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Alternative cropping strategies for assured and efficient crop production in upland rainfed rice areas of eastern India based on rainfall analysis

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Abstract

The productivity of rice in rainfed upland soils of eastern India is very low (<1 t/ha) and unstable because of erratic monsoon, moisture deficit during dry spells, light textured with less fertile soils and several biological constraints (weeds, pests and diseases). Keeping the urgent need of augmenting the productivity of vast rainfed upland rice ecosystem of eastern India (4.3 million ha), crop diversification technology was generated through on-farm research trials in representative upland rice soils of eastern India after analyzing agro-climatic (rainfall variability, probability and onset of effective monsoon) and edaphic (soil water retention properties) constraints and prospects. Based on rainfall analysis, direct seeded, low water requiring, rice substituted alternative upland crops namely maize, groundnut, pigeonpea, greengram and blackgram (sole or intercropping) was sown in light textured upland rice soils on 24th meteorological weeks (11–17 June) in 3 years 2000–2002 with two to three summer ploughings during pre-monsoon shower (May). Study revealed that in deficit rainfall years (2000 and 2002), when rice yield was affected adversely in light textured upland, higher rice equivalent yield and rain water use efficiency were obtained from groundnut + pigeonpea intercropping followed by sole groundnut and sole pigeonpea. Study also revealed that productivity of rice substituted crops in the same upland did not fluctuate much between rainfall excess (2001) and rainfall deficit years (2002 and 2000). Double cropping in rainfed upland rice soils was also explored through maize–horsegram/sesamum rotation with increased productivity and rainwater use efficiency. The crop diversification technology was found to be very effective for drought mitigation.

Keywords: Soil water retention; Crop diversification; Upland rice ecosystem; Drought; Rainwater use efficiency

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1. Introduction

Major part of eastern India (Assam, West Bengal, Orissa, Jharkhand, eastern Uttar Pradesh and Chhattisgarh) receives higher average annual rainfall that varies from 1000 to 2000 mm but due to lack of appropriate water and soil management, the region has one of the lowest agricultural productivity of the country, especially from rainfed upland rice ecosystem. Out of 42.3 million ha of total rice area in India, upland rice occupies 6.1 million ha of which 4.3 million ha are located in eastern India with very low (<1 t/ha) and unstable productivity. In spite of getting low and unstable yield in upland rice ecosystem due to erratic southwest monsoon, moisture stress during crop growth period, light textured soils with low water retention and fertility status, existence of biological constraints like weeds (*Cyperus rotundus, Echinochloa colona*), diseases (blast, brown spot) and pests (gundhi bag, termite, worms), farmers of this region grow rice on such land due to lack of knowledge of alternate sustainable cropping systems. Under this situation crop diversification and rice substitution with low water requiring rainfed crops like maize (*Zea mays* L.), blackgram (*Phaseolus mungo* L.), greengram (*Vigna Aureous* L.), cowpea (*Vigna unguiculata* (L.) walp), groundnut (*Arachis hypogea* L.), pigeonpea (*Cajanas cajan* L.) etc. (through sole or intercropping) may be best option to the hands of farmers for mitigating drought and increased productivity of upland rice ecosystem with assured and early return (Kar and Verma, 2002). Increasing production of legumes without sacrifice of rice in rice area was also possible through intercropping of these crops with rice (Sengupta et al., 1985).

In India, agriculture is mainly dependent on the performance of southwest monsoon (the variability in the amount and distribution, probability of occurrence and onset of effective monsoon). Characterization of onset of effective monsoon (OEM) and prediction of rainfall at different probability levels were of paramount importance in rainfed agriculture for determining sowing time and cropping systems, especially for upland rice ecosystem because slight delay in sowing of direct seeded upland crops may lead to drastic reduction of yield (Bhatnagar and Kundu, 1992; Panigrahi and Panda, 2002).

Studies of soil texture and water retention properties under rainfed conditions were necessary to characterize type of crops to be grown, length of growing periods, availability of residual moisture and ground water contribution to crops, etc. (Kumar Sushil et al., 2002; Gupta et al., 1986; Oswal, 1993; Singh and Bhargava, 1994; Singh and Nayak, 1999).

The objective of this paper, therefore, is to study the rainfall pattern and soil water retention properties of upland rice soils of eastern India and to explore the possibility of crop diversification and rice substitution on such land for assured and efficient crop production.

2. Materials and methods

In the present study to increase cropping intensity and productivity with assured return in rainfed rice area of eastern India crop diversification and rice substitution technologies were generated through demand driven, problem solving, participatory, on-farm research trials in representative rainfed upland rice soils of one eastern Indian states, i.e. Dhenkanal district, Orissa (Fig. 1) in three study years (2000–2002). The total cultivated area of the district was 205,607 ha, out of which 50% is rainfed upland (103,696 ha). The cropping intensity

