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Markov chain approach - dry and wet spell rainfall probabilities for rice-wheat planning

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ABSTRACT : Among different weather variables, rainfall is the major determinant and deciding factor for success or failure of rainfed agriculture. For agricultural planning and farming operations, information about occurrence of dry and wet periods is important and will have dominating effect on the crop yield and thereby influence the livelihoods of rural community. The success or failure of crop closely linked with the rainfall patterns. Even in high rainfall regions, the occurrence of dry and wet spell during the different phenophases of the crop decides the yield. In this study Markov chain model has been employed to know the initial and conditional probability of having a dry or a wet week and also the occurrence of consecutive dry or wet periods of 2 or 3 weeks for selected stations of Bihar State representing different agro-ecological zones. Average annual rainfall of 1222.4, 1538.0, 1162.7 and 1134.5 mm were received at Pusa, Purnia, Bhagalpur and Patna districts, respectively. This indicates that among the different zones, zone-II gets more annual rainfall followed by zone I, but the annual variability is lower for zone-IIIB followed by zone-I. The initial probability of occurrence of dry week is high (more than 60 %) upto 23rd standard meteorological week for zones-I, IIIA and IIIB while it is upto 18th week for zone-II. The probability occurrence of two consecutive wet weeks is high (more than 60 %) from 28th to 34th weeks, but it is fluctuating and in the case of probability of occurrence of three consecutive weeks, it is never above 60 % even in the peak monsoon months of July and August for zone-I. However, the probability occurrence of three consecutive wet weeks is high (more than 50 %) during the 29th week only and all other weeks between 26th to 39th weeks are below 50 per cent for zone-IIIA. Based on the rainfall pattern and its distribution, different crop management strategies as well as remedies are suggested to explore maximum rainfall received during the season to maximize the production and minimize the existing gap between the potential and actual production.

Keywords: Conditional probability ; Crop planning ; Dry and wet spell ; Markov chain approach ; Rainfed

Agriculture is the back bone of Indian economy as well as our food and nutritional security. Adverse weather conditions tilt the balance and badly affect the livelihood and food production system. In Bihar, the economy is basically rural based with greater dependence on agriculture, as the 89.5% of the population is rural population compared to national average of 72.2 % and agriculture contributes 43.8% to state GDP against the national figure of only 26.5%. Similarly, the population Below Poverty Line (BPL) is 42.6 % against the national average of 26.1 %. Out of 70 per cent farmers engaged in agricultural and other allied sectors, 90 per cent are marginal and small farmers. Comprehensive idea regarding the probability of rainfall receipts is essential due to economic implication of certain weather sensitive operations (Virmani et al. 1982). Therefore, any adverse changes in rainfall would have a serious effect on crop production and livelihoods in the State both in canal commands and rainfed areas. Even though Bihar falls under high rainfall region, recurrent floods and droughts during the monsoon season is a serious concern. Surprisingly, the occurrence of severe drought/floods in recent years 2003, 2004, 2005 and 2008 in one or other districts of Bihar emphasize the importance of rainfall based comprehensive crop planning for Bihar, especially in rice-wheat cropping system. Rice followed by wheat is a dominant cropping sequence in Bihar. The success or failure of any crop depends not only on the total rainfall received during the crop season but also the distribution of rainfall during the sensitive pheno-phases of the crop. The concept of estimating probabilities of occurrence of dry and wet spells and also probabilities of occurrence of consecutive 2/3 days dry and wet spells with respect to a threshold amount of rainfall is extremely useful for crop planning, farming operations and design/adoption of moisture conservation measures.

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Several studies have laid stress on the need for the quantification of the variability of rainfall pattern across the Country. The Markov chain probability model has been used by several researchers to study the occurrence of dry and wet spells of different duration for different purposes. Khambete and Biswas (1984) used Markov Chain model to evaluate sequences of wet weeks during southwest monsoon period over dry farming tracts of Maharashtra and developed an index of drought proneness based on initial probability of wetness and dryness. Thiyagarajan *et al.* (1995) applied Markov chain of order one for studying the patterns of occurrences of dry and wet days during the pre-monsoon and the monsoon at east Thanjavur district of Tamil Nadu. Chattopadhyay and Ganesan (1995) attempted to study the variability of annual and seasonal rainfall pattern and its probability using Markov chain probability model in coastal Tamil Nadu and suggested suitable cropping pattern. Pandharinath (1991) applied Markov chain model to determine probability of dry, wet weeks during monsoon period over Andhra Pradesh. Agnihotri (1993), Chaudhary *et al.* (1979), Medhi (1976), Rao and Rajamoni (1980), Basu (1971), Andherson and Goodman (1957), Panigrahi and Panda (2002), Jat *et al.* (2003), Sharma and Kumar (2003) and Kar (2003) also applied Markov Chain model for determination of initial and conditional probability of dry and wet spells of different duration for different climatic conditions and have demonstrated its practical utility in agricultural planning. But such studies were very limited for the State of Bihar. Hence, in the present study, an attempt has been made to analyze the initial and conditional probability of dry and wet spells and also the probability of 2 and 3 consecutive dry and wet spell weeks using Markov chain model for 4 selected stations representing 4 agro-ecological zones of Bihar.

