Spatial and temporal integration of rice, fish, and prawn in the coastal wetlands of central Kerala, India

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Abstract

The traditional system of growing tall rice (*Oryza sativa* L.) varieties during the monsoon season and prawn culture (prawn filtration) during summer season, locally known as *pokkali*, is a sustainable system of production harmoniously blended with natural processes like sea water inundation in the low-lying coastal zones of Kerala. A two year field study at Vyttila, Kerala, India evaluated spatial and temporal integration of high yielding *pokkali* rice genotypes with varying morphological characters (VTL3, culture-1026, and 'Chettivirippu' mutant) with fish [etroplus (*Etroplus suratensis* Bloch), rohu (*Labeo rohita* F. Hamilton) and tilapia (*Oreochromis mosambicus* Peters)] and tiger prawn (*Peneaus monodon* Fabricus) grown in succession. Culture-1026 showed better growth and yield (4391 kg ha^{-1}) over VTL3 (2434 kg ha^{-1}) and 'Chettivirippu' mutant (3950 kg ha^{-1}). Among the fishes tried, all male population of tilapia outperformed etroplus and rohu in terms of survival (37.6, 0.0, and 16% respectively) and yield (216.7, 0.0, and 12.7 kg ha^{-1} respectively) when grown simultaneously with rice. Inclusion of tiger prawn as a rotational component during summer enhanced profitability (prawn yield 425 kg ha^{-1}) and benefit-cost ratio (2.03). Although no direct effect of the components on pH, electrical conductivity, organic carbon content, available phosphorus, available potassium, and available sodium of the soil were noted, seasonal variations in water quality and consequent changes in soil properties were evident. Compatibility of the components, stable yields, favourable soil physico-chemical and hydrological parameters, and economic returns contribute to the sustainability of this production system.

Keywords: Farming system, *Pokkali*, Prawn filtration, Rice-fish dual culture.

Introduction

An integrated system of simultaneous rice (*Oryza sativa* L.) and fish production during *kharif* (June to October) followed by prawn culture in summer (January to April) is prevalent in the coastal belt of central Kerala. Popularly known as *pokkali* cultivation, it is named after the renowned saline tolerant rice cultivar, *pokkali* (Sasidharan, 2006). Salinity tolerant rice varieties are grown when water salinity and soil electrical conductivity are less than 6 mg $g^{-1}$and 6 dS m^{-1} respectively (Shylaraj and Sasidharan, 2005). Paddy is harvested before water reaches high salinity levels. After the harvest of rice, the fields are utilized for prawn filtration (Rajendran et al., 1993)

Simultaneous rice-fish culture is feasible in the *pokkali* tract as these fields are continuously inundated, have built-in peripheral channels, and the tall rice varieties are grown without chemical fertilizer and pesticide additions (Thampy, 2002). However, carps and many brackish water fishes are not performing satisfactorily due to short growing seasons, production of toxic gases like hydrogen sulphide, anoxic and saline field conditions, which are inher-

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ent to the *pokkali* tracts (Rajendran et al., 1993). Monosex male tilapia (*Oreochromis mossambicus* Peters) culture along with rice was, however, found to be promising (Rajendran et al., 1994). Furthermore, during harvest of the *pokkali* crop, only the rice ear heads are removed and the decaying paddy stubbles provide a niche for forage organisms such as zooplanktons and phytoplanktons (Purushan, 2002). Although tall rice varieties with high biomass production are generally preferred in this system, low rice yields adversely affect the profitability of the system. It is therefore necessary to integrate rice varieties with high yield, biomass production potential, and plant architecture suitable for fish culture into the *pokkali* system. Information on fish species thriving under the stress conditions in the *pokkali* environment is also meagre. Therefore, a systematic study on simultaneous rice-fish integration and sequential prawn culture was taken up to assess the performance of various components included in this system. Evaluating the complementary effects of rice varieties of varying morphological characters on fish yield and *vice versa* was yet another objective of this study. The principal focus, however, was on the effect of rice+fish integration and subsequent prawn culture on soil fertility, temporal variations in soil properties, and associated parameters, besides economic advantages of the system.

