crop season (Mean±one-half SD). Similarly, to quantify the influence of temperature on rice productivity during *rabi*, the productivity was grouped into different categories based on ±1 °C intervals from the mean value during the crop season. After grouping the different categories, the deviation of yield from the normal was worked out in each management practice to spell out the best treatment to withstand both extreme rainfall and temperature at each site.

Results

Variability and trends of onset of effective monsoon and length of monsoon season

The mean effective onset of monsoon varies from June 8 at Jorhat to July 1 at Rajendranagar (Fig. 1). A higher SD of 20 days with a CV of 64 % indicates that there is a higher year-to-year variability at Rajendranagar. The length of the monsoon season varies from 86 days at Rajendranagar to 112 days at Jorhat. The trends in the date of effective onset of monsoon indicate 36-day delay during the 30-year period at Rajendranagar, which is statistically significant at 95 % confidence level. The length of monsoon also showed shrinking at the rate of 40 days during the 30-year study period at Rajendranagar. The decreasing trends of monthly rainfall during June and July also support this. Another interesting feature that emerged out of the study will be the increasing trend of October rainfall and rainy days, and this may be due to the delay of the withdrawal of monsoon.

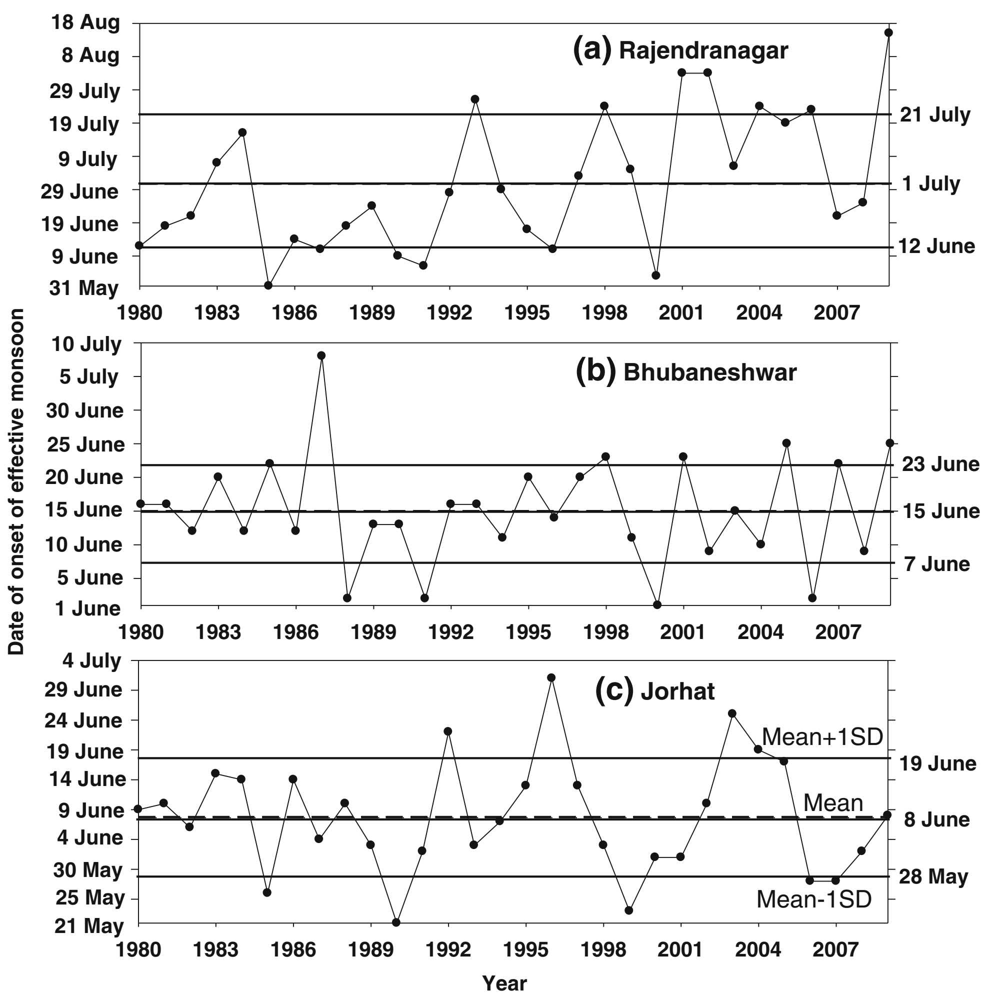

Fig. 1 Variability of effective onset of monsoon over study locations during the period 1980–2009

Rainfall variability and trends

The CV of annual rainfall shows not much difference among the study sites, and it was below 30 % for all the sites (Table 2). Even though the CV during monsoon season was also below 30 %, a higher value of individual months within the monsoon season indicates the large year-to-year variability. August was the rainiest month in Bhubaneshwar and Rajendranagar; however, July was the rainiest month in Jorhat. In the case of the number of rainy days, 73 % of the rainy days fall during monsoon season in Bhubaneshwar to 57 % at Jorhat. Mean rainy days of 12 and 13, respectively, during April and May at Jorhat showed more pre-monsoon showers compared to other sites. It is also noticed that the year-to-year variability in rainfall and rainy days during all months and seasons is higher in a semiarid ecosystem compared to humid ecosystem. Annual rainfall shows an increasing trend over Bhubaneshwar and Rajendranagar, while decreasing trend over Jorhat (Table 3). The seasonal monsoon rainfall shows a decreasing trend at Bhubaneshwar and Jorhat while increasing trend over Rajendranagar. Hence, as far as monthly trends are concerned, a significant decreasing trend of 15.9 mm/30 years has been observed during February at Bhubaneshwar. A significant increasing trend of 121.7 mm/30 years has been noticed during August at Rajendranagar along with the increasing trend of rainy days at the rate of 3.5 days/30 years. This rate of increase was 70.8 % of the mean rainfall of that month, and also, 35 % of the mean rainy days along with delayed trends of onset of effective monsoon by 30 days during the 30-year period support the moving/shifting of "monsoon window."

