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Rice area mapping, yield, and production forecast for the province of Nueva Ecija using RADARSAT imagery

C. Chen, E.J.P. Quilang, E.D. Alosnos and J. Finnigan

Abstract. Monitoring rice production is an important tool for the Government of the Philippines' objective to achieve rice sufficiency by 2013. For decision makers to ensure that the country has an adequate rice supply, it is imperative that timely and accurate information on rice area, yield forecasts, and production be regularly updated with little or no statistical response burden to producers; this study describes a process well suited for the integration and utilization of the methodologies for rice monitoring using radar data. Currently, the national and regional rice production in the Philippines is estimated through a complex and labor-intensive process using surveys of farmers and fields. Faster, reliable, and more efficient methods are needed to monitor production because rice production is affected by seasonal crop prices, climate, and daily weather.

To accurately forecast rice production in near real time, remote sensing technology was used. A rice crop monitoring application using RADARSAT imagery was initially developed and tested in 2001. This application was modified and retested in the wet season of 2007 in Muñoz and Santo Domingo, Nueva Ecija, Philippines. This application demonstrated the capability to forecast rice production over an extended region. The program also offered flexibility in its ancillary data requirements, making it suitable for a practical and operational rice monitoring program.

During the wet season of 2008, the rice area in the province of Nueva Ecija was mapped, and yield and production were forecast using the developed methodology. Data gathered from this project were compared with data obtained from the Philippines Bureau of Agricultural Statistics (BAS). The accuracy, at the provincial level, of the rice area and production estimates derived from remotely sensed data were 97.4% and 96.6%, respectively, when compared with the BAS statistical data.

Résumé. Le suivi de la production rizicole est un outil important pour le gouvernement des Philippines dans son objectif de parvenir à l'autosuffisance en matière de production de riz d'ici 2013. Afin de permettre aux décideurs d'assurer que le pays dispose d'une source adéquate de riz, il est essentiel que les informations à jour et précises sur les superficies de riz, les prévisions de rendement et la production soient mises à jour régulièrement avec peu ou sans charge de réponse statistique pour les producteurs. On décrit dans cet article de recherche, une procédure bien adaptée pour l'intégration et l'utilisation des méthodologies de suivi du riz basées sur l'utilisation des données radar. À l'heure actuelle, l'estimation de la production nationale et régionale de riz dans les Philippines est dérivée par le biais d'une procédure complexe et laborieuse basée sur des enquêtes auprès des cultivateurs et des relevés au niveau des champs. Étant donné que la production rizicole est affectée par les prix saisonniers des récoltes, le climat et la météo journalière, des méthodes plus rapides, fiables et plus efficaces sont requises pour faire le suivi de la production.

Afin de pouvoir prédire de façon plus précise la production rizicole en temps quasi réel, on a eu recours aux technologies de télédétection. Une application de suivi de la production rizicole utilisant des images de RADARSAT a été développée et testée au départ en 2001. Cette application a ensuite été modifiée et testée à nouveau durant la saison humide de 2007 à Muñoz et à Santo Domingo, dans la province de Nueva Ecija, aux Philippines. Cette application a démontré sa capacité à fournir des prévisions de production rizicole sur une région étendue. Le programme a aussi montré une certaine flexibilité par rapport aux besoins en données auxiliaires assurant ainsi son efficacité dans le contexte d'un programme pratique et opérationnel de suivi du riz.

Au cours de la saison humide de 2008, un projet a été octroyé pour cartographier la superficie en riz dans la province de Nueva Ecija et pour fournir des prévisions de rendement et de production en utilisant la méthodologie développée. Les données recueillies lors du projet ont été comparées avec des données obtenues du BAS (« Bureau of Agricultural Statistics ») des Philippines. Au niveau provincial, les précisions des estimations de superficie et de production de riz dérivées des données de télédétection étaient respectivement de 97,4 % et de 96,6 % comparativement aux données statistiques du BAS.

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Introduction

Increases in population growth, increases in per person food demands, and the degradation of agricultural lands threaten long-term stability in any country. In the Philippines, food security is tied explicitly to national rice production and this requires a highly accurate spatial–temporal rice crop monitoring system that can assess rice growth conditions, provide the area of rice crops, and forecast yield in a given region. The Government of the Philippines aims to achieve rice self-sufficiency by 2013 (http://www.philrice.gov.ph//images/pdf/2013 master plan.pdf). Therefore, forecasting rice yield and monitoring rice production at a national scale are essential in determining national food demand, supply balance, and food security. Rice yield estimates and forecasts will greatly influence farm-level management decisions, such as fertilizer applications and irrigation delivery, as well as provide a means for farm income assessment (Van Niel and McVicar, 2001).

