Technical Bulletin
2012 No. 16

Rice in Odisha

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The responsibility for this publication rests with the International Rice Research Institute.

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Suggested Citation:

Das SR. 2012. Rice in Odisha. IRRI Technical Bulletin No. 16. Los Baños (Philippines): International Rice Research Institute. 31 p.

ISSN 0074-7807

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Rice in Odisha

Rice is a unique creation of crop plant domestication. It is unique in having cultivars of maturity duration varying from less then 80 days to more than 180 days and showing adaptability to a wide range of land types and water regimes, including conditions of water stagnation where no other crop could possibly be grown. Domestication of rice might have started before 3000 B.C. and possibly at a number of locations in South and Southeast Asia. Jeypore tract in South Odisha has been identified as a putative secondary center of origin of cultivated rice (Ramiah and Ghose 1951, Ramiha and Rao 1953). The regions comprising western Odisha, Jharkhand, and Chhattisgarh are recognized as the center of origin of only aus ecotypes of rice (Sharma et al 2000).

In Odisha, rice is synonymous with food. Agriculture in Odisha to a considerable extent means growing rice. Age-old social customs and festivals in Odisha have strong relevance to different phases of rice cultivation: *Akhyatrutiya* in May-June marks the seeding of rice, *Rajasankranti* in mid-June marks the completion of sowing, *Garbhanasankranti* in October symbolizes the reproductive phase of rice, while *Nuakhaee* and *Laxmipuja* coincide with the harvesting of upland and lowland rice, respectively. *Makarsankranti* in mid-January is celebrated as *Chaita Parab* by the tribal people as by this time rice is threshed and brought to the granary.

Rice production in Odisha: an overview

Rice covers about 69% of the cultivated area and is the major crop, covering about 63% of the total area under food grains. It is the staple food of almost the entire population of Odisha; therefore, the state economy is directly linked with improvements in production and productivity of rice in the state.

In the 1950s Odisha was a leading rice-producing state in the country and it used to supply a sizable amount of rice grain to the central pool of food stocks. But, the situation was strongly reversed in the post-high-yielding variety (HYV) period. However, during the last 35 years, the state's rice area has stagnated around 4 million hectares, about 10% of the total rice area of the country. Odisha's share in the country's rice production was more than 11% in the pre-HYV period, which gradually declined to 7.9% in 2008-09. Rice in Odisha is now grown on an area of 4.4 million hectares, which accounts for 91% of the area under cereals and contributes about 94% of total cereal production in the state (Table 1).

In fact, the introduction of high-yielding varieties did not have any perceptible impact on rice production and productivity for over two decades: per hectare yield fluctuated between 800 and 977 kg. Yield, however, showed a substantial upward trend from 1986 onward; nonetheless, productivity continued to remain much below the national average (Table 2 and Fig. 1).

Contribution to GDP

Agriculture is the mainstay of the state economy and the principal substance of the life of the people. Odisha is an agrarian state with the agricultural and animal husbandry sector contributing 21.1% of net state domestic product (NSDP) in 2007-08 at 1999-2000 prices and providing employment (direct or indirect) to 70% of its population as per the 2001 census. The share of gross state domestic product (GSDP) from agriculture during 2007-08 at constant prices 1993-94 and at constant prices 1999-2000 was 19.5%. Therefore, agriculture plays an important role in the economy and livelihood of Odisha people (Odisha Agricultural Statistics 2008-09).

Geography of the state

Odisha is located in the subtropical belt in eastern India from 17°31′ to 20°31′N latitude and 81°31′ to 87°30′E longitude. It is bounded by Jharkhand to the north, Chhattisgarh to the west, Andhra Pradesh to the south, West Bengal to the northeast,

Table 1. Odisha's share in India's rice production in the pre- and post-HYV periods.

Period	Area (million ha)		Production (million t)		% of contribution	
	India	Odisha	India	Odisha	Area	Production
1960-65	35.36	4.22	35.95	3.97	11.9	11.0
1970-75	37.64	4.56	41.63	3.90	12.1	9.4
2009-10	41.34	4.41	87.56	6.94	10.7	7.9
% of increase	16.91	4.51	143.56	74.81		

Table 2. Area, production, and productivity of rice in Odisha.

Period	State average			National average
	Area (million ha)	Production (million t)	Productivity (kg/ha)	Productivity (kg/ha)
1970-74	4.56	3.90	855	1,106
1975-79	4.39	4.03	914	1,207
1980-84	4.21	4.13	977	1,350
1985-89	4.30	5.07	1,173	1,584
1990-94	4.48	6.12	1,364	1,807
1995-96	4.53	6.23	1,375	1,797
1996-97	4.47	4.44	993	1,882
1997-98	4.50	6.20	1,380	1,900
1998-99	4.45	5.39	1,212	1,928
1999-00	4.60	5.19	1,127	1,986
2000-01	4.43	4.61	1,041	1,901
2001-02	4.50	7.15	1,589	2,078
2002-03	4.27	3.24	759	1,744
2003-04	4.50	6.73	1,496	2,077
2004-05	4.49	6.54	1,455	1,984
2005-06	4.48	6.96	1,554	2,102
2006-07	4.45	6.92	1,557	2,131
2007-08	4.45	7.65	1,720	2,202
2008-09	4.45	6.92	1,553	2,186
2009-10	4.41	6.94	1,572	2,118

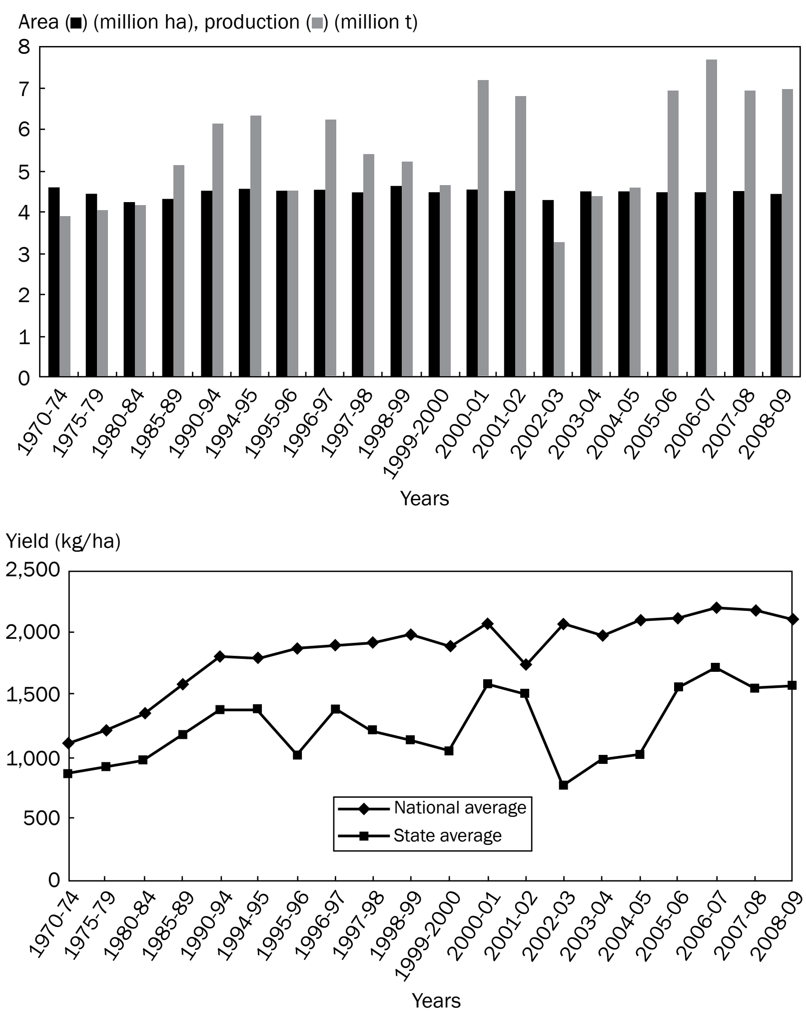

Fig. 1. Area, production, and productivity of rice in Odisha.

and the Bay of Bengal to the southeast. The mountain range of Eastern Ghats runs from northeast to southwest in the middle of the state. This mountain range separates the eastern part of the state, which is a coastal belt with 482 km of coastline, and the western part, which is an extensive plateau. The state has a geographical area of 15.57 million hectares. The state has been divided into four physiographic divisions: the Northern Plateau (25.5%), Central Table Land (24.1%), Eastern Ghat Region (29.2%), and Coastal Region (21.2%).

Climate

The state is located in the subtropical belt of India. The state broadly falls under hot and dry subhumid, warm and humid, hot and humid, and hot and moist subhumid regions and experiences four major seasons: winter (Dec-Feb), summer (Mar-May), rainy (Jun-Sep), and autumn (Oct-Nov). The monthly average minimum and maximum temperatures range between 14 °C in December to 38 °C in May. Whereas the mean maximum temperature is 32 °C in the coastal districts of the state, it sometimes goes up to 42° C in hilly areas. The location of the state, near the Bay of Bengal, moderates the temperature and adds humidity to its climate. The relative humidity of the state varies from 36% to 98%; the average bright sunshine hours range between 3.7 hours/day in July-August to 8.8 hours/day during March to May.

Soil types

Soils of Odisha are broadly divided into eight groups: Red Sandy and Red Loamy, Lateritic, Red and Yellow, Coastal Alluvial, Deltaic Alluvial, Black, Mixed Red and Black, and Brown Forest Soils. The soils are mostly red lateritic and acidic in nature.

Rainfall

The southwest monsoon enters the state during the second half of June and continues up to the first week of October. The annual normal rainfall of the state is 1,451.2 mm, with a unimodal distribution. More than 80% of the precipitation is received from mid-June to September. The rainfall pattern is highly unpredictable in timing, amount, and distribution and therefore the state suffers from either drought or flood. Odisha agriculture depends much on monsoon rains. The normal distribution of rainfall influences crop yield: failure of rain in drought years causes scarcity, while excess rainfall causes flood.

Agro-climatic zones

Depending on physical features, soil types, rainfall, etc., the state is divided into ten distinct agro-climatic zones with varied characteristics (Table 3 and Fig. 2). Rice is considered to be the major crop in all the agro-climatic zones of Odisha (Gangopadhayay 1991). However, the state is broadly divided into two zones, the Plateau Region and coastal alluvial plain (Fig. 3).

The Plateau Region

The Plateau Region contains about 85% of the geographical area, with predominantly red and yellow laterite and lateritic soils. The soils are highly leached, low in exchangeable bases and acidic, low in organic matter, and low in nitrogen, phosphorus, and potassium. Soil texture varies from sandy to sandy loam to loamy to clayey depending on the topography. In the higher reaches, soils are coarse textured and highly drought prone. The region has 2.75 million hectares of rice land constituting about 62% of the total rice area of the state. The region is differentiated into eight distinct agro-climatic zones. Total rice production in this region is estimated to be 4.23 million tons, with a productivity of 1,538 kg/ha.

The Coastal Region

This region contains about 15% of the geographical area of the state and it runs along the coastline having width varying from 24 km to 72 km from the sea coast. The soils are alluvial, both deltaic and coastal. The deltaic alluvial soils are generally fertile but low in N and P. The coastal alluvial soils within 10 km of the sea coast show high total soluble salts, mainly sodium chloride due to tidal inundation. The coastal belt has about 1.70 million hectares of rice land constituting about 38% of the total rice area. The rice land generally suffers from serious waterlogging problems and is flood prone. The region has two distinct agro-climatic zones. Total rice production in this region is estimated to be 2.68 million tons with a productivity of 1,577 kg/ha.

Rice ecosystems of the state

In Odisha, rice is grown under diverse ecosystems and a wide range of climatic conditions. The immense diversity in growth conditions makes classification and characterization of the rice environments a challenging task. But, classification of rice land on the basis of some dominant factors that influence rice productivity is essential to make variety development and formulation of a package of practices for crop management more problem oriented. This will improve communication with rice growers and among rice researchers (Mohanty et al 1995).

Rice is cultivated on an area of 4.45 million hectares, which can be classified into six different ecosystems: irrigated kharif (27.4%), rainfed upland (19.1%), medium land (12.4%), shallow lowland (22.5%), semideep (7.9%), deep (3.4%), and irrigated rabi (7.4%). The rice ecosystems in Odisha and the approximate land area under each appear in Table 4.

Farmers have their own system of classification of rice environments such as uplands, medium lands, and lowlands, primarily on the basis of land topography and water regime. The farmers identified varieties fairly well adapted to different classes of land situations and also developed appropriate cultural practices. Rice researchers nationally and internationally redefined the farmers' system of classification on the basis of water available to the rice crop and quantified water depth during the major part of the life cycle of the crop. Although a broad classification of rice ecosystems in Odisha has been mentioned, the district-wise kharif paddy coverage of the state during 2008-09 revealed that uplands, medium lands, and lowlands constituted 25.3%, 38.8%, and 35.9% of the rice area, respectively (Table 5).

Rice ecosystems and rice culture

Rice cultural types in different ecosystems and in different seasons are presented in Table 6. The tribal people, who in the

Table 3. The agro-climatic zones of Odisha.

Agroclimatic zone	Agricultural districts	Geographical area (000 ha)	Soil types	Irrigation sources	Climate	Rainfall (mm)	Gross cropped area (000 ha)	Cultivated area (000 ha)	Cropping intensity (%)	Major crops grown
Northwestern plateau	Sundergarh, Baneigarh, Panposh, and Kuchinda	1,291	Red, lateritic, red and yellow, red and black, brown forest	Pitamahal Hirakud	Hot and moist and subhumid	1,240	581	457	127.1	Rice, wheat, vegetables, black-gram, greengram, sesamum
North-central plateau	Baripada, Champua, Karanjia, Keonjhar, and Rairangpur	1,726	Red, lateritic, red and yellow, red and black	Baitarani	Hot and moist and subhumid	1,495	818	715	114.4	Rice, vegetables, maize, pulses, niger, mustard, groundnut, til
Northeastern coastal plain	Anandapur, Balasore, Bhadrak, Jajpur, and Keonjhar	884	Red and laterite, deltaic alluvium, coastal saline	New Mohan	Moist and moist subhumid	1,468	889	642	138.4	Rice, groundnut, grams, jute, mustard, vegetables
East and south-eastern coastal plain	Cuttack, Puri, Jagatsinghpur, Kendrapara, Berhampur, Banki, and Chhatrapur	1,685	Coastal saline, sandy, lateritic, alluvial, black and red	Rengali	Hot and humid	1,340	1,932	1,113	173.6	Rice, groundnut, grams, sesamum, and mustard
Northeastern Ghats	Aska, Boudh, Parlakhemundi, Gunpur, Khurda, Nayagarh, Phulbani, and Raygada	2,305	Red, lateritic, red and yellow, black, brown, and alluvial	Pilasalki	Hot and moist and subhumid	1,597	898	606	148.2	Rice, ragi, arhar, grams, maize, niger, and mustard
Eastern Ghats highland	Koraput and Nawarangapur	955	Red, red and yellow, red and black, and alluvial	Pottery Balimela	Warm and humid	1,522	505	400	126.3	Rice, ragi, maize, niger, small millets, turmeric, ginger, arhar, and castor
Southeastern Ghats	Jeypur and Malkangiri	659	Red, lateritic, and black	Badanala	Warm and humid	1,162	296	242	122.4	Rice, ragi, maize, niger, vegetables, sesamum, and horsegram
Western undulating	Bhawanipatna, Dharmagarh, Padmapur, Nawarangapur, and Khariar	1,259	Red, red and yellow, red and black, black and deltaic alluvium	Upper Kolab and Upper Indrabati	Warm and moist and subhumid	1,617	816	586	139.3	Rice, grams, sesamum, ragi, and minor millets
West-central table land	Sambalpur, Bargargh, Bolangir, and Sonpur	1,719	Red, lateritic, red and yellow and black	Hirakud	Hot and moist and subhumid	1,180	1,331	978	136.1	Rice, vegetables, gram, groundnut, and sesamum
Mid-central table land	Angul, Banki Dhenkanal, Kamakhya, Nagar, Jajpur, Sukinda, Athagarh	1,364	Red, lateritic, and black alluvial	–	Hot and dry and subhumid	1,421	734	508	144.5	Rice, vegetables, blackgram, green-gram, sesamum, arhar, groundnut, ragi, and mustard

Fig. 2. Agro-climatic zones of Odisha.