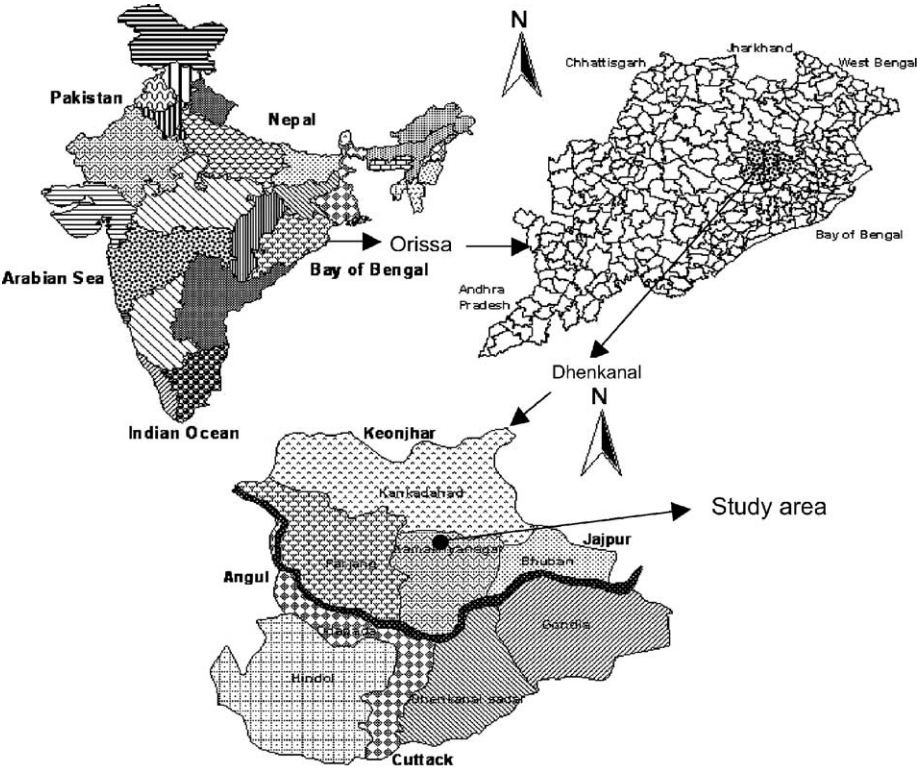

Fig. 1. Location of the study area.

of the district was also very low (only 145%). In regard to crop husbandry practices in upland during *rainy* season (June–September), 96% of the cultivated area was dominated by rice with low and unstable yield and rest 4% was under different crops like groundnut, maize, greengram, sesamum, etc. Thus there was a lot of scope to increase productivity and cropping intensity of the region through alternative cropping strategies and upland rice substitution.

To determine approximate sowing period of direct seeded upland crops, weekly probability of rainfall and wet–dry spell analysis were carried out based on past 30 years' rainfall data (1972–2001).

Initial probabilities (probabilities of week considering being wet or dry) of occurrence of weekly rainfall were determined using the following relationship:

(i) Probability of the week considering being wet, $P(W) = F(W)/N$, where $F(W)$ is the frequency of wet weeks and N the number of years of data used.
(ii) Probability of the week considered being dry, $P(D) = F(D)/N$, $F(D)$ is the frequency of dry weeks and N the number of years of data used.

The conditional probabilities (probability of wet week followed by wet week) were determined using the following relationships:

(i) Probability of wet week, provided the previous week was wet, $P(W/W)$:

$$P\left(\frac{W}{W}\right) = \frac{F(W/W)}{F(W/W) + F(D/W)}$$

$F(W/W)$ is the frequency of wet week given that previous week was wet and $F(D/W)$ the frequency of dry week given that the previous week was wet.

The monthly rainfall at 90, 75, 50, 25, and 10% probability was estimated for crop planning in rainfed upland rice soils of the study area using incomplete gamma distribution.

Onset of effective monsoon was analyzed for sowing time characterization using the criteria described by Ashok Raj (1979).

The commencement of a 7-day rainy spell was defined as the date of onset of the effective monsoon, if the following conditions were satisfied:

(i) The first day rain in the 7-day rainy spell should not be less than e mm, where e is the average daily evaporation of June and July months.
(ii) The total rain during the 7-day rainy spell should not be less than x mm, where x is the amount of rainfall which brings the top 30 cm soil layer to the field capacity. Here x is equal to the total soil moisture content (in terms of depth) at field capacity in the top 30 cm soil layer.
(iii) At least three out of these 7 days must be rainy days with not less than 2.5 mm of rain on each day.

For characterizing upland rice soils, different physical, physico-chemical properties and water retention properties were determined using standard procedures. The soil water retention at different suction values was determined using pressure plate apparatus as per the procedure described by Richards (1949) and particle size analysis was carried out by International Pipette method (Jackson, 1973). In order to establish Ψ–θ, D–θ and K–θ relationships of the soils, methodologies used by Campbell (1974) and subsequently used by Komas et al. (1979), Gupta et al. (1986), Oswal (1993) and Singh and Bhargava (1994) were followed:

- Ψ–θ relationship: $\Psi/\Psi_e = (\theta/\theta_s)^{-b}$;
- D–θ relationship: $D(\theta) = b\Psi_e K_s(\theta^{b-2}/\theta_s^{b+3})$;
- K–θ relationship: $K_\theta/K_s = (\theta/\theta_s)^{2b+3}$;

where Ψ_e is the air entry suction (cm), Ψ the matric potential (cm), θ the moisture content ($cm^3\,cm^{-3}$), θ_s the water content at saturation ($cm^3\,cm^{-3}$), b a soil parameter, D the soil water diffusivity ($cm^2\,s^{-1}$), $C(\theta)$ the specific water capacity or differential water capacity, $d\theta/d\Psi$ and K_s the saturated hydraulic conductivity ($cm\,s^{-1}$).

After analyzing the rainfall pattern and water retention properties of rainfed upland rice soils, a viable, profitable and sustainable cropping system through on-farm participatory research was suggested to improve productivity of upland rice soils of eastern India. Since rice productivity in rainfed upland was uneconomical, in the study, emphasis was given to substitute rice with direct seeded, low water requiring, drought tolerant crops but for very traditional rice farmers, partial substitution of rice through rice based intercropping (mainly legumes) was suggested for yield stabilization of upland.