In the past, the standard yield forecasting procedures were the analysis of crop cuttings at randomly sampled ground plots during harvest or the simulation of rainfall and past yield data using meteorological regression models (Murthy et al., 1996; Karimi and Siddique, 1992). However, these methods often produce results that are neither timely nor spatially explicit.

At present, rice acreage and production in the Philippines are estimated through ground surveys. The Bureau of Agricultural Statistics (BAS) provincial enumerators conduct quarterly interviews of randomly selected rice farmers in the 45 major rice producing provinces to obtain information on the area planted, expected yield, and the production for the next quarter, as well as the estimated area harvested and the production from the previous quarter. A similar survey is done twice a year for the remaining 34 minor rice producing provinces of the country. Data from these surveys are then submitted to the BAS central office for processing and analysis. Based on these survey results and the statistics from previous years, provincial and national production forecasts are made for the next calendar year. This information is then fed to the Interagency Committee for Rice (IAC) who provides the final estimate of the rice supply. The IAC is also responsible for recommending the total volume of rice that should be imported to maintain a 110–120 day buffer stock.

This conventional system of monitoring rice supply presents statistics at the national and provincial level only. It is time consuming, labour intensive, prone to subjectivity, and does not provide real-time, spatially enabled estimates of rice acreage, yield, and production. A quarterly survey of all the provinces in the Philippines, for example, was estimated to cost around 2 000 000 pesos (about $50 000 CAD) for field work expenses only, and it entails approximately a full month's work for all BAS provincial field staff. Some rice areas are remote and inaccessible which makes surveys in these areas difficult, if not impossible. In addition, yield and production forecasts were based on the perceptions of the farmers sampled. Thus, current estimates at the regional or national level are biased and require significant amounts of manpower (Casiwan et al., 2005). Because timely estimates of these data are crucial in formulating rice policies; faster, reliable, and more efficient methods are needed to facilitate the process (Honda et al., 2005).

Remote sensing is readily accepted in many agricultural applications because of its ability to produce timely, accurate, and spatially organized results. Remote sensing is a process for acquiring digital data in the visual, thermal, or microwave portions of electromagnetic spectrum (EMS) through satellite, aircraft, or ground-based systems but characteristically at a distance from the target (McVicar and Jupp, 1998). The remotely sensed images can be manipulated by specialized software to highlight features of soil, vegetation, water, clouds, and land use. The spectral information and spatial density of remote sensing data are ideally suited to the measurement of larger areas (Van Niel and McVicar, 2001).

Spatially meaningful forecasts of yield can be made as early as 1–3 months prior to harvest (Quarmby et al., 1993). The possibility of monitoring agricultural activities over a year at a regional or national scale is high because of the repeat coverage of satellites in one location. Compared with the labour, time, and money invested in field work devoted to collecting field and farmers' data, the availability and ease of acquiring satellite imagery is very attractive.

In the past, remotely sensed optical data have been used extensively in discriminating agricultural land uses, measuring crop area, predicting crop yield, mapping moisture availability, and monitoring water supply (Van Niel and McVicar, 2001). However, the use of optical remote sensing is particularly difficult and even ineffective under poor weather conditions. Rice is traditionally cultivated in environments with extensive cloud coverage. Even during the dry season, the sky is often covered with high-level clouds.

Microwaves, however, penetrate clouds and therefore the radar images, collected from microwave sensors are not hindered by most weather conditions, and provide an excellent imagery source over the entire crop growth cycle. The potential use of synthetic aperture radar (SAR) data in rice monitoring has been scientifically supported by numerous researchers who have demonstrated that there is a high correlation between radar backscatter and rice biomass (Aschbacher et al., 1995; Brisco and Brown, 1995; Kurosu et al., 1995; Le Toan et al., 1997; Ribbes and Le Toan, 1999; Inoue et al., 2002) and have established that fields under rice production can be accurately mapped based on temporal variation in radar backscatter (Chen and McNairn, 2006). Many successful research projects on rice crop monitoring using satellite radar imagery were completed in various rice-growing Asian countries such as Vietnam (Lam-Dao et al., 2005), Indonesia (Le Toan et al., 1997), Sri Lanka (Frei et al., 1999), China (Bouvet et al., 2005); India (Choudhury and

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Chakraborty, 2006), and the Philippines (Chen and McNairn, 2006). Rice growing areas have been accurately determined using multitemporal SAR data, and rice yield has been estimated by coupling the information derived from SAR data with a rice growth model.