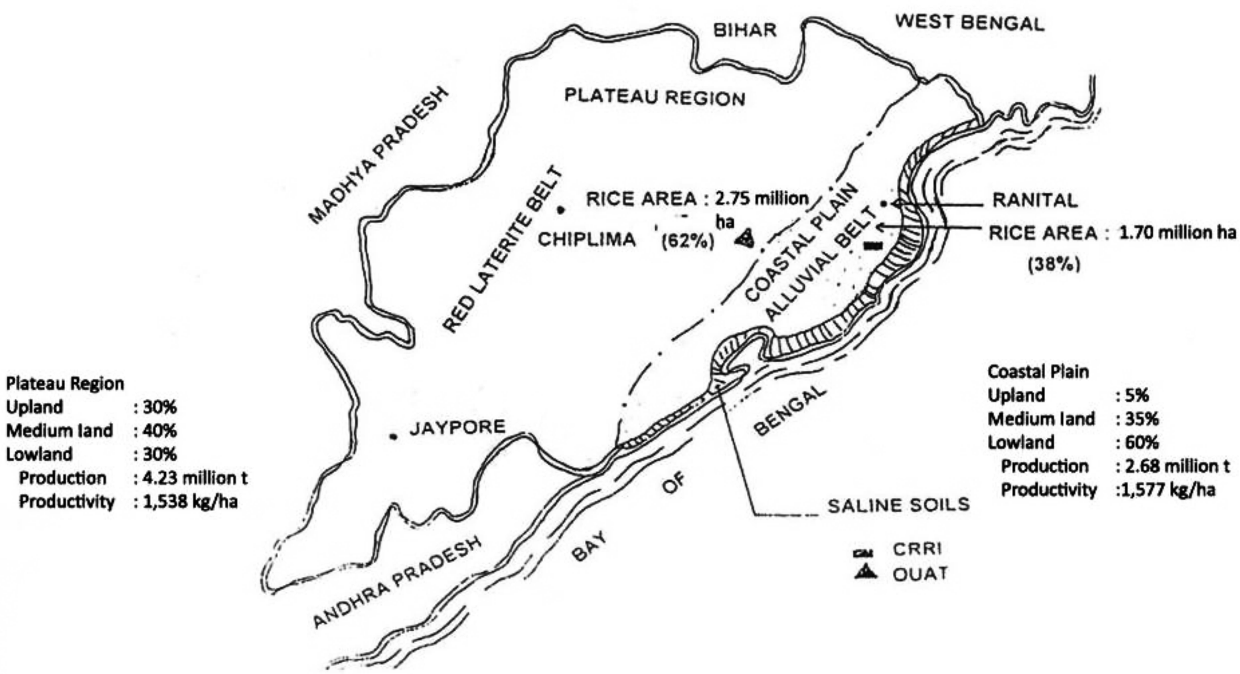

Fig. 3. Physiographic regions of Odisha.

Table 4. Rice ecosystems in Odisha.

	Ecosystems	Area under rice (million ha)		Major stress (physical)
I.	Rainfed	2.90	65%	
	Upland	0.85 (19.1%)		Drought
	Medium land	0.55 (12.4%)		Fairly stress free
	Lowland	1.50		
	Shallow water	1.00 (22.5%)		Waterlogging and flood
	Semideep water	0.35 (7.9%)		Waterlogging and flood
	Deep water	0.15 (3.4%)		Early drought, flood, and waterlogging
II	Irrigated	1.55	35%	
	Kharif (bunded) (upland, medium land, lowlands)	1.22 (27.4%)		Waterlogging; too much irrigation and rain water
	Rabi	0.33 (7.4%)		Low temperature at early seedling stage

Table 5. District-wise paddy coverage in different ecosystems in Odisha during kharif, 2008-09. Area in 000 hectares.

District	Total cultivated area	Kharif paddy coverage				% of total rice area
		High	Medium	Low	Total	
Balasore	250	8	96	107	211	5.12
Bhadrak	176	3	62	100	165	4.00
Bolangir	346	55	70	86	211	5.12
Sonepur	128	17	41	39	97	2.36
Cuttack	188	10	52	66	128	3.11
Jagatsinghpur	104	5	37	46	88	2.14
Jajpur	145	43	48	45	136	3.30
Kendrapara	152	23	66	49	138	3.35
Dhenkanal	186	24	46	40	110	2.67
Angul	216	21	44	33	98	2.38
Ganjam	406	65	109	102	276	6.70
Gajapati	76	10	14	12	36	0.88
Kalahandi	378	75	75	68	218	5.29
Nawapara	189	48	26	28	102	2.48
Keonjhar	298	66	100	39	205	4.97
Koraput	304	35	42	38	115	2.79
Malkangiri	142	38	31	24	93	2.26
Nawarangpur	186	89	39	29	157	3.81
Raygada	193	14	25	22	61	1.48
Mayurbhanj	437	88	125	126	339	8.22
Phulbani	128	22	20	11	53	1.29
Boudh	89	36	21	12	69	1.68
Puri	189	5	30	84	119	2.89
Khurda	129	27	42	46	115	2.79
Nayagarh	134	10	46	39	95	2.31
Sambalpur	194	34	61	36	131	3.18
Bargarh	349	78	90	76	244	5.92
Deogarh	67	13	21	11	45	1.10
Jharsuguda	88	14	25	13	52	1.26
Sundargarh	313	67	95	55	217	5.27
Total	6,180	1,043	1,599	1,482	4,124	100.00
% of different ecosystems		25.3	38.8	35.9	100.0	

ancient past domesticated rice in Odisha, first cultivated dryland rice on the tops and slopes of hills. The cultivation of wetland rice in the valleys and on the plains occurred later. The systems of rice cultivation and seeding/planting method vary with the ecosystem and rainfall pattern. The details of rice cultural types in different ecosystem are shown in Table 6.

Upland ecosystem. It covers an area of 0.7 million ha constituting 15.7% of the rice area and contributes 10.8% of total rice production (Table 7). Upland or autumn rice is photo-insensitive with maturity duration of 80–100 days. The crop is direct seeded in June after the onset of the monsoon and harvested in September.

Yield is about 1,000 kg/ha. Major constraints to rice yields in uplands are poor land preparation, severe weed competition, intermittent drought, and inadequate use of fertilizer. Upland soils in the plateau region are coarse textured, with poor water-holding capacity and inherent low fertility.

Short early-maturing and very early maturing high-yielding varieties such as Parijat, Pathara, Khandagiri, Ghanteswari, Sidhanta, Mandakini, and Udayagiri from OUAT; and Heera, Annada, Shatabdi, Kalinga-III, Vandana, Vanaprava Anjali, and Sahbhagi Dhan from CRRI have been recommended for uplands. But, these varieties in general are less tolerant of drought and are easily smothered by weed growth. In drought years, they even yield less than traditional tall varieties such as Kalakeri, Kulia, Dular, etc. These traditional rice varieties, despite their low yield potential, tolerate moisture stress and therefore are preferred by the farming community.

Medium land ecosystem. It covers about 40% of the total rice area and features the major rice crop of the plateau region. These lands are considered less problematic and more suitable for intensive cultivation of modern short varieties, which are photo-insensitive with maturity duration varying from 115 to 135 days. The crop can be transplanted or direct seeded with beushening. A major problem is damage due to high incidence of brown planthopper, whitebacked planthopper, stem borer, gall midge, sheath rot, and bacterial leaf blight. A number of high-yielding rice varieties combining high yield and resistance are available. These are Bhoi, Sarathi, Daya, Lalat, Konark, Naveen, Manaswini, Gouri, Pratikshya, Surendra, Padmini, Swarna, Swarna-Sub1, and Jajati. Besides these high-yielding rice varieties, hybrids such as Ajay, Rajalaxmi, KRH-2, PHB-71, PA 6201, PA 6444, PA 6129, and Sahyadri are grown in areas with assured irrigation. A package of practices for growing rice is fairly standardized for the rainfed/irrigated medium lands. All the same, rice yield remains low, around 1,500 kg/ha.

Lowland ecosystem. It covers more than 35% of the rice area of the state. Lowland rice is the major crop of the coastal region. Photosensitive varieties of maturity duration from 145 to 165 days with strong seed dormancy and plant height of 100 to more than 120 cm are grown in lowlands. Productivity in lowlands barely reaches 1 t/ha.

Table 6. Rice culture by season and land type in Odisha.

Rice culture	Local name	Percent of total area	Method of planting	Maturity		Stress factor
				Duration (days)	Month	
I. Autumn rice (upland)	*Biali*	15	Broadcast in June	80–100	September	Drought prone
II. Winter rice, early winter (medium land)	*Laghu sarad*	25	Transplanted in July	100–120	October	Insect pests and diseases
Mid-winter (medium and shallow lowlands)	*Sarad*	45	Broadcast in June with beushening in July or transplanted in July	130–150	October-November	Insect pests and diseases; flood prone
Late winter (semideep and deepwater land)	*Bada-Sarad*	7	Broadcast in May-June	150–165	November-December	Early drought; flood prone
III. Summer rice	*Dalua*	8	Transplanted in January-February	120–135	May-June	Insect pests and diseases

Table 7. Yield of different rice cultural types in Odisha.

Rice culture	Area		Production		Productivity (kg/ha)
	million ha	%	million t	%	
Autumn rice Upland	0.70	15.7	0.75	10.8	1,056
Winter rice Medium land and lowland	3.42	76.9	5.35	77.3	1,565
Summer rice Irrigated	0.33	7.4	0.82	11.9	2,488
Total	4.45	100.0	6.92	100.0	1,553

In shallow-water lowlands (water depth up to 30 cm), the crop is transplanted in July, when there is an assured water supply, or direct seeded in June with beushening in July. With an increase in area under high-yielding varieties such as Jagannath, Mahsuri, Savitri, Dharitri, Gayatri, Pooja, Mahanadi, Ramachandi, Indravati, Jagabandhu, and Upahar, the productivity of the shallow-water lowlands has been showing a significant upward trend. In situations where direct seeding is imperative, farmers are growing traditional tall varieties such as T 141, T 90, and other local landraces. Considerable yield loss occurs due to bacterial leaf blight, sheath blight, sheath rot, stem borer, and brown planthopper and leaffolder.

In semi-deepwater lands, the crop is generally direct seeded in May-June with or without beushening depending upon water depth. In deepwater lands, direct seeding in May is rather mandatory. Severe yield loss occurs due to stem borer and bacterial leaf blight. Tall varieties such as CR 1014, BAM 6, and T 1242 are commonly grown in semi-deepwater lands whereas farmers grow their own varieties on deepwater lands. The recently released high-yielding varieties such as Rambha, Tulsi, Durga, Sarala, Jagabandhu, Kanchan, Varsa Dhan, and Hanseswari, etc., recommended for semi-deepwater conditions, are yet to gain popularity among lowland farmers. Thus, a lack of suitable rice varieties with high yield, resistance to stem borer and bacterial leaf blight, and submergence tolerance is the major constraint to high productivity in these ecologically handicapped semi-deepwater and deepwater lands of the state.

The lowland direct-seeded crop often suffers from field problems such as poor seedling establishment due to weed competition, early drought, or occasional submergence; suppressed tillering attributed to prolonged water stagnation; premature lodging favored by general wet conditions and reduced light intensity; and crop damage due to flash-flood submergence and postflood drought.

Coastal saline lands. About 300,000 hectares of the coastal alluvial land suffer from tidal inundation. The most common characteristics of these lands are low-lying topography, inadequate drainage, and fairly high water table of poor-quality water due to higher salinity and moderate to heavy soil texture. However, the salinity of these lands remains low during kharif due to dilution and leaching, and it reaches critical limits after the cessation of monsoon. Tall indica varieties such as Patnai 23, SR 26B, and Lunishree are grown during the kharif season and yield is very low (500–700 kg/ha). Getting a good crop stand is a problem because, at the early stage, the crop is highly sensitive to salinity.

Irrigated ecosystem. In Odisha, about 46% of the rice area is irrigated mainly by gravity flow from a canal system. A sizable part of rabi rice lands is irrigated by lift irrigation from rivers, tanks, and dug wells. Rabi rice is grown on an area of 0.33 million ha, primarily medium lands. Irrigated kharif rice comprising about 1.75 million ha covers bunded uplands, medium lands, and lowlands (Table 8). In kharif, irrigation is mainly protective in nature. Uncontrolled irrigation in lowlands in kharif often aggravates the problem of waterlogging and soil health and adversely affects rice production.

The major problem limiting rice yield in the irrigated ecosystem is crop loss due to high incidence of insect pests such as yellow stem borer, brown planthopper, and whitebacked planthopper and diseases such as bacterial leaf blight and sheath rot. Several high-yielding rice varieties combining high yield potential plus multiple resistance such as Daya, Nabeen, Lalat, Konark, Gouri, Birupa, Meher, Surendra, Kharavela, Gajapati, and Manaswini, etc., are grown during the rabi season.

Zone-wise cropping systems in Odisha

The choice of crops in a cropping system depends on factors such as climate, land type, soil type, length of growing period, availability of moisture, labor availability, inputs and credit, insect pests and diseases, holding size, demand for a part of the produce for self-consumption, disposal of farm produce, and economic returns of marketable surplus. The basic approach in an efficient cropping system is to obtain higher production and better economic returns through the efficient use of inputs. Efforts have been made to design efficient cropping systems that have high yield, more returns, high resource-use efficiency, and sustainability over a longer period (Sharma and Behera 2005). Considering the wider range of variability of the abovementioned parameters and the importance of rice as a major crop in all the agro-climatic zones of Odisha, various rice-based cropping systems and cropping patterns involving pulses, millets, and oilseeds have been outlined in Box 1.

Crop management and systems of cultivation of rice in Odisha

Rice-growing conditions largely influence the system of cultivation. The system of cultivation is determined by the land situation, soil type, class of rice, season, intensity and distribution of rainfall, irrigation resources, and availability of labor (Nayak and Garnayak 2005). Odisha has three systems of rice cultivation: dry, semi-dry, and wet. The dry system accounts for 18% of the rice area and the rest is shared by semi-dry and wet systems (Pani and Patra 2004).

Dry system of cultivation. The dry system of rice cultivation is followed in rainfed uplands, which are characterized by aerobic soil and in which no attempt is made to impound water. The land is prepared several times in summer to obtain the desired tilth and the crop depends on rainfall for its water requirement. Despite several advantages of line sowing, upland rice is usually sown by broadcasting using a high seed rate (100–120 kg/ha) with early-maturing and very early maturing varieties before the onset of monsoon. The seeds are then covered by plowing the land lightly with a country plow or working with a cultivator and are left as such with the miniature ridges and furrows formed in the process of covering the seeds. These miniature furrows act as small drainage channels to carry away the heavy rainwater quickly, but slow enough to not cause soil erosion. In some areas, laddering is done after covering the seeds to compact the soil, which facilitates the availability of subsoil moisture for germination of seeds lying at different depths. In a broadcast crop, the field is cross-plowed on the third day of sowing to destroy germinating weed seeds, break the soil crust, redistribute the seeds, and facilitate aeration and loss of excess

Box 1.