2.1. Complete substitution of upland rice (through sole and intercropping)

Under this experiment, productivity and rainwater use efficiency of five crop combinations viz., sole pigeonpea (cv. UPAS-120), sole groundnut (cv. Smriti), sole blackgram (cv. T9), groundnut + pigeonpea and groundnut + black gram were compared with that of sole rice (cv. Vandana) to explore the possibility of crop diversification in rainfed uplands rice soils of eastern India. The treatments were executed in six farmers' field of 2 ha area, considering one farmer as one replication.

2.2. Partial substitution of rice through rice based intercropping

In this experiment productivity and rainwater use efficiency of three rice based combinations viz., rice + pigeonpea (4:1), rice + groundnut (4:1), rice + blackgram (4:1) were compared with that of sole rice (farmers' practice). The crops were grown using recommended agronomic practices with integrated weed management practices (Butachlor at 1.5 kg a.i./ha + mechanical weeding at 40 DAS). The experiment was conducted in eight farmers' field of about 2 ha of area, considering one farmer as one replication.

2.3. Exploring possibility of double cropping in rainfed upland rice soils through maize–horsegram/sesamum rotation

To explore the possibility of double cropping in rainfed upland rice soils, two short duration pre-winter crops viz., horsegram (cv. Madhu) and sesamum (cv. Gujrat-1) were sown after early harvest of rainy season first crop, maize (cv. Navjyot). The first crop maize was taken as test crop by replacing upland rice owing to its low water requirement, better market prospects, assured and early return. The second crops viz., horsegram and sesamum were sown following two methods of sowing (broadcasting and line) on the same land after harvest of first crop maize utilizing subsequent monsoon rainfall and residual soil moisture. These on-farm experiments were conducted in six farmers' field of 1 ha of area, considering one farmer as one replication.

The crops/crop combinations were grown with recommended agronomic package and practices of the region. The grain yield from each crop/crop combination was collected individually at final harvest and converted into rice equivalent yield for comparison of productivity of rice substituted crops with sole rice (which was originally cultivated in that area before crop diversification) and to visualize the enhancement of yield and rainwater use efficiency due to crop diversification and rice substituted crops.

3. Results and discussion

3.1. Characterization of soil

To characterize rainfed upland rice soils, 12 soil profiles in 5 ha of experimental upland site were dug randomly and soil samples at 0–0.15, 0.15–0.30, 0.30–0.60, 0.60–0.90 and

Table 1
(a) Soil water retention characteristics of upland experimental site; (b) functional relationship between soil water suction (Ψ), hydraulic conductivity (K), soil water diffusivity (D) and water content (θ)

Soil depth (m)	θ_s ($cm^3\ cm^{-3}$)	θ at 0.01 MPa ($cm^3\ cm^{-3}$)	θ at 0.03 MPa ($cm^3\ cm^{-3}$)	θ at 0.15 MPa ($cm^3\ cm^{-3}$)	Available water content ($cm^3\ cm^{-3}$)
(a) Soil water retention characteristics of upland experimental site					
0–0.15	0.355	0.231	0.171	0.061	0.110
0.15–0.30	0.373	0.245	0.173	0.063	0.110
0.30–0.60	0.403	0.291	0.212	0.077	0.135
0.60–0.90	0.405	0.300	0.227	0.078	0.149
0.90–1.20	0.371	0.281	0.199	0.071	0.128

(b) Functional relationship between soil water suction (Ψ), hydraulic conductivity (K), soil water diffusivity (D) and water content (θ)

	Ψ_e (cm)	b	Relationship between Ψ and θ	Relationship between K and θ	Relationship between D and θ
0–0.15	21.21	3.61	$21.21\ (\theta/0.355)^{-3.61}$	$1.19\ (\theta/0.345)^{9.22}$	$91.1\ (\theta^{5.61}/0.345^{6.61})$
0.15–0.30	23.2	3.59	$23.2\ (\theta/0.363)^{-3.59}$	$1.05\ (\theta/0.363)^{9.18}$	$86.2\ (\theta^{5.59}/0.363^{6.59})$
0.30–0.60	28.37	3.87	$28.37\ (\theta/0.393)^{-3.87}$	$0.95\ (\theta/0.393)^{9.74}$	$104.3\ (\theta^{5.87}/0.393^{6.87})$
0.60–0.90	29.13	3.97	$29.13\ (\theta/0.395)^{-3.97}$	$0.76\ (\theta/0.395)^{9.94}$	$87.8\ (\theta^{5.92}/0.395^{6.97})$
0.90–1.20	27.85	3.81	$27.85\ (\theta/0.361)^{-3.81}$	$0.68\ (\theta/0.361)^{9.62}$	$72.2\ (\theta^{5.81}/0.361^{6.81})$

Ψ_e: air entry suction values (cm); Ψ: soil water suction (cm); K: hydraulic conductivity ($cm\ h^{-1}$); D: soil water diffusivity ($cm^2\ h^{-1}$); b: a soil parameter; θ: water content ($cm^3\ cm^{-3}$).

0.90–1.20 m depths were collected for analyzing physico-chemical and water retention properties (Table 1).