Temperature variability and trends

The mean monthly, seasonal, and annual maximum and minimum temperature and its SD and CV are given in Table 4. The CV of annual maximum and minimum temperature shows below 4 % for all the sites. It is noticed that most of the month/seasons, CV is higher for minimum temperature compared to maximum temperature for all the sites. This means that the variability of minimum temperature is more compared to that of maximum temperature. The mean annual maximum temperature shows an increasing trend in all the study sites. However, as far as seasonal or monthly trends are concerned, except an increasing trend of 1.1 °C/30-year study period during December at Rajendranagar; all other trends in maximum temperature show no statistical significance. In the case of average annual minimum temperature, a significant increasing trend of 0.9 °C during the study period has been noted at Jorhat. This indicates that the increasing trend of the minimum may have contributed significantly to the increasing trend of mean temperature at Jorhat. As far as pertaining to seasonal trends is concerned, significant increasing trends of

Table 2 Monthly, seasonal, and annual mean, standard deviation, and coefficient of variation of rainfall and rainy days of study sites

Month/seasonal/ annual	Bhubaneshwar						Jorhat						Rajendranagar					
	Rainfall			Rainy days			Rainfall			Rainy days			Rainfall			Rainy days		
	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)	Mean (mm)	SD (mm)	CV (%)
Jan	13	19	142	0.9	1.3	138	17	14	83	2	1	72	5	11	208	0	1	157
Feb	21	27	130	1.3	1.5	115	40	28	72	4	2	60	6	15	252	0	1	193
Mar	25	38	156	1.7	2.2	130	69	47	68	6	3	54	26	38	149	1	1	136
Apr	34	37	110	2.0	1.5	76	192	80	42	12	4	30	25	22	86	2	1	70
May	100	127	127	4.1	2.3	57	224	87	39	13	4	30	34	36	105	2	2	84
June	208	87	42	10.6	3.1	29	271	99	37	15	4	27	105	53	50	7	2	25
July	321	138	43	14.7	3.6	24	359	85	24	18	3	17	155	87	56	9	3	35
Aug	360	125	35	16.0	3.7	23	294	73	25	15	3	19	172	97	57	10	4	40
Sept	261	124	48	13.0	3.6	28	243	94	39	13	3	27	135	80	59	8	4	46
Oct	163	147	90	7.3	1.7	49	116	76	65	6	2	37	95	79	83	5	3	61
Nov	40	62	154	1.8	1.1	97	19	18	96	2	1	83	28	55	196	1	2	114
Dec	5	10	209	0.6	1.8	198	12	15	121	1	1	107	4	8	232	0	1	182
JF	37	31	91	2.3	1.8	82	57	34	59	6	3	46	11	18	164	1	1	130
MAM	158	132	84	7.8	3.6	47	485	122	25	31	6	18	85	48	56	5	2	43
JJAS	1149	267	23	54.3	7.3	13	1167	180	15	60	7	12	567	146	26	33	6	18
OND	208	170	82	9.7	4.8	50	147	73	49	9	3	33	126	98	78	7	3	51
Annual	1549	316	20	74.1	9.7	13	1856	268	14	106	11	10	789	212	27	46	8	17

Table 3 Trends of rainfall, rainy days, maximum and minimum temperature during 30-year period at different study sites

Month/seasonal/annual	Bhubaneshwar				Jorhat				Rajendanagar			
	Rainfall (mm/30 years)	Rainy days (days/30 years)	Max T (°C/30 years)	Min T (°C/30 years)	Rainfall (mm/30 years)	Rainy days (days/30 years)	Max T (°C/30 years)	Min T (°C/30 years)	Rainfall (mm/30 years)	Rainy days (days/30 years)	Max T (°C/30 years)	Min T (°C/30 years)
Jan	0.0	0.0	0.7	−2.6**	−13.9	0.0	0.3	1.0	0.0	0.0	0.9	−0.8
Feb	−15.9*	0.0	1.1	−1.5*	−3.1	0.0	1.1	0.2	0.0	0.0	−0.2	−0.8
Mar	−6.0	0.0	0.6	0.2	1.7	0.0	0.5	0.5	0.0	0.0	0.3	−0.8
Apr	−8.4	0.0	0.8	0.3	−18.7	0.0	−0.1	1.0	14.6	0.0	−0.5	−0.4
May	29.3	0.0	0.6	0.0	15.6	0.0	0.2	1.1	16.1	0.0	−0.8	−0.1
June	−27.8	−2.3	0.5	0.2	−36.8	0.0	−1.1	0.4	−58.7	0.0	1.0	1.3*
July	−50.5	0.0	−0.1	0.0	−81.5	0.0	0.0	1.0**	−19.6	−2.1	0.6	1.2***
Aug	−50.5	0.0	0.1	−0.1	32.3	1.3	−0.6	0.7*	121.7*	3.5	0.1	0.8**
Sept	35.6	2.5	−0.1	0.1	−74.1	−2.1	1.0	0.5	0.7	1.1	−0.1	0.4
Oct	58.6	0.0	−0.6	0.6	15.0	0.0	0.6	0.6	45.4	1.4	0.0	1.0
Nov	12.0	0.0	0.7	0.6	9.0	0.0	0.2	1.4*	0.0	0.0	0.5	0.7
Dec	0.0	0.0	0.3	−1.2	−9.4	0.0	0.7	1.5*	0.0	0.0	1.1*	−0.4
JF	−25.2	0.0	0.7	−2.1**	−11.1	0.0	0.3	0.9	0.0	0.0	0.5	−0.6
MAM	37.1	0.0	1.0	0.1	−27.3	0.0	0.2	0.9	58.2	1.9	−0.5	−0.4
JJAS	−23.2	0.0	0.1	0.0	−190.4	−3.3	−0.3	0.6**	91.6	1.7	0.3	0.9**
OND	62.3	1.3	0.2	0.2	4.6	0.0	0.5	1.3**	22.6	0.0	0.7	0.6
Annual	49.0	0.0	0.4	−0.2	−239.1	0.0	0.1	0.9*	187.8	4.3	0.1	0.3