1. Northwestern plateau zone		
Upland	Monocropping	Groundnut/arhar/blackgram/greengram/cotton/maize/castor/niger/mesta
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, castor + greengram
	Sequence cropping	Rice-horsegram/mustard/castor, mung-niger, maize-mustard
Medium land	Sequence cropping	Rice-mustard/linseed/Bengalgram
Lowland	Sequence cropping	Rice-Bengalgram/pea/lentil/linseed
2. North-central plateau zone		
Upland	Monocropping	Groundnut/arhar/blackgram/greengram/cotton/ maize/castor/niger/ragi/cotton/ sesamum
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, castor + greengram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, groundnut-castor/horsegram/ greengram
Medium land	Sequence cropping	Rice-mustard/linseed/Bengalgram/safflower/blackgram/lentil/greengram
Lowland	Sequence cropping	Rice-Bengalgram/pea/blackgram
3. Northeastern coastal plain zone		
Upland	Monocropping	Arhar/blackgram/greengram/sesamum/cowpea/rice
	Mixed cropping	Arhar + rice, arhar + groundnut, arhar + greengram
	Sequence cropping	Rice-horsegram/blackgram/greengram, ragi-mustard/greengram
Medium land	Sequence cropping	Rice-mustard/greengram/blackgram/pea/castor/groundnut
Lowland	Sequence cropping	Rice-Bengalgram/greengram/blackgram/pea
4. East and southeastern coastal plain zone		
Upland	Monocropping	Groundnut/arhar/blackgram/greengram/ragi/sesamum/sugarcane
	Mixed cropping	Arhar + rice, arhar + groundnut, arhar + ragi castor + greengram, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, groundnut-castor/horsegram/ greengram
Medium land	Sequence cropping	Rice-rice, rice-mustard/greengram/horsegram, Bengalgram/blackgram, rice-potato-sesamum, early rice-vegetables
Lowland	Sequence cropping	Jute-rice-pulse, rice-rice, rice-greengram/blackgram/groundnut
5. Northeastern Ghat zone		
Upland	Monocropping	Groundnut/brinjal/maize/cotton/tobacco/rice/ginger/turmeric/tapioca/arhar/ sugarcane
	Mixed cropping	Ragi + cowpea, ragi + horsegram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, maize-mustard/cotton/tobacco, ragi-niger
Medium land	Sequence cropping	Rice-greengram/lathyrus/groundnut/vegetable
Lowland	Sequence cropping	Rice-groundnut/lathyrus/pulses/potato
6. Eastern Ghat highland zone		
Upland	Monocropping	Ragi/rice/niger/kulthi/minor millet/maize/ginger/turmeric/monsoon potato
	Mixed cropping	Arhar + rice, arhar + groundnut, arhar + maize/castor + greengram, arhar + ragi
	Sequence cropping	Rice-horsegram/blackgram/greengram, groundnut-castor/horsegram/greengram
Medium land	Sequence cropping	Rice-mustard/linseed/ragi/gram/lentil/maize
Lowland	Sequence cropping	Rice-rice/lentil/niger/mustard/pulses
7. Southeastern Ghat zone		
Upland	Monocropping	Rice/ragi/minor millet/maize/pulses/cotton
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, groundnut-castor/horsegram/greengram
Medium land	Sequence cropping	Rice-Bengalgram/safflower/blackgram/lentil
Lowland	Sequence cropping	Rice-Bengalgram/greengram/blackgram

Continued

Box 1. Continued.

8. Western undulating zone		
Upland	Monocropping	Rice/ragi/minor millet/maize/sesamum/cotton
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, castor + greengram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, maize-niger/mustard/arhar, ragi-mustard, minor millet-mustard/horsegram/sweet potato
Medium land	Sequence cropping	Rice-horsegram/greengram/Bengalgram/ blackgram/vegetables, maize-greengram/arhar/ niger/mustard/sesamum, ragi-niger/mustard/sesamum
	Sequence cropping	Rice-rice/wheat/Bengalgram/blackgram/mustard/ niger/sesamum
9. West-central table land zone		
Upland	Monocropping	Rice, greengram, groundnut, sesamum
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram, groundnut-castor/horsegram/greengram
Medium land	Sequence cropping	Rice-mustard/Bengalgram/vegetable/rice/blackgram/groundnut/sesamum
Lowland	Sequence cropping	Rice-rice/Bengalgram/blackgram/groundnut/ sesamum/vegetables
10. Mid-central table land zone		
Upland	Monocropping	Rice/groundnut/arhar/blackgram/greengram/ maize/sesamum/niger
	Mixed cropping	Arhar + rice, arhar + groundnut, cotton + greengram, arhar + ragi, arhar + maize
	Sequence cropping	Rice-horsegram/blackgram/greengram/mustard/sesamum, maize-mustard/ sesamum
Medium land	Sequence cropping	Rice-horsegram/sesamum/blackgram/mustard groundnut-sesamum/ horsegram/greengram
Lowland	Sequence cropping	Rice-Bengalgram/pea/blackgram/sesamum/groundnut/vegetables

Table 8. Area under high-yielding rice varieties in Odisha (000 ha).

Years	Area		Percentage of		Total rice area	Production (million t)	Productivity (kg/ha)
	HYV	Normal	HYV	Normal			
1976-77	557.6	3,821.9	12.7	87.3	4,379.5	3.96	904
1986-87	1,845.4	2,548.2	42.0	58.0	4,393.6	4.88	1,111
1996-97	1,894.4	2,572.8	42.4	57.6	4,467.2	4.48	1,003
1999-2000	2,575.9	2,024.2	56.0	44.0	4,600.1	5.19	1,172
2006-07	3,544.6	905.7	79.6	20.4	4,450.3	6.92	1,557
2007-08	3,583.7	868.1	80.5	19.5	4,451.8	7.66	1,720
2008-09	3,430.4	1,024.2	77.0	23.0	4,454.6	6.92	1,553

moisture. This type of blind tillage is called "*mendha*" in Odisha. Two weeks after germination, mechanical weeding is done by using a country harrow (known as a "*bida"* in Odisha) in sunny weather. Agronomic studies over the years indicated that, in uplands, seeding in lines at a depth of 4–6 cm was effective in raising a rice crop with a good stand and, in a line-sown crop, the interspace is worked with a rake weeder or hoe and weeds are removed from the rows by hand. Weeds are also controlled by using preemergence herbicides such as butachlor or thiobencarb. Application of a recommended dose of fertilizers and need-based plant protection measures can maximize the yield of rice in rainfed uplands.

Semi-dry system of cultivation. The semi-dry system of rice cultivation is usually followed in rainfed medium and shallow lowlands. Under this system, the field is prepared and seeded dry. The crop is treated as a dry crop for 1 to 1 1/2 months after seeding and then treated as a wet crop after the monsoon becomes intense. Sowing is usually done in May-June using a seed rate of 80–100 kg/ha. When the crop is 4 to 6 weeks old, cross-plowing is done with a light (worn-out) country plow in 5–10 cm of standing water once or twice depending upon the density of weeds and crop stand. This operation is called "*beushen*" in Odisha. Following this operation, the crop is weeded, thinned, and gaps are filled with the uprooted seedlings, which is called *"Khelua."* In some areas, *Khelua* is done immediately after *beushening* whereas in other areas it is done a week or 10 days after beushening. The beushening process helps in weed control and improves the aeration of soil. It can be pointed out that beushening, while controlling weeds to a considerable extent, reduces the crop stand to a submarginal level and is one of the reasons for the low productivity of direct-seeded rice in Odisha. This practice can be overcome by seeding the crop in line and doing interculture in between the rows. Maintenance of an optimum plant population, soil test-based fertilizer application, judicious water management, and need-based plant protection can improve productivity in the semi-dry system of rice cultivation.

In lowlands, a well-managed rice crop involving dry seeding plus beushening is as good as one using transplanting. To maintain the plant population, beushening is to be followed by *khelua*, preferably with seedlings raised in the nursery on about one-tenth of the area of the same piece of land. In a beushened crop, all P can be applied at the time of seeding or at the time of beushening along with all K and one-half N; the remaining one-half N is to be applied 30 days later. In lowlands, planting of aged seedlings (50 to 60 days old) is more remunerative under adverse soil conditions or postflood situations.

Research efforts on P management indicate that rock phosphates can be applied directly to a crop in a highly acidic soil with pH 5.0 or less. In moderately acidic, neutral, or saline soils, mixtures of rock phosphate and single superphosphate in proportions of 3:1 or 1:1 are as effective as superphosphate on crop yield. In rice-rice or rice-based cropping systems, the required P can be applied to the rabi crop, whereas the next crop can be raised on residual P. Potassium application was found to reduce the adverse effects of iron toxicity in rice.

Wet system of cultivation. In this cultivation system, rice is grown as a wet crop in tracts that have an assured supply of water. The field is brought to a soft puddled condition by repeated plowing with 5–7 cm of standing water. After getting the requisite puddles, rice seedlings raised in a nursery can be transplanted or sprouted seeds can be directly sown. Transplanting is usually carried out by a random method using 3–4-week-old seedlings. Hand weeding is done once or twice depending upon the weed population. Chemical weed control is also popular in many areas where the wet system of rice cultivation is advocated. Efficient water management, soil test-based balanced fertilizer application, and need-based plant protection measures can improve the productivity of this system in rice significantly. It has been shown that wet seeding or direct seeding of sprouted seeds on puddled soil gives as much yield as a transplanted crop, but it is not usually advocated. The cultural practices of wet seeding are similar to those of a transplanted crop. However, the wet-seeding method is adopted as a contingent measure when there is a shortage of seedlings, especially in postflood situations (Pani and Patra 2004).

High-yielding variety coverage and Irrigation facilities available in the state

The adoption of high-yielding varieties coupled with improved management practices and assured irrigation potential are imperative for maintaining the stability of rice production and productivity in the state. The production and productivity growth rate trends of rice in Odisha indicated that the introduction of high-yielding varieties did not have any perceptible impact over two decades since their introduction during the mid-1960s and productivity remained below 1 t/ha. However, yield has shown a substantial upward trend since 1986, primarily because of the gradual increase in irrigation potential as well as the spread and adoption of high-yielding varieties in the state (Table 8).

During 2008-09, 77% of the total rice area (3.43 million hectares) was under high-yielding varieties whereas 75% (3.09 million hectares) was covered by high-yielding varieties during the kharif season and the rest was under local and improved varieties. Ganjam is fully saturated with high-yielding varieties and in Phulbani only 25.1% of the area is covered with high-yielding varieties during the kharif season. More than 90% of the area is under high-yielding varieties in districts Ganjam, Sonepur, Bargarh, Gajapati, Sambalpur, Deogarh, Angul, and Jharsuguda during the kharif season (Table 9).

Some 46% of the total rice area (2.08 million hectares) is irrigated and 42% (1.75 million hectares) is irrigated in the kharif season. During the summer season, the entire rice area of 0.33 million hectares is irrigated and covered by 100% high-yielding varieties of early and mid-early maturity duration (Table 9). One of the major constraints to rabi rice cultivation is the delay in availability of canal water. Yield of milled rice on irrigated lands is still low, about 1.5 t/ha in kharif and 2.0 t/ha in rabi, which is only 50% of the potential yield exploited in spite of the availability of suitable varieties and an appropriate package of practices. Better variety input management and suitable water management can raise productivity considerably.

History of rice breeding in Odisha and the most popular rice varieties/hybrids

Improvement of tall rice

Before the inauguration of the Indian Council of Agricultural Research and the Rice Research Schemes in India, the State Agricultural Departments were doing the routine work of pure-line selection of popular landraces available in the state during the early 1920s. D.R. Sethi, the then deputy director of agriculture of Odisha Range, was responsible for the development of certain improved varieties: Benibhog for autumn rice, Cuttack-1 (early winter), Cuttack-2 (mid-winter), Cuttack-3 and 5 (late winter), and Kujang-1 and Kujang-2 for the saline tracts of the state.

Rice research, especially variety improvement, began in 1932 following the establishment of the Rice Research Station at the State Agricultural Farm, Cuttack. In 1938, an ICAR (then the Imperial Council of Agricultural Research)-sponsored rice breeding project was in operation with a paddy specialist. The late P.D. Dixit was the first paddy specialist, and this position was subsequently redesignated as the economic botanist-I. Rice varietal work was also in operation at two substations in South Odisha: one at Berhampur and the other at Jeypur. As part of the Odisha Rice Research Scheme, a physiological section was started under the guidance of Prof. P.K. Parija in the Botany Department of Ravenshaw College. Research on agronomy, entomology, and pathology started in the 1940s with the appointment of an agronomist, entomologist, and mycologist, respectively.

In 1946, the State Agricultural Farm at Cuttack was handed over to ICAR for establishment of the Central Rice Research

Table 9. District-wise HYV and irrigated area in Odisha in 2008-09. Area in 000 hectares.

Districts	Total kharif area	Total rice area	HYV area			% of HYV	% of HYV in kharif	Irrigated area			% of irrigated area
			Kharif	Rabi	Total			Kharif	Rabi	Total	
Balasore	211.4	245.5	156.0	34.1	190.1	77.4	73.8	84.3	34.1	118.4	48.2
Bhadrak	164.7	179.4	128.2	14.7	142.9	79.7	77.8	101.6	14.7	116.3	64.8
Bolangir	210.8	214.9	184.2	4.1	188.3	87.6	87.4	41.8	4.1	45.9	21.4
Sonepur	97.2	125.6	97.1	28.4	125.5	99.9	99.1	62.7	28.4	91.1	72.6
Cuttack	128.4	133.1	98.9	4.7	103.6	77.8	77.0	88.3	4.7	93.0	69.9
Jagatsinghpur	88.2	91.1	70.6	2.9	73.5	80.7	80.1	63.1	2.9	66.0	72.5
Jajpur	135.8	138.9	95.5	3.1	98.6	70.9	70.3	45.3	3.1	48.4	34.9
Kendrapara	138.0	143.0	79.7	5.0	84.7	59.2	57.8	55.0	5.0	60.0	42.0
Dhenkanal	110.3	112.1	81.2	1.8	83.0	74.0	73.6	36.3	1.8	38.1	34.0
Angul	98.1	98.9	92.1	0.8	92.9	93.9	93.9	31.3	0.8	32.1	32.4
Ganjam	275.8	275.9	275.8	0.1	275.9	100.0	100.0	196.9	0.1	197.0	71.4
Gajapati	35.8	36.1	35.3	0.3	35.6	98.6	98.6	19.6	0.3	19.9	55.1
Kalahandi	218.3	268.3	204.8	50.0	254.8	94.9	93.8	100.0	50.0	150.0	55.9
Nawapara	101.7	105.6	81.1	3.9	85.0	80.5	79.8	37.0	3.9	40.9	38.7
Keonjhar	205.2	207.2	151.4	2.0	153.4	74.0	73.8	52.8	2.0	54.8	26.5
Koraput	114.7	130.8	87.1	16.1	103.2	78.9	75.9	56.3	16.1	72.4	55.3
Malkangiri	93.0	93.9	55.8	0.9	56.7	60.5	60.0	42.0	0.9	42.9	45.8
Nawarangpur	157.1	158.9	84.6	1.8	86.4	54.4	53.9	17.9	1.8	19.7	12.4
Raygada	61.0	63.1	53.1	2.1	55.2	87.5	87.1	30.1	2.1	32.2	50.9
Mayurbhanj	339.4	345.2	169.2	5.8	175.0	50.7	49.9	97.2	5.8	103.0	29.9
Phulbani	53.1	53.8	12.8	0.7	13.5	25.1	24.1	11.8	0.7	12.5	23.2
Boudh	69.0	71.0	55.9	2.0	57.9	81.6	81.0	39.2	2.0	41.2	57.9
Puri	118.7	170.8	73.4	52.1	125.5	73.5	61.8	84.8	52.1	136.9	80.1
Khurda	114.7	123.1	66.7	8.4	75.1	61.0	58.2	50.0	8.4	58.4	47.5
Nayagarh	94.5	94.6	62.0	0.1	62.1	65.7	65.6	36.9	0.1	37.0	39.1
Sambalpur	131.1	151.3	126.0	20.2	146.2	96.6	96.1	55.80	20.2	76.0	50.2
Bargarh	244.0	305.4	241.5	61.4	302.9	99.2	98.9	133.3	61.4	194.7	63.8
Deogarh	44.6	45.0	42.8	0.4	43.2	96.0	95.9	16.6	0.4	17.0	37.8
Jharsuguda	52.1	53.9	47.7	1.8	49.5	93.1	91.6	10.5	1.8	12.3	22.9
Sundargarh	217.0	218.4	89.1	1.4	90.5	41.4	41.1	53.1	1.4	54.5	24.9
Total	4,123.7	4,454.6	3,099.4	330.9	3,430.4	77.0	75.2	1,751.9	330.9	2,082.9	46.8

Institute (CRRI). The Rice Research Station was shifted to the new State Agricultural Farm at Bhubaneswar. In 1963, following the establishment of the Odisha University of Agriculture and Technology (OUAT) at Bhubaneswar, the Rice Research Station along with the State Agricultural Farm were transferred to the control of the university.

