Plant Sciences Research Programme

FINAL TECHNICAL REPORT

R7541 'Assessing the potential for short duration legumes in South Asian rice fallows'.

Executive Summary

Rice is the most extensively grown crop in South Asia (Bangladesh, India, Nepal, and Pakistan; Sri Lanka is not included in this study), occupying nearly 50 million ha. Much of it is grown in the *kharif* (rainy) season. A substantial part of this area remains fallow during the *rabi* (postrainy) season because of several limitations, the prime one being limited availability of soil moisture. Precise estimates of such rice-fallows and their spatial distribution are not available. Since rice is grown on some of the most productive lands of this region, there is substantial scope to increase cropping intensity by introducing a second crop during the *rabi* season. This project has quantified rice-fallows in South Asia by using satellite image analysis and has documented their spatial distribution. Using geographical information system (GIS) tools, we have overlaid the spatial distribution of the rice-fallows on to the available climatic and soil information data to identify possible strategies to utilize these lands for suitable short-season crops.

Satellite image analysis estimated that rice-area during 1999 *kharif* season was about 50.4 million ha (Table 1). Rice-fallows during the 1999/2000 *rabi* season were estimated at 14.29 million ha. This amounts to nearly 30% of the rice-growing area. These rice-fallows offer a huge potential niche for legume production in this region. Nearly 82% of the rice-fallows are located in the Indian states of Bihar, Madhya Pradesh, West Bengal, Orissa, and Assam. The GIS analysis of these fallow lands has indicated that they represent diverse soil types and climatic conditions; thus a variety of both warm season legumes (such as soybean, mung bean, black gram, pigeonpea, groundnut) and cool season legumes (such as chickpea, lentil, khesari [lathyrus], faba bean, pea) can be grown in this region. Available soil water-holding capacity (1 m soil profile) for most of these lands ranges from 150 mm to 200 mm. If it is assumed that the soils in these lands are fully saturated during most of the rice growing season, the residual moisture left in the soil at the time of rice-harvest may be sufficient to raise a short-season legume crop. A number of abiotic (soil acidity, salinity, alkalinity, and terminal drought), biotic (diseases and insect pests), and socioeconomic (social unrest, lack of awareness among farmers of legume technologies, and lack of effective policy initiatives to promote legumes, etc.) constraints contribute to the lack of cropping during this period in this region. These will have to be addressed by appropriate research and policy initiatives in addition to developing suitable legume varieties that have targeted adaptation to these rice-fallows.

Table 1. Estimates of rice areas during the 1999 *kharif* season, and rice-fallows during the *rabi* season of 1999/2000 based on satellite image analysis.

Country	Kharif-rice area(million ha)	Rabi fallow(million ha)	Rabi-fallow as % of rice area	% total rice-fallow in South Asia
Nepal	1.45	0.39	26.9	2.7
Bangladesh	6.36	2.11	33.2	14.8
Pakistan	2.45	0.14	5.7	1.0
India	40.18	11.65	29.0	81.5
Total	50.44	14.29	28.3	

A review of existing technologies indicates that it is possible to productively cultivate legumes in most of these identified rice-fallows. An economic analysis has shown that growing legumes in rice-fallows is profitable for the farmers with a benefit-cost ratio exceeding 3.0 for many legumes. Also, utilizing rice-fallows for legume production could result in the generation of 584 million person-days employment for South Asia (66.7 in Bangladesh, 503 in India, 10.2 in Nepal, and 3.6 in Pakistan; values are in million person-days). Thus, introducing legumes into these rice-fallows will have a multi-faceted impact on the economy through employment generation, poverty alleviation, food security, quality of nutrition to humans and animals, and contribution to the sustainability of these production systems in South Asia.