Materials and Methods

Field experiments were conducted from 1999 to 2001 in a 0.4 ha *pokkali* rice field at Vyttila (10°08'N; 76°20'E) in Kerala. Factorial combinations of three rice genotypes differing in plant architecture (VTL3: tall, pendulous leaves; culture 1026: semi-tall, slanting leaves; 'Chettivirippu' mutant: semi-tall, erect leaves; Fig. 1) and three fishes [etroplus (*Etroplus suratensis* Bloch), rohu (*Labeo rohita* F. Hamilton), and tilapia (*Oreochromis mosambicus* Peters)] were evaluated in a randomized block experiment with three replications. The rice and fish treatments were allocated to 110 m^2 plots of which 72 m^2 was earmarked for rice (Fig. 2). On either side of the paddy growing area, peripheral ditches (2 m wide and 0.5 m deep) were provided as fish hideouts. Each plot was separated by nylon nets connecting the outer risers ('bunds') to contain the fish within the respective plots (Fig. 2). During the pre-monsoon period, mounds (1 m^2 at base and 0.5 m height) were made (2500 mounds ha^{-1}) which facilitated washing down of salts during the rains. Sprouted seeds of the test rice varieties were sown on the top of the mounds and the seedlings were raised as per recommended practices (KAU, 1996). When the seedlings were 25 days old, the mounds were dismantled by cutting them into bits and seedlings with a clod of earth were uniformly distributed in the entire area maintaining a spacing of approximately 20 cm between rows and 15 cm within the row with 2–3 seedlings per hill. The native weed fishes were eradicated by applying 'mahua' (*Madhuca indica* J.F. Gmel*)* oil cake. Manually sexed male tilapia (by examining the vent: Mar et al., 1966) and etroplus fingerlings were stocked in the peripheral ditches at a density of 5000 ha^{-1}. During the second year, rohu was used instead of etroplus as the survival of the latter was not satisfactory. The fingerlings were stocked on 28 July 1999 and 20 July 2000 respectively during the first and second year of experimentation at an average stocking size of 45, 5, and 3 g for tilapia, etroplus, and rohu respectively. The fields were not manured and no supplementary feeding was done for the fishes. A water depth of 20 to 30 cm was maintained throughout the period. The rice crop was harvested during the second week of October. Plant height, vegetative tillers, panicles $hill^{-1}$, chaff %, thousand grain weight, grain and straw yield, besides biomass yield were monitored. Leaf angle of rice was measured by tracing the main culm of sample plants at panicle initiation stage and measuring the leaf angle of lower leaves in comparison to the penultimate leaf. Light intensity at the basal portion of rice was measured with a digital lux meter (93408 model) at active tillering and panicle initiation stages. Fish harvests were made on 12 January

Figure 1. Pokkali rice genotypes at seedling stage, Vyttila 2000.

Figure 2. A view of the rice-fish dual culture field experiment, Vyttila, 2000.

2000 and 27 November 2000. After the fish harvest, tiger prawn at a density of 50,000 ha^{-1} was stocked in the field on 3 February 2000 and 15 January 2001. After ten weeks of growth, the fields were drained and the prawns were harvested. Fish and prawn survival and growth (length and weight) were periodically monitored, besides the final fish yield. Soil samples (0–15 cm depth) were collected after fish harvest and after the harvest of tiger prawns. Samples were analysed for pH, electrical conductivity, organic carbon, available phosphorus (P), available potassium (K), and sodium (Na) following standard methods (Jackson, 1958). Water samples at weekly intervals from the rice-fish and prawn culture fields were analyzed for pH, electrical conductivity, salinity, dissolved oxygen, and dissolved ammonia as per APHA (1989). The data other than the water quality parameters were analyzed statistically using analysis of variance. Economic analysis was done based on the prevailing wage rates and market rates for agricultural commodities in Indian Rupees (1 USD is equivalent to Rupees 49.80).

Results and Discussion

Pooled data on height, number of vegetative tillers, leaf angle and illuminance at the base (Table 1) showed significant differences ($p<0.05$), implying variations in architecture of the rice genotypes. All

Table 1. Incident light at the ground level and morphological characters of *pokkali* rice genotypes, Vyttila, Kerala (1999–2000).