The development of improved varieties fulfilling the varietal requirements of the three broad rice ecosystems dates back to the late 1930s. Breeding method was limited to pure-line selection in indigenous tall varieties or farmers' varieties. Enormous differences existed in the cultivated rice varieties in Odisha, reflecting great diversity in the agroecological conditions under which the crop has been cultivated for hundreds of years. Many of these indigenous rice varieties are tall (more than 130 cm) and evolved by farmers mainly on the basis of their adaptation to local conditions. These are in general poor yielders but most have many other desirable traits. Through pure-line selection, altogether 30 different rice varieties were released in 1944 from the three research stations: Cuttack (T series), Berhampur (BAM series), and Jeypore (J series) for different ecosystems in Odisha (Table 10).

Most of these improved tall varieties are low yielders primarily because of lodging and nonresponsiveness to better crop management and they are now out of cultivation except for varieties such as T 141, T 90, T 1242, BAM 6, SR 26, FR 13A, and FR 43B, which maintain their popularity for lowland ecosystems and/or as donor parents in high-yielding breeding programs, and these have been recently notified to meet the requirements of seed multiplication under the Seed Act of 1966.

After the establishment of the Central Rice Research Institute at Cuttack, systematic efforts were made to screen exotic types from genetic stocks and many Chinese, Japanese, Taiwanese, and Russian types were tested for the purpose of direct introduction. Some Chinese types such as Ch 4, Ch 45, and Ch 55 were found promising, combining high yield with earliness and *Helminthosporium* resistance was used in some modern varieties.

Short-height high-yielding rice

The International Rice Commission within the FAO framework recognized nonlodging habit, fertilizer responsiveness, early maturity, and wide adaptability as the important varietal characteristics for achieving higher and more stable yields. The ambitious indica/japonica hybridization program launched in 1952 was the earliest international effort to explore the possibilities of breaking the yield barrier in indica rice. The relatively higher yielding ability of japonicas believed then to be due to their nonlodging habit and responsiveness to more fertilizer was what prompted the formulation and execution of this massive program in Asia. The extensive hybridization program with CRRI at Cuttack as the primary hybridization center and countrywide screening of segregating material lasting for ten years proved a major disappointment. Partial sterility and skewed segregation toward parental types were attributed to the low frequency of stable fertile recombinants. This genetic hurdle could have been averted had breeders been careful to choose tropical japonica parents such as Norin 6, Norin 8, Norin 16, Rikue 12, Asahi, etc., instead of temperate japonica types as parents in the program. Except for three varieties, ADT-27, an early-maturing type found suitable for *kuruvai* season in Tamil Nadu, and two medium-late-maturing types, Mahshuri and Malinja, identified in Malaysia that became widely popular in India and Malaysia, respectively, and Circina in Australia, the project hardly yielded any good variety combining the desirable features of japonica and indica. Therefore, such an intersubspecific hybridization strategy did not yield anything substantial and led to the abrupt termination of the project (Siddiq and Viraktamath 2001).

The realization that an intersubspecific hybridization strategy would not yield anything substantial led to the abrupt termination of the FAO-sponsored indica/japonica hybridization project, which nearly coincided with the advent of the short-statured indica variety Taichung Native 1 and *Ponlai* varieties such as Taichung 65, Tainan 3, etc. Taichung Native 1 that heralded the era of plant type-based high-yielding varieties is a derivative of a cross between the spontaneous dwarf mutant Dee-Geo-Wu-Gen and the Taiwanese tall variety Tsai-Yuan-Chung. This early-maturing dwarf variety (well adapted to year-round cultivation) provided the basis for developing the "plant type" concept and a series of high-yielding dwarf varieties, including the miracle rice IR8, suited to an irrigated ecology, and IR5, a semitall variety bred for less favorable environments. IR8 provided the momentum for the development of a series of high-yielding dwarf varieties by national agricultural research and extension systems. Thus, this new plant type of short stature, nonlodging habit, profuse tillering and upright foliage, photo-insensitivity, high fertilizer responsiveness, and early maturity helped to break the centuries-long yield barrier of tropical rice (Siddiq and Viraktamath 2001).

The breeding program for short high-yielding varieties in Odisha in fact dates back to 1957. The mutation breeding program then in operation yielded a short mutant, BBS 873, from the popular lowland tall rice T 141. The mutant was photosensitive (while modern semidwarfs, such as TN 1 and IR8, possessing the *dgwg* dwarfing gene, are photo-insensitive), moderately responsive to nitrogen fertilization, matured in about 155 days, and yielded about 50% more than parent T 141 in shallow-water conditions. BBS 873 was released by the Central

Table 10. Improved tall rice varieties released in the 1940s in Odisha.

Ecosystem	No. of releases	Variety
Upland	5	B76, EF 86, T 136, J 1, J 2,
Medium land	8	BAM 12, BAM 13, BAM 14, BAM 15, T56, T 442, T 608, T 1145
Lowland	12	BAM 3, BAM 6, BAM 9, BAM 11, T 90, T 141, T 412, T 812, T 1242, J 4, J 5, J 7
Saline land	1	SR 26B
Flood-prone land	2	FR 13A, FR 43B
Dalua (summer rice)	2	D.I. 3, D.I. 4

Variety Release Committee (CVRC) in 1969 as Jagannath for lowlands in the coastal districts of Odisha, West Bengal, and Andhra Pradesh. For a decade or so, Jagannath was the leading high-yielding variety in Odisha. Because of rice breeders' deep involvement in the improvement of high-yielding varieties for irrigated lands and rainfed medium lands, the realization of the breeding potential of Jagannath and its exploitation for lowland rice breeding were delayed until the 1980s.

In the first phase of the HYV breeding program, the primary objectives were high yield and adaptability to irrigated medium lands in both kharif and rabi and also favorable rainfed medium lands in the kharif season. In the second phase, the emphasis was on early duration (100 days or less) for rainfed upland ecosystems besides resistance to gall midge and bacterial leaf blight (BLB), particularly in the mid-season (110 to 135 days) varieties. In the next phase of the breeding program, major emphasis was given to developing varieties for unfavorable ecosystems such as drought-prone uplands, flood-prone lowlands, and coastal saline areas. The development of hybrid rice was the next important rice breeding strategy to break the yield plateau in irrigated ecosystems.

Varietal improvement for lowlands

In 1969, Pankaj (a sister selection of IR5) was released by the CVRC along with Jagannath and, at a later date, Mahsuri (developed from a japonica/indica cross). These three releases were being increasingly used in rice breeding work for rainfed shallow and semi-deepwater lowlands. One significant achievement in lowland breeding during the 1980s was the evolution of the short, photosensitive, late-maturing (about 155 days) variety Savitri (CR 1009), developed from the cross of Pankaj/Jagannath at CRRI. Similarly, in OUAT, the lowland rice breeding program was intensified in the late 1970s with major objectives such as short to intermediate plant height (90–100 cm), photosensitivity with maturity duration of 145 to 155 days, panicle weight type, and tolerance of flood submergence for shallow-water areas; intermediate to tall plant height (110–130 cm), photosensivity with maturity duration of 150–165 days, panicle weight type, and adaptability to stagnating water conditions through both submergence tolerance and moderate elongation ability at the seedling stage and also tolerance of drought at the early seedling stage for semi-deepwater areas. In both ecosystems, resistance to stem borer, gall midge, leaffolder, brown planthopper, bacterial leaf blight, sheath blight, and sheath rot was an important breeding objective.

Both CRRI and OUAT were responsible for the development and release of more than 100 varieties during the last 50 years to meet the varietal requirements for different land situations of the state. As a result, the farmers of Odisha had a very wide choice of rice varieties suitable for different ecologies and the pest and disease stresses of the state. The most popular rice varieties and hybrids suitable for different ecosystems are listed in Table 11.

Postharvest operations. Threshing is mostly accomplished by trampling by men, animals, and tractors. Besides threshing by animals, many farmers use either manually operated pedal threshers or pedal threshers have been converted for power operations by using small air-cooled engines. Generally, threshed grains are cleaned and sun-dried by uniformly spreading the grains on the threshing floors in thin layers and intermittently stirring them manually for several days till the grains become dry and brittle and attain the desirable moisture content.

People in Odisha prefer parboiled rice. Parboiling of paddy requires three steps: soaking, steaming, and drying. Traditionally for parboiling, the grains are soaked in water at room temperature for 24–48 hours or more, and then steamed in iron kettles in small batches under atmospheric pressure. The parboiled paddy is then dried in the sun before milling. Parboiling seals the cracks and hardens the grains, and heals incomplete grain filling and chalkiness due to starch gelatinization, thereby improving head rice recovery during milling. Parboiling also improves the nutritional and cooking quality of rice grains.

Rice milling is the removal of hulls and bran from paddy grains to produce polished rice. A variety of indigenous milling equipment such as a mortar and pestle, *dhenki*, and hand stones are being replaced by modern rice-milling machines such as precleaners, dehuskers/shellers, paddy separators, polishers, and graders to enhance milling recovery in rice.

It has been estimated that maximum food spoilage takes place due to many intrinsic and extrinsic factors such as moisture, temperature, oxygen concentration, microorganisms, insects, and rodents under storage. Therefore, it is essential to store grains in efficient storage structures such as *Bukhari*-type, *Kothar*-type, and *Morai*-type structures or in modern storage structures such as metal bins, plastic bins, R.C.C. bins, cement masonry bins, and large-scale storage structures such as silos and bag storage structures that can store 25–500 tons of grain.

Traditional cultivars/varieties grown and Indigenous technical knowledge

Odisha has been considered as the center of origin and genetic diversity for cultivated rice. Thousands of rice varieties were cultivated in Odisha earlier and, even after the spread of high-yielding rice varieties, farmers still cultivate hundreds of these traditional types. Many traditional rice varieties such as Bobblibhuta, Mahulakunchi, Kulia, Kulia sankar, Kumarmani, Anjana, Benibhog, Chhetka, Kalakeri, Badamfarm, etc., for rainfed uplands; Barangachudi, Sarumundabali, Assam chudi, Boropanko, Saruchinamali, Rangalata, Kakudimanji, etc., for medium lands; Karandi, Bayahunda, Ratnachudi, Galleiganthi, Dudumani, Padmakeshari, Machhakanta, Magura, Kalambanka, Cuttackchandi, Mahipal, Mayurakantha, Champeisiali, Kedargouri, Champa, etc., for lowlands; and Sanakalasura, Badakalasura, Matiaburus, Khajuria chanar, Bankosa, Pani begunia, Potia, Pateni, etc., for semi-deepwater situations are grown in the state.

A majority of these traditional cultivars are low yielders and their low yield ability is primarily due to their tall stature; weak culm, making them susceptible to lodging; low tillering ability; and poor panicle features. These cultivars were grown for specific traits such as maturity duration, plant stature, panicle features, yield potential, tolerance of biotic and abiotic stresses, and other elusive traits such as aroma, cooking quality, and grain quality.

Table 11. List of popular rice varieties released for different ecosystems in Odisha.

Institute where developed	Name	Designation	Cross combination	Year of release	Days to 50% flowering	Ecosystem[a]	Grain type[b]
Very early group							
OUAT	Subhadra	DR 92	TN-1/SR 26 B	1980	55	RUP	MB
CRRI	Kalinga III	CR 237-1	AC 540/Ratna	1983	55	RUP	LS
OUAT	Rudra	OR 165-97-15	Parijat/IET 3225	1983	60	RUP	MB
OUAT	Shankar	OR 165-86-12	Parijat/IET 3225	1983	60	RUP	MB
CRRI	Heera	CR 544-1-1	CR 404-48/CR 289-1208	1988	65	RUP	MB
CRRI	Vanaprabha	CR 289-7045-16	ARC2422/ARC 12751	1988	65	RUP	MS
CRRI	Dhala Heera	CR 544-1-3-4	CR 404-48/CR 289-1208	1998	60	RUP	MB
CRRI	Vandana	RR 167-982	C 22/Kalakeri	2002	65	RUP	MS
Early group							
OUAT	Parijat	OR 34-16	TKM 6/TN 1	1976	70	RUP	MS
OUAT	Pathara	OR 83-23	Hema/CO 18	1985	75	RUP	MS
CRRI	Annada	CR 222-MW-10	MTU 15/Waikoku	1987	75	RUP	SB
OUAT	Khandagiri	OR 811-2	Parijat/IR13429-94-3-2	1992	70	RUP	MS
CRRI	Satabdi	CR 146-7027- 224	CR 10-114/CR 10-115	2000	75	RUP	MS
CRRI	Anjali	RR347-166	Sneha/RR 149-1129	2001	75	RUP	MB
OUAT	Sidhanta	ORS 102-4	Jajati/Annapurna	2005	65	RUP	SB
OUAT	Jogesh	OR 1519-2	CR 544-1-3-4/NDR 1008	2005	59	RUP	LB
CRRI	Sahabhagi Dhan	IR74371-70-1-1-CRR-1	IR55419-04*/Way Rarem	2009	83	RUP	LB
OUAT	Mandakini	OR 2077-4	Ghanteswari/IR27069	2010	78	RUP	MS
Mid-early group							
OUAT	Daya	OR 131-13-13	Kumar/CR 57-49	1984	95	IRME	MS
OUAT	Lalat	ORS 26-2014-4	OBS 677/IR2071//Vikram/W 1263	1988	95	IRME	LS
OUAT	Konark	OR 1143-230	Lalat/OR 135-3-4	1998	95	IRME	MS
OUAT	Bhoi	OR 987-13	Gauri/RP 825-45-1-3	1998	90	IRME	LB
CRRI	Naveen	CR 749-20-2	Sattari/Jaya	2005	90	IRME	MB
OUAT	Manaswini	OR 1912-24	Swarna/Lalat	2008	100	IRME	LS
CRRI	CR Boro dhan-2 (Chandan)	CR 898	Mutant of China 45	2010	100	IRBO	MS
Hybrids							
CVRC	PA 6201	–	–	2000	95	IRME	LS
CVRC	KRH-2	–	IR58025 A/KMR 3	2001	90	IRME	LS
CVRC	PA 6444	–	–	2001	90	IRME	LS
CRRI	Ajay (hybrid)	CRHR 7	CRMS 31 A/IR42266-29-3	2005	95	IRME	LS
CRRI	Rajalaxmi (hybrid)	CRHR 5	CRMS 32 A × IR42266-29-3	2005	95	IRME	LS
Medium group							
OUAT	Jajati	OR 47-2	Rajeswari/T 141	1980	105	IRM	MS
OUAT	Gouri	OR 148-1-44	T 90/IR8//Vikram	1984	102	IRM	MS
OUAT	Gajapati	OR 820-29	OR 136-3/IR13429-196-1-120	1998	105	IRM	MS
OUAT	Kharavela	OR 815-3	Daya/IR13240-108-2-2-3	1998	102	IRM	MS
OUAT	Surendra	OR 447-20-P	OR 158-5/Rasi	1998	102	IRM	MB
CRRI	Tapaswini	CR 331-6-1	Jagannath/Mahsuri	1998	105	IRM	MS

Continued

Table 11. Continued.