Over the years, neural networks have received considerable attention in radar remote sensing because they are more robust in datasets with high levels of noise. Using the back propagation of error learning algorithm, the neural network method for multisource remote sensing data classification has generally outperformed conventional statistical approaches (Benediktsson et al., 1990). The method is not constrained by the distribution of the data, requires no prior knowledge about the statistical distribution of the classes, and is able to perform better than the maximum likelihood classification.

Using this approach, Chen and McNairn (2006) were able to develop a new method for rice mapping in the Philippines that integrated change detection and neural network methods using RADARSAT-1 fine beam mode imagery. Using this method, they were able to delineate the rice area in Muñoz and Santo Domingo, Nueva Ecija, in 2001 for a wet and a dry season, and they were able to extract information on rice planting dates. A minimum mapping accuracy of 96% was achieved. The rice maps were then used in a neural-network-based yield model to predict rice yields for a wet season. When the yields predicted were compared with government statistics, the result was a prediction accuracy of 94% (Chen and McNairn, 2006).

A similar method was tested in the same cities over a wet season in 2007 and it was refined using RADARSAT-1 standard beam mode imagery. Switching to standard beam reduced the number of scenes required for mapping rice area at a provincial or national scale. Although individual rice fields can be small, the increased pixel size of standard beam imagery did not affect the monitoring performance, and it was shown that integrated change detection and the neural network approach was best suited to carry out rice production estimates over an extended region.

This study discusses a rice crop monitoring application completed in 2008 over the province of Nueva Ecija. The methodology developed and tested in the previous years was used, and no ground truth data was utilized in the process. To validate the performance of this regional application, the BAS data from the provincial agricultural office of Nueva Ecija, Philippines, were compared with the data derived from this project.

Study area and data

Study area

The study area was the province of Nueva Ecija in the Philippines. The province consists of 27 municipalities and 5 cities (Cabanatuan, Gapan, Muñoz, Palayan, and San Jose) and encompasses an area of approximately 5750 km^2. This is a landlocked province located in the Central Luzon region of the Philippines. Agriculture, in cities and municipalities, is the main industry because of naturally rich soil. Lowland crops such as rice, corn, onions, other vegetables, and sugarcane are produced in great quantities.

Nueva Ecija is the province with the highest rice production in the Philippines and is widely referred to as the "rice bowl" of the country. The headquarters of the Philippine Rice Research Institute (Philrice) is located in the city of Muñoz. There are two rice production seasons a year in Nueva Ecija: a dry season from December to April and a wet season from late May to November. Rice is typically sown on wet soil during the dry season and transplanted during the wet season. Overall rice production is lower in the dry season than during the wet season. The dry season is characterized by limited rainfall, few typhoons, and higher temperatures. The wet season is characterized by frequent rain showers and typhoons. On average, there are six typhoons per annum. Rainfall averages about 1500 mm per year and the mean temperature is 27.3 °C.

Table 1. List of imagery used

Sensor	Acquistion date	Beams	Polarization	Orbit
RADARSAT-1	31 May 08	S7	HH	Descending
RADARSAT-1	10 Jun 08	S4	HH	Descending
RADARSAT-1	24 Jun 08	S7	HH	Descending
RADARSAT-1	04 Jul 08	S4	HH	Descending
RADARSAT-1	18 Jul 08	S7	HH	Descending
RADARSAT-1	28 Jul 08	S4	HH	Descending
RADARSAT-1 and ASAR mosaic	10 Aug 07/12 Aug 07	S6/IS4	HH/HH	Descending/Descending
RADARSAT-1 and ASAR mosaic	22 Aug 07/25 Aug 07	S4/IS7	HH/HH	Ascending/Descending
RADARSAT-1 and ASAR mosaic	03 Sep 07/04 Sep 07	S6/IS6	HH/HH	Descending/Ascending
RADARSAT-2	16 Sep 08	S7	HH	Descending
RADARSAT-2	26 Sep 08	S4	HH	Descending
RADARSAT-2	10 Oct 08	S7	HH	Descending
RADARSAT-2	20 Oct 08	S4	HH	Descending
RADARSAT-2	03 Nov 08	S7	HH	Descending