Background

From the mid-1990s, ICRISAT has been implementing a project, funded by the Asian Development Bank (ADB) from May 1997, on “legume technologies for rice and wheat cropping systems for South and South-East Asia”. Part of the project activities has involved assessment of constraints and opportunities for legumes in rotation with rice (Johansen *et al*., 2000). This has involved use of GIS to map legume distribution and productivity in relation to edaphic and climatic factors, and abiotic and biotic constraints. The project has been studying components of technology that would enhance legume production after rice (DFID/KRIBHCO, 1998; Harris *et al*., 1999; Awadhwal *et al*., submitted) and evaluating technology packages in farmers’ fields (Musa *et al*., 1999; Pande, 1999). Particular success has been obtained in expanding the area of chickpea cultivation after rice in the High Barind Tract of Bangladesh (Kumar et al., 1994; Musa *et al*., 1998). It is considered that the success with chickpea obtained here can be extended to legumes cultivation in rice fallows elsewhere throughout South Asia. However, to define extrapolation domains, more precise estimation is needed of actual area of rice fallows in the region and characteristics of such areas to assess potential for legume cultivation. Although the study of Johansen *et al*. (in press) has produced GIS maps of crop distribution in the Indo-Gangetic Plain, GIS and remote sensing technology needs to be combined to establish potential rice fallow areas.

Project Purpose

Methods to optimize cropping systems by agronomic means developed and tested (PSP Programme Output 4).

Despite the ever-increasing demands for food production in South Asia there are vast areas of fallow lands following cultivation of rainfed rice, and even following irrigated rice when there is insufficient irrigation water for year-round cropping. After harvest of rice, there is often adequate stored soil moisture, along with any subsequent rainfall, to support a following crop, of at least short duration. For example, grain legumes like *Lathyrus*, chickpea and lentil are grown after rice in north-eastern India, in the Terai of Nepal and in Bangladesh. However, yields are often low and large areas with potential for cultivating a post-rice crop are left fallow. The main reasons for this are the suite of agronomic difficulties in establishing and growing a crop in paddy soils, where a hard plough-pan is deliberately created to retain water for rice culture. However, there are now proven technologies available (e.g., short-duration varieties of legumes, seed treatments, mechanization, etc.) that would make it feasible and profitable to grow post-rice crops over a much larger area than is now the case. Successful demonstration and extension of these technologies would open the way for greater income generation by the generally economically disadvantaged rice cultivators of South Asia, who are locked into the necessity of annual rice cropping but with few options for enterprise diversification.

A first step in mobilizing technologies for post-rice cultivation is compilation of an inventory of rice fallow lands with potential for post-rice (unirrigated) cultivation and of the technologies that could be deployed. Presently, there are only approximate estimates of area of rice fallows across South Asia. This project is therefore aimed at better and updated quantification of rice fallow lands and classification of their potential and constraints for post-rice legume cultivation.

Research Activities

Planned activities (*in italics*) are followed by a description of the actual activities undertaken.

1. Survey literature and assemble database

Following a standard library search relevant people in the target countries were contacted and current information on areas of rice fallows was assembled and analysed. Many of the relevant GIS maps of climatic and edaphic factors had aleady been produced but needed assembly for use in assessing the potential of fallow lands, as did areas and yields of rice crops and crops grown in rotation with rice that were also available in GIS form.

2. Use satellite imagery to estimate rice fallow areas

Satellite remote sensing is now considered as an appropriate tool for deriving information in spatial and temporal domains by providing multi-spectral reflectance data at regular intervals in a synoptic mode. Also, satellite data are amenable to geo-referencing, thus making it compatible with analysis by GIS. The rice acreage and production at district, state, and national levels are being routinely generated with the techniques developed and tested under the Crop Acreage and Production Estimation (CAPE) project using single date Linear Imaging Self Scanning Sensor (LISS-I/II) data of Indian Remote Sensing Satellites (IRS 1A/1B) (Parihar *et al*. 1990).