Institute where developed	Name	Designation	Cross combination	Year of release	Days to 50% flowering	Ecosystem[a]	Grain type[b]
OUAT	Pratikshya	ORS 201-5	Swarna/IR64	2005	110	IRM	MS
CRRI	Geetanjali (basmati rice)	CRM 2007-1	Mutant from Basmati 370	2005	105	IRM	LS
OUAT	Tejaswini	OR 1912-22	Swarna/Lalat	2010	105	IRM	MB
Late group							
OUAT	Jagannath	BBS 873	Xray irradiation of T 141	1969	120	RSL	MS
CRRI	Savitri	CR 210-1009	Pankaj/Jagannath	1982	120	RSL	SB
CRRI	Dharithri	CR 210-1017-607	Pankaj/Jagannath	1988	120	RSL	SB
CRRI	Gayatri	CR 210-1018	Pankaj/Jagannath	1988	125	RSL	SB
CRRI	CR 1014	CR 563-1014	T 90/Urang Urangan	1988	120	SDW	MS
CRRI	Padmini	CRM-25	Mutant of CR 1014	1988	115	RSL	MS
CRRI	Panidhan	CR 260-30	CR 151-79/CR 1014	1988	140	SDW	MS
OUAT	Kanchan	OR 609-15	Jajati/Mahsuri	1992	125	RSL	MS
OUAT	Ramachandi	OR 912-10-190	IR17494-32-2-2-1/Jagannath	1999	130	RSL	MB
CRRI	Pooja	CR 629-256	Vijaya/T 141	1999	125	RSL	MS
OUAT	Mahanandi	OR 1301-13	IR19661-131-1-3-1/Savitri	1999	125	RSL	MB
OUAT	Jagabandhu	OR 1206-25-1	Savitri/IR4819 sel.//IR27301 sel.	1999	115	RSL	MS
CRRI	Sarla	CR 260-77	CR 151-79/CR 1014	2000	125	SDW	MS
CRRI	Durga	CR 683-123	Pankaj/CR 1014	2000	125	SDW	SB
CRRI	Ketekijoha	–	Badshahbhog/Savitri	2005	115	RSL	MS
OUAT	Uphar	OR 1234-12-1	Mahalaxmi/IR 62	2005	130	SDW	SB
CRRI	Varshadhan	CRLC 899	IR31342-8/IR31406-3//IR26940-3-3-	2005	130	SDW	LB
CRRI/OUAT	Nua Kalajeera	–	Pure line of Kalajeera	2008	115	RSL	SB
CRRI	Nua Dhusura	–	Pure line of Dhusura	2008	115	RSL	SS
OUAT	Ranidhan	–	Swarna/ORR 48-1	2009	115	RSL	MS
CRRI	Swarna-Sub-1	CR 2539-1	Swarna*3/IR49830-7	2009	115	RSL	MS
CRRI	Nua Chinikamini	CR 2580-7	Pure line of Chinikamini	2010	115	RSL	SB
OUAT	Mrunalini	OR 1898-18	Mahalaxmi/OR 633-7	2010	120	RSL	SB
Pure-line selection of landraces							
OUAT	T 141		Pure-line selection Saruchinamali	1988	120	RSL	MS
OUAT	T 90		Pure-line selection Machhakanta	1988	120	RSL	LS
OUAT	T 1242		Pure-line selection Magura	1988	125	RSL	LB
OUAT	BAM 6		Pure-line selection Ratnachudi	1988	125	RSL	MS
OUAT	SR 26 B (T)		Pure-line selection Kalambanka	1988	115	RSL	LB
OUAT	FR 13A		Pure-line selection Dhalaputia	1988	125	SDW	LB
OUAT	FR 43B		Pure-line selection Betanasi	1988	125	SDW	LB

[a]RUP = rainfed upland, IRME = irrigated mid-early, IRM = irrigated medium, RSL = rainfed shallow lowland, SDW = semi-deepwater.
MB = medium bold, MS = medium slender, LS = long slender, SB = short bold, LB = long bold.

However, in recent years, the development and spread of semidwarf high-yielding rice varieties replaced the diversity of the locally adapted varieties developed by farmers over generations. Thus, the loss of diversity and genetic erosion are a serious concern. The traditional varieties grown by farmers are likely to be lost in the near future if measures are not taken to protect these valuable genetic resources. Recently, the Directorate of Agriculture & Food Production, government of Odisha, has made a massive effort to collect more than 1,000 indigenous rice varieties still available with farmers from different districts of the state. Efforts are being made for their systematic evaluation and characterization during the current wet season. It is proposed to register them as farmers' varieties with all passport traits according to the Protection of Plant Varieties and Farmers' Rights Authority (PPV & FRA, Ministry of Agriculture, government of India).

These traditional tall types are still favored by farmers in rainfed uplands, semi-deepwater and deepwater situations, and saline areas of the state. Despite their low yield potential, they are preferred for favorable traits such as early seedling vigor, rapid germination, deep root system with higher proportion of thick roots, superior grain quality, better yield stability, and tolerance of moisture stress, submergence, and salinity. Dixit and Challam collected nearly 3,000 rice germplasm accessions mainly from the six districts then constituting the state of Odisha: Balasore, Cuttack, Puri, Ganjam, Koraput, and Sambalpur. Some of the traditional tall varieties such as Kalakartik in Sambalpur; Saruchinamali in Cuttack and Puri; Bayahunda and Ratnachudi in Ganjam; Karandi in Koraput; Machhakanta, Pateni, and Kalambanka in Balasore; and Magura in Puri and Cuttack are the most adaptable types and they are widely grown.

It has been estimated that more than 50 traditional aromatic rice varieties with pleasant aroma are grown in various parts of the state. These indigenous scented rice varieties such as Kalajeera, Badsabhog, Neelabati, Krushnabhog, Govindabhog, Padmakeshari, Tulasiphoola, Chinikamini, Saragdhuli, and Thakurabhog are predominant in coastal belts, whereas a few traditional scented varieties such as Pimpudibasa, Karpurakeli, Kalikati, Laxmibilas, Jubraj, Durgabhog, Karpurakranti, and Makarakanda are common in the plateau regions of the state.

These scented rice varieties traditionally grown in the state usually have small and round grains without much elongation on cooking, but have very strong aroma under the prevailing warmer climate during the grain maturity period in the kharif season. The small- and medium-grain aromatic rice varieties are regarded as a separate class of nonbasmati aromatic rice. A survey of rural as well as urban markets indicated that generally these small- and round-grain aromatic types of local origin are sold with a price range of Rs.20–25 per kg (about double the price of normal nonaromatic rice). Therefore, there is a continued demand for the production and marketing of these indigenous scented rice varieties for socioeconomic development of the farmers of Odisha.

Traditional rice varieties have been explored, collected, and conserved. The Central Rice Research Institute, under an ICAR project known as the Jeypore Botanical Survey, collected about 1,745 accessions of cultivated rice and 150 accessions of wild rice from the Jeypore tract of Odisha. These are known as JBS varieties. In recent years, the CRRI and NBPGR have collected almost all the traditional rice varieties of Odisha, numbering about 2,000, which are conserved in medium-term storage at CRRI and in long-term storage at NBPGR (Pani and Patra 2004).

Indigenous technical knowledge

Indigenous technical knowledge is predominantly embedded in the practices and experiences that are commonly exchanged through personal communication and demonstration, from master to apprentice, from parents to children, and from neighbor to neighbor. It is stored in people's memories and activities and is expressed in the form of stories, songs, folklore, proverbs, dances, myths, cultural values, beliefs, rituals, and community laws. ITK is shared and communicated orally by specific examples and through culture (Das 2009). It is gradually gaining momentum in every field of development. Some of the ITK related to rice research has been outlined below for ease of comprehension (B. Parashar, personal communication, 2010).

Control of rice leaf roller *(Cnaphalocrocis medinalis)*

Cut pieces of bamboo shoots about a half inch in size are soaked in 2–3 L of water overnight. The next morning, water from a container is collected and mixed with fresh water and sprayed over the affected field by means of a broomstick, preferably during morning hours. One kg of cut pieces of bamboo shoots in 10 L of water is used to cover about 10% of the area affected by leaf roller.

Stems of fish-tail palm having the web of a spider are chosen and dibbled in the affected field, and they attract other spiders within 2–3 days to the crop field. These spiders together feed on leaf roller and thus the crop is saved. This predator is identified as a wolf spider. They are good hunters, active, and very quick in their movement. They feed on insects such as brown planthopper, whitebacked planthopper, green leafhopper, leaf roller, case worm, and whorl maggot.

Control of rice case worm *(Nymphula depunctalis)*

A weed locally known as *Kolathia* (*Tephrocea purpurea*) is used to control case worm infestation in rice. Bundles of such weeds are scattered in the field and pressed in the mud. The plants decompose and mix with the soil, and consequently compel the case worm to leave the field.

The seeds of *Suan* (*Panicum milliare*) are kept in the water passage of the rice field and during irrigation the seeds are scattered throughout the field by the flowing water within a few hours. It is interesting to note that, by doing so, the infestation of case worm in rice decreases significantly.

Dried maize stems without leaves (10–12 stems per 100 m^2) are placed inside case worm–infested fields in a scattered manner to check the infestation of case worm in rice.

Begunia (*Vitex negundo*) or *Karada* (*Polyalhia tuberoja*) branches (4–5 branches per 100 m^2) are placed in the infested field in a scattered manner to control case worm infestation in rice.

The umbilical cord of new-born babies is sun-dried and preserved with *"sindur,"* which acts as a preservative for controlling case worm infestation in rice. The umbilical cord is carefully tied with a piece of clean cloth and is kept in the water passage with the help of a wooden peg for support. During irrigation, it is believed that the chemical substance present in the umbilical cord mixed with water spreads throughout an infested field and acts as a repellant for the case worm.

Control of rice gundhi bug *(Leptocorisa varicornis)*

Snails available in the water mass are collected, killed, and broken into small pieces. These broken pieces are kept for 2–3 days for rotting. A handful of such rotten snails is kept in a cloth and tied to the tip of a stick. Ten to 15 such sticks are prepared and installed in a gundhi bug–infested field covering an area of about 0.4 ha. The rotten snails placed in different places emit a foul smell and act as a repellant for gundhi bug, thus effectively controlling infestation of gundhi bug in rice.

Control of green leafhopper *(Nephotettix virescens)* in rice

Green leafhoppers in rice are controlled by putting a locally available tree known as "*Raata*" in the early morning only on Saturday or Sunday in an infested field.

Control of rice stem borer *(Scirpophaga incertulas)*

The control of this pest with the help of a bird predator is quite interesting. A branch of *Kendu* tree (*Coromandel ebody*) is dibbled in a stem borer–infested field. The bird predator locally known as "*Bhadua*" sits over the dibbled branch and observes the behavior of the stem borer moth. The predator catches the flying stem borer moth and feeds on it. Thus, the traditional wisdom possessed by farmers effectively controls the infestation of stem borer in rice.

Control of rodents

Dried banana leaf sheaths are kept in the paddy field when the rice crop is ready for harvest. Rats are scared by the peculiar sound produced by the dried banana leaf sheaths during the night and do not enter the rice field at harvest time.

Deseeded maize cobs are placed randomly in the paddy field when the rice crop is ready for harvest. The rats, seeing the deseeded cobs during night time, sense the presence of some other animals, get scared, and leave the rice field.

Use of herbal pesticides in rice

Herbal mixtures are made with 1 L of neem oil, 3 kg of fine sand, and 3 kg of cow dung, and are kept in shade for 3 days. The herbal mixture is dissolved in 150 L of water on the 4th day and sprayed uniformly in the rice crop. The antifeedant property of neem oil used in the herbal mixture acts as a repellant for sap-sucking insects and thus effectively controls the infestation of green leafhopper, brown planthopper, gundhi bug, aphids, and thrips in rice.

By-products of rice specific to the state

The people of Odisha prefer to consume parboiled rice. Parboiling not only improves milling quality and head rice recovery but also enhances the nutritional and cooking quality of rice grain. Several processed products and by-products of rice are used in Odisha. The physico-chemical properties of grains of a rice variety and the amount and type of starches determine their suitability for the preparation of a particular processed product. Flattened or flake rice, popped rice, and puffed rice are used as breakfast food. Rice cakes, sweets, puddings, and special dishes are prepared from many varieties of rice grown in Odisha. A special and very common preparation of rice in Odisha is cold rice or *Pakhala.* Parboiled rice is considered suitable for the preparation of "cold rice." It is cooked rice mixed with water and eaten either fresh or kept overnight for a little fermentation. The overnight cooked and water-soaked rice is believed to have medicinal properties and to make the body system cool. *Handia* is a fermented rice product consumed by the tribal people of Odisha and is considered to be a natural drink and possess a cooling effect. Considering the importance of several processed and value-added products of rice, it is desirable to collect, identify, characterize, and preserve such rice varieties and valuable germplasm suitable for various processed products in rice (Sharma et al 2008).

Special development programs in the rice sector of the state and status of recent methods/technologies

Important strategic interventions were taken up by the Directorate of Agriculture, government of Odisha, under the work plan for Macro Management of Agriculture, in centrally assisted programs such as Rashstriya Krishi Vikas in Yojana (RKVY), National Food Security Mission (NFSM), National Project on Management of Soil Health and Fertility, etc., for increasing the production and productivity of rice in the state.

Under Macro Management of Agriculture, efforts were made for farmers' training in a farmer field school (FFS), on important aspects of rice production such as soil testing, land preparation, variety selection, SRI method, demonstration on integrated nutrient management, integrated pest management, integrated weed management, postharvest technology, and a package of production of quality paddy seeds. This program was carried out in the 15 non-NFSM districts during 2008-09. Similar programs were also proposed for 2009-10 (Table 12).

The National Food Security Mission (NFSM)–Rice launched during 2007-08 operating in 15 districts of the state made some important strategic interventions such as demonstrations on an improved package of practices for high-yielding varieties, hybrid rice, the SRI method, seed production, incentives for farm implements, and farmers' training in a farmer field school during 2008-09 for increasing production and enhancing the productivity of rice in a sustainable manner. The achievements of the program during 2008-09 and the proposed plan for 2009-10 are presented in Table 13.

Table 12. Achievements during 2008-09 and program for 2009-10 under Macro Management of Agriculture.

Component	2008-09 achievement	2009-10 program
Demonstrations		
SRI in hybrid/HYV rice technology	864 hectares	864 hectares
Rice-based cropping system	72 hectares	47 hectares
Seeds		
Subsidy on certified seed distribution	4,013 tons	5,136 tons
Subsidy on green manure seed distribution	42.5 tons	200 tons
Incentives on certified seed production	2,000 tons	5,063 tons
Training activities	566	619
Farmers' exposure visit		
Outside the state	5 groups	4 groups
Inside the state	405	400

Source: Activity report of Agriculture Department for 2008-09.

Table 13. Achievements during 2008-09 and the program for 2009-10 under NFSM-Rice.

Component	2008-09 achievement	2009-10 program
Demonstrations of SRI	3,391 ha	543
HYV rice technology	996 ha	272 ha
Improved package of practices	3,509 ha	1,630 ha
Certified seed distribution	11,764 tons	22,000 tons
Hybrid rice seed distribution	29 tons	200 tons
Seed minikit distribution (no.)	45,549	40,270
Liming for soil acidity amelioration	84,073 ha	80,400 ha
Rectification of micronutrient-deficient soils	27,535 ha	68,400 ha
PP chemicals at subsidy for pest control	25,986 ha	50,000 ha
Farmers' training in FFS	456	552
Cono weeder and other implements at subsidized cost	8,226	9,000
Pump sets provided at subsidized cost	7,036	5,000

Source: Activity report of Agriculture Department for 2008-09.

Institutes involved in rice development in the state and their contribution

Central Rice Research Institute

It is one of the leading rice research institutions of the country and was established in Cuttack in 1946. It had the responsibility to initiate, strengthen, and intensify organized rice research to support and to transfer technology relevant to the entire country. The administrative control of the institute was transferred to the Indian Council of Agricultural Research (ICAR), New Delhi, in 1966. During the last 65 years of its existence, the Institute has not only released more than 85 rice varieties suitable for almost all agroecosystems and with tolerance of most of the major insect pests and diseases but also developed several viable rice production technologies for the farming communities of the whole country. Besides the development of HYVs, the Institute is also credited with the development of three late-duration hybrids, Ajaya, Rajalaxmi, and CRHR 32, suitable for rainfed lowlands. The Institute is responsible for the collection, evaluation, conservation, and exchange of rice germplasm and the generation of appropriate technology through basic and strategic research for increasing and stabilizing the productivity of rice and rice-based cropping systems in the rainfed ecosystem of eastern India.