Study revealed that water content at saturation (θ_s) varied from 0.355 to 0.405 $cm^3\ cm^{-3}$ at different depths of the soil profile. At maximum water retention capacity (0.01 MPa), highest water was retained by soils at 0.60–0.90 m depth, i.e. 0.300 $cm^3\ cm^{-3}$ and the lowest was at 0–0.15 m depth (0.231 $cm^3\ cm^{-3}$). At 0.033 MPa, the highest amount of water was retained by soils at 0.60–0.90 m depth (0.227 $cm^3\ cm^{-3}$) and the lowest was at 0–0.15 m depth (0.171 $cm^3\ cm^{-3}$). The values of water content at 0.15 MPa (permanent wilting point) varied from 0.061 to 0.078 $cm^3\ cm^{-3}$ and highest water was retained by soils at 0.60–0.90 m depth (0.078 $cm^3\ cm^{-3}$). Available water capacity of the soils varied from 0.110 to 0.149 $cm^3\ cm^{-3}$ at different depths and saturated hydraulic conductivity (K_s) of soil ranged between 0.68 and 1.19 $cm\ h^{-1}$. The values of air entry suction (Ψ_e) varied from 21.21 to 29.13 cm and highest value of it was observed at 0.60–0.90 m depth. The highest value of b, a soil parameter was observed at 0.60–0.90 m depth with the values being 3.97. The values of saturated moisture content (θ_s), saturated hydraulic conductivity (K_s), air entry suction values (Ψ_e) and b, a soil parameter (b) were used to develop functional relationship between soil water suction (Ψ) and water content (θ), hydraulic conductivity (K) and water content (θ) and between soil water diffusivity (D) and water content (θ) (Table 1b). These functional relationships can be utilized in a algorithms of dynamic simulation model for estimation of unsaturated hydraulic conductivity or soil water diffusivity.

In general, from soil analysis it can be said that upland experimental rainfed rice soils were light textured with low water retention and available water capacities. The fertility status was also very low. Therefore, addition of organic matter with integrated nutrient management and inclusion of legumes in the cropping system of upland rainfed rice ecosystem will be helpful to improve soil fertility and water retention capacity. Idea of rice substitution in upland rice soils is to emphasize that these crops can provide an assured return in soils with low retention capacity. Substituted crops, especially pulses have inherent capacity to trap the moisture from the lower strata of soil; therefore, they are considerably moisture stress tolerant and fit well in light textured upland under rainfed conditions. The heavy leaf fall of legumes also adds sufficient organic matter to the light textured upland rice soils.

3.2. *Rainfall analysis for crops/cropping system characterization*

Any pragmatic rainfed crop planning needs a through understanding of rainfall and in particular, the variability in the amount, distribution, probability of occurrence and onset of effective monsoon. Since in India agriculture is mainly dependant upon the performance of southwest monsoon rainfall, so rainfed crop planning is also decided by the onset and withdrawal of effective monsoon. Slight delay in sowing of rainfed crops may lead to drastic reduction of yield of the region. Rainfall studies are thus helpful to characterize earliest probable sowing time, defining risk levels in arable agriculture, characterizing length of growing period and cropping system under rainfed farming. Therefore, rainfall data of past 30 years (1972–2001) of the study area were analyzed to develop an alternate sustainable crop plan for rainfed upland rice ecosystem of eastern India to improve its productivity.

3.2.1. *Onset of effective monsoon*

As per the criteria mentioned in the methodology, the mean date of onset of effective monsoon was found to be 15 June and southwest monsoon generally ended on 27 September. The earliest and latest probable dates of OEM were found to be 1 and 20 June, respectively. Whereas, earliest and latest probable dates of monsoon withdrawal were worked out to be 15 September and 5 October, respectively. Based on OEM analysis, farmers are advised to initiate sowing of short duration, low water requiring, direct sown rainy season crops in upland rice soils from second week of June and complete the sowing within 20 June to obtain full southwest monsoon period. The early sowing will also ensure double cropping and reduces pest, diseases and weed infestation in upland rice soils.

3.2.2. *Weekly probability of rainfall and wet–dry spell analysis*

The week in which initial probability of receiving 20 mm or more rainfall exceed most dependable limit (70% probability) can be considered as wet week. After the onset of southwest monsoon in first wet week, sowing of upland crops can be initiated. To identify earliest sowing dates, initial and conditional probabilities of receiving 10, 20 and 30 mm or more weekly rainfall were analyzed for the study area and results are presented in Fig. 2. Result revealed that initial probability of receiving 20 mm or more rainfall first exceeded most dependable limit (70% probability) in the 24th standard meteorological week, which can be utilized for final land preparation and sowing of upland crops in the region. The conditional probability (wet week followed by wet week) of occurring 20 mm or more rainfall exceeded 70% probability after onset of full fledge southwest monsoon, which occurred from 23rd to 28th and 36th to 42nd standard weeks whereas, the 70% conditional

