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Resource Management Domains of *Kharif* and *Rabi* Season Fallows in Central Plateau Region of India: A Strategy for Accelerated Agricultural Development

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Abstract

Over last few decades, acreage of total fallow lands (*Kharif* and *Rabi* seasons) in India has remained almost unchanged around 25Mha. The acreage of *Kharif* (summer) and *Rabi* (winter) Fallows in Madhya Pradesh (MP) are 1.98Mha and 5.51Mha, respectively. In the semi-arid agroclimatic zones of the states, Fallow-Wheat/ Gram/Indian-Mustard cropping systems are practiced. After harvest of *Kharif* rice, kodo-kutki, maize or sorghum, farmers generally practice post-rainy season *Rabi* fallows in the sub-humid regions, south of Narmada River. *Kharif* fallowing is largely the result of the inability of the farmers to make planting dates independent of monsoon forecasts, and make efficient use of rain water. It appears that factors responsible for *Kharif* and *Rabi* fallows are distinctly different and a general consequence of distinctly different soil moisture regimes prevailing in the two crop seasons. *Kharif* and *Rabi* fallows have two distinct resource management domains. Whereas, *Kharif* fallows can be tackled with "PMP-dry seeding" agronomy, production constraints of *Rabi* fallows can be substantively tackled by shifting from tilled to zero-till agriculture with residue management to make efficient use of the conserved rain water. Some irrigation support will prove useful to tackle mid-season droughts in both situations. Conservation agricultural practices can significantly improve and stabilize crop yields in black soils and other associated soils of in the semi-arid tropics region of the Central India.

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Introduction

Since 1960s, India has pursued an agricultural policy aimed largely at enhancing productivity through input based approaches. This strategy resulted in substantial gains in crop production and productivity to overcome recurring food shortages in the country. The strategy however, has ignored the impact of input interventions on the soil health and the associated ecoservices, resulting in declining factor productivity and widespread problems of natural resource degradation [1]. Such gains were generally limited to well-endowed regions where it was possible to alter the production environment through input use. This has raised some serious questions on the suitability of the past approaches considered for achieving the food security goals.

Sustainable agriculture requires land based solutions for management of natural resources, which integrates biophysical and socioeconomic parameters for characterizing the land management units, known as resource management domains. A resource management domain is a homogenous land unit having similar constraints, requiring a similar management approach for specific land use [2-4]. The concept of homogenous resource management domains / zones/ has progressed through many stages such as agroclimatic zones and agro-ecological sub-regions which has now found its way into precision farming. Agro-ecoregional concept [5] adopted by NBSS&LUP however, ignored the fact that introduction of irrigation water alleviates a major production constraint besides providing opportunities for diversification of agriculture. Hence an approach that integrates productivity concerns with conservation of natural resources is a pre-requisite for achieving enhanced productivity on a sustained basis. The high-input rice-wheat systems of the Indo-Gangetic plains (IGP) is showing signs of resource fatigue and diversification of this production is long overdue. Therefore, additional food will have to come from regions outside the IGP. A potential opportunity for enhancing food growth exists in eastern and central India wherein a large area remains fallow during the *Kharif* (rainy season) or the *Rabi* (winter) season. In Central Plateau region of India (Madhya Pradesh + Chhattisgarh), total acreage of lands that remain fallow during *Kharif* season is about 3.5 Mha [6,7]. *Rabi* season fallows have been reported to vary between 4.5 -5.5 mha [8-10]. Although crop production in fallow lands was set an early goal for research institutions located in rainfed semi-arid tropics (SAT), but the institutional deficits did not allow a fuller understanding of the problems associated with land fallowing.

Using the cropping system field survey data and the assessments of the remote sensing studies on seasonal land follows, the present study was aimed to achieve a better understanding of the issues associated with seasonal land fallows and to examine if the two land fallowing systems (*Kharif* and *Rabi*) constitute distinct resource domains, calling for specific crop-soil-water management approaches for agricultural intensification in the region.

Agro-Climatic Zones in Central Plateau Region, Madhya Pradesh

Until 2000, Madhya Pradesh (MP) was a very large state (44.34 Mha area) in the central belly of India. In 2000, the state of Chhattisgarh (CG) was carved out of MP to accelerate economic development in the tribal dominated backward districts adjoining the states of Orissa, Jharkhand and Telangana states. Madhya Pradesh is located between 18^o-26^o 30' N latitude and 74^o-84^o 30' E longitude. MP contributes 13.7 percent to the total geographical area of India but makes up 28.6% of the total fallow lands of India (~ 25 Mha), which is a rather disproportionate contribution. Fallow lands cover about 7.5 Mha area in the two main crop seasons. Therefore, fallow lands in the Central Indian Plateau offer an excellent opportunity for growing additional food if their production potential can be unlocked quickly.

Following the FAO methodology, NBSS & LUP had earlier delineated 60 agro-eco-sub-regions (AESRs) in the country[5]. Vijay Shankar [11] made some refinements in the boundaries of the AESRs for the MP state by (i) adjusting AESR boundaries to match district boundaries used for ACZs (agro-climatic zones), and (ii) make regions more people centric through clustering of tribal dominated districts into neighboring AESR to enable special treatment for upliftment of the poor. The districts comprising the 9 ACZs and the zone boundaries are shown in the map (Fig. 1). The special features of the each of the 9 ACZs are given in table 1. Length of growing period (LPG) is calculated, starting when rainfall exceeds 50% of the PET and ends with utilization of the stored soil moisture after rainfall, varied between 120-210 days. Madhya Pradesh has significant climatic differences varying from moist semi-arid to hot and moist sub-humid climates. Agroclimatic zones, namely the Grid zone, the Malwa and Nimar Plateaus receive annual rainfall between 800-1000mm. On the other hand, districts constituting the Wainganga, Chhattisgarh Hills and Plains ACZs receive high annual rainfall varying from 1000-1600mm. Negative moisture index values point to acute water deficient situations in Malwa and Nimar Plateaus and Grid Zone, resulting in reduced LGPs (Table 1). Long growing periods (180-210 days) and positive moisture indices in the Wainganga, Chhattisgarh Hills and the CG Plain zones indicate that annual rainfall is more than adequate to meet atmospheric potential evapotranspiration (PET) demands of two crops in a year.