MATERIALS AND METHODS

About the study area

The State of Bihar with an area of 93.60 lakh-ha between north latitudes 240 20' 10" and 270 31'15" and east longitudes 830 19' 15" and 880 17' 40", is the high potential resource rich region with low level of productivity. The state is bounded on the north by Nepal, on the east by West Bengal,

Table 1. *Mean total potential evapotranspiration of selected stations of Bihar (www.fao.org)*

Months	Bhagalpur	Patna	Purnea	Pusa
Jan	28.6	64	55.2	55.9
Feb	48	87	76.6	78.6
Mar	129.6	148	131.7	142.1
Apr	175.1	189	167.6	186.4
May	199.1	219	178.7	199.9
Jun	188.3	166	133.5	142.6
Jul	181.8	140	117.2	114.8
Aug	174	115	113.2	108.2
Sep	158.5	114	108.8	105.7
Oct	142.3	122	111.5	111.6
Nov	69.1	81	73.6	74.8
Dec	36.4	60	51.8	53
Annual	1530.8	1505	1319.4	1373.6
per day	4.19	4.12	3.61	3.76
per week	29.4	28.9	25.3	26.3
70 % PET	20.6	20.2	17.7	18.4

Table 2. *Important characteristics of the Agro-ecological zones of Bihar*

Agro-ecological zone	Total area (m ha)	Net sown area (m ha)	Irrigated area (m ha)	Cropping intensity	Rainfall (mm)	Major cropping systems
Zone-I	3.26	2.15 (65.95)*	0.89 (40.00)**	142.17	1122	Rice-wheat, Maize-wheat, Maize-Arhar, Maize-potato-moong, Maize-sweet potato-onion
Zone-II	2.08	1.21 (58.17)	0.24 (19.83)	158.43	1387	Rice-wheat, Jute-rice, Jute-rice-wheat, Jute-potato, Jute-mustard, Rice-wheat-moong
Zone-IIIA	1.11	0.49 (44.14)	0.21 (42.86)			Rice-wheat, Rice-wheat-moong, Rice-gram-rice, Rice-potato-onion, Rice-rai-moong, Rice-berseem
Zone-IIIB	2.92	1.68 (57.53)	1.37 (81.15)			Rice-wheat-moong, Rice-wheat-rice, Rice-gram-rice, Rice-gram-moong
Total	9.37	5.53 (59.02)	2.68 (48.46)	143.05	1234	

(* Figures in parenthesis are % to geographical area, ** Figures in parenthesis are % to net area sown)
(Adopted from MANAGE SREP Series-25 (2003))

on the west by Uttar Pradesh and on the south by Jharkhand. The state lies between 35 to 85 meters above the mean sea level. The river Ganges divides the state into two zones, north Bihar and south Bihar. The state is divided into four agro-ecological zones with zone-I and zone-II corresponding to north Bihar whereas the agro-ecological zone-IIIA and zone-IIIB comprising the districts of south Bihar (Fig. I). Net sown area as percentage of geographical area is higher for zone-I (66%) and lowest for zone-III (53%) against the state average of about 60%. The highest gross irrigated area as percentage of gross cropped area (76.35 %) lies in zone-III followed by zone-II (44.97 %) and zone- I (42.03 %). However, in spite of higher gross irrigated area in zone-III, the cropping intensity is only 135.11 %. Water stagnation for longer duration during *Kharif* (monsoon) season hampers crop cultivation. Some important agro-ecological characteristics of different zones are given in Table-1.

Table 3. *Details regarding data*

Zone	Station	Data type Daily/Weekly	Period
Zone-I	Pusa	Weekly	1953-2004
Zone-II	Purnea	Weekly	1969-1999
Zone-IIIA	Bhagalpur	Weekly	1969-2001
Zone-IIIB	Patna	Weekly	1960-2003

Data

Weekly rainfall data of 4 stations - Pusa, Purnea, Bhagalpur and Patna representing different agro-ecological zones of Bihar were procured from India Meteorological Department, Pune. The details regarding