The second generation Indian Remote Sensing Satellites (IRS-1C & 1D) have three sensors on-board, viz., the Panchromatic Camera (PAN), the LISS-III, and the Wide Field Sensor (WiFS). The PAN data are of high resolution at 5.8 m in a single spectral band of 520 to 750 nm, and is mainly useful in micro-level planning, e.g., for infrastructure development. The LISS-III provides reflectance data in green, red, and near-infrared bands at 23.5 m spatial resolution and at 24 days re-visit, covering a swath of about 141 km. These data are found to be useful for identification of cash crops such as chillies (*Capsicum annuum* L.), tobacco (*Nicotiana tabacum* L .) etc. grown in small land holdings and for improved discrimination between different crops grown in multiple crop situations (Krishna Rao *et al*. 1997).

The WiFS sensor provides reflectance data in red and near-infrared bands at 188 m spatial resolution and at 5 days re-visit, covering a swathe of about 812 km, and is useful in deriving regional level crop information. High frequency of the availability of the WiFS data due to the short re-visit period also facilitates the monitoring of crops (Kasturirangan *et al* . 1996). WiFS data was found to be suitable for deriving regional information on the spatial distribution of *rabi* rice crops grown in the Godavari delta of East and West Godavari districts and pulse crops cultivated in the *kharif* rice-fallow fields of the Krishna delta of Krishna and Guntur districts of Andhra Pradesh, India (Navalgund *et al*. 1996). National level wheat (*Triticum aestivum* L .) production forecasts using multi-date WiFS data are operational under the Forecasting Agricultural Output using Space, Agrometeorology and Land-based Observations (FASAL) project (SAC 1999). Also, the procedures were developed and are operational to estimate rice cropped area using microwave data from RADARSAT (Chakraborty *et al*. 1997) under FASAL to overcome the problem of non-availability of cloud-free optical satellite data during the *kharif* season.

In the present study, WiFS data of the 1999 *kharif* and the *rabi* 1999/2000 seasons were used to derive the regional level information on the spatial distribution of the *kharif* rice and *rabi* rice-fallow lands in the South Asian countries of Bangladesh, India, Nepal and Pakistan.

The reflectance spectra of plant canopies are a combination of the reflectance spectra of the plants and of the underlying soil (Guyot 1990). When a plant canopy grows, the soil contribution progressively decreases. Thus, during the active vegetative growth phase, the visible and middle infrared reflectance decreases and the near infrared reflectance increases. During senescence, the reverse phenomenon occurs. Maximum reflectance from the vegetation is sensed when the crop canopy fully covers the ground, which coincides mostly with the beginning of the reproductive phase. Hence, in this study, satellite data corresponding to this stage were selected to discriminate the rice crop in the *kharif* season.

After the harvest of *kharif* rice, the land will be either left fallow or cultivated with a suitable crop in the following *rabi* season. The time gap between the harvest of the kharif rice and the cultivation of the *rabi* crop depends upon the suitability of the prevailing weather, availability of water, etc. Satellite data of the period soon after the harvest of *kharif* rice crop will depict large area under fallows though these lands are sown with *rabi* crop because of poor manifestation on the image leading to an over-estimation of the fallow lands. In order to properly estimate the post-*kharif* rice-fallows, the satellite data of *rabi* period was selected based upon the prevailing cropping pattern of the region, and coinciding with the likely maximum vegetative stage of the dominant crop when the crop is manifested clearly and discernable on the satellite data.

Agronomic information is essential and is utilized in the selection of satellite datasets to identify and best discriminate the rice crop from other agricultural land covers. The crop calendar, which provides information on the staggering in the transplantation operations of the paddy crop across the study area, was utilized in the selection of the appropriate satellite data. Efforts were also made to have a uniform database across the study area so as to obtain the standardized estimates as well as to optimize the number of satellite datasets required for the investigation. In case of administrative regions (e.g., state in India) occupying large width, greater than the WiFS swath of 812 km, multiple (2 to 3) satellite datasets within a season were used. Subsets of the satellite data, to the extent of the administrative region coverage, were extracted and the analysis was carried out at individual administrative region level. The corresponding datasets were mosaicked and the administrative boundaries were overlaid.