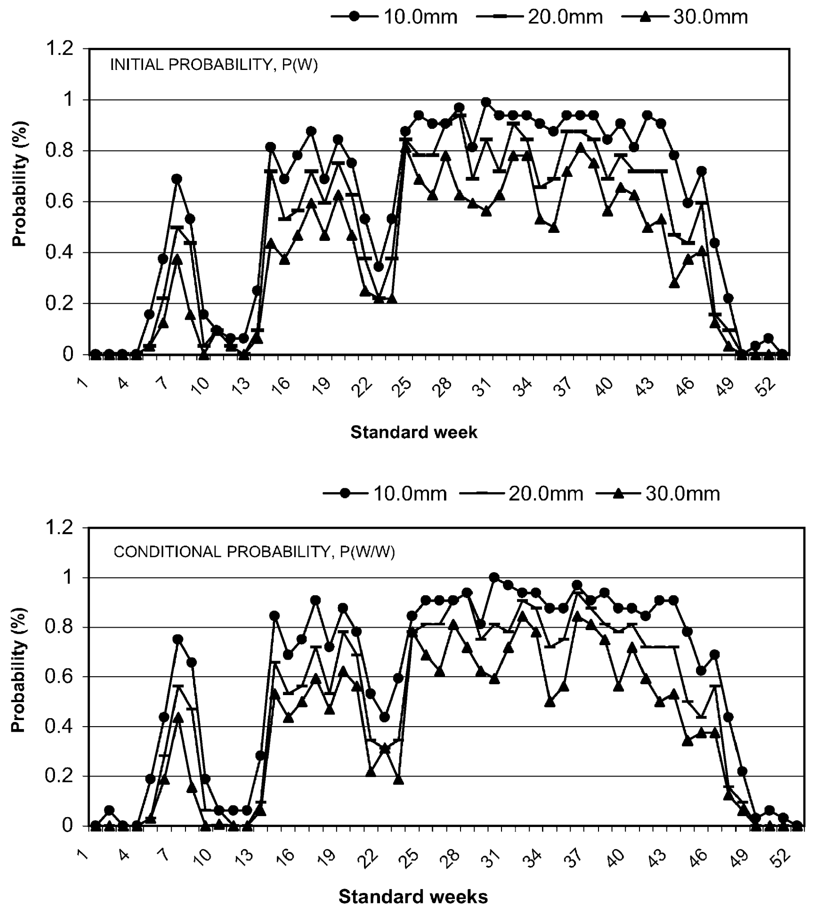

Fig. 2. Weekly probability of rainfall at the experimental site.

probability of receiving 30 mm or more rainfall occurred in 33rd, 37th, 38th standard weeks. At 16th to 19th weeks (during pre-monsoon period) probability of receiving 10 mm or more rainfall exceeded 70% probability level (dependable limit), so in those weeks light pre-monsoon shower can be expected.

In general from weekly rainfall probability analysis it can be said that: (i) pre-monsoon shower may occur between 16th and 19th weeks making summer tillage and preparation of seed beds for rainy season upland crops feasible then; (ii) rainfed, low water requiring, direct seeded upland crops can successfully be grown in upland rice soils during rainy season (24th–38th weeks) and earliest sowing can be done in 24th standard meteorological weeks (second week of June).

3.2.3. Monthly rainfall probability analysis for crop planning

The monthly rainfall at different probability levels was computed using incomplete gamma distribution method and are presented in Table 2. Study revealed that at 90% proba-

Table 2
Monthly rainfall at different probabilities for the study area

Month	Rainfall (mm) at probability levels of					Normal rainfall (mm)
	90 (%)	75 (%)	50 (%)	25 (%)	10 (%)	
January	1	1	1	1	2	1.2
February	4	14	28	63	105	42.8
March	0	1	5	16	34	11.2
April	50	76	116	166	223	128.7
May	71	95	129	171	214	136
June	119	181	196	238	274	195.5
July	163	237	265	320	369	224.8
August	166	200	236	275	308	237
September	124	154	173	188	232	174.2
October	98	113	146	170	201	128.7
November	16	35	70	123	189	87.8
December	0	1	3	8	15	4.7
Annual	832	1148	1453	1899	2378	1442.9

bility level, 119 mm rainfall occurred during June while at 75%, it was 181 mm. Therefore, at higher probability level sufficient rainfall occurred which was enough for sowing direct seeded, low water requiring rainy season crops like maize (*Z. mays* L.), cowpea (*V. unguiculata* (L.) walp), pigeonpea (*C. cajan* L.), groundnut (*A. hypogea* L.), blackgram (*Vigna mungo* L.), etc. in the second week of June (24th standard meteorological week) with the commencement of southwest monsoon in the region. Maximum amount of rainfall occurred during July, i.e. 163 and 237 mm at 90 and 75% probability, respectively. This higher amount of rainfall at 75% probability level could be utilized for rice transplanting starting from first fortnight of July in medium and low land rainfed rice ecosystem after completion of sowing of diversified crops in upland rice area in the month of June itself.

3.3. Results of rice substitution and crop diversification in rainfed upland rice soils

As per sowing time characterization based on rainfall probability and OEM analysis, diversified and rice substituted low water requiring crops were grown in representative light textured rainfed upland rice soils of Dhenkanal district, Orissa (Fig. 1) in 24th standard week under different on-farm research experiments during three study years (2000–2002). Among these three study years, in the first year (2000), rainfall (1149 mm) was below long term annual average (1442 mm) and in that year, 38.4 and 29.8% deficit rainfall were observed in two critical months of growing rice, i.e. in June and July, respectively (Fig. 3). The second year (2001) rainfall (1617 mm) was above the long term average (1442 mm) and well distributed. In the third crop year (2002), again deficit rainfall (1002 mm) occurred with 58.4% less rainfall in July. Thus, three contrasting rainfall distribution patterns were found during three crop seasons (2000–2002), which made different impact on upland rice crop. Study revealed that at 26th–28th (25 June–15 July) standard weeks of first crop season (2000) and 27th–30th standard weeks (2 July–28 July) of third season (2002), dry spells existed which coincided with initial tillering stage of rice and vegetative stage of all other

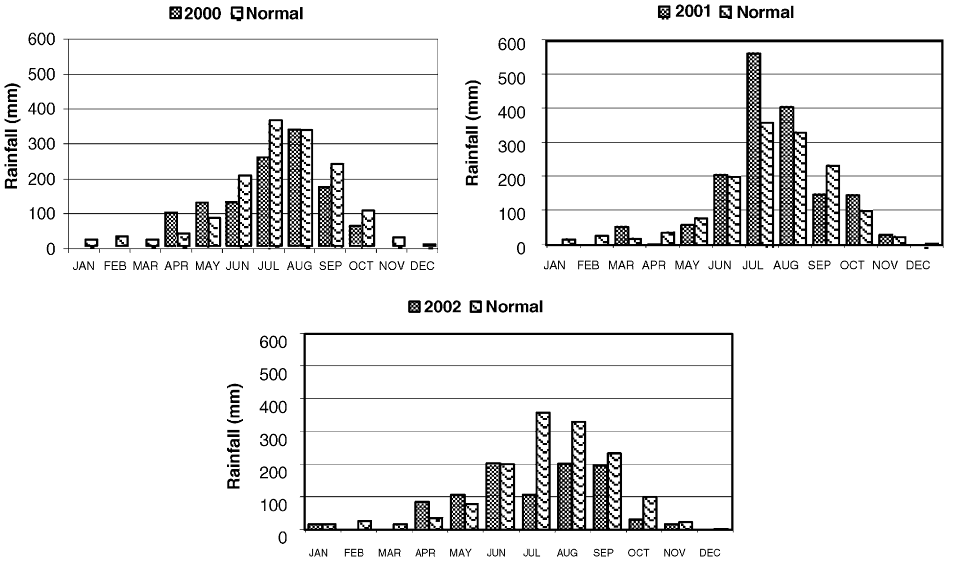

Fig. 3. Actual monthly rainfall in three study years with normal rainfall.