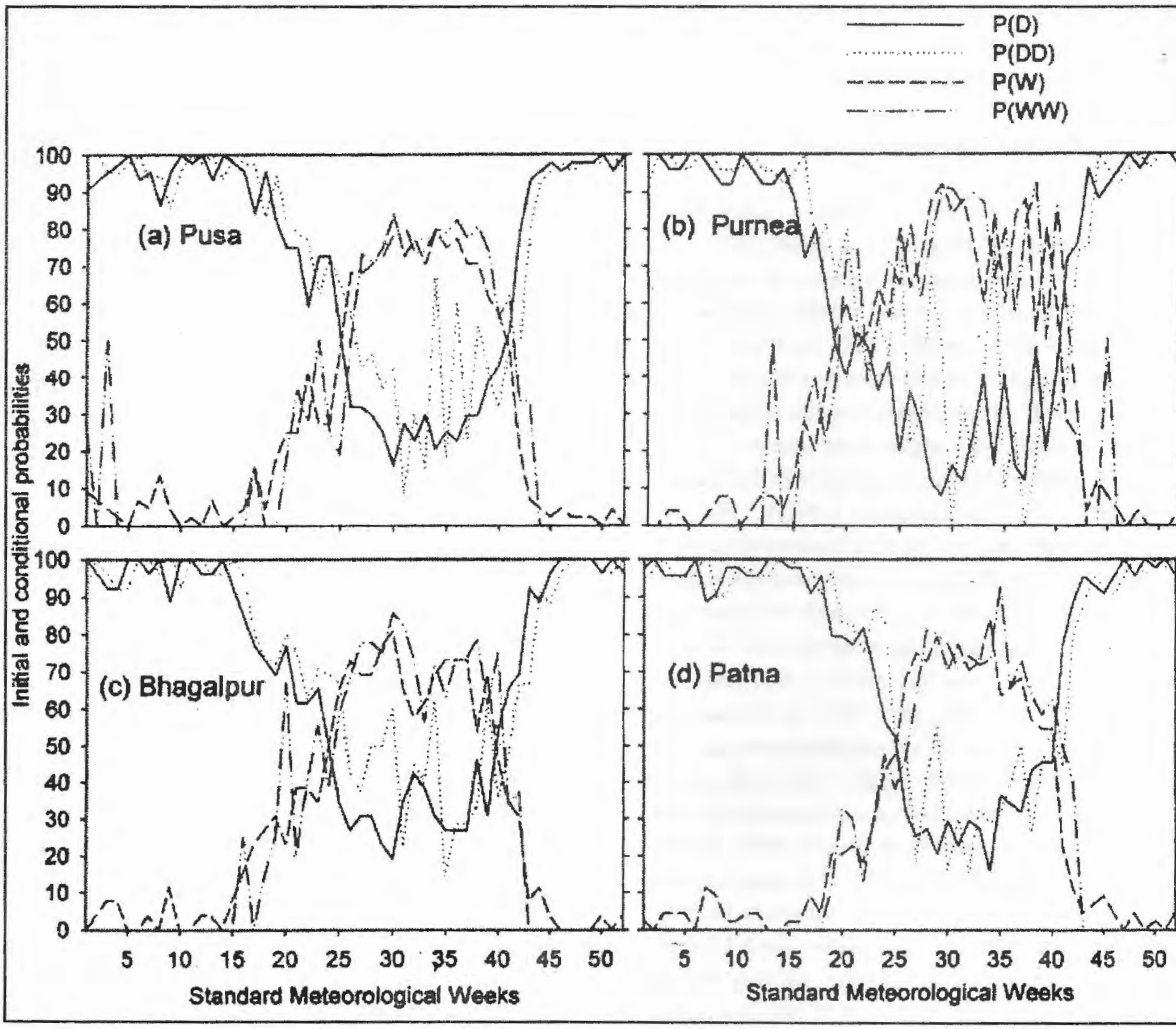

Fig. 1. *Initial and conditional probabilities of selected stations of Bihar*

data are shown in Table 2. For demarcating dry and wet weeks, a threshold value of 70 per cent of the potential evapotranspiration was used. Table 3 provides the mean monthly total potential evapotranspiration of selected stations. The 70 % of potential evapotranspiration is between 17.7 mm and 20.2 mm and therefore, the weekly dry and wet spell analysis was carried out considering less than 20 mm rainfall in a week as a dry week and 20 mm or more as wet week (Pandarinath 1991; Singh and Bhandari 1998, Kar 2003).

Methodology

Robertson (1982) used Markov chain model to establish drought frequencies during 10-day periods. This method makes use of the fact that the atmosphere is persistent in its behavior, and the events are not independent of those, which closely precede them. The Markov chain approach used by Gabriel and Neumann (1957 & 1962) for analyzing the rainfall data with the assumption that the outcome of any trial depends only on the outcome of the directly preceding trial is employed in this study. The probabilities of dry, wet weeks, conditional probabilities of dry week preceded by a dry week, wet week preceded by a wet week, consecutive 2 or 3 dry/wet weeks starting with the week were calculated using the following formulae,

$$P(D) = F(D)/N$$
$$P(DD) = F(DD)/F(D)$$
$$P(W) = F(W)/N$$
$$P(WW) = F(WW)/F(W)$$
$$2D = P(D_{w1}) \,.\, P(DD_{w2})$$
$$3D = P(D_{w1}) \,.\, P(DD_{w2}) \,.\, P(DD_{w3})$$
$$2W = P(W_{w1}) \,.\, P(WW_{w2})$$
$$3W = P(W_{w1}) \,.\, P(WW_{w2}) \,.\, P(WW_{w3})$$