In general, IRS-WiFS data corresponding to the peak biomass stage of rice during the *kharif* 1999 season (October to November) and the data of the *rabi* 1999/2000 (January to March) were used. The state-specific crop calendar information was utilized in this step considering the variations of rice cropping period within the kharif rice season across regions. This was also essential, as the post-kharif season would also vary as influenced by the actual rice-growing period during the kharif season.

In Bangladesh, use of several images, from early February to March were required to differentiate lands remaining fallow throughout the winter. Some *rabi* crops, such as mustard and lentil were harvested during February and thus their vegetative signatures can only be obtained in early February. In some areas *boro* rice is planted during February and thus its signatures can only be obtained in March. Hence, satellite data of March acquisition was considered optimal and used for analysis in deriving the post-*kharif* rice-fallows. Therefore, rice-fallows were calculated by subtracting areas shown as cropped in February but fallow in March from the area shown as fallow in March.

Survey of India - generated toposheets on 1:1000000 scale were used in the study, which were geo-referenced to polyconic Everest projection and subsequently used for geometric correction of the satellite datasets. The first date satellite data of kharif or rabi seasons were registered with these projected toposheets using an affine transformation technique followed by re-sampling to obtain the geo-referenced image, which was subsequently considered as the master image. In this step, adequate number of well-distributed ground control points (GCPs) were identified and used to minimize the errors in registration of the datasets. The satellite data of the subsequent dates were co-registered with this master image. ERDAS - IMAGINE 8.0v (ERDAS 1999) was used in geo-referencing of the data. Polyconic projection was applied uniformly to all the datasets with graticular (latitude/longitude) information in degrees. Common central meridian points and origins were used in developing models for geo-referencing of wider regions, which were not covered in a single swath of WiFS; this enabled efficient geo-referencing while mosaicing and facilitated easier import into GIS via Arc-Info software.

The administrative boundaries of the countries were overlaid on the satellite data to generate country level information and to develop the output products. In case of India, state-wise boundaries were overlaid. Forest masks were also generated and were excluded in the classification of satellite data.

3. Ground truth visits to selected areas

In order to calibrate spectral pattern and ground surface characteristics particularly for target rice-based cropping systems, it was necessary to visit certain locations in some countries for visual observations, discussion with local persons with intimate knowledge of cropping patterns and to examine recent local crop statistics. Some ground truthing was also required to validate conclusions drawn from remote sensing studies.

Ground information is essential, right from the selection of the data to the verification of the results at various intermediate steps such as defining the training areas, generation of spectral signatures and testing the separability and classification of the satellite data. Since the analysis was carried out corresponding to the postharvest period of these crops, real time ground truth was not used in this project. Hence, ground information as available in the form of published literature was used to derive the information on the growing period and distribution of crops in India.

Ground information for Pakistan and Bangladesh was provided by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for use in the analysis. In case of Nepal, the ground information of Uttar Pradesh and Bihar states of India was extrapolated because of the spatial contiguity of these two regions.

The classified outputs of *kharif* 1999 showing the cropped areas and the rice-fallows of *rabi* 1999/2000 of Bangladesh were provided to ICRISAT for verification of the cropping pattern. The feedback enabled the labelling of different crop classes properly and it was possible to discriminate early and late transplanted rice crops due to their characteristic variations in the spectral reflectance patterns.

The *kharif* rice area estimates using RADARSAT data and those of wheat area using WiFS data of the national level rice and wheat production estimation projects under the ongoing FASAL project were also used in verifying the classification results for the estimation of *kharif* rice and the wheat area in the following *rabi* season.

4. GIS mapping of total and potential fallow areas

Remote sensing output on spatial distribution was converted to GIS format for overlaying with other GIS-based data on crops, soils and climate. Total rice fallow areas was first estimated and then an assessment made of potential for legume cultivation in these fallow areas.