Rice genotypes	Leaf angle (o)	Incident light (lux) at Active tillering	Incident light (lux) at Flowering	Height (cm)	Vegetative tillers ($no.hill^{-1}$)
VTL3	35 [a]	874 [a]	957 [a]	156 [a]	8.3 [a]
Cul.1026	15 [b]	1611 [b]	1582 [b]	130 [b]	12.4 [b]
'Chettivirippu' mutant	7 [c]	1641 [b]	1554 [b]	117 [c]	11.3 [c]

Values followed by the same superscript do not differ significantly.

the varieties were either semi-tall or tall (Fig. 1), which made them ideal for a high water regime and suited for rice+fish dual culture. This is consistent with the observations of Thampi (2002), who recommended tall rice varieties for such production systems. 'Chettivirippu' mutant intercepted 88% more sunlight than VTL3, owing to its acute leaf angles. VTL3 had a closed canopy with a leaf angle of 35^{o} while the canopies of 'Chettivirippu' mutant and cul.1026 were relatively open permitting greater infiltration of solar radiation to the ground.

Inter annual variations in growth and yield were profound. For example, grain yield was higher for the 'Chettivirippu' mutant during the first year (Table 2). Yields were generally lower during the second year, and this decline was more pronounced for 'Chettivirippu' mutant. Cul. 1026 performance was more consistent with less inter annual variations in yield. However, the pooled mean yield did not show any significant differences among the varieties. Straw yield also showed pronounced variations with VTL3 and 'Chettivirippu' mutant recording higher straw yields than Cul 1026 during 1999. Cul.1026 was also consistent in terms of total biomass yield. Significantly, integration of fish with rice did not bring about any marked changes in grain, straw, and biomass production. Manjappa et al. (1987) observed modest differences in grain yield from plots with and without fish. This is, however, in contrast to the results obtained by certain workers (e.g., Lightfoot et al., 1992; Naegel, 1988) who reported grain yield increase to the tune of 15% by rice+fish integration. In the present investigation, the changes brought about by rice+fish integration on physico-chemical properties of the soil were also marginal (Table 4), which probably can explain this lack of perceptible variations in grain, straw, and biomass yields. The rice varieties also varied significantly with respect to grain yield at-

Table 2. Effect of rice fish integration on yield of rice genotypes, Vyttila 1999–2000.

Treatments	Grain ($kg\ ha^{-1}$)			Straw ($kg\ ha^{-1}$)			Biomass ($kg\ ha^{-1}$)			Harvest index		
	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Rice genotypes												
VTL3	3052 [c]	1812 [c]	2434	7186 [a]	2523 [b]	4855	10240 [a]	4335 [b]	7258	0.44 [b]	0.73 [b]	0.59 [b]
Culture 1026	3726 [b]	3063 [a]	3395	4725 [b]	4057 [a]	4391	8451 [b]	7121 [a]	7756	0.80 [a]	0.78 [b]	0.79 [a]
'Chettiviruppu' mutant	4396 [a]	2580 [b]	3488	5215 [b]	2684 [b]	3950	9611 [b]	5265 [b]	7438	0.85 [a]	0.99 [a]	0.92 [a]
Fish												
Without fish	3714	2283	2999	6021	2925	4473	9735	5209	7472	0.66	0.80	0.73
Male Tilapia	3682	2572	3127	5725	3230	4478	9407	5802	7605	0.68	0.80	0.74
Etroplus/rohu*	3782	2601	3192	5379	3109	4244	9161	5710	7436	0.74	0.88	0.81

Values followed by the same superscript do not differ significantly; Treatments involving fish were not statistically significant.
* Etroplus during 1999 and rohu during 2000.

tributes (Table 3). VTL3 had less chaff % and higher thousand grain weight, but the grain yield was probably limited by the fewer number of panicles. Cul. 1026, on the other hand, had significantly higher panicle number and thousand grain weight. Low chaff % and higher filled grains were the positive yield attributes of 'Chettivirippu' mutant.

Yield characters and yield of fish

Survival of the fish species under dual culture differed significantly at 5% level (Table 5). Tilapia recorded significantly higher survival % during both years than the other two species. Etroplus did not survive at all and the survival of rohu also was not quite encouraging. Among the hydrological parameters, pH and dissolved oxygen levels (Fig. 3) were conducive for fish growth. However, lower water depth in the paddy area, rapid salinity build up, higher dissolved ammonia and the small stocking size of etroplus and rohu probably affected their survival. Padmakumar et al., (1993) reported higher survival (75%) for a higher stocking size (15 g) in these species.