The Institute maintains more than 25,000 accessions of rice germplasm, including nearly 6,000 accessions of the Assam Rice Collection (ARC) and 5,000 accessions from Odisha. Passport information on more than 29,000 germplasm lines has been compiled and submitted to the NBPGR, New Delhi.

The applied research carried out at this Institute generates appropriate technologies for increasing and sustaining productivity and income from rice and rice-based cropping/farming systems in all ecosystems of the country, thereby improving the income and quality of life of rice farmers in India. Apart from basic and applied rice research, it works on the characterization of rice environments and the evaluation of different constraints to rice production under different agroecological conditions and develops remedial measures for ameliorating the situation. The

Institute also maintains a database on rice ecology, ecosystems, farming situations, and comprehensive rice statistics in relation to the production and productivity of rice for the whole country. The Institute trains rice research workers, trainers, and subject matter specialists/extension specialists on improved rice production and rice-based cropping and farming systems. Some other significant contributions of CRRI follow:

- Use of DNA markers for genetic analysis of bacterial leaf blight, blast, and gall midge resistance and use of marker-assisted selection for pyramiding BLB-resistance genes and the development of BLB-resistant lines in the background of Swarna and IR64.
- Development of rice-based farming systems for ensuring food and nutritional security, and stable income employment generation for rural farm families.
- Development of N management strategies for increasing N-use efficiency for rainfed lowlands through the use of integrated N management.
- Development of eco-friendly and economically viable technologies for fewer greenhouse gas emissions from tropical paddy.
- Development and use of agricultural implements such as manual seed drill, drum seeder, multicrop bullock- and tractor-drawn seed drill, flat disc harrow, finger weeder, conostar weeder, paddy transplanter, rice husk stove, mini parboiler, and power thresher to reduce drudgery and cost of cultivation.
- Evaluation, development, and testing of several plant-based products with pesticide potential against field and storage insects and pathogens.
- Development of a nondestructive screening technique based on chlorophyll fluorescence spectrophotometry to identify submergence-tolerant rice germplasm.
- Crop modeling of G × E interaction studies to indicate the simulation of crop growth under various environments.
- DUS testing facilities and Institute Profile, Crop Profile, and Rice Knowledge Bank were developed.
- The Institute provides consultancy services and training for scientific and technical personnel from state agriculture departments, different agricultural universities, and other educational institutions.

Odisha University of Agriculture and Technology, Bhubaneswar

Under the university setup, major emphasis was given to varietal improvements in rice. The Rice Research Station, Bhubaneswar, was responsible for the development of rice varieties for almost all ecosystems. It continued functioning with an assistant economic botanist as a full-time worker and a reader of the Department of Plant Breeding and Genetics as a part-time worker. Rice research in different disciplines was confined to different departments of the College of Agriculture, Bhubaneswar. The Rice Research Substation at Berhampur has been redesignated as a Regional Research Substation to carry out research on crops other than rice and since then the station has become a location for rice variety testing. Similarly, rice research at the Jeypore Substation has become only a center for variety testing with a junior rice breeder funded by AICRIP (All India Coordinated Rice Improvement Programme). However, rice breeding got infrastructure for variety testing with the establishment of Regional Research Stations, one in each of the ten agro-climatic zones in Odisha. The Regional Research Station, Chiplima, a center for conducting the AICRIP test program on rice breeding, agronomy, entomology, and pathology, started functioning in 1970 with specialists in each of the above disciplines.

The breeding program in Odisha on short high-yielding varieties, in fact, dates back to 1957. A mutation breeding program yielded a short mutant, BBS 873, from popular lowland tall rice variety T 141. The mutant was photosensitive (while modern semidwarfs such as TN 1 and IR8 possess the *dgwg* dwarfing gene and are photo-insensitive), moderately responsive to nitrogen fertilization, matured in about 155 days, and yielded about 50% more rice than parent T 141 in shallow-water land conditions. BBS 873 was released as Jagannath by the Central Variety Release Committee (CVRC) in 1969 for lowlands for the coastal districts of Odisha, West Bengal, and Andhra Pradesh. For a decade or so, Jagannath had been the leading high-yielding variety in Odisha.

Breeding for short high-yielding varieties was accelerated after the introduction of two short varieties, TN 1 from Taiwan and IR8 developed at IRRI, into India in 1965 and 1966, respectively. These two varieties of exotic origin ushered in a revolution in rice production and were extensively used in the hybridization programs for indigenous development of high-yielding rice varieties, primarily for irrigated lands and for rainfed uplands and medium lands. Varietal improvement for lowlands was intensified in the late 1970s. Altogether, 55 HYVs have been released during the last 40 years and these are shown in Table 14.

Some of these varieties that have gained popularity among the farmers of Odisha and neighboring states and that are cultivated in a sizable area follow:

- Parijat, Pathara, Khandagiri, Udayagiri, Sidhant, and Mandakini for uplands in kharif and irrigated lands in rabi season.
- Lalat, Konark, Jajati, Gouri, Gajapati, Surendra, and Pratikshya in medium rainfed and irrigated lands.
- Kanchan, Mahanadi, Indravati, Jagabandhu, and Upahar in lowlands.

The AICRIP and INGER, besides assisting variety evaluation, assured a free flow of elite germplasm to participating breeders. The rice breeding program at OUAT has benefited greatly because elite lines made available under the systems are being used as parents in the hybridization program. In 1980, OUAT introduced IR36 for commercial cultivation in Odisha. Materials have also gone in the opposite way. In 1985, through INGER, rice breeders in Cambodia identified the suitability of an OUAT breeding line, OR 142-99 (Pankaj/Sigadis), as promising and later released the line under the popular name Santep Heap-3 for commercial planting and the variety is now one of the leading varieties of the country. In 1992, variety Rambha

Table 14. High-yielding varieties (HYVs) released during the last 40 years.

Year of release	No. of HYVs released	Variety
1969	1	Jagannath
1971	3	Hema, Kumar, Rajeswari
1976	2	Parijat, Suphala,
1980	3	Keshari, Subhadra, Jajati
1983	5	Shankar, Rudra, Sarathi, Daya, Pratap
1985	3	Pathara, Gouri, Rambha
1988	4	Shrabani, Lalat, Ananga, Bhuban
1992	12	Nilagiri, Khandagiri, Badami, Ghanteswari, Birupa, Bhanja, Samant, Meher, Manik, Urbasi, Mahalaxmi, Kanchan
1999	12	Lalitagiri, Udayagiri, Bhoi, Sebati, Konarka, Kharavela, Gajapati, Surendra, Prachi, Mahanadi, Indrabati, Ramachandi
2002	1	Jagabandhu
2005	4	Sidhanta, Jogesh, Pratikshya, Upahar
2008	1	Manaswini
2009	1	Ranidhan
2010	3	Mandakini, Tejaswini, Mrunalini

(Pankaj/W 1263) was identified as suitable for Myanmar and Sarathi (T90/IR8//W 1263) for irrigated lands in Thailand, Malayasia, Indonesia, Vietnam, Bangladesh, and Egypt. In 2000, one of our lowland varieties, OR 1128-7-1, was released in Tamil Nadu under the popular name of ADT 44.

Besides applied research on rice breeding and varietal improvement, basic studies with relevance to the HYV breeding program have been going on since the 1980s, and some of the important findings follow:

- A competition study involving four established early varieties (Annapurna, Parijat, Suphala, and Bala) showed Annapurna to be the most competitive, followed by Parijat; there appears to be a relationship between competitive ability and adaptability.
- The Annapurna + Parijat combination was the best forming mixture, with more than a 14% yield increase over that of monoculture.
- Heterotic hybrids often generate better recombinants in the advanced generation.
- Inheritance of short height in mutant variety Jagannath appeared to be multigenic.
- Both additive and nonadditive gene action are important in the inheritance of yield and its components grain number and 100-grain weight.
- Selection response is higher for grain yield as a basis of selection than any of its important components.
- Submergence tolerance is governed by a few dominant genes; growth vigor, sturdy stem, tight leaf sheath, and regeneration ability greatly improve the expression of tolerance.
- Standardization of rapid generation advance (RGA) in lowland rice.

In lowland breeding programs for advancing the segregating population, it normally takes 7 years to reach homozygosis as only one crop can be raised in a year because the plants are photosensitive with strong seed dormancy. On the other hand, it takes only 3 to 4 years in the case of photo-insensitive short breeding materials that can be grown to maturity in both kharif and rabi. The following method for rapid generation advance has been standardized to raise a rabi crop of photosensitive breeding materials:

- Collect bulk seed samples from each of the breeding populations of F_2 through F_5 at the latest by the last week of December in the kharif season.
- Dry the seeds in the oven at 55 °C for 5 days.
- Do direct seeding in the field at the latest by 10 January.
- In May-June, collect ears from the bulk population on the basis of visual selection for grain number and grain quality and use them in raising pedigree lines in the ensuing kharif.
- Do normal single plant selection for plant type and better agronomic features in the wet season.

Success has been achieved in the generation of appropriate adoptable technologies in the field in varietal improvement and production, protection, and conservation (storage) technologies over the years of location-specific research in different agro-climatic zones of the state and their adoption has resulted in the boosting of rice production to a comfortable stage in Odisha. Some important findings in rice research in other disciplines follow.

Agronomy

Poor agronomic management is the single most important factor for the chronically low yield of rice in Odisha. However, many of the agronomic problems can be attributed to socioeconomic factors and the following agronomic problems need priority attention: a delay in farm operations, particularly in seeding/planting and weeding; low plant population, to a considerable extent due to harsh intercultural operations for weed control, such as the use of a tooth-harrow (*bida*) in upland rice and beushening in medium or lowland rice; and insufficient fertilizer application. The following measures improved crop management:

- Seeding in lines at a depth of 4–6 cm was effective in raising a rice crop with a good stand and facilitating weeding by hoeing or a rake weeder in uplands.
- In lowlands, a well-managed rice crop involving dry seeding plus beushening is as good as one using transplanting. To maintain the plant population, beushening is to be followed by *khelua*, preferably with seedlings raised in the nursery on about one-tenth of the area of the same piece of land.
- In a beushened crop, all P can be applied at the time of seeding or at the time of beushening along with all K and one-half N; the remaining one-half N is to be applied 30 days later.
- In lowlands, planting of aged seedlings (50 to 60 days old) would be more remunerative under adverse soil conditions or in postflood situations.
- Organic farmyard manure at 5–6 t/ha in combination with 100 kg of N per ha produced the highest yield on medium lands.
- Split application of slow-release nitrogenous fertilizers such as urea supergranules gave maximum net returns in lowland rice.

Soil science

One of the major contributions of the Department is its findings on the use of insoluble sources of P fertilizer in Odisha soil. Research efforts on P management have been directed toward the cropping system as a unit instead of an individual crop. The major recommendations in rice-based cropping systems follow:

- Rock phosphates can be applied directly to a crop in a highly acidic soil with pH 5.0 or less.
- In moderately acidic, neutral, or saline soils, mixtures of rock phosphate and single superphosphate in the proportions of 3:1 or 1:1 were found to be as effective as superphosphate on crop yield.
- In rice-rice or rice-based cropping systems, the required P should be applied to the rabi crop; the next crop is to be raised on residual P.
- Studies on long-term P fertilization response to phosphate observed that soil P went down to 10 kg/ha in kharif and 15 kg/ha in rabi.
- Potassium application reduced adverse effects of iron toxicity in both tolerant and susceptible varieties.

Plant physiology

- Drought tolerance in rice varieties at different stages of growth and different levels of water stress indicated significant varietal differences in relation to days to wilting, chlorophyll content, proline content, and nitrogen reductase activity in leaves.
- The uptake of N, P, and K decreased and there was a reduction in seed protein in soils with high iron toxicity.
- Shoot dry matter production at flowering and grain-filling stages, and shoot K content at flowering stage are used as parameters for predicting yield in rice.
- Treatment with 20 ppm of GA under field conditions caused an early canopy buildup and gave a competitive advantage over weed growth up to 45 days and application of boron at 2 kg/ha enhanced crop yield in upland rice.
- Spraying of borax at 0.25% (2.5 g in 1 L of water) at 5–10 days before flower initiation helped reduce chaffiness of grains in seed production plots.

Entomology

Yellow stem borer causes serious damage to the rice crop in almost all rice ecosystems while rice in irrigated and shallow-water lowlands suffers because of a number of insect pests such as gall midge, brown planthopper, whitebacked planthopper, and green leafhopper, and to a moderate extent gundhi bug and rice hispa.

A study of incidence over the years showed that the insect pest pattern changed and continued changing. Gall midge was one of the most damaging pests in the 1960s and 1970s and since then its seriousness has been greatly suppressed. Brown planthopper was a serious pest up to 1985 and again revived in the late eighties. Whitebacked planthopper was a serious pest in the 1970s and 1980s, attacking the rice crop at the vegetative stage up to August. Now, it causes damage in Novemeber when the crop is in the reproductive phase and it also damages summer rice. Thrips and whorl maggot were not recorded as serious pests till the mid-seventies and now they are regular in occurrence.

Some important recommendations for insecticidal control measures for different insect pests follow:

- One or two applications of phosphamidon at 0.3 kg a.i./ha at the boot leaf/flowering stage resulted in a reduction in hopper incidence.
- Dipping of whole seedlings in chlorpyriphos solution (0.09%) for 1–2 minutes was most effective in suppressing deadheart (DH) up to 40 days after transplanting. It was, however, recorded that the use of chlorpyriphos caused a resurgence of BPH and WBPH.
- Foliar application of monocrotophos at 0.4 kg a.i./ha at 20 days after sowing (DAS) proved very effective against stem borers, gall midge, leaffolder, grasshopper, and whorl maggot. Further, spraying with monocrotophos at 0.5 kg a.i./ha at 70 DAS successfully arrested the activities of gundhi bug and stem borers at the heading stage of the rice crop.
- Application of Flubendiamide + Buprofezin 20 SC at 35 g a.i./ha at 30 and 45 DAT controlled stem borer, gall midge, and BPH effectively.
- Seed treatment with neem products such as neemazal at 10,000 ppm (1.5 mL/kg seed) and Econeem at 3,000 ppm (5 mL/kg seed) provided effective management of stored grain pests infesting paddy for 3 months after storage.

Pathology

Bacterial leaf blight is the most serious disease of the rice crop in all the rice ecosystems. Considerable crop damage occurs also due to blast, sheath rot, and brown spot. False smut assumed epidemic proportions in 1992 and grain discoloration occurred regularly in years of high rainfall and caused yield loss and affected grain quality in rice:

- A complex set of pathogens such as *Helminthosporium oryzea, Curvularia* spp., *Trichoconis padwicki, Aspergillus* spp., *and Fusarium* spp., along with a bacterial pathogen, *Ralstonia* spp., are involved in grain discoloration. The conducive factors for grain discoloration are high humidity and moderate temperature.
- Soil application of kitazin at 3 g/m^2 before flowering was effective against sheath blight and sheath rot.

Nematology

White-tip nematode (*Aphelenchoides besseyi*) and rice root nematode (*Hirschmanniella* sp.) are of wide occurrence in rice. A number of other nematodes such as *Ditylenchus anqustus* and *Meloidogyne graminicola* (root-knot nematode) are also found causing damage to the rice crop:

- Screening for resistance to root-knot nematode showed a high degree of resistance in as many as nine rice varieties and breeding lines, including rice variety Manik suitable for lowland situations. Resistance in Manik was due to the activity of two enzymes, tyrosin ammonia-lyase and phenylalanine ammonia-lyase.
- A survey revealed the occurrence of root-knot nematode in upland and medium land soils. Seed soaking with 1% carbosulfan 25 EC reduced root-knot nematode infestation in rice.

M.S. Swaminathan Research Foundation

The M.S. Swaminathan Research Foundation (MSSRF) is a nonprofit research organization and was established in 1988. It carries out research and development in six major thematic areas: coastal system research, biodiversity, biotechnology, ecotechnology, food security, and information, education, and communication. It carries out research and development through regional centers in Tamil Nadu, Pondicherry, Kerala , and Odisha (MSSRF, Annual Report 2010).