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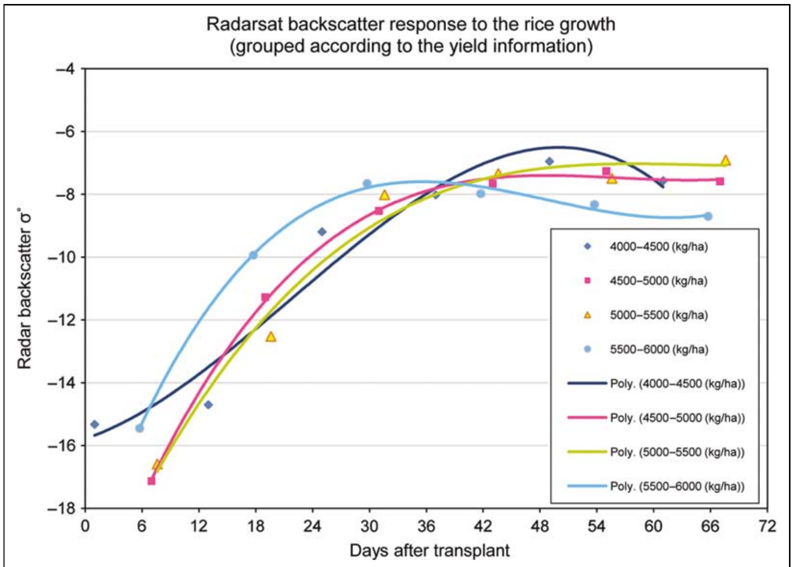

Figure 1. Radar backscatter response to rice growth. The graphics were grouped according to the yield information acquired in 2001 wet season.

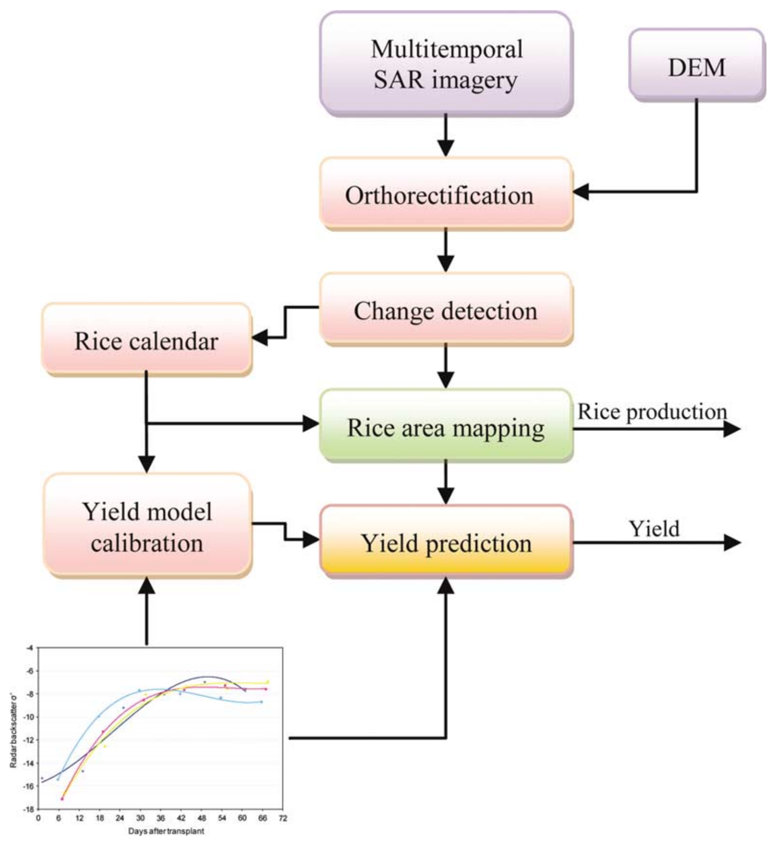

Figure 2. A flow diagram of the rice monitoring system.

Although there are two rice production seasons, the beginning of rice cultivation within each season varies substantially. In December 2008, different fields were seen in all stages from planting to harvesting, indicating that production is relatively continuous. The time span for the initiation of rice production was more than three months during the wet season of 2008. Some farmers began rice cultivation as early as May while others did not start until late August.

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Imagery

RADARSAT-1 image acquisitions were initially planned and programmed every 10–14 days beginning at the end of May through to November 2008. However, because the onboard tape recording capability of the RADARSAT-1 satellite was lost, only six RADARSAT-1 images from 31 May to 28 July 2008 were acquired. Three 2007 RADARSAT-1 and Envisat ASAR mosaics were used to fill in the missing images for August and early September. Five RADARSAT-2 images were also used to cover the later rice cultivation period. **Table 1** contains a list of radar imagery used for this project.