Rice varieties with varying leaf architecture did not influence fish yield, which implies that the existing

Table 3. Effect of rice fish integration on yield attributes of rice, Vyttila, Kerala (1999–2000).

Treatments	Panicle no. hill^{-1}			Filled grains panicle^{-1}			Chaff (%)			Thousand grain weight (g)		
	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Rice genotypes												
VTL3	4.7^{b}	8.1^{b}	6.4^{b}	73.6^{b}	97.7^{a}	88.7^{a}	12.4^{b}	8.4^{b}	10.4^{b}	35.8^{a}	35.5^{a}	35.7^{a}
Culture 1026	8.5^{a}	11.0^{a}	9.8^{a}	69.8^{c}	90.4^{a}	80.1^{a}	26.1^{a}	22.0^{a}	24.1^{a}	28.6^{b}	28.9^{b}	28.8^{b}
'Chettiviruppu' mutant	7.1^{a}	6.7^{c}	6.9^{a}	81.6^{a}	99.4^{a}	90.5^{a}	8.7^{c}	6.7^{bc}	7.7^{b}	25.4^{c}	25.7^{c}	25.6^{c}
Fish												
Without fish	6.7	8.9	7.8	74.7	83.4	79.1	15.7	12.5	14.1	30.1	30.2	30.2
Male tilapia	6.8	8.2	7.5	70.8	88.5	79.7	15.5	11.2	13.4	29.9	30.2	30.1
Etroplus /rohu*	6.9	8.8	7.9	74.0	78.0	76.0	15.9	13.4	14.7	29.9	29.7	29.8

Values followed by the same superscript do not differ significantly; Treatments involving fish were not statistically significant.
* Etroplus during 1999 and rohu during 2000.

Table 4. Effect of rice-fish integration on the physico-chemical characters of soil after harvest of fish and prawn, Vyttila, Kerala, India during 2000–2001.

Rice-fish integration	Soil pH	EC (dS m^{-1})	Organic carbon (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available Na (mg kg^{-1})
Rice genotypes						
VTL-3	3.9	7.5	2.7	5.76	220	1483
Cul.1026	3.5	8.3	2.9	5.89	183	1480
'Chettivirippu' mutant	3.5	10.1	2.9	5.94	197	1493
Fish treatments						
Without fish	3.8^{a}	8.4^{a}	2.6^{a}	5.89^{a}	167^{a}	1593^{a}
Male tilapia	3.5^{a}	8.6^{a}	2.8^{a}	5.54^{a}	183^{a}	1440^{a}
Etroplus/ rohu	3.6^{a}	8.9^{a}	3.6^{a}	6.16^{a}	251^{a}	1422^{a}
After prawn harvest	5.8^{b}	8.0^{a}	2.8^{a}	5.31^{a}	207^{a}	5245^{b}

Values followed by the same superscript do not differ significantly; rice genotypes were not statistically significant.