Where,

- P(D) - Probability of the week being dry
- P(DD) - Conditional probability of a dry week preceded by a dry week
- P(W) - Probability of the week being wet
- P(WW) - Conditional probability of a wet week preceded by a wet week
- F(D) - Number of dry weeks
- F(DD) - Number of dry weeks preceded by another dry week
- F(W) - Number of wet weeks
- F(WW) - Number of wet week preceded by another wet week
- N - Number of years of data
- 2D,3D - Probability of 2 and 3 consecutive dry weeks, respectively starting With the week
- 2W,3W - Probability of 2 and 3 consecutive wet weeks, respectively starting With the week
- $P(D_{w1})$ - Probability of the week being dry (first week)
- $P(DD_{w2})$ - Probability of second consecutive week being dry given the Preceding week dry
- $P(DD_{w3})$ - Probability of third consecutive week being dry, given the Preceding week dry
- $P(W_{w1})$ - Probability of the week being wet (first week)
- $P(WW_{w2})$ - Probability of second consecutive week being wet given the Preceding week wet
- $P(WW_{w3})$ - Probability of third consecutive week being wet, given the Preceding week wet
- w_1, w_2, w_3 - Indicate three consecutive weeks

RESULTS AND DISCUSSIONS

Mean weekly rainfall

The mean weekly rainfall, standard deviation, coefficient of variation and percent contribution to annual rainfall for the selected stations are given in Table 4. Average annual rainfall of 1222.4, 1538.0, 1162.7 and 1134.5 mm, respectively were received for Pusa, Purnia, Bhagalpur and Patna districts with a standard deviation of 328.4, 426.1, 382.1 and 274. 5 mm, respectively. This indicates that average annual rainfall is highest in zone-II followed by zone-I and zone-III. Rainfall of more than 70 % of the potential evapotranspiration (PET) was received from 23rd week (21.1 mm) onwards continuously upto 40th week (43.1 mm) with a maximum of 81.3 mm received during the 28th week, which is about 6.7 % of the mean annual rainfall for zone-I, whereas for zone-II it is from 19th week (23.7 mm) onwards continuously up to 41st week (20.5 mm) with a maximum of 97.3 mm received during the 28th week, which is about 6.3 % of the mean annual rainfall. For zone-IIIA, rainfall of more than 70 % of the PET was received from 20th week (22.7 mm) onwards, while it was from 24th week (31.4 mm) for zone-IIIB and continued up to 42nd week with a maximum of 67.1 mm received during the 28th week for zone-IIIA and up to 41st week (21.4 mm) with a maximum of 90.1 mm received during the 28th week for zone-IIIB. This indicates that zone-IIIA and zone-II gets 23 wet weeks followed by Zone-III B and zone-I (18 weeks).

Table 4. *Standard weekly mean rainfall (mm), standard deviation (SD) (mm), coefficient of variation and its per cent contribution (C) to annual rainfall of selected stations of Bihar*