Methodology

Radar backscatter, (**Figure 1**), is uniquely defined because of changing water levels in rice paddies (Chen, 2002). The backscatter changes as the rice crop matures from one growth stage to another. Prior to transplanting or seeding, the recorded radar backscatter was very low because of specular reflection from the flooded fields (below -15 dB). At this stage, rice fields are easily detected on the radar images because of the significant backscatter difference between flooded and nonflooded areas. During the vegetative phase, the radar backscatter steadily increases because of volume scattering within the rice canopy and multiple reflections between the plants and water surface. This results in an increase in backscatter from approximately -14 dB to approximately -8 dB in a 14–30 day period. This is traditionally the stage where rice growth is monitored using radar imagery. As the crop ripens the backscatter decreases; this corresponds with a reduction in plant water content. The backscatter reaches a minimum prior to harvest. This temporal backscatter pattern is unique to paddy rice crops.

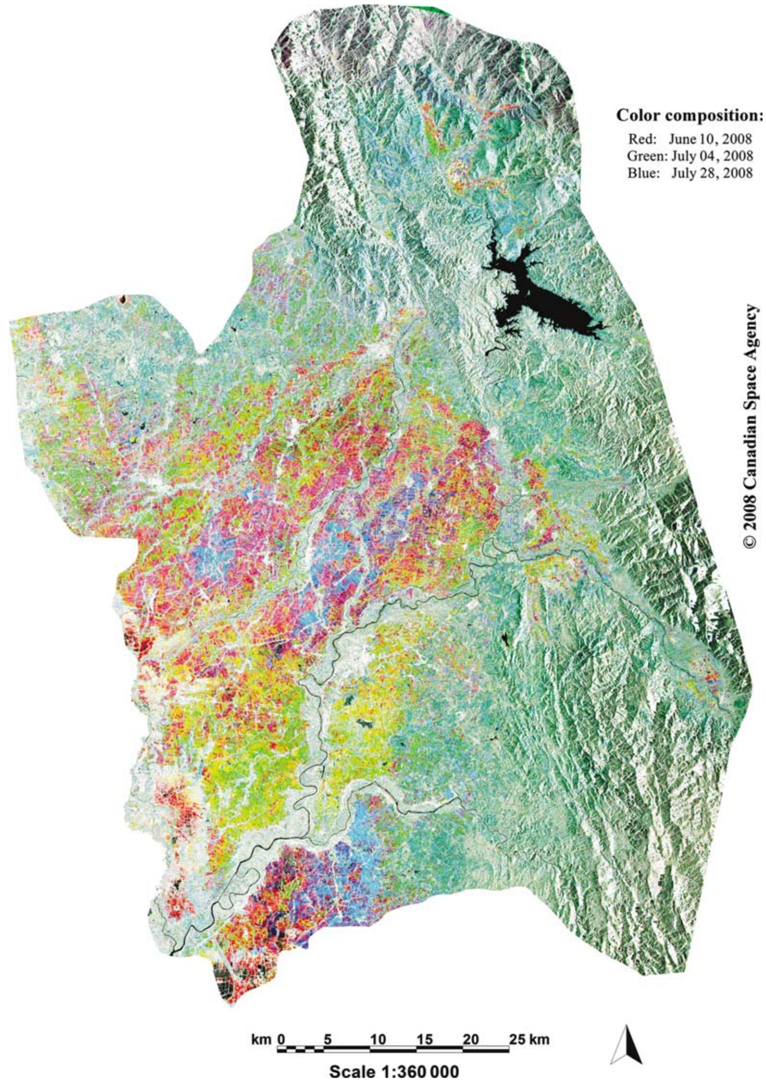

Figure 3. RADARSAT-1 color composite image of the province of Nueva Ecija, Philippines, 2008.

Variations in backscatter over the rice growing season are much larger relative to any other agricultural crop (Aschbacher et al., 1995).

Figure 2 shows a flow diagram of this project, which consisted mainly of image preprocessing, rice area mapping, and yield forecasting.

Image preprocessing

All RADARSAT scenes obtained in 2008 were collected in descending mode with only two incidence angles: S7 and S4. Two sets of ground control points (GCPs), one for S7 and another for S4, were collected from an existing ortho-rectified Landsat 7 ETM image, and these two sets of reference points along with the Shuttle Radar Topography Mission (SRTM) digital elevation data were used to ortho-rectify respective S7 and S4 RADARSAT images. A 3×3 Lee despeckle filter was then used to reduce the radar speckle noise.