*Significant at 90 % confidence level, ** at 95 % confidence level, ***at 99 % confidence level

Table 4 Monthly, seasonal, and annual mean, standard deviation, and coefficient of variation of maximum and minimum temperature of study sites

Month/ seasonal/ annual	Bhubaneshwar						Jorhat						Rajendranagar					
	Max T			Min T			Max T			Min T			Max T			Min T		
	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)	Mean (°C)	SD (°C)	CV (%)
Jan	28.8	1.1	4	15.4	1.4	9	22.6	1.1	5	9.7	1.0	10	29.3	0.9	3	13.6	1.3	10
Feb	31.7	1.6	5	18.7	1.0	5	24.3	1.7	7	12.4	1.5	12	32.4	1.0	3	16.1	1.6	10
Mar	34.9	1.2	3	22.4	0.8	3	26.9	1.4	5	15.7	1.3	8	35.7	1.1	3	19.7	0.9	5
Apr	36.9	1.2	3	25.1	0.9	3	28.1	1.0	3	19.0	1.4	7	38.0	1.1	3	23.3	0.8	3
May	37.4	1.3	3	26.5	0.6	2	30.2	1.2	4	22.2	1.3	6	39.1	1.7	4	25.7	0.8	3
June	35.0	1.5	4	26.2	0.6	2	31.8	0.9	3	24.6	0.6	2	34.3	1.6	5	24.2	0.8	3
July	32.4	0.8	2	25.7	0.5	2	32.0	0.7	2	25.1	0.7	3	31.1	0.9	3	23.1	0.6	2
Aug	31.9	0.6	2	25.5	0.4	2	32.4	0.7	2	25.3	0.7	3	29.9	0.7	2	22.6	0.4	2
Sept	32.3	0.6	2	25.2	0.4	2	31.5	0.7	2	24.5	0.9	4	30.8	0.9	3	22.3	0.4	2
Oct	32.1	0.9	3	23.1	0.7	3	30.0	0.8	3	21.7	1.0	5	30.8	1.0	3	19.7	0.9	5
Nov	30.6	0.9	3	18.6	1.3	7	27.4	0.7	3	15.8	1.0	6	29.4	0.8	3	15.7	1.9	12
Dec	28.7	0.9	3	14.9	1.3	9	24.1	0.9	4	10.8	1.1	10	28.5	0.8	3	12.7	1.8	14
JF	30.2	1.1	3	17.1	1.1	6	23.5	1.2	5	11.0	1.0	9	30.8	0.7	2	14.9	1.2	8
MAM	36.4	0.9	2	24.7	0.6	2	28.4	0.7	3	19.0	1.2	6	37.6	0.7	2	22.9	0.6	2
JJAS	32.9	0.6	2	25.6	0.4	1	32.0	0.4	1	24.9	0.6	3	31.5	0.6	2	23.0	0.4	2
OND	30.5	0.7	2	18.9	0.7	4	27.2	0.6	2	16.1	0.8	5	29.6	0.7	2	16.1	1.0	7
Annual	32.7	0.4	1	22.3	0.4	2	28.5	0.5	2	18.9	0.7	4	32.4	0.4	1	19.9	0.4	2

0.6 and 1.3 °C, respectively, have been noted during monsoon and post-monsoon seasons at Jorhat. Similarly, a significant increasing trend of 0.9 °C during monsoon has been noticed over Rajendranagar. However, a significant increasing trend of 2.1 °C has been noted over Bhubaneshwar during winter. As far as related to monthly trends are concerned, significant increasing trends of 1.3, 1.2, and 0.8 °C, respectively, have been noticed at Rajendranagar during June, July, and August. Thus, both increasing trends of maximum and minimum temperature obviously increase the evaporative demand of the atmosphere during *kharif* season. However, a significant increasing trends of 1.0 and 0.7 °C, respectively, during July and August maximum temperature have been noticed over Jorhat. A significant decreasing trend in minimum temperature at the rate of 2.6 and 1.5 °C, respectively, has been noticed during January and February over Bhubaneshwar.

Effect of effective onset of monsoon on yield

At Bhubaneshwar, during the early onset of effective monsoon years, the average percent deviation of yield from normal years is noticed to be negative in all the treatments with the highest yield loss of 15.8 % with the application of 50 % NPK through inorganic during *kharif* and 100 % NPK through inorganic during *rabi* (Table 5). The lowest yield loss of 2.1 % from normal years occurred with the application of 75 % NPK through inorganic with 25 % N through FYM during *kharif* and 75 % NPK through inorganic during *rabi* season (Fig. 2). There is an average yield loss of 7.3 % under the early onset of effective monsoon irrespective of the treatments. All the treatments noted a higher yield under late onset of monsoon with an average increase of 25.5 % from normal with a high value (43.2 %) under control treatment and lowest value (16.4 %) under 100 % recommended dose of fertilizer (RDF) through inorganic fertilizers under both the seasons. This higher value of yield under control condition under late onset may be due to timely availability of rainfall at water-sensitive phenophases of the crop. However, as far as overall performance is concerned, after control treatment, application of 25 % green manure in combination with 75 RDF through inorganic fertilizers followed the highest yield. This could be due to retention of available moisture within the root zone of the crop and thereby proper utilization at sensitive phases of the crop. However, at Jorhat and Rajendranagar, all the treatments except control, during early-onset years, showed a negative yield anomaly. During late-onset years, all the treatments showed a negative yield anomaly, and this may be due to expose of vegetative/tillering phase of the crop with drought-like situation. As far as overall performance is concerned, at Jorhat and Rajedranagar, substitution of 25 % N through crop residue produced lower yield anomaly.