Standard	Zone I Pusa				Zone II Purnea				Zone III A Bhagalpur				Zone III B Patna			
	Mean	SD	Var %	% C	Mean	SD	Var %	% C	Mean	SD	Var %	% C	Mean	SD	Var %	% C
1	3.0	10.0	339.0	0.2	0.4	1.5	326.8	0.0	1.0	2.6	244.8	0.1	2.4	5.7	234.2	0.2
2	3.6	14.3	402.1	0.3	1.3	3.2	242.8	0.1	2.9	6.0	210.8	0.2	1.2	2.8	232.1	0.1
3	4.3	12.8	297.1	0.4	1.7	6.3	370.7	0.1	3.0	8.2	279.4	0.3	3.2	7.2	228.0	0.3
4	4.2	8.9	211.6	0.3	2.4	7.3	305.4	0.2	7.7	29.3	378.8	0.7	2.6	6.1	235.3	0.2
5	5.4	11.6	212.3	0.4	0.7	1.8	241.9	0.0	2.9	5.6	191.4	0.3	3.1	6.9	219.8	0.3
6	2.9	8.7	300.1	0.2	0.9	2.1	239.6	0.1	2.4	4.7	197.4	0.2	2.6	5.0	194.1	0.2
7	3.7	9.2	250.1	0.3	2.5	7.1	288.1	0.2	3.1	7.2	230.5	0.3	4.7	11.4	242.4	0.4
8	2.5	5.8	229.0	0.2	3.3	7.5	225.1	0.2	2.4	4.9	210.2	0.2	4.2	9.9	237.3	0.4
9	1.7	4.3	246.1	0.1	3.7	6.9	184.6	0.2	3.6	7.1	195.2	0.3	2.2	5.0	223.4	0.2
10	1.4	5.0	366.4	0.1	0.4	1.1	270.6	0.0	1.5	3.4	221.8	0.1	2.0	5.5	272.0	0.2
11	1.4	4.1	294.9	0.1	2.1	7.8	377.4	0.1	0.3	0.8	281.7	0.0	2.2	7.6	351.4	0.2
12	2.4	7.3	303.5	0.2	3.7	7.1	193.7	0.2	2.6	4.9	187.2	0.2	2.8	5.8	207.9	0.2
13	1.2	3.2	267.0	0.1	5.6	13.1	232.5	0.4	3.2	6.0	190.3	0.3	0.9	2.4	262.3	0.1
14	1.4	6.2	434.7	0.1	1.7	4.7	276.2	0.1	0.5	1.5	319.5	0.0	0.3	1.1	394.0	0.0
15	2.6	6.6	257.7	0.2	7.1	16.3	227.9	0.5	7.2	20.2	281.7	0.6	0.9	3.5	397.2	0.1
16	5.1	10.6	207.4	0.4	16.3	25.3	155.2	1.1	14.2	39.4	276.7	1.2	3.0	6.9	226.2	0.3
17	7.2	13.2	182.3	0.6	10.4	15.8	151.8	0.7	9.2	16.2	175.4	0.8	5.9	12.4	208.4	0.5
18	10.1	15.3	151.7	0.8	18.9	19.4	102.6	1.2	12.4	15.9	128.2	1.1	4.0	8.4	211.8	0.4
19	10.9	17.6	161.1	0.9	23.7	26.1	110.2	1.5	13.9	16.2	117.1	1.2	10.6	18.5	174.4	0.9
20	14.1	27.0	191.5	1.2	32.1	30.5	95.0	2.1	22.7	36.8	161.8	2.0	9.5	16.4	172.3	0.8
21	19.7	26.0	132.1	1.6	25.7	24.8	96.5	1.7	20.7	27.8	134.6	1.8	12.8	25.8	201.5	1.1
22	14.2	19.0	134.3	1.2	49.5	75.8	153.2	3.2	19.1	22.6	118.4	1.6	9.0	15.2	168.2	0.8
23	21.1	31.3	148.4	1.7	65.2	103.6	158.9	4.2	34.0	54.4	160.0	2.9	16.4	25.3	154.7	1.4
24	29.2	34.8	119.2	2.4	53.8	60.8	112.9	3.5	37.9	50.6	133.4	3.3	31.4	42.4	134.8	2.8
25	58.0	66.4	114.6	4.7	52.3	38.7	74.0	3.4	47.9	48.9	102.2	4.1	34.4	50.6	147.1	3.0
26	60.7	71.5	117.9	5.0	73.6	68.6	93.3	4.8	62.7	57.3	91.4	5.4	62.8	64.7	103.1	5.5
27	68.7	69.0	100.3	5.6	88.7	77.8	87.7	5.8	64.7	58.7	90.9	5.6	72.3	74.8	103.3	6.4
28	81.3	75.1	92.3	6.7	97.3	73.0	75.1	6.3	67.1	64.6	96.2	5.8	90.1	92.3	102.5	7.9
29	74.6	69.6	93.2	6.1	94.5	58.6	62.0	6.1	61.0	44.4	72.8	5.2	74.3	58.6	78.8	6.5
30	68.5	61.6	89.9	5.6	64.8	45.9	70.8	4.2	64.4	65.1	101.2	5.5	73.2	75.2	102.7	6.4
31	71.8	66.7	92.8	5.9	92.7	82.9	89.5	6.0	65.7	102.4	155.9	5.7	67.8	57.1	84.2	6.0
32	66.1	72.1	109.0	5.4	51.6	40.2	77.9	3.4	39.8	44.8	112.4	3.4	56.4	47.8	84.8	5.0
33	70.7	69.9	98.9	5.8	61.2	69.2	113.0	4.0	55.7	71.0	127.4	4.8	47.2	42.7	90.4	4.2
34	76.4	83.9	109.8	6.3	76.6	78.6	102.6	5.0	60.5	53.1	87.7	5.2	78.9	70.6	89.5	7.0
35	50.1	46.4	92.6	4.1	53.3	62.3	116.9	3.5	40.4	34.5	85.3	3.5	46.0	42.5	92.4	4.1
36	62.3	68.9	110.6	5.1	68.4	69.5	101.6	4.4	48.9	47.4	97.0	4.2	56.1	54.7	97.6	4.9
37	68.0	73.3	107.8	5.6	95.7	83.7	87.4	6.2	58.4	48.3	82.6	5.0	48.7	46.9	96.4	4.3
38	43.9	56.9	129.8	3.6	33.4	45.3	135.4	2.2	40.9	47.0	115.0	3.5	49.0	75.8	154.6	4.3
39	42.1	55.9	132.9	3.4	92.1	90.9	98.8	6.0	47.4	39.2	82.5	4.1	41.3	62.2	150.4	3.6
40	43.1	80.0	185.9	3.5	48.5	78.4	161.7	3.2	46.7	61.8	132.3	4.0	46.9	58.7	125.3	4.1
41	14.1	24.6	174.0	1.2	20.5	39.4	192.4	1.3	24.2	43.0	177.7	2.1	21.4	48.1	224.9	1.9
42	9.8	29.7	303.2	0.8	19.2	45.7	238.4	1.2	21.3	45.9	215.7	1.8	10.4	32.7	314.0	0.9
43	5.5	25.2	459.6	0.4	2.0	9.3	457.8	0.1	3.4	10.7	312.0	0.3	3.6	11.9	335.0	0.3
44	3.2	9.9	309.2	0.3	4.3	8.7	203.7	0.3	5.1	11.9	234.1	0.4	2.5	7.0	276.7	0.2
45	1.7	7.0	422.6	0.1	5.3	20.0	374.5	0.3	1.5	5.2	348.9	0.1	4.1	14.3	347.3	0.4
46	1.5	7.2	497.7	0.1	1.1	4.3	394.0	0.1	0.7	2.4	374.4	0.1	2.0	7.5	371.3	0.2
47	0.6	3.4	562.4	0.0	0.0	0.2	500.0	0.0	0.0	0.2	509.9	0.0	0.6	1.8	309.7	0.1
48	2.0	9.7	496.1	0.2	3.5	16.2	462.9	0.2	1.0	3.8	363.6	0.1	1.4	5.0	355.5	0.1
49	0.2	1.1	543.4	0.0	0.0	0.2	500.0	0.0	0.0	0.2	509.9	0.0	0.3	1.6	628.6	0.0
50	1.2	6.0	485.3	0.1	0.5	1.8	343.2	0.0	1.6	7.3	459.1	0.1	0.7	4.2	577.3	0.1
51	0.8	2.8	371.3	0.1	0.6	2.1	346.1	0.0	0.8	3.0	364.7	0.1	0.8	2.5	305.6	0.1
52	2.2	5.1	227.0	0.2	2.9	6.9	238.3	0.2	2.5	7.7	301.4	0.2	3.5	9.2	262.9	0.3
Annual	1222.4	328.4	26.9		1538.0	426.1	27.7		1162.7	382.1	32.9		1134.5	274.5	24.2	