Soils Resources in Different ACZs of Madhya Pradesh

Broadly, Central India is dominated by two groups of soils; the heavy textured black soils and the relatively coarser textured red soils (alfisols). Alluvial soils can be found in the Grid region of the Chambal river command. The coarse textured red soils have low capacity to retain soil moisture, nutrients and soil organic matter and develop hard crusts on drying which become highly impermeable to water and pose problems

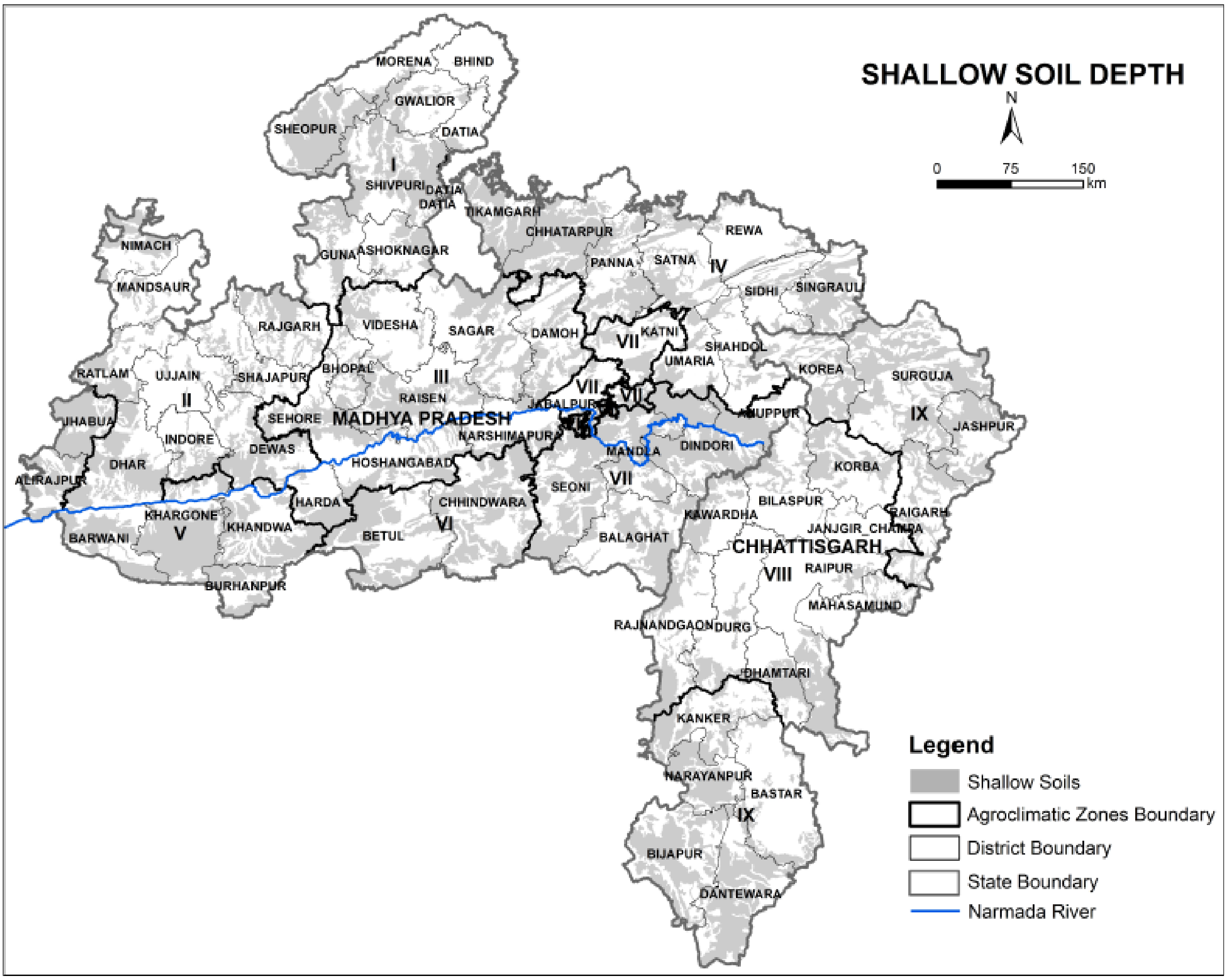

Figure 1. Map showing districts comprising agroclimatic zones (I-IX). Grey areas depict the spatial distribution of moderately shallow depths (< 70cm) of Red and Black soils of the Central Plains.

Table 1. Length of growing periods, moisture index and area attributes of different agroclimatic zones (ACZ) in Central Plateau of Madhya Pradesh and Chhattisgarh.