Rice area mapping

The rice area for the province of Nueva Ecija was extracted using change detection and the neural network integrated approach developed in a previous research project (Chen and McNairn, 2006). This approach consists of the following:

1. Create a sequence change map from RADARSAT imagery to identify rice fields. The change map was created based on a simple ratio of two consecutively acquired radar images. The rice fields were identified as a function of the degree of change in radar backscatter between the two images. Any areas where the backscatter change value was above a predefined threshold were retained within the rice class.
2. Extract rice cultivation data. The project area was the province of Nueva Ecija with an area of 5750 km^2. Because of the geography of the province and the distribution of irrigated water, farmers do not start their rice cultivation at the same time. Some farmers

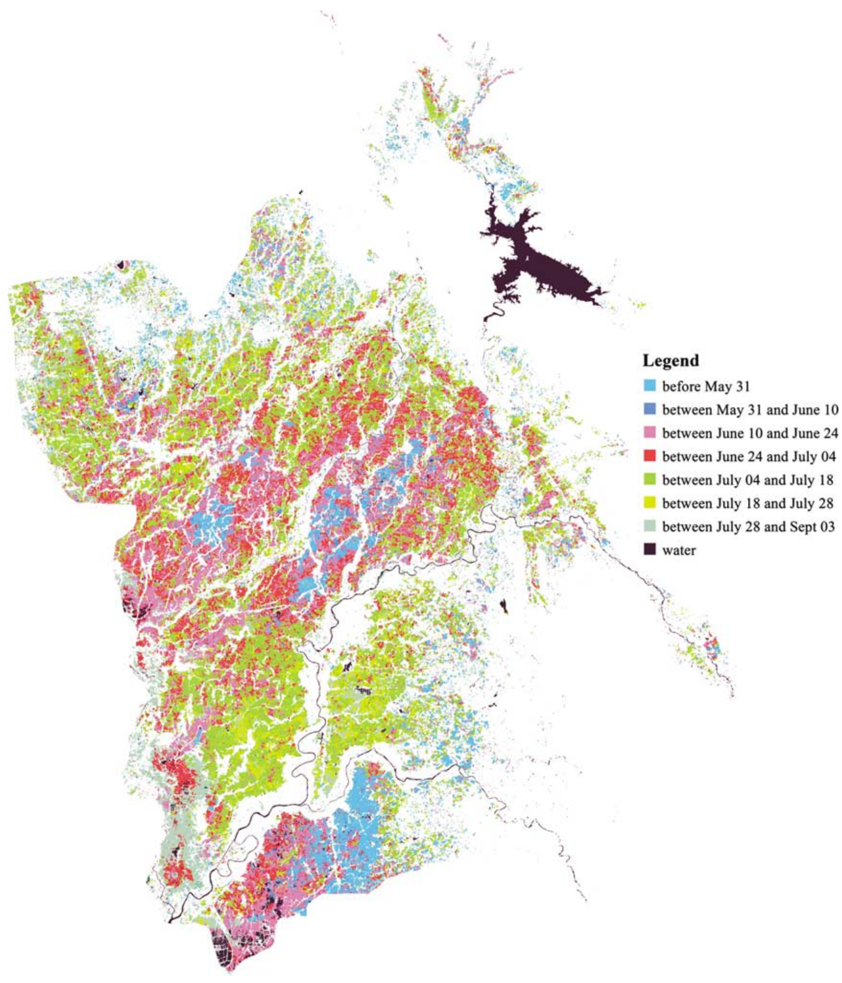

Figure 4. Rice areas in production and their associated cultivation intervals as determined using radar data.