Table 5. *Normal rice growing calendar for short, medium and long duration varieties*

Transplanting Date	Maximum Tillering	Panicle Development	Flowering	Milky Stage	Grain Hardening	Harvest
Short Duration Varieties, eg. Thuranda, Bala, Cauveri (Maturity 90-100 days after transplantation)						
June 25- July 1	July 23-29	Aug 6-12	Aug 20-26	Sept 3-9	Sept 17-23	Sept. 25-30
Medium Duration Varieties, eg. Sita, Rajasree (Maturity 110-115 days after transplantation)						
June 25- July 1	July 30-Aug 5	Aug 13-19	Sept 17-23	Sept 23-30	Oct 1-7	Oct 7-15
Long Duration Varieties, eg. MTU 7029, MTU 1001 (Maturity 130-140 days after transplantation)						
June 25- July 1	July 30-Aug 12	Aug 27-Sep 2	Sept 28- Oct 7	Oct 24-30	Nov 4-11	Nov 11-17

Initial and conditional probability of wet and dry weeks

The initial probability of occurrence of a dry week is high (more than 60 %) up to 23rd week for zone-I, zone-IIIA and zone-IIIB, whereas it is up to 18th week for zone-II, but it rapidly falls in subsequent weeks. But it starts increasing from 38th week for zone-IIIB, whereas for all other zones it starts increasing from 41-42nd week onwards.