ACZ	AESR	Soils	Shallow soils, %	Districts in the ACZ	Area	LGP	MI
I. Grid zone	4.4	Alluvial & Black soils	39.65	Bhind, Morena, Sheopur, Guna, Datia, Gwalior,Shivpuri, Ashoknagar	4.43	120-150	-30 to -40
II. Malwa Plateau	5.2	Black soils	35.91	Dhar,Dewas, Indore, Mandsaur, Neemuch, Rajgarh, Ratlam, Shajapur, Ujjain	5.32	120-150	-35 to -49
III. Vindhyan Plateau	10.1	Black soils	38.70	Bhopal, Hoshangabad, Narsinghpur, Raisen, Sagar, Sehore, Vidisha, Harda, Damoh	5.76	150-180	-03 to -22
IV.Baghelkhand	10.3	Red & Black soils	44.12	Chhatarpur, Panna, Rewa, Satna, Sidhi, Singrauli, Shahdol,Tikamgarh, Umaria	5.76	150-180	-20 to -26
V. Nimar Valley	5.3	Black soils	64.03	Alirajpur, Barwani, Burhanpur, Jhabua, Khandwa, Khargone	3.10	120-150	-35 to -49
VI. Satpura Plateau	10.2	Black soils	53.04	Betul, Chhindwara	2.21	150-180	-18 to -22
VII. Wainganga	10.4	Red,Yellow& Black	55.00	Balaghat,Dindori, Mandla,Seoni, Katni, Jabalpur, Anupur	3.99	180-210	-02 to +17
VIII. Chhattisgarh Plains	11.1	Red & Yellow, Mixed Red & Black	27.32	Bilaspur, Durg, Dharamtari, Raipur, Jangir-Champa, KorbaKawarda, Mahasamund, Rajnanadangaon,	6.21	150-210	-04 to +13
IX. Chhattisgarh Hills	12.1	Red & Lateritic	48.63	Bijapur, Bastar, Kanker, Dantewada, Surguja, Koriya, Raigarh, Jashpur, Narayanpur,	7.54	180-210	-06 to +14

Units for Area, (Mha);

Length of growth period(LGP) - Days; Moisture Index(MI) = (Precipitation- PET)/ PET taken from Vijayshankar (2005)

Shallow soils depth < 75 cm in (%) of arable lands ; NBSS&LUP, Nagpur in seedling emergence and crop establishment during the *Rabi* season. In Chhattisgarh region, soils primarily belong to Alfisol and Inceptisol. In the mid plains of CG, Vertisols are also found in pockets. Red soils are derived from granite, gneiss, schists, sandstone and shale and are laid out in gently undulating geomorphic surfaces. Red Bhata soils occur on the ridge tops, following down the slope are the yellow Matasi, yellowish brown Dorsa and the black (Kanhar) soils in the valley toposequences. Whereas Bhata and Matasi red soils are shallow in depth, the other two (Dorsa and Kanhar) are deep soils used primarily for rice or double cropping of rice-wheat system, respectively. Red soils have variable soil depth but generally have low water storage due to low organic matter and clay contents.

Black soils also vary in their depths. In India, shallow (< 22.5 cm), and medium-black (22.5- 70 cm) Vertisols have been reported to occupy 39.2 and 10.3 Mha respectively [12]. Deep Vertisols (70-150 cm) and associated vertic-intergrades occupy about 26.9 Mha [5]. Recently NBSS & LUP [13] has estimated the total acreage of shallow soils (<75cm depth) in MP and CG at 12.14 Mha and 6.4Mha, respectively and their distribution is mapped in different districts (fig.1). The acreage of medium to deep back soils (> 70 cm) in MP and CG are 17.2 and 6.9 Mha respectively. Data presented in the map (fig. 1) brings out that medium to deep back soils (> 75 cm) are generally found in the north of Narmada River. On the other hand, shallow soils predominate in the Nimar and Satpura Plateau (around 57-58%) in the south of Narmada in the Wainganga and CG Hills regions where shallow soils are close to 50 percent. It is also pointed out that acreage of deep soils is more in CG Plains than in CG hills and the Bastar Plateau (Table 1; Fig.1, 2).

Black soils are characterized by presence of high amounts of smectitic clay. Swell-shrink smectitic clay black soils becoming very sticky when wet and extremely hard to develop wide and deep cracks upon drying. Black soils inherently have low infiltration rates due to finer texture and swelling type clays. Bulk density of black soils change very swiftly with soil moisture content which adversely affect planting operations during rainy season. Although shrink swell smectitic clayey black soils enable them to have high water holding capacity but the coarser and shallower depths of black soils generally limit their capacity to retain more moisture in the soil profile for crop use.

In the SAT region, rainfall is generally more than evapotranspiration and soil moisture storage. High intensity rains very often result in runoff, soil erosion and some degradation of black soils. *This description would suggest that any effort aimed at improving the productivity of black soils must aim at 'closing the rainy season window' with a crop cover before the actual on-set of monsoons such as to reduce runoff and soil erosion*. Thus, it would appear that reversal of degradation processes from bare soils during rainy season is a pre-requisite for addressing concerns of *Rabi* Fallows and to enhance total system productivity in vertisols and other associated soils.

Tillage effects in red and black soils are short-lived due to structural instability [14-16]. Tillage creates a cycle of declines in which tillage increases the need for another tillage operation to maintain infiltration capacity [17-18]. Residue incorporation improved the productivity of crops in red soils [19] and rice-wheat in black soils [16, 20]. In Central India where erosion through run off rain water is the major agent of soil degradation and fertility decline, the maximum benefit of residues is likely to be when residues are retained on the soil surface in the tropics [17]. It must also be mentioned here that aquifer formations in plateau region, is by and large restricted to rocky formations wherein natural rate of replenishment of ground water is quite low. Unfortunately, these are also areas (e.g. Malwa Plateau) where ground water development has already reached unsustainable levels [11,21].