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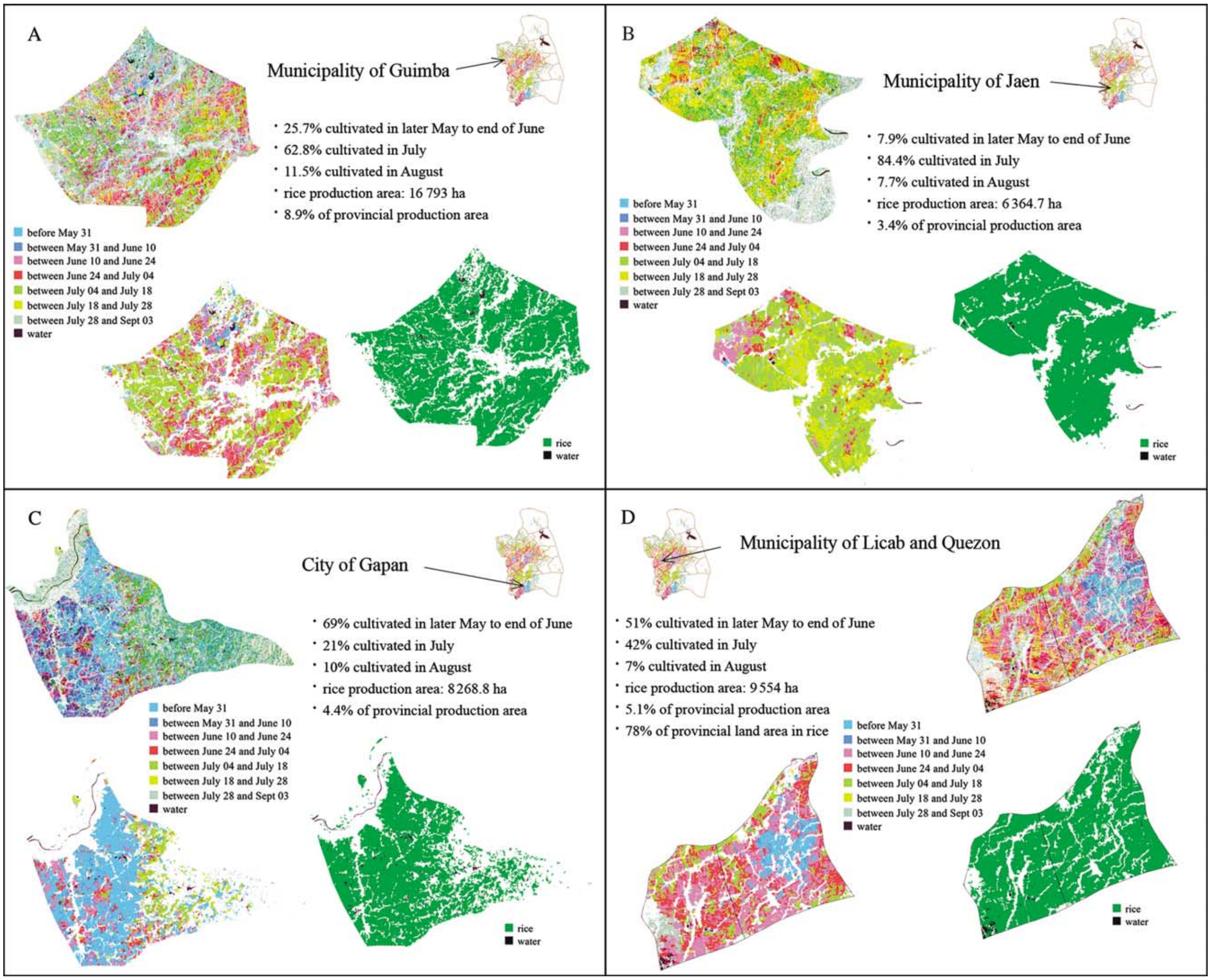

Figure 5. Examples of rice area and statistics of (A) Guimba, (B) Jaen, (C) Gapan, and (D) Licab and Quezon.

started their rice fields early in May while others did not start until later in August. The preparation dates of the fields were determined by vegetation change detection between images.

3. Generate random rice samples from the change map. A neural network classification was used to delineate rice fields. The neural network classification, however, requires extensive and representative training data and these training data should not be acquired through a ground truth approach in an application project; they were randomly created from the change detection map.
4. Edit randomly generated samples to eliminate outliers. Due to the nature of radar imagery, even with a noise reduction filter applied, the results from the change detection were noisy and contained errors. To ensure the integrity of these randomly generated samples, they were edited manually with the background of original images to eliminate outliers.
5. Train and classify using neural network. Neural networks are computational models with the ability to "learn" or organize data based on a parallel processing system (Erbek et al., 2004). The result of the neural network classification depends on both the network structure and the learning parameters. A configuration of a neural network, with two hidden layers provided the best performance given that the number of neurons in the hidden layers was not close to the input and output layers. This result is consistent with a previous result (Chen and McNairn, 2006).