crops like maize, blackgram, pigeonpea and groundnut. Where as, in second crop season (2001), no dry spell was found and rainfall was also well distributed. Since at initial stage, water requirement of maize, groundnut, pigeonpea and blackgram was less as compared to rice, these crops suffered less due to occurrence of dry spell in first (2000) and third (2001) study years. But high water requiring rice crop suffered adversely because it was under active tillering stage during that period which required irrigation during that stage to meet the crop water requirement in rainfall deficit years (2000 and 2002). Due to reduction of tiller number, rice yield was reduced significantly. Whereas in second study year (2001), rice was grown with assured rainfall, resulted more yield from upland rice. But through crop diversification and rice substitution productivity of rainfed upland rice ecosystem were stabilized with increased productivity, cropping intensity and rainwater use efficiency, which may be visualized from the following results below.

3.3.1. Complete rice substitution in rainfed upland rice area increases productivity

The study revealed that in deficit rainfall years (2000), when rice yield was affected adversely (Fig. 4) rice substituted crops like groundnut, pigeonpea, blackgram, etc. produced good yield. Highest rice equivalent yield was obtained from groundnut + pigeonpea (6656 kg ha^{-1}), followed by sole groundnut (5640 kg ha^{-1}) and sole pigeonpea (5550 kg ha^{-1}). In the second year (2001, excess rainfall year), due to well distributed rainfall, upland rice produced higher yield (2850 kg ha^{-1}) than that of first year (1010 kg ha^{-1}) but in the second year also, highest rice equivalent yield was obtained from groundnut + pigeonpea (7023 kg ha^{-1}), followed by sole groundnut (6240 kg ha^{-1}) and sole pigeonpea (5081 kg ha^{-1}). Again the third study year (2002) rainfall was less, which affected rice yield adversely but through crop diversification and rice substitution the productivity of upland

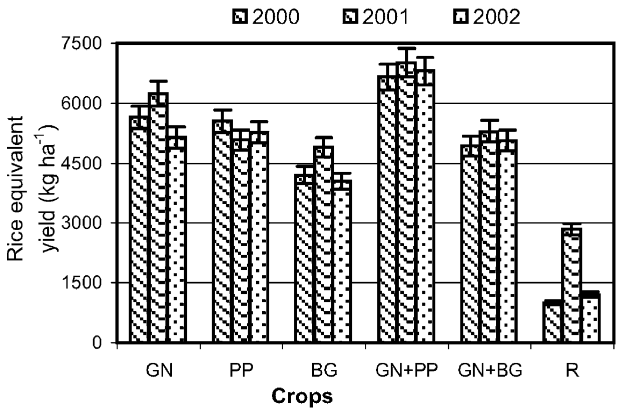

Fig. 4. Rice equivalent yield from rice substituted crops: GN, groundnut; PP, pigeonpea; BG, blackgram; GN + PP, groundnut + pigeonpea; GN + BG, groundnut + blackgram; R, rice.

rice ecosystem was increased and stabilized. In that year also, the best productive combination was groundnut + pigeonpea which produced rice equivalent yield of 6806 kg ha^{-1} with less rainfall.

The study of on-farm trials revealed that groundnut + pigeonpea intercropping was more promising as rice substituted crops in upland rice ecosystem. The yield of groundnut was higher in association with pigeonpea, which might be due to less competition between these two crops for light, nutrient and space because of their different growth habits. Study also revealed that yield of groundnut and blackgram was higher in rainfall excess year whereas pigeonpea produced more yield in rain deficit years. It might be due to capacity of this crop to draw soil moisture from lower strata owing to tap root system and it grows well even with less rainfall as compared to other crops. The rice substituted crops performed well in all the study years and productivity did not fluctuate much between rainfall deficit or excess years.

3.3.2. Enhancement of rainwater use efficiency and drought mitigation through crop diversification

The rainwater use efficiency (kg ha^{-1} mm^{-1}) in terms rice equivalent yield (rice equivalent weight per unit amount (mm) of rain drops received on the soil surface) was computed for all the crops/crop combinations to visualize the enhancement of rainwater use efficiency in upland rice soils through rice substitution and crop diversification. Study revealed that highest rainwater use efficiency in terms of rice equivalent yield was obtained from groundnut + pigeonpea intercropping system in rainfall deficit years with the values being 7.04 and 7.91 kg ha^{-1} mm^{-1} in the year 2000 and 2002, respectively (Fig. 5). In rainfall excess year (2001), the highest rainwater use efficiency was obtained from sole groundnut (5.38 kg ha^{-1} mm^{-1}) followed by blackgram (5.13 kg ha^{-1} mm^{-1}) and groundnut + pigeonpea (4.81 kg ha^{-1} mm^{-1}). Whereas, the rainwater use efficiency of rice was the lowest for all the study years irrespective of rainfall amount with the values being 1.60, 2.62 and 1.96 kg ha^{-1} mm^{-1} in first (2000) second (2001) and third years (2002), respectively. Therefore, the on-farm, adaptive crop diversification trials strongly revealed