Extent of Kharif and Rabi Fallows and the Prominent Fallow-Cropping Systems

The acreage of total fallow lands in India have been reported to fluctuate between 25.6 and 26.2 million hectares (Mha) over the last few decades [22-24]. Using remote sensing techniques the acreage of rice fallows (*Rabi* fallows) in India were estimated close to 11.7 Mha [8,25]. They indicated that *Rabi*/ Rice Fallows were due to soil moisture stress at sowing time or during the winter crop season. Based on these studies, we deduce that nearly 14.5 Mha (26.2-11.7) area remains fallow during the south-west monsoons in *Kharif* season in India. Nageswara Rao et

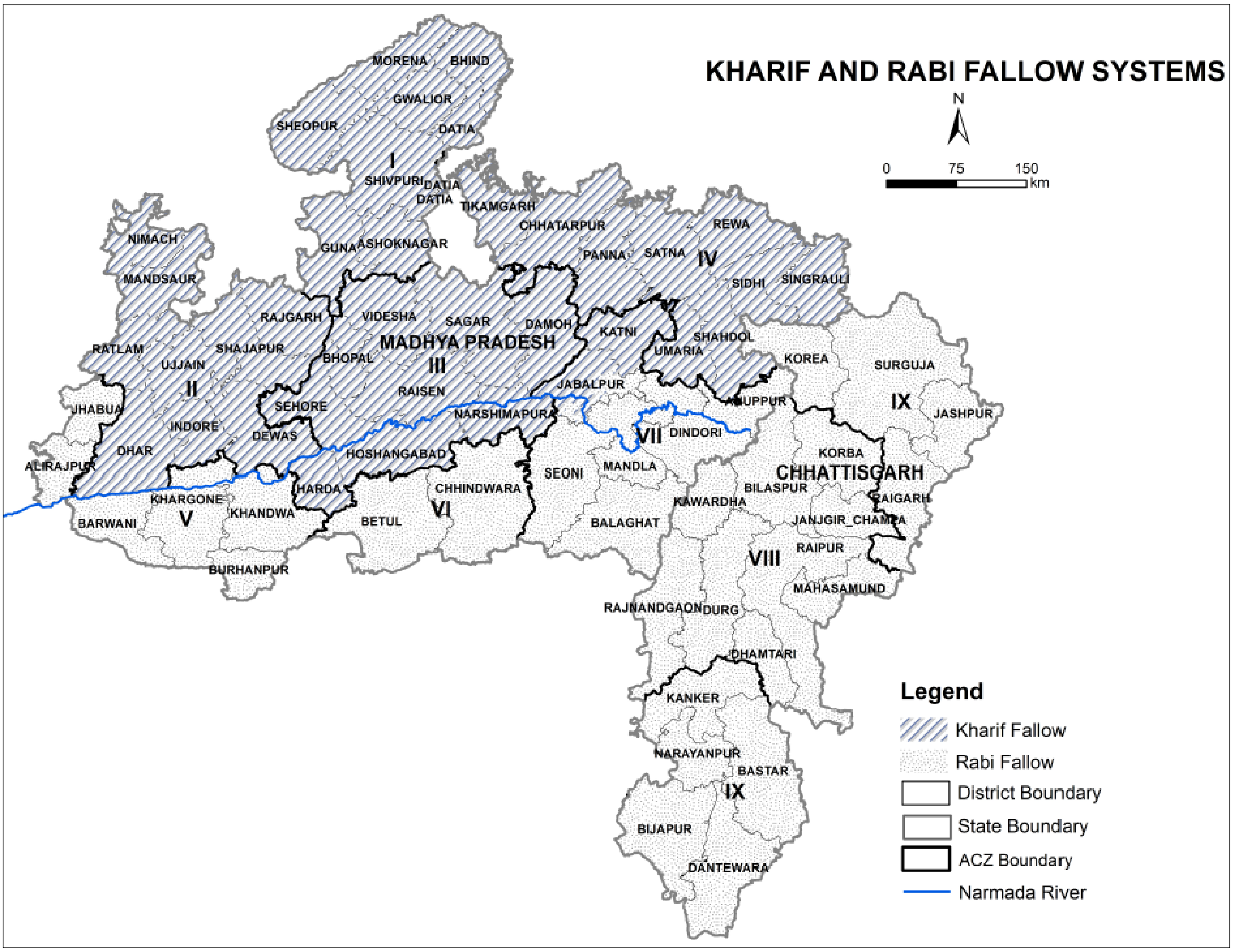

Figure 2. Domains of predominantly Kharif or Rabi fallow systems in Madhya Pradesh and Chhattisgarh states in Central India plateau .

al. [26] indicated that *Kharif* fallows cover about 14.8Mha in India.

In the central highland states of MP and CG, the total acreages of *Kharif* fallows were found to vary between 1.38 Mha [6] and 1.99Mha [7]. *Rabi* Fallow area in MP and CG has earlier been reported at 4.38 Mha [9] and 5.51Mha [8]. Earlier reports suggest that 80 percent of *Kharif* Fallows of the whole country are found in the Vertisols region (14.5*0.8= 11.6Mha) [27-29]. Thus, it appears that nearly 17.2% (1.99/11.6) of the black soils that remain fallow are confined to central plateau of MP alone in the country. The rest of the *Kharif* fallows can be found in other SAT regions of the country.

Decision Matrix for Land Fallowing

Farmers generally pursue a complex decision matrix for seasonal land fallowing. Krishnamoorthy [30] related land fallowing in black soils of the Central Plateau region to rainfall-soil depth-topography matrix. We have added to this matrix, a water supply filter (through canal and ground water development) because irrigation provision strongly impacts crop production, cropping system diversification and dynamics of fallow lands. Matrix filters as indicated in table (2) together with resource endowment of the farmers determine the land fallow systems. Shallow and medium soils generally occupy upland landscape positions. In shallow and medium soils, farmers prefer to take a rainy season crop in both low and high rainfall areas (Table 2) and keep fields fallow in *Rabi* (Post-rainy season) if there is no provision for irrigation water supplies. *Rabi* Fallows are

Table 2. Geographic settings of Kharif and Rabi season fallows in Central Plains of India, Madhya Pradesh.