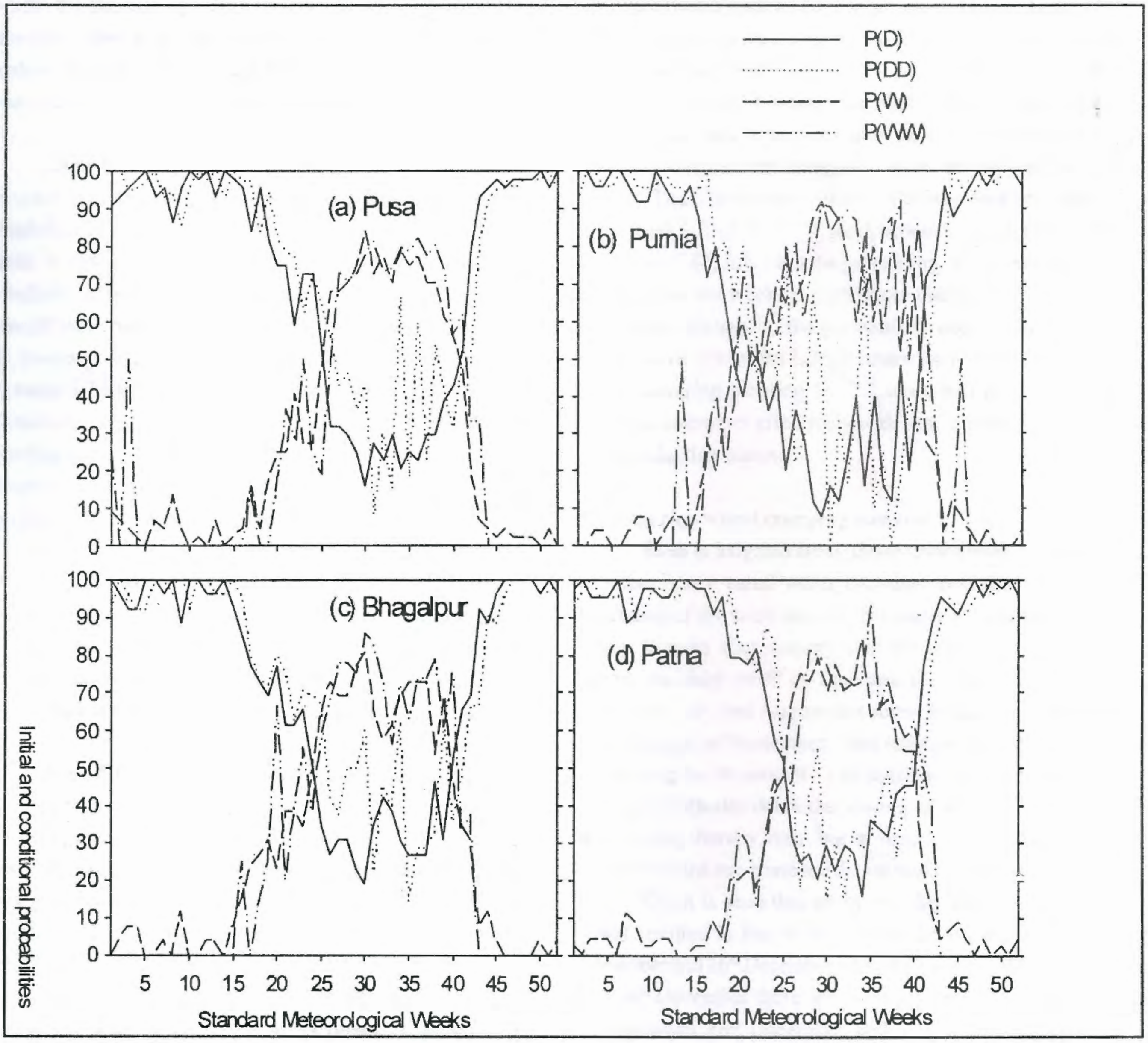

Fig. 2. *Probability of 2 and 3 consecutive dry and wet weeks starting with the week for the selected of Bihar*

Zone-I: The conditional probability of dry week preceded by a dry week is high up to 25th week, but the probability of occurrence of two or three consecutive dry weeks is low from 25th week onwards. The conditional probability of wet week preceded by a wet week is also high from 26th week onwards, which falls in the period June 25- July 1. But the probability occurrence of two consecutive wet weeks is high (more than 60 %) from 28th to 34th weeks, but it is fluctuating and in the case of probability of occurrence of three consecutive weeks is never above 60 % even in the peak monsoon months of July and August. This suggest that even though the floods occurs regularly in this region, additional assured irrigation facilities could be created to cope up with the fluctuating nature of the rainfall, particularly at the reproductive stage which starts from last week of August for short duration varieties and from last week of September to early October for long duration varieties.

Zone-II: The conditional probability of dry week preceded by a dry week is also high upto 20th week, but the probability of occurrence of two or three consecutive dry weeks is low from 20th week onwards. The conditional probability of wet week preceded by a wet week is also high from 20th week onwards, which falls during the period May 14-20th. But the probability occurrence of two or three consecutive wet weeks is high (more than 50 %) from 27th to 39th week. This indicates that from 27th week to 39th week, there is fair chance of getting consecutive wet weeks of more than 20 mm rainfall. This means from July 2nd to September 30th there are almost 90 days in which probability of getting rainfall of more than 70 % of PET and hence, transplanting of rice should be done on 26th week to utilize the maximum amount of rainfall received during this period of time. Short & Medium duration rice varieties can be taken without any irrigation. Long duration varieties may require one irrigation during early October if runoff water is not available in the low lands.