The GIS was used to create simple overlays of pedo-climatic variables along with the rice-fallow data generated from remote sensing satellite. The rice-fallow data were vectorized and used as a layer for overlay. ArcView software from ESRI (Environmental Systems Research Institute, California, USA) was used to make the overlays. The pedo-climatic variables were obtained from different sources: soils from the Digital Soil Map of the World (DSMW, FAO 1996); climatic variables as gridded surfaces from the International Water Management Institute (IWMI)]. A soil water balance model (WATBAL - Keig and McAlpine 1974) was used to estimate the available soil water spatially (2.5 arc minutes = 4.5 km approximately) and temporally (monthly) using the above pedo-climatic datasets. The program coded in Fortran, used in running the water balance model, was developed by P Jones of CIAT who patterned it after the Basic-Plus example of Reddy (1979). The program was modified to suit the available data. The input data for the WATBAL model are the precipitation, potential evapotranspiration (PE) as gridded interpolated surfaces from point data. The interpolated climatic surfaces are available at monthly temporal resolution. The maximum soil water-holding capacity (SWHC) is extracted from the Digital Soil Map of the World and its derived soil properties (FAO 1996). The SWHC is the upper bound of the moisture storage capacity class with highest percent value under the mapping unit. These raster surfaces, which are a matrix of grided cell values, were converted to ASCII format for the purpose of faster processing and used as inputs to the model. The model estimates the available soil water at each precipitation during the month minus the soil water loss as actual evapotranspiration (AE) during the month. The AE during the month is calculated as the ratio of AE/PE multiplied by PE. The ratio of AE/PE was taken as equal to 1.0 for soil moisture percentages from 100% down to X% and decreases linearly to 0 thereafter, where X is calculated from a square root function, 3+3.868*(SQRT(SWHC)), that fits the three values of X supplied by Reddy (1979)-30, 50, 70 for soil holding capacities of 50, 150, 300 mm, respectively. The outputs in the ASCII format, are again converted into raster surfaces using ArcInfo GIS. This averaging process was intended only to give an overall impression at a national level of spatial and temporal variations in soil water availability parameters. It would not necessarily be sufficiently rigorous to accurately simulate soil water status at a given point in space and time.

5. Compile report and assemble website

The information and interpretations generated above has been presented in attractive hardcopy form, primarily targetting research and development administrators but also readily usable for practising researchers and extension personnel. The book '*Spatial distribution and quantification of rice-fallows in South Asia – potential for legumes*.' Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 316 pp. ISBN 92-9066-436-3 by Subbarao, G. V., Kumar Rao, J. V. D. K., Kumar, J., Johansen, C., Deb, U. K., Ahmed, I., Krishna Rao, M. V., Venkataratnam, L., Hebbar, K.R.,Sesha Sai, M. V. R., and Harris, D. (2001) has been published.

The output is also presented as a website cross-referenced for maximum visibility and accessibility and may be found at:

www2.icrisat.org/text/research/nrmp/dfid/text/home5.asp

The following short article was also produced.

Subbarao, G.V., Kumar Rao, J.V.D.K., Kumar, J., Johansen, C., Deb, U.K., Ahmed, I., Krishna Rao, M.V., Venkataratnam, L., Hebbar, K.R., Sai, M.V.R.S., and Harris, D. 2001. Spatial distribution and quantification of rice-fallows in South Asia – Potential for legumes. Pages 47-53 in Research Highlights of DFID-PSP Annual Report 2000.

Outputs

This report is submitted in conjunction with the book mentioned above which contains all the planned outputs. Below is a brief summary of the contracted outputs and their OVIs.

1. Enhanced knowledge of the extent and distribution of land left fallow after the harvest of rainfed rice in S. Asia.

- *GIS database of all major rice-fallow areas in S. Asia.*

2. Informed estimates of amount and distribution of fallow land suitable for growing short-duration legumes after rice in S. Asia.