Soils	Rainfall (mm/yr)	Landscapes	Irrigation Provisions	Fallowing Season	
				Kharif	Rabi
Shallow soils	Low rainfall 800- 1100	Uplands	Yes	X	X
			No	X	√Yes£
Shallow soils	High Rainfall >1100	Uplands#	No	X	√Yes£
Deep soils	Low Rainfall	Valleys	No	√Yes£	X
Deep soils	High Rainfall >1100	Lowlands / Valleys	Yes	X/ √Yes¶	X
			No	√Yes¶	√Yes£

Uplands in high rainfall areas generally lack canal water provisions and have poor aquifer formations for tube-well operations.
£ Late planting ends-up in terminal droughts and lower yields. Farmers accumulate rain water for success of winter season crops.
As a risk management strategy, farmers keep fields fallow during kharif season.
¶Farmers unable to plant during rainy season in sub-humid regions due to drainage congestion and agronomic fatigue.
Some farmers practice rice transplanting during rainy season and irrigate through canal/ tube-wells.

found in the high rainfall moist sub-humid domain comprising eastern districts of MP in Wainganga and the Hills and Plains of Chhattisgarh. In the humid and sub-humid Central Peninsular upland regions having shallow soils, tribal farmers grow drought tolerant rainy season crops such as ragi (*finger millet or Eleusine coracana*), kodo (*Paspalum scrobiculatum*) or kutki (*Panicum sumatrense*), and Niger etc during *Kharif* season and practice *Rabi* fallows. This is because of the limited moisture storage capacity of shallow soils preclude growing a second post-rainy season crop unless there is a provision for irrigation water.

Kharif Fallows predominantly are found in the semi-arid domain comprising the Grid zone having alluvial soils, the Baghelkhand, Satpura and Malwa plateaus and Nimar valley (north of Narmada River). In low rainfall areas of deep Vertisols, farmers frequently accumulate soil moisture during monsoon season for the success of a post-rainy season crop thereby avoiding the threat of mid-rainy season droughts. In many high rainfall areas having deep black soils, farmers are often forced to practice rainy season-*Kharif* fallows because of their inability to timely plant a crop before on-set of the monsoon season. Black soils offer formidable difficulty for tillage operations when wet or dry. *Rabi* fallows are common to deep black and deep red soils in tribal dominated areas due to lack of irrigation infrastructure. Total acreage of fallow lands during *Kharif* and *Rabi* seasons in MP and CG have been estimated at 1.98 and 5.51 Mha respectively. Thus, MP and CG together contribute nearly one-third (7.5/25.6= 29.3%) of the total fallow lands in the country.

Data presented in table (3) indicate that irrigation cover is unequal between different regions; minimum in tribal dominated areas such as in CG Hill zone (8.5 %), Nimar Valley (22%), Satpura plateau (30%) and Wainganga (28%). Maximum irrigation cover has been provided to Grid Zone (65.1%), followed by Vindhyan plateau (60.9%). In MP with irrigation development of 8.55 Mha (upto 2013-14), canal water is made available primarily for growing *Rabi* season crops and to provide life-saving irrigation to rice in *Kharif* season in high rainfall regions of the state. This strategy has significantly improved the cropping intensity in MP.

Table 3. Kharif and Rabi Fallow systems practiced by farmers in different ACZ of Central Plateau of Madhya Pradesh and Chhattisgarh.

ACZ	AESR	Kharif Fallow system¶	Kharif Fallow Area(ha)¥	Rabi Fallow system¶	Rabi Fallow Area (ha)ϕ	Irrigation cover (%)	GW Share (%GIA)	Net sown Area, Mha
Grid zone	4.4	Fallow-Wheat/ Mustard/Gram	245761	Minor systems£	15299	65.1	53	2.231
Malwa Plateau	5.2	Fallow-wheat/ Gram	153834	Soybean/ Cotton- Fallow	6476	50.0	95	3.391
Vindhyan Plateau	10.1	Fallow-wheat/ Gram	942442	Soybean- Fallow	45609	60.9	56	3.055
Baghelkhand	10.3	Fellow- wheat gram	392869	Soybean- Fallow	91745	29.5	79	2.491
NimarValley	5.3	Minor	45791	Maize/Cotton/ Soybean- Fallow	151642	22.0	76	1.400
Satpura Plateau	10.2	Minor	78972	Kodokutki/ Maize-Fallow Soybean/ Sorghum-Fallow	289256	30.0	89	0.933
Wainganga	10.4	Fallow -Wheat	132020	Rice/ Kodokutki-Fallow	800891	28.0	34	1.684
Chhattisgarh Plains	11.1	Minor	ND	Rice/ Kodokutki-Fallow,	2535527	38.6	15	2.847
Chhattisgarh Hills	12.1	Minor		Rice/ Kodokutki-Fallow	1576072	8.5	42	1.444
Total			1991689		5512517			19.457

GW refers to share of ground water in net irrigated area in percentage,

£ - Refers nondescript cropping systems having small area under them

¶ Major kharif and Rabi Fallow systems as observed by Yadav and Rao (2001)

¥ Acreage of Kharif fallows as reported by Dwivedi et al. 2002.

ϕ Acreage of Rabi fallows as reported by Gumma et al., 2016.

A low cropping intensity of 121.8% in CG suggest that canal water supplies are primarily used in rice season and only a small portion of it is available for growing *Rabi* season crops. The share of ground water in gross irrigated area in AESRs (Malwa, Wainganga, Baghelkhand and Satpura plateau) is more than 75 % indicating excessive mining of the aquifers particularly in the rocky formations (Table 3). With the exception of moist sub-humid region, growth of tube-well irrigation is increasingly dominating the quality of irrigation in semi-arid regions of MP but still low in CG state. Impressive growth of tube-well irrigation has increased the cropping intensity which now stands at 151% in MP compared to 122% in CG.