Table 5 Average percent deviation of yield during kharif rice from normal years during early and late effective onset of monsoon years under different treatements

Treatments	Bhubaneshwar			Jorhat			Rajendranagar		
	Average percent deviation of yield under early and late onset of effective monsoon years (%)								
	Early	Late	Overall	Early	Late	Overall	Early	Late	Overall
T1	−9.6	43.2	16.8	1.0	−22.7	−10.8	1.8	−3.8	−1.0
T2	−8.5	27.5	9.5	−1.8	−19.3	−10.5	−17.2	−13.0	−15.1
T3	−15.8	19.8	2.0	−5.1	−23.7	−14.4	−18.6	−8.7	−13.7
T4	−6.2	23.1	8.5	−8.0	−21.9	−14.9	−18.3	−11.1	−14.7
T5	−3.6	16.4	6.4	−8.5	−16.9	−12.7	−20.8	−9.0	−14.9
T6	−7.2	22.6	7.7	−14.4	−17.2	−15.8	−20.0	−10.5	−15.3
T7	−2.1	24.3	11.1	−10.9	−15.1	−13.0	−18.6	−10.1	−14.3
T8	−9.0	25.3	8.1	−12.1	−17.5	−14.8	−16.2	−10.3	−13.3
T9	−3.9	25.2	10.7	−9.2	−9.4	−9.3	−17.7	−6.8	−12.2
T10	−7.1	26.4	9.7	−13.4	−18.9	−16.2	−25.3	−8.9	−17.1
T11	−2.5	26.8	12.1	−12.3	−21.3	−16.8	−24.1	−10.3	−17.2
T12	−12.4	24.8	6.2	−1.2	−23.7	−12.5	−21.1	−11.4	−16.3
	−7.3	25.5	9.1	−8.0	−19.0	−13.5	−18.0	−9.5	−13.8

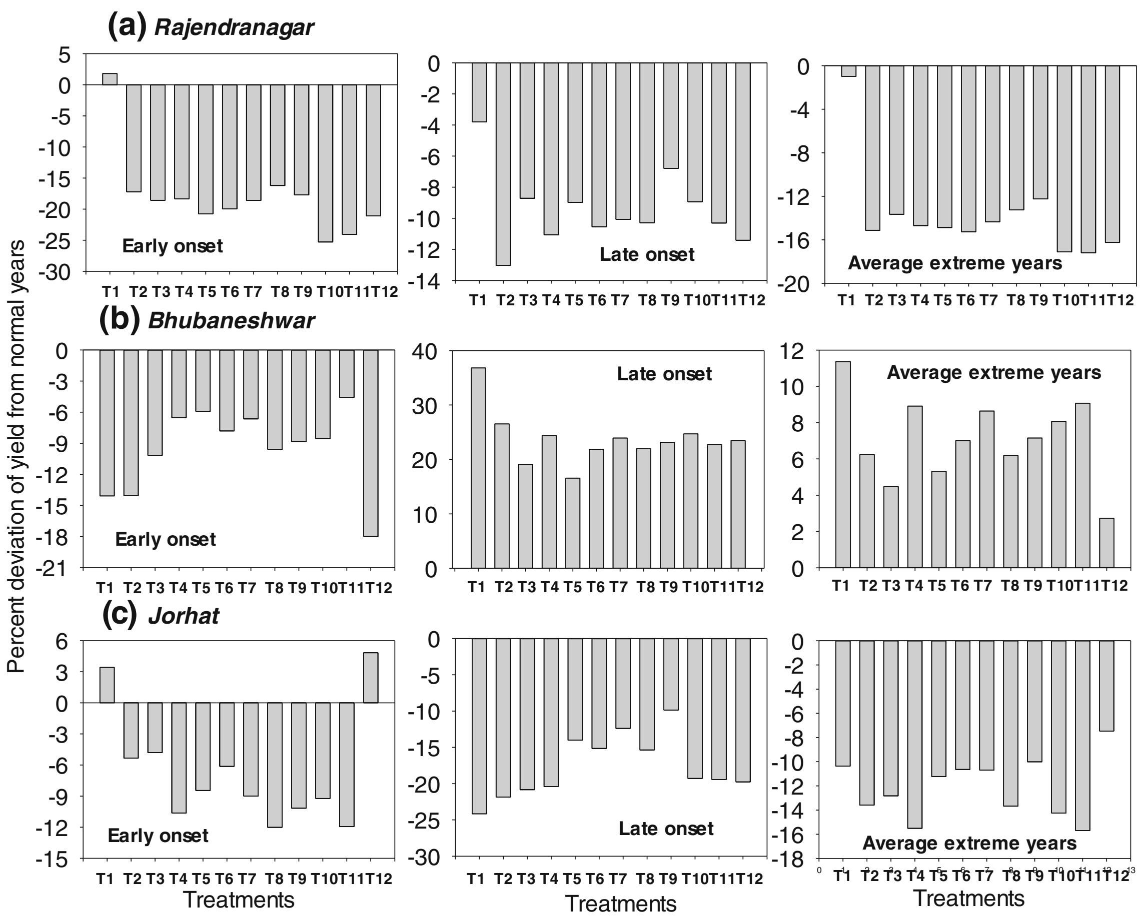

Fig. 2 Percent deviation of yield during early- and late-onset years and average extreme years over study locations during the period 1980–2009