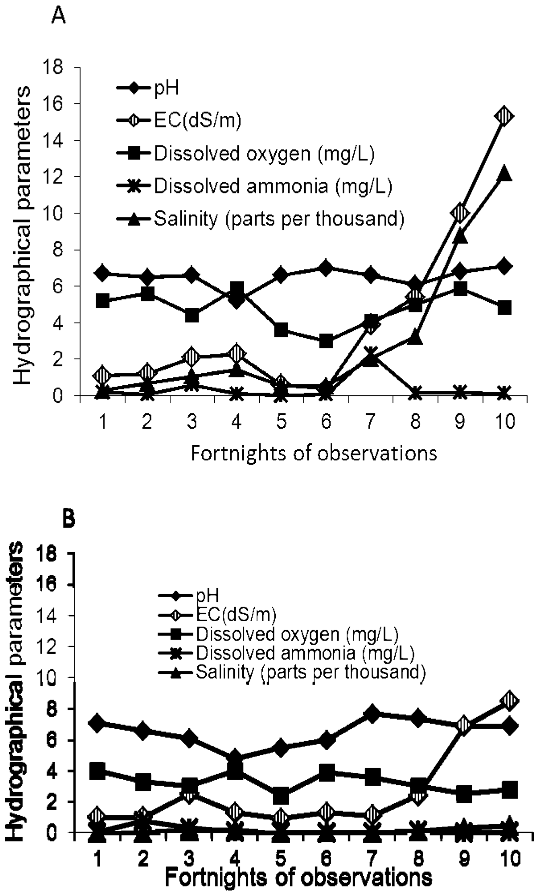

Figure 3. Hydrographical parameters of rice-fish dual culture systems at Vyttila, Kerala in 1999–2000 (A) and 2000–2001 (B).

area under the peripheral channels alone are sufficient to achieve yields up to 245 kg ha^{-1}. The higher survival % of tilapia was reflected on its yield as well. Yield attributes and yield of tilapia were significantly high in both the years of experimentation. During the first year no yield could be obtained from etroplus while the performance of rohu, its substitute in the second year, was not satisfactory. The small stocking size, unfavourable living conditions in the paddy fields, and absence of supplementary feeding might have affected etroplus, while the rise in salinity might be an additional reason for the poor performance of rohu. Rajendran et al., (1993) observed that in the anoxic post paddy soils, production of toxic gases like hydrogen sulphide and the sharp rise in salinity affect most of the cultured fish species. Tilapia on the contrary shows considerable tolerance to high levels of ammonia, hydrogen sulphide, and carbon dioxide (Pullin and Lowe Mc Connel, 1982). Tilapia is macrophagous and feed either on plankton or detritus that are available in plenty in the *pokkali* fields. This is consistent with the finding of Rajendran et al. (1994), who identified tilapia as the ideal species for integrated agriculture-aquaculture systems in the tropics.

Rotational prawn culture

Intensive culture of tiger/white prawn using com-

Table 5. Effect of rice genotypes on yield and yield attributes of fish grown in rice+fish system at Vyttila, Kerala, India.

Treatments	Survival (%)			Fish yield (kg ha^{-1})			Mean length (cm)			Mean weight (g)		
	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Male tilapia												
VTL3	33.9*	42.7	38.3	200	215	208	20.8	20.3	20.6	138	136	137
Culture 1026	37.0	38.9	38.0	230	212	221	19.7	22.0	20.9	133	139	136
‘Chettiviruppu’ mutant	37.6	35.1	36.4	197	245	221	20.7	21.4	21.1	149	141	145
Etroplus/rohu*												
VTL3	0	11.5	–	0	18	–	0	10.4	–	0	31.7	–
Culture 1026	0	19.4	–	0	30	–	0	10.9	–	0	31.5	–
‘Chettiviruppu’ mutant	0	17.0	–	0	28	–	0	10.7	–	0	31.7	–

Treatments involving rice-fish integration were not statistically significant.
* Etroplus during 1999 and rohu during 2000.

mercial prawn feed is an improvement over the traditional practice of prawn filtration. In the present study, during the short culture period of 10 weeks a prawn yield of 425 kg ha^{-1} could be obtained without any supplementary feeding. Hydrographical parameters (Fig. 4) were conducive for the growth and development of prawn as evident by the high survival rate (49%) and remarkably good growth rate (15.9 g in 50 days and 20 g in 70 days), which is regarded as satisfactory under the conditions of no artificial feeding. Pillai (1999) reported survival of 31.4% and prawn yield of 261 kg ha^{-1} by adopting semi-intensive culture of tiger prawn where the operations are similar to that of selective culture. The economic prospect of tiger prawn culture was demonstrated by Verghese et al. (1982) and Thampi (2002), which are consistent with the present findings.

Changes in soil chemical characters

The data in Table 4 show that the temporal effect on soil chemical characters rather than that of integration was more pronounced. *Pokkali* soils are acidic and low pH values are typical of these acid sulphate soils. Soil organic carbon content remained high after fish harvest and remained to be the same even after the prawn harvest, implying high fertility.