Seeding Practices Contribute to Agronomic Fatigue and Seasonal Fallows

In the SAT region of Central India, having finer textured black soils, preparatory tillage is performed in the residual soil moisture of harvested winter crops (February end - early April) to facilitate preparation of seed-beds for *Kharif* crops [31-34]. Traditionally, *Kharif* season planting is linked to on-set of monsoon rains. *Kharif* planting season sets-in when an accumulated rainfall of 70-75 mm is received. Historically, this date usually falls around mid-June in the central plateau highlands. Crops are seeded at a soil depth of 5-7cm, pulverized immediately before or after soaking of the first few pre-monsoon showers [35]. This seed depth is considered safe for retaining seed viability in pre-monsoon showers. Most crops, are planted on flat beds. In black soils, farmers plant soybean in ridge-furrow system, in mid-July to avoid high temperatures and ensure good germination during rainy season [36,37]. Poor crop stands is a serious issue in rainy season crop production. This is because above field capacity, small changes in soil water content of clayey black soils impact low-tension oxygen diffusion processes more than the water content itself [38]. Thus, black soils easily develop anoxic environment to adversely affect seed germination in the rainy season. For this reason, farmers have to complete sowing between periods of pre-monsoon rains and actual on-set of monsoon season. Resource poor farmers have to be content with rainy season bare fallows due to energy problems and scarcity of resources. Dry sowing in black soils is usually done immediately before or after the first few pre-monsoon showers. Krantz [32] reported that 'dry sowing' on deep Vertisols is successful if the early monsoon rains are 'dependable'. Early dry seeding in *Kharif* season was considered a significant innovation to achieve timely crop cover and do double cropping in high rainfall regions having black soils.

Chhattisgarh (CG) farmers traditionally grow long/medium duration rice varieties by 'Biasi or Bushening' system (seeding rice by direct broadcasting in dry or wet soils and control rice and weed populations by planking in ponded water conditions after a month or so). Many CG farmers do not take up *Rabi* season cropping due to their poor resource endowments, except those located close to canals and tanks. Farmers having irrigation provisions practice relay cropping of lentil, lathyrus and linseed in standing rice crops seeded after puddling. In post-rice season, farmer practice *Nagari* system (plough and harrowing) – because puddled red soils become very hard and develop crusts on drying. Farmers have to plough rice fields for seeding of *Rabi* crops and also knock down rice ratoons which sprout in mild winters. Ploughing results in loss of residual soil moisture of rainy season besides late planting of *Rabi* crops. Late planting of *Rabi* crops in short winter season reduces their productivity. In order to avoid *Rabi* fallows, MP farmers practiced '*Haveli*'*and Utera*' system. In Haveli system, rain water is stored in bunded fields during monsoon season. The stored water is drained off for seeding of *Rabi* crops. In *Utera* system, *Lathyrus* and linseed are relay seeded by broadcasting in standing mature rice crop when there is sufficient moisture in surface soils.

From the foregoing discussion it emerges that principal barriers to rainy season cropping in black soils, include (a) difficulties in land preparation and short time window available for sowing of *Kharif* season crops (termed as 'wet fallowing' due to difficulties in tilling wet black soils); (b) undependable on-set of rains and uncertainty of in-season rains (referred to as 'dry fallowing' due to soil moisture stresses); (c) threat of flooding and drainage congestion due to heavy rains in low-lying areas; (d) difficulties in management of rainy season weeds in absence of viable technologies and availability of rain-free period for herbicide sprays, and (e) rainy season crop may adversely affect productivity of *Rabi* season crops through soil moisture depletion.

Rabi crops are often perceived as more secure than the *Kharif* crops.

Results of several studies [39] bring out that land kept fallow during rainy season have more stored soil moisture at planting than the continuously cropped systems. *Rabi* fallowing is generally practiced in areas having (i) shallow soils not able to store sufficient moisture to support a full season winter crop, (ii) agronomic fatigue resulting in significant losses in stored soil moisture due to excessive tillage, and (iii) non-availability of water for supplemental irrigation. Virmani et al. [33] have indicated that Indian Vertisols can store and supply 41% of the total rainfall to post-rainy season crop. Sahoo et al. [40] reported that preparatory tillage for planting result in loss of 30-40% of total stored soil moisture by seeding time in mid-November from alfisols and vertisols. According to them, *Rabi* fallowing is practiced on about 43 % Alfisols and 39% of Inceptisol in eastern India including Chhattisgarh.

Opportunities to Address Agronomic Fatigue

Management options to address two distinct land fallowing domains basically relate to (i) efficient management and use of rain water during the *Kharif* season, and (ii) *in situ* soil moisture storage, conservation and efficient use of soil moisture for *Rabi* crops after *Kharif* harvest. Dry seeding in no-till conditions, in presence of residues, drastically reduces the turn-around time and also the loss of residual soil moisture through evaporation before planting of *Rabi* crops. Residue mulch enhances the availability of soil moisture; moderates soil temperature and reduce weed pressure [41]. Provision of supplementary irrigation help reduce climatic aberrations during *Kharif* season and also facilitate sowing of the *Rabi* crops in deficit surface moisture situations. Agronomic techniques that focus on 'manageable part of climatic variability' can significantly reduce the acreages of 'fallow lands' and improve the adaptive capacity of rainfed agriculture to climate changes. Quality of irrigation services (timely availability of supplemental irrigation) can also help in drastically reducing the acreage of fallow lands and unlock their production potentials in the two distinct resource management domains (RMDs- *Rabi* and *Kharif* Fallow lands) in Central India.