Discussion

Statistical correlations between yield and weather parameters

The statistical correlations between kharif rice yields and monthly rainfall during the growing season under different integrated nutrient management practices showed that no uniform relation exists over the study sites (Table 6). This may be due to the differences in varietal characteristics, soil physical properties, and climatology that exist between the sites. At Bhubaneshwar and Rajendranagar, rice yields are positively correlated with July rainfall, which generally coincides with the transplanting period of the crop. At Jorhat, June rainfall is negatively correlated with yields for all the treatments and even highly significant (0.01 level) in 50 % substitution of N through straw along with inorganic fertilizers. At Bhubaneshwar and Jorhat, September rainfall is positively correlated with yield because this period coincides with the flowering phase of the crop and most sensitive to water stress. As far as maximum temperature is concerned, no significant correlations are found between monthly maximum temperature during the crop season and rabi rice yields at Rajendranagar and Jorhat (Table 7). However, monthly maximum temperature during all the months is positively correlated with yields at Bhubaneshwar, and even some correlations, particularly during December, are highly correlated with yield, and this shows that the higher temperature activated the vegetative phase of the crop. As far as minimum temperature is concerned, the average minimum temperature during the growing season is negatively correlated with yields in all the study sites in all the treatments. However, these correlations are not significant at Bhubaneshwar and Jorhat. At Bhubaneshwar, the average minimum temperature during the crop-growing season is negatively correlated with yields irrespective of the treatments, and correlations are statistically significant at 0.05 level except in 50 % substitution of N through straw along with inorganic fertilizers. Among the months, minimum temperature during December is negatively correlated (significant at 0.05 level) with yields. Similar results were reported by Peng et al. (2004) and found that a close linkage between rice grain yield and mean minimum temperature during the dry cropping season and grain yield declined by 10 % for each 1 °C increase in growing-season minimum temperature in the dry season, whereas the effect of maximum temperature on crop yield was insignificant.

Rational quantification of influence of rainfall on yield under different nutrient management

Rice yields are strongly influenced by monsoon rainfall with a contribution of 67 % to productivity variation over India (Subash and Rammohan 2010). Different integrated nutrient management practices responded differently to the excess/

Table 6 Correlation coefficient (r^2) between *kharif* rice yield and rainfall under different integrated nutrient treatments in three study sites

Treatments	Correlation coefficient (r^2) between rainfall during different months and *kharif* rice yield					
	June	July	August	September	October	Total
Rajendranagar						
T1	0.12	0.16	−0.12	−0.08	−0.21	−0.08
T2	0.02	0.25	−0.02	0.02	0.01	0.15
T3	0.10	0.20	−0.04	0.02	0.01	0.13
T4	0.05	0.24	0.00	−0.06	−0.10	0.08
T5	−0.04	0.17	0.00	−0.03	0.12	0.14
T6	0.11	0.17	−0.04	−0.07	0.03	0.10
T7	0.03	0.15	0.04	0.01	0.03	0.14
T8	0.14	0.12	0.07	−0.04	0.07	0.18
T9	−0.06	0.19	−0.04	−0.08	0.04	0.06
T10	−0.05	0.11	0.02	0.10	0.03	0.12
T11	−0.05	0.07	0.07	0.06	0.00	0.09
T12	−0.02	0.13	−0.16	0.02	0.01	−0.02
Bhubaneshwar						
T1	−0.21	0.06	−0.22	0.30	−0.11	−0.05
T2	0.09	0.13	−0.07	0.45*	−0.18	0.17
T3	0.06	0.10	−0.07	0.50*	−0.03	0.25
T4	0.16	0.17	−0.05	0.43*	−0.14	0.22
T5	0.16	0.17	−0.11	0.36	−0.24	0.11
T6	0.20	0.20	−0.08	0.42*	−0.07	0.27
T7	0.19	0.21	−0.09	0.39*	−0.09	0.24
T8	0.19	0.21	−0.09	0.39*	−0.09	0.24
T9	0.09	0.23	−0.09	0.31	−0.14	0.16
T10	0.14	0.20	−0.06	0.38*	−0.11	0.22
T11	0.15	0.25	−0.08	0.31	−0.22	0.15
T12	0.01	0.16	−0.13	0.31	0.04	0.19
Jorhat						
T1	−0.32	0.05	0.19	0.00	0.10	−0.01
T2	−0.27	0.02	0.34	0.24	−0.07	0.11
T3	−0.35	0.08	0.29	0.22	−0.04	0.08
T4	−0.34	0.07	0.34	0.22	−0.08	0.08
T5	−0.46*	−0.19	0.40*	0.08	−0.09	−0.12
T6	−0.44*	−0.09	0.30	0.08	−0.12	−0.12
T7	−0.48*	−0.19	0.32	0.04	−0.11	−0.19
T8	−0.53**	−0.10	0.25	0.02	−0.11	−0.21
T9	−0.42*	−0.29	0.38*	0.03	−0.18	−0.21
T10	−0.42*	0.05	0.32	0.12	−0.03	0.01
T11	−0.42*	−0.11	0.31	0.11	−0.17	−0.12
T12	−0.28	−0.10	0.21	0.02	0.11	−0.02

*Significant at 0.05 level, **Significant at 0.01 level

Table 7 Correlation coefficient (r^2)between *rabi* rice yield and maximum and minimum temperature under different integrated nutrient treatments in three study sites