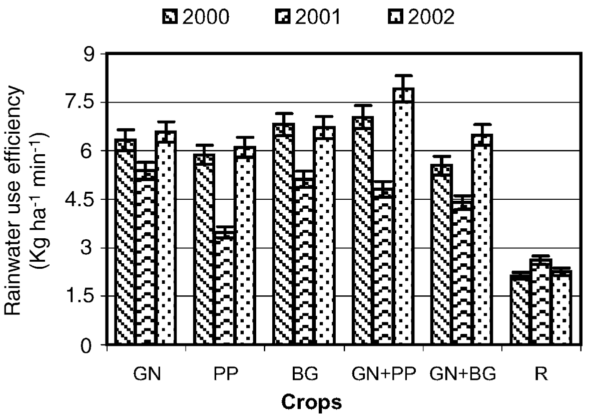

Fig. 5. Rainwater use efficiency of rice substituted crops: GN, groundnut; PP, pigeonpea; BG, blackgram; GN + PP, groundnut + pigeonpea; GN + BG, groundnut + blackgram; R, rice.

that there was a lot of scope to increase rainwater use efficiency of rainfed upland rice ecosystem through introduction of rice substituted, diversified legumes and oilseed crops.

3.3.3. Enhancement of productivity of upland rice soils through partial substitution of rice

In rice dominant area and for those farmers who cannot afford to leave rice, partial substitution of rice in light textured upland rice soils with some intercrops may give some yield certainty as an insurance against total rice failure due to drought or dry spells during crop growth period. If rice fails to grow with full potential, low water requiring or deep rooted intercrops will produce some return by mitigating the effect of drought and thus productivity of upland rice soils will be enhanced. The study revealed that when rice yield was adversely affected in light textured upland soils and its sole crop cultivation was found uneconomical in rain deficit years (2000 and 2002) due to occurrence of dry spells, intercropping of rice with pigeonpea, groundnut and blackgram produced rice equivalent yield of 3618, 2856 and 2890 kg ha^{-1} (Fig. 6) in first year (2000). Whereas, in third crop year (2002), intercropping of rice with pigeonpea, groundnut and blackgram produced rice equivalent yield of 3891, 3003 and 2850 kg ha^{-1}, respectively, whereas rice gave only 1215 kg ha^{-1} yield. In the second year (2001) rice produced good yield due to uniform distribution and good amount of rainfall but its association with intercrops gave much higher yield than that of sole rice crop. In the second year also among intercropping combinations, rice + pigeonpea produced more yield (4645 kg ha^{-1}), while yield from sole rice was only 2750 kg ha^{-1}. This on-farm study clearly justified the adoption of rice based intercropping with low water requiring crops instead of sole rice for traditional upland rice farmers.

3.3.4. Increased rainwater use efficiency and drought mitigation through rice based intercropping

The rainwater was also effectively utilized by rice based intercropping system as can be seen from rainwater use efficiency (in terms of rice equivalent weight, kg ha^{-1} mm^{-1}) of sole rice and rice with intercrops (groundnut, pigeonpea and blackgram). Among the

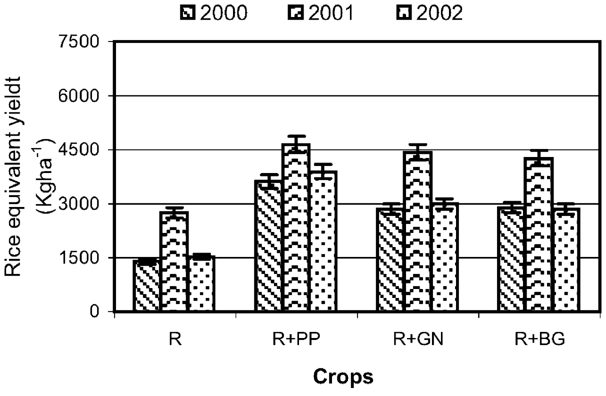

Fig. 6. Rice equivalent yield from rice based intercropping: R, rice; R + PP, rice + pigeonpea; R + GN, rice + groundnut; R + BG, rice + blackgram.

crop combinations highest water use efficiency was achieved by groundnut + blackgram with the values being 4.70, 4.46 and 4.75 kg ha^{-1} mm^{-1}, in the year 2000, 2001 and 2002, respectively (Fig. 7). It might be due to the fact that this combination produced higher yield with less rainfall owing to their short duration. Whereas, rice achieved water use efficiency of 2.20, 2.53 and 2.46 kg ha^{-1} mm^{-1} in 2000 (rain deficit), 2001 (rainfall excess) and 2002 (rain deficit), respectively.

3.3.5. Increased productivity and rain water use efficiency by double cropping in rainfed upland rice soils

Possibility of double cropping in rainfed upland rice soils was also explored utilizing rainfall and residual moisture through maize–horsegram/sesamum rotation. During rainy

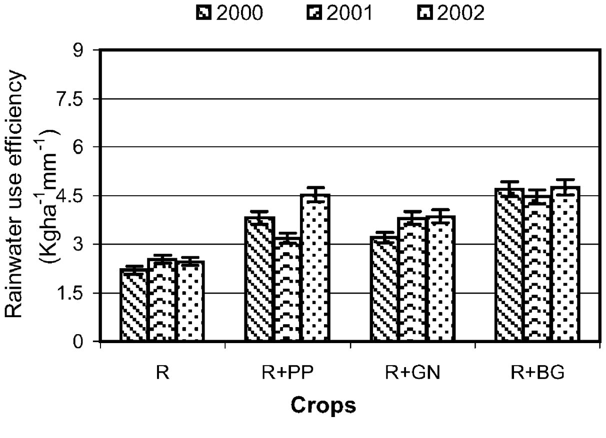

Fig. 7. Rainwater use efficiency of rice based intercrops: R, rice; R+PP, rice+pigeonpea; R+GN, rice+groundnut; R + BG, rice + blackgram.