The MSSRF has been working in the Jeypore region of Odisha for the last 12 years. Activities in the area include the conservation of biodiversity; promotion of sustainable livelihoods through micro-level interventions; the establishment of community-managed gene, seed, grain, and water banks; promotion of genetic literacy; and documentation of local conservation traditions:

- The MSSRF, in collaboration with CRRI-Cuttack, KVK-Semiliguda, and the Odisha Rural Development and Marketing Society (ORMAS), undertook a project to enable enhanced income generation through large-scale cultivation and value addition of market-driven prominent, potential, and promising rice landraces Machhakanta, Kalajeera, and Haladichudi.
- Establishment and management of community seed and grain banks to avoid seed consumption by farmers during lean periods and ensure a community-managed food security system.
- Establishment of community gene banks to preserve farmer-conserved varieties to revitalize the agrodiversity conservation tradition of tribal and rural farm families. With the support of the DUS descriptors, the gene bank has taken the initiative and facilitated the registration of farmers' varieties still available in Koraput District (Jeypore area) to provide rights to farmers as prescribed under the Protection of Plant Varieties and Farmers' Rights Authority (PPVFRA).

Constraints to rice production

The annual productivity gains for rice in eastern India were only 36 kg/ha vis-à-vis 44 kg/ha in India during 1970-71 to 2003-04. The annual productivity gain for rice in Odisha was only 24 kg/ha during the last 35 years. This is mainly due to the concentration of rainfed area under rice in the region, which constrains the adoption of available technology, and a lack of dependable market support, which makes the cropping and associated technology used in the production process uneconomical (Naik et al 2008).

Our understanding of the production constraints that tend to reduce yield and factor productivity in rice farming and strategies to remove them are still inadequate. Several studies have been made in the past to examine the constraints and the strategies to eliminate them at the farm level but the impact of these efforts at the farmers' level is marginal. Therefore, an analysis is made to consolidate the production constraints of rice and broadly group them under biophysical, technological, institutional, and socioeconomic constraints that are known to limit rice production

Biophysical constraints

Frequent occurrence of drought and flood. The plateau regions, that is, the southern and western parts of Odisha, are prone to drought while the coastal districts are prone to flood with saline water inundation into the cultivated area in the coastal belts.

Farming communities experience drought once in three to four years due to scanty and erratic rainfall. A loss of 1.9 million tons and 1.77 million tons of paddy occurred during 1982-83 and 1987-88, respectively, in the state due to severe moisture stress. Similarly, during 1992-93 and 2002-03, dry spells resulted in estimated crop loss varying from 35% to 50% due to drought and erratic rainfall. Therefore, the average rise in productivity of rice in the state is estimated to be only 24 kg/ha. It is therefore suggested to do research not only on varietal improvement but also on the refinement of existing production technologies suitable for rainfed areas to combat moisture stress in drought years.

Frequent floods in the coastal regions of the state lead to waterlogging, submergence, and siltation, thus causing maximum damage to crops of the state. The coastal deltaic alluvial plains comprising the districts of Cuttack, Puri, Balasore, Bhadrak, Kendrapara, Jajpur, Jagatsinghpur, and Ganjam are most vulnerable to floods and salinity, affecting 380,000 hectares in Odisha. Due to recurrent floods, the rice crop is transplanted three to four times and transplanting continues until the second week of September and the average yield is as low as 0.5–1.0 t/ha. Rice varietal tolerance of flash flood and production technology for late-planting conditions can improve productivity to 1.0–2.5 t/ha in flood-affected areas of the state.

Poor irrigated commands and low and imbalanced input use. Nearly 35% of the total rice area in the state is irrigated and, in the irrigated commands, rice productivity is only 2.8–3.4 t/ha. Farmers apply only 50–60% of the recommended dose of fertilizer in irrigated rice and 25–30% of the recommended dose in rainfed rice. The application of NPK fertilizer in the wet season in an irrigated district such as Puri is 2.93:0.44:1.0 and in a rainfed district such as Mayurbhanj is 5.3:1.6:1.0, which is imbalanced. The low productivity in this favorable ecosystem is due to low and imbalanced input use and therefore 50% of the potential yield of high-yielding varieties grown in these areas is not realized, causing a loss in productivity.

Soil problems. The major soils of Odisha are predominantly red and yellow laterite and lateritic soils. The soils are highly leached, low in exchangeable base and acidic, and low in organic matter and in nitrogen, phosphorus, and potassium. Soil texture varies from sandy, sandy loam, and loamy to clayey depending on the topography. In the higher reaches, soils are coarse textured and highly drought prone.

Technological constraints

Lack of flexible technology options for varied rainfall situations. Farmers do not have much flexibility in making management adjustments in rice cropping due to the frequent occurrence of drought and erratic rainfall regarding choice of variety, sowing time, and method of crop establishment. Farmers mostly follow a standard set of practices even under the occurrence of drought, flood, and irregular rainfall. This fixed set of technology does not meet their needs during changing climatic situations such as delayed monsoon, early drought, and continuation of stress for a longer period, resulting in poor yield (Naik et al 2008).

Preventive and contingent measures as suggested by the Directorate of Agriculture and Food Production, government of Odisha, in association with the Directorate of Research, Odisha University of Agriculture and Technology, regarding the selection of efficient crops and cropping systems, varietal choice, agronomic management, including time and method of crop establishment and input use, etc., need to be available to farmers for risk management in agriculture. It is imperative to provide information on flexible technologies to mitigate risks such as early-, medium-, and late-season droughts, floods, delay in beushening, delayed transplanting, infestation of insect pests, and diseases to sustain the production and productivity growth of rice in the state.

Delay in sowing/transplanting. This is the major cause of low yield in the state and sowing and transplanting are delayed due to fluctuation in the onset of monsoon, erratic rainfall, and poor infrastructure. Delayed sowing of upland rice and transplanting of paddy after the third week of July adversely affect yield even with proper crop management practices. Infrastructure development in irrigation, transportation, and electricity is inadequate and not that effective; in fact, the shortage of electricity and efficient farm laborers is acute and this causes delays in farm operations such as seeding, transplanting, and intercultural operations associated with rice cultivation.

Continuance of the rice-rice cropping system. The rice-rice cropping system in irrigated commands deteriorates the physical condition of soil, encourages physiological disorders, and creates problems of multinutrient deficiencies such as phosphorus, zinc, and sulfur, thus causing a decline in factor productivity in rice. Rice-based cropping sequences in different ecosystems such as rice-horsegram/blackgram/greengram in uplands, rice-mustard/Bengalgram/blackgram/lentil/greengram in medium lands, and rice-Bengalgram/blackgram in lowlands will not only increase rice productivity but also improve the physical condition of soil.

Institutional constraints

Lack of research-extension linkage. The lack of proper research-extension linkage is the cause of the low adoption of improved technologies, which tends to constrain the yield of rice. It is desirable to provide location-specific research support emerging from the Regional Agricultural Research Stations to the farming community and implement the newly developed technologies at the farm level by extension workers to enhance and sustain the productivity of rice. However, the regional research system is becoming weak and has poor or no linkage with the extension setup.

Inadequate credit facilities. As 65% of the total rice area is rainfed, rice is mainly grown as a rainfed crop and is mostly dependent on monsoon rainfall. Returns from crop cultivation are not assured and this ultimately affects the repaying capacity of the farmers. Therefore, credit institutions are not encouraged to extend credit support to farmers for implementing modern rice production technologies for increasing production and productivity of rice in the state. It is found that the availability of credit is only Rs.1,269/ha in Odisha compared with Rs.5,340/ha at the national level and Rs.5,353/ha in Andhra Pradesh (Naik et al 2008). The poor credit delivery system is one of the main causes of the low productivity of rice.

Nonavailability of quality seeds and fertilizers. The lack of timely availability of quality seeds and fertilizers is another factor limiting higher productivity. Seed replacement of rice in Odisha is only 6–7%. More than 50% of the farmers use their own seeds, which they grow for 10–15 years with low genetic potential. The use of fertilizer is lower in Odisha than in other regions of the country. Thus, the use of genetically poor-quality seeds and the application of a suboptimal level of fertilizer fail to realize the genetic potential of the high-yielding varieties grown in the region. The formal arrangement of seed production strategies for supplying quality seeds to farmers is not adequate and has not met the requirements of even 25–30% of the farmers.

Socioeconomic constraints

Farming community. The farming community in Odisha can be grouped into four different classes. The first is scheduled tribes, constituting about 25% of the total population of the state and largely in the plateau region. They have confined themselves to the cultivation of dryland rice on the top and slopes of the hills. They are small farmers or landless laborers. They have not yet given up *Podu* or *Jhum* cultivation and the practice of collecting grains of wild rice (apparently the earliest phase of domestication of rice) is still prevalent among certain tribes in the Jeypore tract. Scheduled castes constitute nearly 15% of the total population. They are mostly landless or small farmers and constitute a greater proportion of the agricultural labor force. Middle-caste farmers constitute almost 50% of the population. They are small and marginal farmers and/or sharecroppers. This class of farmers constitutes the backbone of Odisha's agriculture. High-caste farmers in general own a relatively better class of rice lands with inherent high soil fertility and productivity. They have medium- and large-size farm holdings. The benefits of high-yielding varieties have mostly gone to this class. However, a large number of them are absentee landlords and they lease their land to sharecroppers; this shift from owner-farming to sharecrop farming is on the increase. Net profit is high for the landlord; in a way, it is unearned profit. The sharecroppers are not expected to carry out any land improvement or better crop management involving investment in inputs. Thus, productivity remains low.

Small and fragmented landholdings. Due to continuous fragmentation of landholdings, almost 70% of the rural households have holding sizes of less than a hectare. A majority of the rural households (about 82%) are small or marginal farmers or landless agricultural laborers and resource poor. Thus, they are unable to adopt modern rice production technologies such as high-yielding varieties, quality seeds, recommended doses of fertilizers and pesticides, and the use of agricultural implements for increasing productivity in rice.

Concentration of poverty. Rural poverty and rural indebtedness are the highest among the small and marginal group of households. About 48% of the rice farmers in Odisha are below the poverty line and are resource poor. Absent landlordism is rampant and involves mostly the so-called high-caste households that coincidently have the most productive agricultural lands. They commonly put their lands into sharecropping, which is not conducive to high productivity.

Poor credit-market-technology linkage. Farmers usually fail to recover the cost of paddy production in the existing market infrastructure. Because of the poor procurement strategies of government organizations, farmers depend on traders and are exploited by mill owners to sell their marketable surplus at prices less than the minimum support price. A majority of farmers in rainfed areas are resource poor and do not have the ability to avail of institutional credit. They grow traditional rice varieties to overcome the risk associated with rainfed rice farming, resulting in low productivity of rice. Thus, the poor performance of agriculture is the major cause of the low credit-deposit ratio in the state. This situation results in a poor credit flow to agriculture and per hectare credit in Odisha is lower than in other states of the country. Therefore, the lack of dependable market support, poor flow of credit to agriculture, and nonadoption of modern rice production technology, that is, lack of credit-market-technology linkage, is the cause of low rice productivity in Odisha.

Major constraints to rice production in different ecosystems

The major constraints limiting rice production in different ecosystems are summarized in Table 15 and discussed below:

The rainfed rice ecosystem. Erratic rainfall and uncontrolled water situations are the major constraints in rainfed ecosystems; some of the adverse factors in the rainfall pattern are

- A delay in the onset of monsoon adversely affects timely seeding.
- The break in monsoon is unpredictable in timing and duration and leads to intermittent drought.
- Continuous heavy rainfall aggravates waterlogging, flood, and submergence of the rice crop.
- Early cessation of monsoon likely causes terminal drought.

Rainfed upland ecosystem. Rainfed upland rice is generally cultivated in 700–1,100-mm rainfall zones. Upland or autumn rice is photo-insensitive with maturity duration of 100 days or less. The crop is direct-seeded in June after the onset of the monsoon and harvested in September and per hectare yield is about 700 kg/ha. The major constraints to rice yield in uplands are

- Erratic and often inadequate rainfall and lack of facilities for moisture conservation and life-saving irrigation.
- Fragile and impoverished soils with poor soil fertility.
- Soil erosion leading to losses of soil, nutrients, and moisture.
- Soil acidity leading to aluminum saturation, phosphate fixation, and aluminum and manganese toxicity.
- Iron chlorosis in alkaline/calcareous soils.
- Poor land preparation and stand establishment; low plant population due to direct seeding.
- Severe weed competition, intermittent drought, and inadequate use of fertilizer.
- Lack of suitable variety with resistance to moisture stress and seed dormancy and continued use of traditional low-yielding varieties.
- Pest and disease problems such as blast, leaf spot, gundhi bug, and stem borer.

Rainfed lowland ecosystem. Rainfed lowland rice is grown on around 1.5 million hectares mostly in the coastal regions where soil moisture is available for a longer period and photosensitive rice varieties of 140–155-day duration are grown. Water depth varies in rainfed lowlands and it can be shallow up to 25 cm, medium-deep waterlogged up to 50 cm, and deepwater rice where the water depth varies from 50 cm up to 2 m. The rainfed shallow-water ecosystem is further divided into four subecosystems: favorable, drought prone, submergence prone, and drought and submergence prone. Coastal Odisha is now

Table 15. Constraints to rice production in different ecosystems.

	Ecosystem	Major constraints
I.	Rainfed	65% of total rice area
	Upland	Weed growth, drought, and lack of suitable variety
	Medium land	Fairly stress free. High incidence of insect pests and diseases; poor variety-input management.
	Shallow lowland	High incidence of insect pests and diseases, waterlogging, adverse soils, flash flood, lack of wider choice of varieties with resistance to flood and submergence
	Semi-deepwater and deepwater rice	Seedling drought, waterlogging and adverse soils, flash flood, lack of suitable rice varieties with resistance to lodging and submergence, high incidence of stem borer and bacterial leaf blight
	Coastal wetland (saline)	Salinity less severe in kharif and acute after cessation of monsoon
II.	Irrigated	35% of total rice area
	Kharif (bunded) (upland, medium land, lowland)	Waterlogging, too much irrigation and rain water
	Rabi	Early cold adversely affects seedling growth in the nursery, insect pests and diseases, inadequate and untimely supply of irrigation water, poor variety-input management

under boro or dry-season rice because of the low productivity of deepwater rice. The major constraints to rice yield in different types of rainfed lowlands are presented below.

- **Rainfed shallow and semi-deepwater lowland rice**
  - Impeded drainage and waterlogging.
  - Accumulation of toxic substances due to ill-drained soil.
  - Soil reduction encouraging problems of iron toxicity and sulfide injury.
  - Flash floods causing inundation at vegetative phase and intermittent drought at various stages of crop growth.
  - Delay in monsoon often leading to delayed planting.
  - Agro-energy crisis and inadequate mechanization leading to delayed agricultural operations such as sowing, planting, and harvesting.
  - Poor stand establishment and suboptimal plant population.
  - Excessive weed growth under broadcast-sown conditions.
  - Poor tillering and reduced panicle production.
  - Inadequate and imbalanced use of fertilizer and other agro-inputs.
  - New emerging problems of multinutrient deficiencies such as P, zinc, and sulfur.
  - Continuous use of traditional low-input-responsive and low-yielding varieties.
  - Inadequate and untimely supply of quality seeds of recommended varieties.
  - Incidence of BLB, sheath rot, sheath blight, tungro, leaffolder, and stem borer.

- **Deepwater rice**
  - Traditional monocropping with long fallow periods.
  - Lack of appropriate HYVs possessing tolerance of submergence and elongation ability with rising water levels and built-in resistance to stem borer and sheath blight.
  - Delayed sowing and poor stand establishment due to high seedling and higher tiller mortality.
  - Inadequate and improper use of fertilizer.
  - Severe incidence of stem borer and Ufra nematodes, damage due to crabs during flooding, and rat damage at various stages of crop growth.