Treatments	Maximum temperature						Minimum temperature					
	Nov	Dec	Jan	Feb	Mar	Mean	Nov	Dec	Jan	Feb	Mar	Mean
Rajendranagar												
T1	−0.18	−0.26	−0.22	−0.16	0.28	−0.14	−0.07	−0.45*	−0.50*	−0.03	−0.41	−0.41*
T2	−0.02	−0.16	−0.29	−0.07	−0.13	−0.25	−0.39*	−0.48*	−0.30	−0.12	−0.30	−0.49*
T3	0.13	0.05	−0.26	0.07	−0.15	−0.08	−0.34	−0.43*	−0.27	−0.11	−0.32	−0.45*
T4	0.03	−0.09	−0.25	0.00	−0.15	−0.18	−0.36	−0.41*	−0.31	−0.14	−0.37*	−0.48*
T5	0.17	0.08	−0.15	0.01	−0.15	−0.04	−0.35	−0.41*	−0.29	−0.15	−0.40*	−0.48*
T6	0.11	0.00	−0.25	−0.01	−0.16	−0.13	−0.33	−0.37*	−0.20	−0.13	−0.33	−0.41*
T7	0.01	−0.06	−0.15	−0.04	−0.16	−0.16	−0.33	−0.45*	−0.30	−0.13	−0.36	−0.48*
T8	0.07	−0.03	−0.27	0.05	−0.16	−0.13	−0.38*	−0.47*	−0.30	−0.19	−0.38*	−0.52**
T9	0.07	−0.02	−0.23	0.02	−0.03	−0.07	−0.24	−0.45*	−0.33	−0.09	−0.34	−0.43*
T10	0.01	0.03	−0.25	0.01	−0.16	−0.14	−0.26	−0.31	−0.27	−0.11	−0.35	−0.38*
T11	0.06	0.08	−0.22	−0.01	−0.13	−0.10	−0.27	−0.30	−0.24	−0.17	−0.37*	−0.39*
T12	0.04	−0.03	−0.28	0.03	−0.09	−0.12	−0.33	−0.38*	−0.29	−0.07	−0.37*	−0.43*
Bhubaneshwar												
T1	0.23	0.23	0.33	0.32	0.37*	0.50*	0.17	0.12	−0.14	−0.08	0.21	0.07
T2	0.22	0.44*	0.43*	0.35	0.27	0.56**	−0.03	0.15	−0.15	−0.04	0.05	−0.01
T3	0.20	0.52**	0.28	0.25	0.21	0.45*	−0.05	0.10	−0.12	−0.04	0.12	−0.01
T4	0.21	0.48*	0.30	0.18	0.24	0.43*	0.03	0.14	−0.17	−0.05	0.10	0.01
T5	0.14	0.39*	0.23	0.20	0.30	0.40*	−0.04	0.01	−0.32	−0.16	−0.04	−0.16
T6	0.16	0.42*	0.26	0.26	0.24	0.43*	−0.10	0.00	−0.23	−0.11	0.05	−0.13
T7	0.22	0.46*	0.39*	0.31	0.28	0.54**	−0.02	0.09	−0.15	−0.03	0.09	−0.02
T8	0.14	0.40*	0.28	0.27	0.27	0.44*	−0.11	0.00	−0.23	−0.09	0.06	−0.13
T9	0.24	0.42*	0.39*	0.24	0.27	0.49*	0.00	0.13	−0.19	−0.10	0.07	−0.03
T10	0.12	0.41*	0.31	0.32	0.27	0.47*	−0.07	0.06	−0.21	−0.07	0.05	−0.08
T11	0.17	0.31	0.34	0.41*	0.30	0.52**	−0.05	0.06	−0.21	0.00	0.03	−0.06
T12	0.19	0.35	0.25	0.10	0.23	0.34	−0.08	−0.06	−0.34	−0.33	0.00	−0.24
Jorhat												
T1	0.15	−0.22	−0.27	−0.10	−0.02	−0.13	0.01	−0.12	−0.35	−0.34	−0.13	−0.31
T2	0.17	−0.03	−0.18	−0.20	−0.08	−0.12	0.01	−0.03	−0.16	−0.26	−0.25	−0.23
T3	0.23	0.04	−0.09	0.02	0.09	0.06	0.03	−0.06	−0.28	−0.14	−0.12	−0.18
T4	0.17	0.03	−0.16	−0.16	−0.12	−0.10	0.13	−0.03	−0.18	−0.23	−0.28	−0.20
T5	0.32	0.13	−0.08	0.03	0.03	0.07	0.06	−0.01	−0.12	−0.20	−0.17	−0.15
T6	0.16	−0.08	−0.19	0.11	0.07	0.03	−0.05	−0.06	−0.21	−0.13	0.00	−0.15
T7	0.03	−0.05	−0.15	0.04	0.02	−0.02	0.00	−0.12	−0.19	−0.16	−0.03	−0.17
T8	0.31	0.13	−0.09	0.07	0.03	0.09	0.19	0.05	−0.15	−0.21	−0.16	−0.10
T9	0.20	0.03	−0.16	0.04	−0.03	0.00	0.06	0.06	−0.01	−0.14	−0.04	−0.03
T10	0.22	−0.01	−0.16	0.10	0.08	0.05	0.08	0.02	−0.20	−0.18	0.02	−0.09
T11	0.12	0.00	−0.13	−0.05	−0.02	−0.04	0.02	−0.06	−0.17	−0.24	−0.14	−0.20
T12	0.26	−0.07	−0.12	−0.31	−0.02	−0.13	0.04	−0.26	−0.41	−0.41	−0.24	−0.44

*Significant at 0.05 level, **Significant at 0.01 level

deficit quantity of monsoon rainfall at different study sites (Table 8). At Bhubaneshwar, all the treatments performed well when rainfall >1,464 mm with a maximum yield increase of 15.6 % compared to normal with the application of 50 % of RDF during kharif and *rabi* through chemical fertilizers. Under drought situations (when rainfall <1,154 mm), all the treatments showed a lower yield compared to normal years, and application of 100 % RDF through inorganic fertilizers during both the seasons shows the least affected treatment. The higher rainfall during monsoon season increased the *rabi*

Table 8 Average yield deviation (%) pertaining to years with extreme rainfall years (mean±one-half standard deviation) compared to normal years under different nutrient management treatments during *kharif* rice, *rabi* rice, and rice-rice system