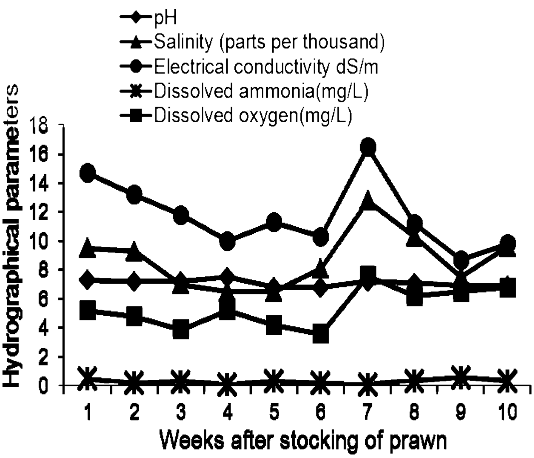

Figure 4. hydrographical parameters, during selective culture of tiger prawn at Vyttila, Kerala during 2001.

Available soil P after the fish and prawn harvest were, however, medium. The fish treatments and its interaction with rice varieties did not have any significant effect on the available soil P. Available K content after the fish harvest also did not differ between the treatments. Conversely, available Na content increased significantly after the prawn harvest, presumably reflecting the changes in water salinity levels.

Overall, the effect of rice varieties, fish treatments, and their interactions on soil pH, electrical conductivity, organic carbon content, available P, available K, and available Na were not significant. Any marginal changes occurred in the chemical characters of the soil by fish introduction were masked by the innate fertility of this unique *pokkali* system. Although the integration of rice and fish did not alter the soil physico-chemical parameters *per se*, rotational prawn culture during summer evoked positive changes in soil pH. Unfavourable changes like increase in electrical conductivity and Na levels are, however reversible and may not affect the sustainability of the system.

Economic analysis

Net returns (Table 6) increased by 39 and 44% when VTL3 was replaced with cul. 1026 and 'Chettivirippu' mutant with corresponding increases in benefit: cost ratio. Cost of rice production under the *pokkali* system is generally lower than that of other rice ecosystems in view of the saving in fertilizer, pesticide, and herbicide costs (Sasidharan, 2006). Spatial integration of fish also did not increase the cultivation costs substantially as the *pokkali* fields already had deep inner channels. Removal of weed fishes, cost of fingerlings, and harvest operations were the items that required major expenditure. The low yield from rohu decreased the net returns and benefit: cost ratio while male tilapia increased the returns by Rs. 4836 ha^{-1}. Although Shanat (2000) observed reduction in cost of cultivation of rice following rice+fish integration by 29% in Kuttanad, owing to reduced cost on weeding and fertilizers for

Table 6. Economic analysis of rice-fish-prawn integration in *pokkali* fields, Vyttila.

Farming system	Cultivation expenditure (Rs. ha^{-1}) Main crop	Subsidiary crops			Returns (Rs ha^{-1}) Main crop	Subsidiary crops			Net returns (Rs. ha^{-1})	Benefit: cost ratio	Additional employment generated (man days ha^{-1})
	Rice	Fish	Prawn	Total	Rice	Fish	Prawn	Total			
Rice alone											
Vyttila-3	22900	–	–	22900	31642	–	–	31642	8742	1.38	83
Cul. 1026	22900	–	–	22900	44136	–	–	44136	21236	1.93	83
'Chettivirippu' mutant	22900	–	–	22900	45344	–	–	45344	22444	1.98	83
Rice-fish dual culture											
Rice + rohu	22900	12500	–	35400	45344	2032	–	47376	11976	1.34	113
Rice + male tilapia	22900	12500	–	35400	45344	17336	–	62692	27292	1.77	113
Rice-fish-prawn integration											
Rice + tilapia followed by prawn	22900	12500	58000	93400	45344	17336	127500	190180	96780	2.03	149

Rice @ Rs.12000 Mg^{-1} ; Fish @ Rs.80 kg^{-1} ; Prawn @ Rs.300 kg^{-1}; Labour @ Rs.250 manday^{-1}

rice, no such trends were discernible in the present study. Nonetheless, temporal integration of tiger prawn increased the cultivation costs by 163% and the returns by 203% over rice+tilapia. Overall, temporal integration of tiger prawn rather than spatial integration of fish is the key for enhancing economic returns through integrated farming system in the *pokkali* fields. Additional employment generation to the tune of 149 man days ha^{-1} is yet another advantage of this system.

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