It must be mentioned here that many farmers consider dry seeding before the onset of monsoons as a risky proposition in conventionally tilled areas with erratic early-season rainfall [32]. SAT farmers are reluctant practitioners of dry seeding for fear of:

- Seed loss through termites and picking by birds,
- Loss of seed viability due to extended exposure to high summer temperatures ranging between 38 and 47°C for about a month or so,
- Mortality of young seedlings or loss of seed viability in alternate wetting-drying seed cycles during pre-monsoon period, and
- Surface sealing and crusting in bare red soils pose serious problem for seedling emergence and crop stand. Reseeding was an inevitable consequence at times.

In recent years, Borlaug Institute for Sustainable Agriculture (BISA) [42] developed a *pre-monsoon rainwater seed priming (PMP) and dried-back dry seeding (DS) technology (PMP-DS)* for establishment of *Kharif* crops. Extensive field trials have shown that PMP-DS technology hold promise for making *Kharif* season planting independent of monsoons, allow efficient rain water use and reduce soil erosion from black soils. In PMP-DS technology, seed placed near the surface soil layers undergo several cycles of water imbibition and drying-backs based on the amount of precipitation and the intervening periods between rainfall events. Seed must pass through all three priming stages (imbibition stage-1, activation stage-2, growth stage-3) to trigger a germination event. Prior to radicle emergence in stage-3, seed is desiccation tolerant and does not lose its viability even if it loses seed moisture [43-45]. Normally, seed priming is known to advance germination, but PMP-DS processes extend the seeding period of *Kharif* season crops and also help seed escape loss in seed viability.

Before pre-monsoon summers, both surface soil and the residue covers are dry. Pre-monsoon light rains are partly soaked by mulch and rest by surface soil. A limited rainwater supply, intermittent bright sunshine and high temperatures in pre-monsoon season hardly allows a build-up in seed moisture to levels necessary to trigger germination event. Water soaked seed soon get dehydrated and remain dormant in the soil for variable periods. Seed hydration-dehydration cycle can operate several times under natural field conditions until a good rainfall event or an *external water supply through sprinklers allow protrusion of the radicle*, seed germination and enable crop establishment. Surface mulch reduces surface crusting and enables seed to germinate with a good pre-monsoon rain. Dry seeding on no-till platforms makes *Kharif* planting more independent of monsoon forecasts in moist semi- arid/ sub-humid regions. Also, PMP-DS technology avoids the need for dry primary tillage for both raised-bed and the flat surface planting systems. The technology differs from the direct dry seeding technology in several ways, as explained through a comparison presented in Table (4).

PMP-DS follows the basic tenets of conservation agriculture and is an iteratively guided and fine-tuned crop production technology. Identification and availability of pre-and post-emergence herbicide molecules has opened new windows for practicing dry seeding in conservation agriculture [46, 47]. Conservation agriculture has been shown to increase production and improve soil health, make ecosystems more resilient and reduce their vulnerability to climate change [1,47].

On-Farm Technology for Rainfed Farming

In rainfed agriculture, risks of crop failure vitally depends on effective *in-situ* soil moisture conservation and availability and use of crop cultivars adapted to prevailing agro-climatic conditions. Over the last few decades, most of research efforts were focused on soil conservation engineering and plant breeding. Soil and water conservation (SWC) technology as applied in India include basically engineering works (bunding, terracing, drainage channels, gully stabilization, runoff storage tanks, percolation tanks) and some vegetative measures. Concerning conservation of moisture for crop use, two thrusts need to be pursued: (a) one aimed at increasing moisture storage within soil profile and reducing evaporation losses (by surface mulching) and the other (b) aimed at runoff collection, storage for 'life saving irrigation' in the lean period. Much of the initial work focused on propagating the concept of life saving irrigation. It is now widely recognized that *in-situ* moisture conservation is far more effective and with proper guidance can be accomplished by farmers themselves. Tillage along contour is a most effective means of reducing runoff and soil erosion but when combined with minimum tillage and residue covers can prove as the best practice on mild slopes [48]. Planting suitable grasses along the selected contours can help establish contour lines and eliminates the perceived need for land leveling and bunding in rainfed agriculture. With adequate soil moisture supply for the plants, interactions of fertilizers and improved crop management practices can result in significant yield gains up 50% in rainfed pulses and oilseeds crops [49].

In medium and high rainfall regions, some runoff is inevitable particularly during the short duration high intensity rainfall events. If possible such run-off water can be stored in dammed-up gullies, nalas or natural depressions to help recharge ground water or to provide life-saving irrigation. It must also be mentioned that it is a good strategy to keep all natural drainage lines clean and open to allow unimpeded safe rapid evacuation of excess runoff water. As a good practice, drainage lines should be stabilized with suitable vegetative barriers to prevent soil erosion and gully formation.

Timely crop establishment is crucial for improving and stabilizing the yields in rainfed agriculture. Results of a replicated large dry seeding field trial conducted on Jabalpur deep black soils under sub-humid rainfed and irrigated conditions are presented in figure (3). Data presented bring out that conventionally tilled-dry seeded rice without surface mulch had very low grain yields. Retention of surface mulch significantly improved crop stand for all the tillage and crop establishment (TCE) methods in rainfed situations. Yield of ZT-DSR rice crop in flats and on wide-beds were higher compared to the tilled black soils. Results also indicated that provision of supplemental water supplies (rains + irrigation), seems to mask the impact of bad agronomy (absence of surface mulch and excessive tillage practiced) on crop stand and yields. Mohanty et al. [50] have earlier reported that its futile to practice puddling for rice and dry tillage for wheat in rice-wheat system on finer textured Vertisols, already having low saturated hydraulic conductivity. Hobbs et al. [51] have also indicated that puddling and