Treatments	Bhubaneshwar						Jorhat						Rajendranagar					
	Kharif rice		*Rabi* rice		Rice-Rice system		*Kharif* rice		*Rabi* rice		Rice-Rice system		*Kharif* rice		*Rabi* rice		Rice-Rice system	
	>1,464	<1,154	>1,464	<1,154	>1,464	<1,154	>1,364	<1,168	>1,364	<1,168	>1,364	<1,168	>792	<621	>792	<621	>792	<621
T1	1.5	−6.1	8.1	−18.1	4.8	−12.1	3.5	10.9	75.7	18.1	31.5	13.7	−16.8	−20.2	33.4	1.5	3.0	−11.6
T2	15.6	−8.4	43.4	2.4	29.0	−3.2	10.2	0.4	48.1	−3.2	25.3	−1.0	7.6	−4.2	18.1	13.7	12.4	4.1
T3	14.5	−14.2	30.8	5.5	23.0	−3.8	8	0.7	42.3	−6.9	22.1	−2.4	5.3	−5.4	29.4	17.8	17.1	6.0
T4	11.1	−6.5	39.3	1.8	27.7	−2.4	9.6	0.8	46.1	−0.7	24.2	0.2	3.9	−1.6	29.1	15.2	16.0	6.4
T5	6.4	−1.4	28.0	−2.1	17.2	−1.7	−6.4	2	18.6	−1.7	3.9	0.5	6.4	0.2	23.4	7.9	14.7	4.0
T6	14.9	−7.3	33.3	5.9	24.3	−0.5	−3.2	6.7	39.4	4.4	14.2	5.8	5.5	−1.6	28.8	17.7	17.0	7.9
T7	10	−2.8	39.2	1.5	24.1	−0.7	−6.6	6.4	38.4	6.8	11.8	6.6	4.9	−2.8	29.7	14.8	16.4	5.3
T8	13	−7.9	29.7	1.7	21.6	−3.0	−4.5	10.6	27.6	−0.1	8.9	6.1	6.9	−4.4	28.3	14.6	17.6	5.1
T9	9.1	−5	35.2	−6.2	22.0	−5.6	−5.6	7.1	20.2	2.1	5.3	5.0	6.4	2.6	29.6	14.1	17.7	8.2
T10	15.3	−5.2	35.7	2.2	25.5	−1.5	−1.5	−1.3	39.5	−0.9	15.0	−1.1	11	6.1	40.8	20.7	25.1	13.0
T11	7.9	−3.7	30.2	−0.8	18.6	−2.3	−2.1	8.9	40.5	1.5	15.0	5.9	11.2	8.3	32.3	11.8	21.4	9.0
T12	8.5	−7.3	30.6	2.6	19.5	−2.4	−11.5	−4.7	31.9	4.2	5.9	−8.1	6.3	4.5	35.6	19.4	20.3	11.6

rice yield irrespective of nutrient management practices with the lowest increase of 8.1 % in control to the highest increase of 43.4 % in 50 % of RDF through chemical fertilizer treatment in both the seasons. As far as pertaining to rice-rice system is concerned, higher rainfall during monsoon increased yield in all the treatments to a maximum of 29 % under 50 % RDF through chemical fertilizer application during both seasons to only 4.8 % increase under control treatment. However, drought affected the system yield drastically in control treatment, and application of FYM during *kharif* rice recorded less yield reduction in system yield compared to normal years. At Jorhat, the treatment which followed the farmers' practice suffered a drastic reduction in yield during *kharif* season under both excess and deficit rainfall years. During excess years (>1,364 mm), 50 % RDF in both the seasons recorded an increase in yield of 10.2 %. Water deficit during *kharif* reduced the *rabi* rice yield in inorganic fertilizer treatments while substitution of N through FYM (50 % through chemical and 25 % through FYM) enhanced yield. This could be due to a high moisture retention capacity in organic manure-treated plots as well as better nutrient supply by the integrated nutrient management treatment (Srinivasarao et al. 2012). Application of 25 % N through straw and green manure also increased the productivity compared to normal years. As far as system productivity is concerned, 75 % NPK through chemical and 25 % N through FYM during *kharif* and 75 % NPK through chemical fertilizers effectively withstand the adverse rainfall and produced a higher yield of 6.6 % compared to normal years. At Rajendranagar, all the treatments except control yielded a

Table 9 Average yield deviation (%) from normal years when the maximum temperature during the rabi rice period increases to mean+1 °C under different nutrient management treatments over different study sites

Treatments	Average yield deviation from normal (%) when maximum temperature (°C)		
	Bhubaneshwar ≥35	Jorhat ≥27.4	Rajendranagar ≥35.9
T1	3.1	1.0	−27.2
T2	2.3	5.0	−40.9
T3	−0.6	4.1	−21.6
T4	5.5	5.7	−20.4
T5	1.2	9.7	−14.0
T6	5.9	13.2	−28.3
T7	5.0	14.5	−24.6
T8	5.0	16.1	−11.8
T9	1.4	15.7	−13.2
T10	5.2	10.2	4.9
T11	2.0	6.2	6.9
T12	−10.8	19.2	−5.4