Shallow lowland and irrigated ecosystem. These lands (especially shallow lowlands) are considered less problematic and more suitable for intensive cultivation of modern short varieties, which are photo-insensitive with maturity duration varying from 115 to 135 days. The crop can be transplanted or direct seeded with beushening. A major problem is damage due to high incidence of brown planthopper, whitebacked planthopper, stem borer, gall midge, sheath rot, and bacterial leaf blight. Several high-yielding rice varieties combining high yield and resistance are available. The package of practices for growing the rice crop is fairly standardized for this ecosystem. Improvement in productivity could be possible through

- Timely seeding/transplanting and intercultural operations, particularly weeding.
- Better variety-input management.
- Integrated pest management with resistant varieties as the key component.
- The use of quality seeds of recommended varieties.

Coastal saline lands. Rice is also grown in coastal wetlands where tidal water inundation causes soil salinity. Around 300,000 hectares are under coastal salinity in Odisha. The most common characteristics of these lands are low-lying topography, inadequate drainage, and a fairly high water table of poor-quality water due to higher salinity and moderate to heavy soil texure. However, salinity of these lands remains low during the wet season due to dilution and leaching and reaches critical limits after the cessation of monsoon. Tall indica varieties such as Patnai 23 and SR 26B are grown during the kharif season and yield is very low (500–700 kg/ha). Getting a good crop stand is a problem because at the early stage the crop is highly sensitive to salinity.

- **The irrigated ecosystem**
  - About 1.55 million hectares (35%) of the total rice area in Odisha are under the irrigated ecosystem, where double cropping of rice is possible.
  - This ecosystem is mainly irrigated by gravity flow from the canal system. A sizable part of the rabi rice lands is watered by lift irrigation from rivers, tanks, and dug wells.
  - Irrigated kharif rice covers bunded uplands, medium lands, and lowlands. In kharif, irrigation is mainly protective in nature.
  - Uncontrolled irrigation in lowlands in kharif often aggravates the problem of waterlogging and soil health and adversely affects rice production.
  - The major problem limiting rice yield in the irrigated ecosystem is crop loss due to high incidence of insect pests such as yellow stem borer, brown planthopper, and whitebacked planthopper and diseases such as bacterial leaf blight and sheath rot.
  - A number of high-yielding rice varieties combining high yield potential plus multiple resistance are available.
  - High-yielding photo-insensitive varieties with maturity duration of 110–125 days in the dry season and 120–135 days in the wet season are ideal in this ecosystem.
  - Average productivity is 3.0 t/ha and seeds of modern rice varieties, fertilizer, water, and pest control technologies with concomitant input supplies have enabled farmers to achieve a substantial yield increase.
  - One of the major constraints to rabi rice cultivation is a delay in the availability of canal water.

Strategies and modern techniques to enhance rice production

The future priorities for increasing rice production and productivity in different ecosystems are summarized below:

- **Rainfed uplands**
  - Encouraging the present trend among farmers for shifting from rice to crops such as groundnut, soybean, sesamum, etc., or to rice-based mixed cropping.
  - Development of suitable machinery for line seeding and mechanical weeding.
  - Use of herbicides to control weeds effectively.
  - Land shaping (bunding, terracing, and leveling) to conserve rainwater and to reduce drought hazard.
  - Development of semi-tall high-yielding varieties with early seedling vigor and tolerance of intermittent moisture stress.

- **Rainfed medium lands and lowlands**
  - Timely seeding/transplanting and intercultural operations, particularly weeding.
  - Better variety-input management.
  - Use of quality seeds of recommended varieties.
  - Development and use of farm implements to reduce drudgery and enhance income through value-added products in rice.
  - Development of efficient postharvest technology and integrated farming system (subsistence monoculture to diverse commercialized system).

- **Irrigated ecosystems**
  - Yield in terms of paddy (not milled) in irrigated lands is still low, about 3.0 t/ha in kharif and 3.5 t/ha in rabi, that is, only 50% of the potential yield has been exploited in spite of the availability of suitable varieties and an appropriate package of practices.
  - Better variety-input management and suitable water management can raise productivity considerably.
  - Increasing production by growing hybrid rice varieties with higher yield potential.
  - Increasing input-use efficiency and factor productivity while securing environmental quality (ICM, SRI)
  - Integrated pest management (IPM) with resistant varieties as the key component.
  - Integrated nutrient management (INM) of both organic and inorganic fertilizer for enhanced rice production.

Conclusions and future outlook

Total rice production in Odisha in 2009-10 was recorded as 6.94 million t with productivity of 1,572 kg/ha. The targeted rice production of 10.13 million t (at compound growth rate of 3.5%) with productivity of 2,295 kg/ha by 2020 has been computed over the rice production in 2009-10.

However, rice production during the preceding years varied greatly from year to year (Table 2 and Fig. 1). Thus, yield fluctuation is a serious concern and all efforts need to be directed not only to attain the targeted production of 10.00 million t but also stability in rice production. It is equally important to identify the factors responsible for yield fluctuation during this period.

The slow and fluctuating growth rate of rice production in Odisha is considerable due to several important interacting factors:

- Rice area is shrinking as prime rice lands are being used for housing, industrialization, and infrastructure development.
- Uncertain weather conditions appear to be the main causal factor for dismal growth.
- 82% of the total operational holdings belong to small and marginal farmers.
- Continuous fragmentation of landholdings; about 50% of the rural households have holding size of less than a hectare.
- Problems of absent landlordism, tenancy, and sharecropping.
- Delay in sowing and planting due to poor infrastructure development in irrigation, transportation, and electricity, and a shortage of farm labor.
- Salinization and degradation of the irrigation system due to poor drainage and the quality of irrigated land is declining.
- Yield under the most favorable environment is stagnating. More fertilizer is required today to harvest the same yield obtained a decade ago.
- A decline in factor productivity (fertilizer application is only 62 kg/ha) and low irrigation potential.
- Suboptimum variety-input management for different rice ecosystems.
- Price distortion between nitrogen and phosphatic fertilizer had affected the balanced use of fertilizer in rice.
- Because of a shortage of efficient farm laborers and increasing labor problems, rice lands are being used for more remunerative labor-saving crops.
- An increasingly complex pest-disease syndrome limits rice production in endemic areas.
- Inadequate credit facilities for small and marginal farmers.
- Socioeconomic conditions of the farmers standing in the way of effective use of modern rice production technologies.
- Incidence of poverty is high and 48% of the population is below the poverty line.
- Poor credit and market facilities; therefore, farmers fail to recover the cost of production in the existing market infrastructure.
- Poor seed replacement, which is barely 7–8%, and more than 50% of the farmers use their own seed that is 10–15 years old.
- Unfavorable trade and volatile prices.
- Deterioration of the resource base, diminishing returns regarding resource-use efficiency, and declining profit margins.

With the existing available technology in the shape of suitable varieties and an appropriate package of practices, productivity in irrigated lands, favorable rainfed medium lands, and shallow-water lowlands could be increased to reach the targeted rice production by 2020. For this, special emphasis should be given to shallow-water lowlands. The inherent fertility of these lands is high and, with suitable high-yielding rice varieties and better variety-input management, the productivity of these lands covering an area of more than 50% of the total rice area could be increased from the present level of 1.3 t/ha to 2.0 t/ha.

However, as a long-term strategy going beyond 2020, it is imperative to resort to remedial measures against maladies associated with various types of socioeconomic problems. There is a need for measures to maintain soil fertility and land development. Further, research programs should be re-oriented to develop technologies for mostly rainfed situations, which have so far been neglected.

Socioeconomic problems

- More than 70% of the rice area in Odisha is under HYVs, but the state's rice productivity continues to remain far below the national average. Without drastic socioeconomic reforms regarding ownership of farm lands and/or their management, exploitation of the full potential of the available technologies will continue to remain far below expectations. Socioeconomic maladies are many, and one that needs immediate attention is "sharecropping," which is fast replacing "owner-farming."
- The remedial measures to be taken up are a fair deal for sharecroppers in the form of a higher proportion of the produce over the present 50:50 through necessary legislation.
- It should be the responsibility of the land owner to make available necessary funds to the sharecropper for seeds of suitable varieties and inputs, which have to be returned at the time of disposal of the produce.
- Infrastructure development and favorable pricing policy are necessary for increasing crop productivity and production.

Land development

Farmers in general are not inclined to make any investment in land development. The following measures need urgent attention:

- In the plateau regions, productivity of uplands could be increased considerably through bunding, terracing, and land leveling. These would enhance the moisture-retaining status of the soil.
- In irrigated lands, better water management through field channels would bring about water economy, prevent land degradation, and enhance productivity.

- The provision of effective drainage facilities would greatly improve the productivity of waterlogged lands with adverse soil conditions.

Technology development

At present, as mentioned earlier, we don't have any high-yielding varieties for handicapped rice ecosystems such as drought-prone uplands, semi-deepwater lowlands covering an area of about 800,000 hectares, and saline land of more than 200,000 hectares. Further, no suitable package of practices for crop management, crop nutrition, and plant protection against diseases and pests have been developed. It is necessary to intensify or reorient the ongoing research programs, with emphasis on the following aspects:

- **Variety development for harsh ecosystems:**
  - Flood-prone semi-deepwater lands.
  - Drought-prone uplands with severe weed competition.
  - Coastal saline lands.

Crop management: Improved packages of practices are to be developed with special emphasis on the maintenance of an optimum plant population.

- In rainfed uplands where the plant population becomes severely reduced due to drastic intercultural operation through a toothed-harrow.
- Beushening operation on direct-seeded lands needs improvement or substitution by better alternatives.
- A lack of suitable management practices has been a continuing problem for semi-deepwater lands and saline lands.
- An appropriate rice-based cropping system for lowlands that regularly suffer from flash flood.

Integrated nutrient management. Existing information on nutrition of rice under rainfed upland and semi-deepwater conditions is meager. Research efforts should be directed to develop a suitable package of practices to meet nutritional requirements for the rice crop under these handicapped ecosystems.

Integrated management for plant protection. Multidisciplinary research programs are to be initiated to combat the increasingly complex pest-disease syndrome that limits rice production in endemic areas.

Significant progress has been made in identifying the constraints to rice production and various strategies have been worked out during the last ten years to step up rice production and productivity in the state. However, despite the progress made, it is still desirable to enhance production and productivity growth rates to meet the growing food demand.

Rice productivity fluctuated around 14 quintals/ha for a long time. It increased to 1.59 tons/ha and 1.72 tons/ha during 2001-02 and 2007-08, respectively, but again declined drastically to 0.76 ton/ha during 2002-03, mainly because of severe drought (Table 16). It is now proposed to increase yield from around 1.5 tons/ha (frequently occurring) to 1.9 tons/ha so as to catch up with the national average of more than 2 tons/ha.

Table. 16. Production and productivity of rice in Odisha during the last 15 years.

Period	State average		National average
	Production (million tons)	Productivity (kg/ha)	Productivity (kg/ha)
1995-96	6.23	1,375	1,797
1996-97	4.44	993	1,882
1997-98	6.20	1,380	1,900
1998-99	5.39	1,212	1,928
1999-2000	5.19	1,127	1,986
2000-01	4.61	1,041	1,901
2001-02	7.15	1,589	2,078
2002-03	3.24	759	1,744
2003-04	6.73	1,496	2,077
2004-05	6.54	1,455	1,984
2005-06	6.96	1,554	2,102
2006-07	6.92	1,557	2,131
2007-08	7.65	1,720	2,202
2008-09	6.92	1,553	2,186
2009-10	6.94	1,572	2,118

Considering the constraints to rice production for different rice ecosystems for both rainfed and irrigated areas, various strategies have been worked out for increasing rice production and productivity in the state. It is proposed to achieve feasible yield in different districts of the state (arrived at on the basis of the past 15 years' achievements) as follows.

Efforts should be made to achieve this targeted yield in different districts of the state. Except for Keonjhar and Sundargarh, all other districts have attained 1.4 tons/ha at least once during the last 15-year period. The highest yield so far recorded in these districts is 1.38 tons in Sundargarh and 1.34 tons in Keonjhar. The inland districts, including the above two, have considerable area under autumn paddy, which is mostly uplands, prone to recurrent drought stress and therefore consequently low yield. The yield in these districts can be increased considerably by

- Growing very early and early-maturing high-yielding varieties.
- Adopting cultural practices such as early sowing, line sowing, weed control, and maintenance of optimum plant population.
- Application of an optimum dose of chemical fertilizers in conjunction with organic manure and biofertilizers.
- Adopting intercropping with arhar, groundnut, etc., which should be propagated extensively to combat yield loss due to recurrent drought.

Similarly, yield in favorable rainfed medium lands and shallow lowlands as well as irrigated areas is also showing wide variation from year to year. It fluctuates around from 1.5 to 1.9 tons/ha due to waterlogging, increased soil salinity, and faulty adoption of a package of practices leading to wastage of critical inputs. Further, an imbalanced use of plant nutrients (N,P,K) favoring more use of N has led to a depletion of soil fertility, severe problems of pest and disease incidence, improper variety-input management, and new emerging problems of multinutrient deficiencies that reduce yield in rice. Yield in these favorable ecosystems could be improved considerably by

- Timely seeding/transplanting and intercultural operations.
- Better variety-input management and suitable water management.
- Use of quality seeds of recommended varieties.
- Use of farm implements to reduce labor cost and increase the efficiency in rice farming.
- Use of efficient postharvest technology and integrated farming systems.
- Increasing production by growing hybrid rice varieties with higher yield potential.
- Increasing input-use efficiency and factor productivity (ICM, SRI).
- Integrated pest management (IPM) with resistant varieties as the key component to minimize the use of pesticides.
- Integrated nutrient management (INM) to minimize the use of inorganic fertilizer in rice farming and to sustain soil fertility.

Predominantly rainfed lowland rice is grown in the coastal regions of the state comprising Bhadrak, Balasore, Cuttack, Jajpur, Jagatsinghpur, Kendrapara, and Puri districts, where photosensitive rice varieties of 140–155-day maturity duration are grown. The water depth varies from 25 cm for shallow lowlands to medium-deep waterlogged up to 50 cm, and deep-water rice, where the water depth varies from 50 cm up to 2 m. The yield in these districts fluctuates from 1.3 to 1.9 tons/ha mostly due to impeded drainage and waterlogging, flash-flood submergence causing inundation at the vegetative phase, and intermittent drought at various stages of crop growth. Poor stand establishment and suboptimal plant population and inadequate and imbalanced use of fertilizers are the major causal factors of low productivity. The yield of unfavorable ecosystems could be improved substantially by

- Timely sowing/transplanting and intercultural operations.
- Better variety-input management.
- Development and use of rice varieties tolerant of submergence and stagnant flooding.
- Use of quality seeds of recommended varieties.
- Development and use of a suitable package of practices for crop management, crop nutrition, and plant protection against diseases and pests.

In Odisha, rice is grown under highly diverse ecosystems and a wide range of climatic conditions. Rice forms the major crop of all the agro-climatic zones of the state and is the staple food of almost the entire population of Odisha. Therefore, the state economy is directly linked to the improvement in production and productivity of rice in the state.

As much as 65% of the total rice area is rainfed and therefore rice is mostly grown as a rainfed crop in Odisha. Considering the constraints to rice production for different rice ecosystems for both rainfed and irrigated areas, various strategies have been worked out for increasing rice production and productivity in the state. Several studies have been made in the past to examine the constraints and the strategies to eliminate them at the farm level but the impact of these efforts at the farm level is marginal.

The water crisis we are facing today is the greatest threat to crop cultivation. Inadequate rainfall, depletion of groundwater, and misuse of water for agriculture have brought down the per capita availability of water by 40–60% in many Asian countries, including India, and as a state Odisha is also not an exception. It is time now to consider more crops per drop of water. Therefore, strategies should be used to increase productivity in rainfed systems to meet the growing food demand. Unfortunately, no suitable package of practices for crop management, crop nutrition, and plant protection against diseases and pests for rainfed farming systems has been developed. It is therefore necessary to intensify or reorient the ongoing research programs to develop technologies for mostly rainfed situations that have so far been neglected. The development and adoption of an efficient technology for rainfed rice systems will not only help to enhance production and productivity but also maintain the stability of rice production in the state.

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