Table 4. Attributes that differentiate dry seeding with PMP-DS technology

Dry seeding technology	Dry seeding with PMP-DS in CA platforms
Seeding time is generally a week before the historical onset dates of monsoons. Leaves little time for completion of tillage and seeding operations.	Dry seeding is carried out any time between April –June. This enable farmers to seed more area and reduce acreage of rainy season fallows.
Seed placement depth is 5-7 cm below surface, soils need to be excessively tilled and pulverized for seed placement.	Seeding is within surface-2cm in permanent no-till conditions on flats or raised beds. Tillage is not required.
Preparatory tillage incorporates residues, leaves a bare soil surface. Soil crusting during rains often leads to poor crop stand in rainfed Alfisols.	Soil surface is always covered with crop residues. Avoid dry seeding in no-till conditions without a crop residue cover.
Tillage does not leave any surface mulch for dry seeding in broad bed and furrow (BBF) system	Presence of residue mulch is critical for success of PMP-DS in flat and raised bed- furrow systems.
Dry seeding in BBF is practiced on wide-raised beds (90 cm or more). Beds are dismantled every season.	No-till dry seeding with mulching can be practiced in any land configurations that facilitates control traffic.
BBF is practiced on the sloping black soils to provide drainage for the established crops. If farmers are not able to establish the crops before monsoons, tilled bare fields make black soils highly prone to soil erosion during rains.	PMP-DS technology is practiced in no-till fields with residues on the surface. Mulching reduces crusting and soil erosion risks to minimum before the establishment of a crop cover and thereafter.
No natural priming of seed with rain water/ water.	PMP-DS allow seed to experience several natural cycles of hydration-dehydration.

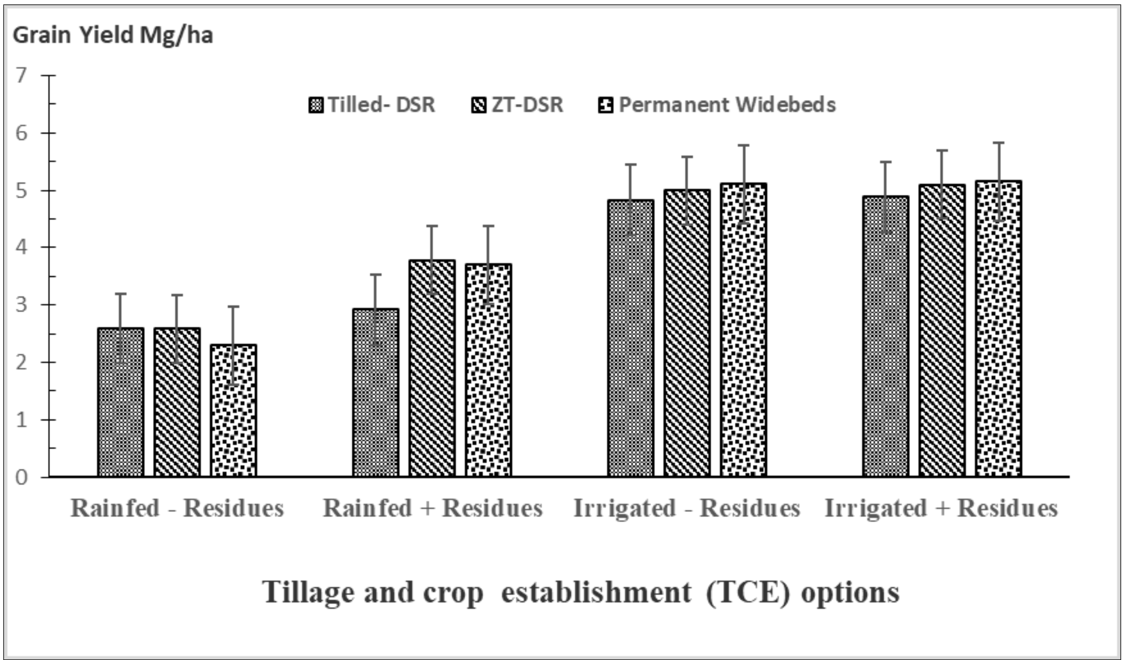

Figure 3. Effect of TCE options, residue retention and irrigation provisions (+/-) on rice productivity following the PMP-DS technology.

preparatory tillage invariably reduced the yield of the following wheat crop. Thus, *Kharif* crops established with pre-monsoon rains, ensures vigorous seedlings, efficient use of rainwater, provide soil cover against erosive forces of rain water and facilitate entry of water into the soil profile.

In the SAT region, surface cover and tillage methods seem to play a very vital role in establishment of the crops under monsoonal climates. Tillage is known to speed-up loss of soil moisture from surface soils and also shift the receding soil moisture zone into deeper soil layers below 15cm [52] . Surface mulching can slow down the loss of soil water [53] and hence the recession of soil moisture front. This has an important bearing on the depth of seed placement and soil overburden on seed. In central India, *Rabi* crops must be sown immediately after harvest of *Kharif* crops, and seeding depth should allow maximum use of moisture from receding soil moisture profiles. Else we need to develop a new design for openers and seeding boots in planters to be able to reduce soil load over the seed for good germination and speedy seedling emergence.

Conclusions

Kharif and *Rabi* Fallows are found in distinctly different resource management domains (RMD)in the Central Plateau region of India. Delineation of the two resource domains help us understand the causal factors leading to fallowing and identify the management options to bring the two categories of lands under cultivation. *Kharif* and *Rabi* fallows are a consequence of distinctly different soil moisture conditions which help us identify the crop-soil-water management practices (CSWMP) for possible double cropping. In the SAT region, surface soil covers and no-till methods apparently play a very critical role in crop establishment and stabilization of the yields of rainfed crops in black and other associated soils.

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