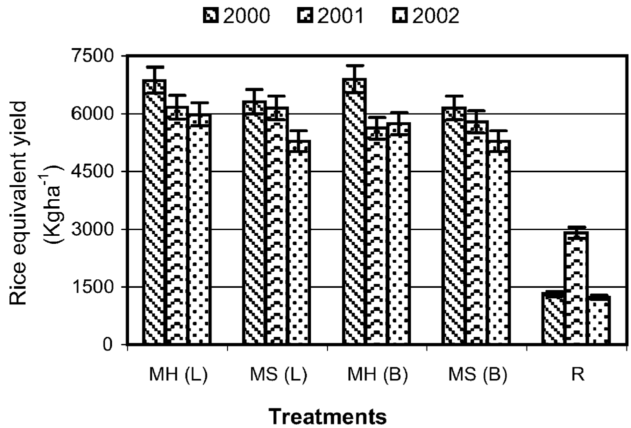

Fig. 8. Rice equivalent yield from maize–horsegram/sesamum rotation: MH(L), maize–horsegram (line sowing); MS(L), maize–sesamum (line sowing); MH(B), maize–horsegram (broadcasting); MS(B), maize–sesamum (broadcasting); R, rice.

season rice was substituted by maize as test crop considering its better market prospects in the region. Owing to low water requirement of maize, the crops produced much higher yield even in rainfall deficit years (2000 and 2002) as compared to sole rice (farmer's practice) in rainfed upland rice soils. The grain yield of 5350, 4380 and 4508 kg ha^{-1} was produced in first (2000, rainfall deficit), second (2001, rainfall excess) and third (2002, rainfall deficit) years, respectively. After harvesting of maize on the same land two pre-winter crops viz., sesamum and horsegram were sown in broadcasting as well as line methods of sowing. Study revealed that line sown horsegram produced 610, 720 and 590 kg ha^{-1} grain yield in first, second and third years, respectively. Whereas line sown sesamum produced 320, 590 and 330 kg ha^{-1} in respective 3 years. Total yield of two sequential crops (maize–horsegram/sesamum) were converted into rice equivalent yield and compared with that of sole rice yield on the same land

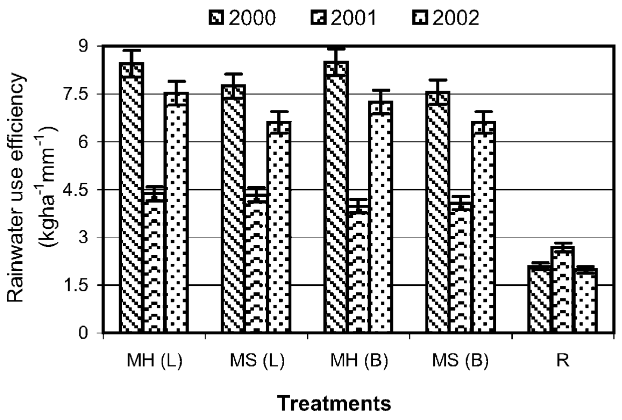

Fig. 9. Rainwater use efficiency of maize–horsegram/sesamum rotation: MH(L), maize–horsegram (line sowing); MS(L), maize–sesamum (line sowing); MH(B), maize–horsegram (broadcasting); MS(B), maize–sesamum (broadcasting); R, rice.

(Fig. 8). Study revealed that productivity was much higher from maize–horsegram/sesamum rotation than that of sole rice.

The rain water use efficiency was also enhanced in maize–horsegram/sesamum rotation with the values being 8.4, 4.3 and 7.5 $kg\,ha^{-1}\,mm^{-1}$ in the first (2000), second (2001) and third years (2002), respectively, from maize–horsegram (line sowing). Whereas, from maize–sesamum (line sowing) cropping system the rainwater use efficiency was 7.7, 4.3 and 6.6 $kg\,ha^{-1}\,mm^{-1}$ in the first (2000), second (2001) and third (2002) years, respectively (Fig. 9). Based on that study farmers were advised to adopt maize–horsegram/sesamum cropping system as one of the alternatives for upland rainfed area rice which will not only increase the productivity of upland rice ecosystem but cropping intensity and rain water use efficiency as well.

4. Conclusion

From the study, it can be concluded that studies of rainfall analysis and soil water retention–transmission studies are having practical utility for rainfed crop planning in upland rice soils of eastern India. Study revealed that the yield of rice substituted crops did not differ significantly in rainfall excess (2001) and rainfall deficit (2000 and 2002) years though rice yield was fluctuated drastically. In deficit rainfall years (2000 and 2002) when rainfed upland rice yield was affected adversely, much higher rice equivalent yield per annum was obtained through crop diversification from maize cob (6500–8125 $kg\,ha^{-1}$) followed by groundnut + pigeonpea (6656–6801 $kg\,ha^{-1}$), sole groundnut (5480–5640 $kg\,ha^{-1}$), sole pigeonpea (5268–5550 $kg\,ha^{-1}$) and rice + pigeonpea intercropping (3618–3891 ha^{-1}) on the same land. Whereas, the yield of rice was 1010 and 1215 $kg\,ha^{-1}$ in 2000 and 2002, respectively (rain deficit years). Double cropping in rainfed upland rice area was explored through maize–horsegram/sesamum rotation to increase the cropping intensity of such land. The experience of crop diversification in upland rice area showed that the technology was very much useful for drought mitigation and yield stabilization with increased rainwater area efficiency.

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