- *Typology of rice-fallow systems based on climate and physical factors (e.g. temperature, rainfall, soil type and water balance estimates, disease index) and socioeconomic factors (seed and input supply, markets, prices, labour issues etc.).*

3. Prioritised recommendations for action to promote legumes in rice-fallows in each of the four S. Asian countries.

- *One report for each country, with recommendations for follow-up action required to promote use of legumes on fallow lands. To include likely costs and benefits for increased use of legumes.*

Contribution of Outputs

The conclusions of this study identify an enormous opportunity to improve the livelihoods of poor people in South Asia. More than 14 million hectares of fertile land are underutilised and it seems likely that the productivity of at least a proportion of that area can be improved by deploying appropriate technologies. This study has identified where large concentrations of rice fallows are to be found and has attempted to match legume technologies to the soil- and climatic characteristics of those areas. Although it has operated at a regional and sub-regional level, the study is a valuable resource for planners, researchers and extensionists.

a. What further market studies need to be done?

This study has been able to identify, locate and quantify the areas of rice fallow land in S. Asia and has linked its distribution to various soil- and climatic factors. Thus it is easy for planners to find large areas of rice fallow, if they exist, in regions for which they are responsible. In order to target research or promotion efforts on these areas effectively however, more location-specific studies are necessary to identify the exact nature and relative importance of the local constraints to rainfed *rabi* cropping.

b. How the outputs will be made available to intended users?

The output of this project is available in two forms. The book '*Spatial distribution and quantification of rice-fallows in South Asia – potential for legumes*.' Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 316 pp. ISBN 92-9066-436-3 by Subbarao, G. V., Kumar Rao, J. V. D. K., Kumar, J., Johansen, C., Deb, U. K., Ahmed, I., Krishna Rao, M. V., Venkataratnam, L., Hebbar, K. R., Sesha Sai, M. V. R., and Harris, D. (2001) has been published and distributed to policymakers, research managers, funding agencies and other interested parties. The initial distribution list is attached as Annex 1. The contents of the book are also available online at:

www2.icrisat.org/text/research/nrmp/dfid/text/home5.asp

c. What further stages will be needed to develop, test and establish manufacture of a product?

The report has alerted people to the large scale of the problem. A sample of location-specific studies in rice fallow areas to identify and prioritise constraints is necessary. Other PSP-funded projects, e.g. **R7438** *'Participatory promotion of 'on-farm' seed priming'*, **R7540** *'Promotion of chickpea following rice in the Barind area of Bangladesh'* and **R7838** *'Rapid generation advancement of a chickpea population for farmer participatory selection'* have all suggested promising ways to improve the feasibility of rainfed *rabi* cropping in rice fallows. Preliminary, on-farm trials of simple, generic rainfed *rabi* cropping technologies should be implemented in representative rice fallow areas in parallel with the constraints analysis. Synthesis of the results from these twin studies would inform larger-scale efforts to promote more productive use of rice fallows in S. Asia.

d. How and by whom, will the further stages be carried out and paid for.

The Plant Sciences Research Programme is to support such preliminary parallel studies in India (Jharkhand, Orissa, West Bengal, Chattisgarh, and Madhya Pradesh) and Nepal (Jhapa, Moran and Dhanusha districts) in collaboration with ICRISAT, NGOs and District Agriculture Development Offices (Nepal). Linkages are being forged with other legume-related projects implemented by ICRISAT and NARC (Nepal).

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Annex 1

Initial distribution list for copies of ‘*Spatial distribution and quantification of rice-fallows in South Asia – potential for legumes*.’ Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 316 pp. ISBN 92-9066-436-3 by Subbarao, G. V., Kumar Rao, J. V. D. K., Kumar, J., Johansen, C., Deb, U. K., Ahmed, I., Krishna Rao, M. V., Venkataratnam, L., Hebbar, K. R., Sesha Sai, M. V. R., and Harris, D. (2001).

As of 03 October 2001

1) Dr Dave Harris, DFID PSP – 50 copies
2) ICRISAT MG Members (numbering Five) comprising DG, DDG (Res), Dr B I Shapiro, Director (NRM), Mr S Parthasarathy, ADG (L), Mr K A Akoto – one copy each.
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