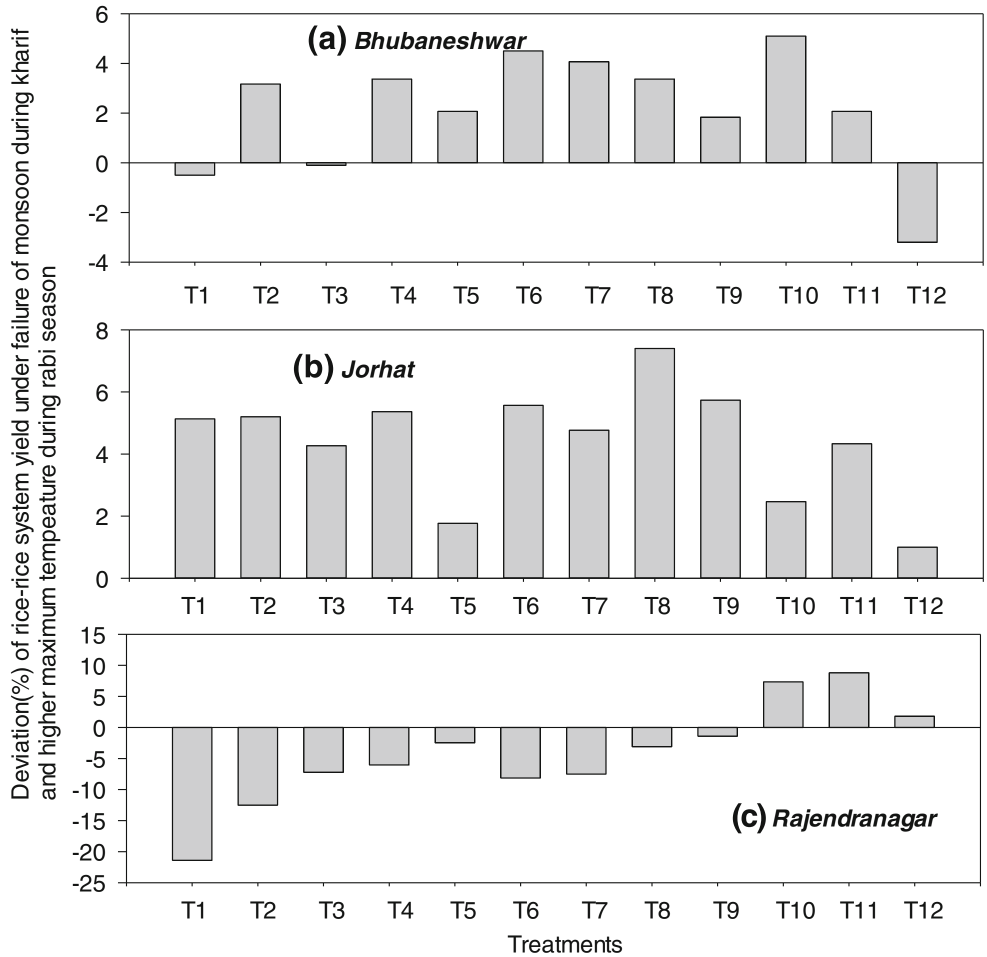

Fig. 3 Average percent deviation of rice-rice system yield during failure/excess of monsoon years during *kharif* and higher maximum temperature during *rabi* season over study locations during the period 1980–2009

higher productivity during *kharif* rice when rainfall >792 mm. Application of 25 % N through green manure along with 75 % RDF through inorganic during *kharif* produced a higher productivity of 11.2 and 8.3 %, respectively, during excess (>792 mm) and deficit (<621 mm) years compared to normal years. It is visible that all the treatments responded positively during *rab*i season irrespective of drought/excess rainfall situation during monsoon season. However, as far as pertaining to the rice-rice system is concerned, 50 % substitution of green manure along with 50 % NPK through inorganic produced higher yield of 25.1 and 13.0 %, respectively, under excess and drought rainfall years compared to normal.

Rational quantification of influence of maximum temperature on yield under different nutrient management practices

The threshold maximum temperature varies with the study sites due to different kinds of ecosystems that exist in these places. At Bhubaneshwar, when the mean crop season maximum temperature >35 °C, all the treatments, except farmers' conventional practice and 50 % NPK through chemical during *kharif* and 100 % during *rabi*, produced higher yield (Table 9). At Jorhat, also, maximum temperature during the crop season is found favorable for higher productivity with the highest yield increase of 19.2 % under farmers' conventional practice

Table 10 Site-specific primary, secondary, and tertiary climate-resilient integrated nutrient management practices and system productivity deviation (%) in extreme climate situation

Site	Primary	Secondary	Tertiary
Bhubaneshwar	50 % NPK (C)+50 % (GM) (5.1)	50 % NPK (C)+50 % (FYM) (4.5)	75 % NPK (C)+25 % (FYM) (4.1)
Jorhat	50 % NPK (C)+50 % (Straw) (7.4)	75 % NPK (C)+25 % (Straw) (5.7)	50 % NPK (C)+50 % (FYM) (5.6)
Rajendranagar	75 % NPK (C)+25 % (GM) (8.8)	50 % NPK (C)+50 % (GM) (7.3)	Farmer's conventional practice (1.8)

C chemical fertilizers, *FYM* farmyard manure, *GM* green manure, *Straw* crop residue
Figures in paranthesis indicate the yield deviation compared to normal years

to 1 % under control treatment. The increase in productivity at Bhubaneshwar and Jorhat may be due to less water demand of the atmosphere under humid to semihumid situation, which in turn avoids possible drought/water stress situation during the sensitive states of the crop. However, at Rajendranagar, where arid situation exists, all the treatments, except green manure treatments, responded negatively when the average maximum temperature reached ≥35.9 °C. It is found that both green manure treatments withstand the higher temperature with an increase of 6.9 and 4.9 %, respectively, under 25 and 50 % N through green manure.

Identification of climate-resilient nutrient management treatment

The intraseasonal variability in rice-rice system is largely driven by rainfall during *kharif* rice and maximum temperature during rabi rice; the average yield deviation during deficit and excess rainfall years during *kharif* rice and yield variation during higher maximum temperature during *rabi* rice is taken as the indicator for identifying site-specific integrated nutrient management practices for rice-rice system. The system productivity deviation revealed that there is no uniform INM to withstand extreme climatic situations under the study locations. It is found that the treatment of 50 % recommended NPK through chemical fertilizers and 50 % N through green manure resulted in an overall average higher increase of 5.1 % productivity under both excess and deficit rainfall years and also during the years having seasonal mean maximum temperature ≥35 °C and thus this treatment has the adaptive capacity to withstand extreme climates, and we can say that this treatment is the primary climate-resilient integrated nutrient management practice for rice-rice system at Bhubaneshwar (Fig. 3). Application of 50 and 25 % organic manure along with inorganic fertilizer treatments found secondary and tertiary climate-resilient integrated nutrient management practice for Bhubaneshwar. Similarly, we have identified the primary, secondary, and tertiary climate-resilient integrated nutrient management practice for Jorhat and Rajendranagar also (Table 10).

Conclusions

Significant observational changes were noticed in effective onset of monsoon, length of the effective monsoon period, monthly minimum temperature, and rainfall at some of the study sites. Evidence of moving of the monsoon window under the semiarid condition at Rajendranagar may be a great concern, and there is an urgent need to change/modify the crop calendar according to the climatic changes to sustain the productivity. The quantified system yield deviation under extreme climatic condition under different nutrient management practices emphasized the importance of site-specific integrated nutrient management practices to overcome the ill effects of extreme climatic situations under rice-rice system. The identification of primary, secondary, and tertiary site-specific climate-resilient nutrient management practices at the study sites provides an opportunity for the farming community to choose the organic fertilizers according to the availability.

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