Zone-IIIA: The conditional probability of dry week preceded by a dry week is also high (more than 60 %) upto 25th week, but the probability of occurrence of two or three consecutive dry weeks is low from 25th week onwards. The initial probability of occurrence of a wet week is never above 85 per cent even in the monsoon period, this indicates the high year-to-year variability of rainfall during the monsoon weeks. The conditional probability of wet week preceded by a wet week is high from 26th week onwards, which falls during the period 25th June to 1st July. But the probability occurrence of two consecutive wet weeks is high (more than 50 %) from 26th to 39th week, except weeks 31 to 34 and 38th. However, the probability occurrence of three consecutive wet weeks is high (more than 50 %) during the 29th week only and all other weeks between 26th to 39th weeks are below 50 per cent. This indicates the chance of occurrence of dry period is more within the monsoon weeks and this suggests that droughts/water deficit during the tillering/ to panicle initiation phase of rice crop is common and as much as water should be conserved in paddy field to avoid/minimize crop failure.

Zone-IIIB : The conditional probability of dry week preceded by a dry week is also high (more than 60 %) upto 25th week, but the probability of occurrence of two or three consecutive dry weeks is small from 24th week onwards. The initial probability of occurrence of a wet week is never above 85 per cent even in the monsoon period, this indicates the high year-to-year variability of rainfall during the monsoon weeks. The conditional probability of wet week preceded by a wet week is high from 27th week onwards, which falls during the period 2-8th, July. But the probability of occurrence of two consecutive wet weeks is high (more than 50 %) from 27th to 34th week. However, the probability occurrence of three consecutive wet weeks is high (more than 50 %) only in 34th week. Ensuring planting by 26th week will help to use the available rainwater effectively with supplementary irrigation in reproduction states.

Existing rice-wheat cropping scenario

Even in irrigated areas, timely availability of water is a problem, since canal water becomes available during the beginning of the rainy season. Normally in most parts of the Bihar, farmers start nursery with the onset of monsoon ie, during the third week of June and they start transplanting during the July and August and some farmers do it even the first fortnight of September. This reduces the potential yield of rice crop by 50 percent. The possible delay of rice harvest may automatically delay the sowing of wheat by more than one month, thereby resulting in drastic reduction in wheat yield. From the experimental data at the Institute for the season (2001-02), it is seen that every one-day delay in sowing of wheat resulted in loss of 56.7 kg/ha grain yield between 6th December and 16th December whereas, between 16th December and 26th December there was a reduction of 75.4 kg/ha/day and between 26th December and 5th January there was a reduction of 88.3 kg/ha/day under prevailing conditions of

Patna (Annual report 2001). This is the major reason for late sowing of wheat in the rice-wheat cropping sequence, resulting in lower yields of the system.

Crop management and planning strategies for the region

Under the ideal situation, rice crop of medium to long duration transplanted during the end of June will have its flowering period during the middle of September to early October (Table 5). Flowering is a critical phase with respect to water requirement, as shortage of water during this time will affect subsequent grain filling and hence yield. Therefore farmers, especially those having their crops in upland need to arrange supplemental irrigation through tube wells. Where the rice crop is totally dependent on rainfall for water requirement, it is advisable to take short and medium duration varieties, which complete major reproductive stage by September. In lowlands of Zone-II a successful rainfed crop is possible with medium to long duration varieties and timely planting by 26th week. Measures like storage of runoff water in the fields, increasing bund height to 25-30 cm needs to be adopted for a successful rainfed crop.

Even under irrigated condition, transplanting by 26th week is crucial to make use of all rainwater and harvest a good crop of rice and a subsequent good wheat crop. Under late planting situation in farmer's field, the phenophases like maximum tillering and panicle development comes during the month of September. Since panicle development decides the number of grains in the panicle and tillering decides the number of panicles and hence capacity for higher yield, the availability of water during these periods is critical. Hence, it is important to ensure availability of irrigation water during the period. Scientific water management practices like irrigation at 3 days after disappearance of earlier ponded water instead of maintaining standing water continuously in the field can save up to 50 % of irrigation water and make it available to irrigate more area. Increasing the bund height in the field up to 30 cm can also retain more rainwater in the field and increase the moisture content of the soil. Balanced fertilizer application ie, application of phosphorus and potash along with nitrogen (urea) can give the crop a certain extent of drought tolerance. By ensuring the release of irrigation water during the critical phases like tillering (30-40 days after transplanting), panicle development (50-65 days after transplanting) and flowering (70-90 days after transplanting), the crop failure and yield reduction can be avoided. Similarly, traditional water harvesting structures like ponds and tanks should be rejuvenated to enhance storage of runoff water and increase groundwater recharge. In lowlands and high residual moisture condition, to reduce the delay in sowing of wheat after harvesting rice, zero till seed drill and rotavator-cum-seed drill can be used for sowing of wheat. Surface seeding with balanced nutrition is also in good strategy for wheat sowing under such conditions.

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