Yield prediction

Rice yield is positively related to the slope of the backscatter curve for the first 6–36 days after transplanting, as is shown in **Figure 1**. Consider that the radar backscatter of an individual pixel can be described as a vector in n-dimensional space, where n is the number of observations, i.e., images acquired during a rice growth season. Backscatter measurements corresponding to an unknown yield are compared with the reference curves using slope comparison. The

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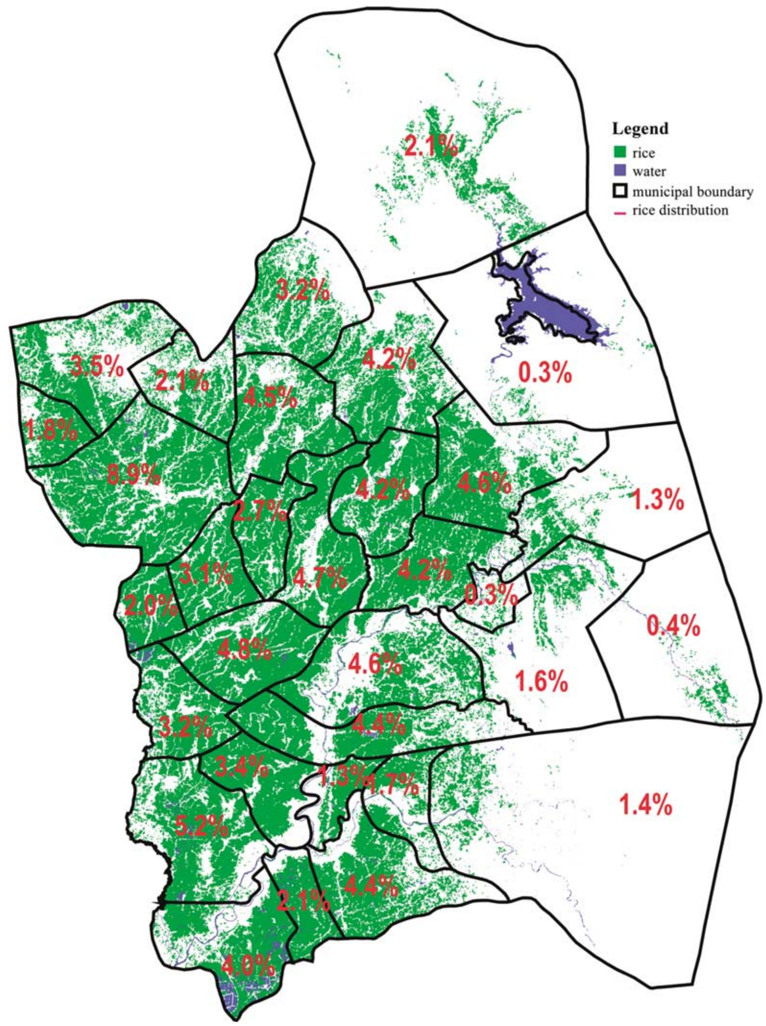

Figure 6. Percent of provincial rice area by city and municipality in 2008, based on the analysis of radar data.

slope calculated between any two observation points on the unknown curve is compared with the corresponding points on the reference curve. The degree of similarity with the reference curve is expressed as the angle between the two slope lines. This angle κ can have a value between 0 and $\pi/2$ and is calculated from the following algorithm (Bertels et al., 2005):

$$\theta = \cos^{-1}\left(\frac{\sum_{i=1}^{n} p_i r_i}{\sqrt{\sum_{i=1}^{n} p_i^2 \sum_{i=1}^{n} r_i^2}}\right) \tag{1}$$

where n is the number of observations, p is the vector of the backscatters of the present year, and r is the reference vector derived from **Figure 1**. This algorithm computes an angle between the two vectors and this angle is interpreted as a measurement of ''similarity'' between the two vectors. The smaller the angle, the greater the similarity. Each vector from the 2008 data set was compared with all the reference vectors in **Figure 1** and the corresponding yield value from which the smallest angle, or greatest similarity, calculated was taken as the yield value.

Results and discussion

Rice production and distribution

Figure 3 shows a color composite of RADARSAT-1 imagery of Nueva Ecija. The red image was taken on 10 June, the green image on 4 July, and blue image on 28 July 2008. The composition of radar images highlights the rice fields in bright colors, and these colors depict the variations over time of rice cultivation. **Figure 4** shows the extracted rice fields and their associated cultivation time in 10–14 day intervals. During the 2008 wet season, 29% of the rice fields were cultivated in late May and early June, 54% were

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Table 2. Rice area, yield, and production data derived from remote sensing technology for the cities and municipalities within the province of Nueva Ecija in the 2008 wet season.

City or municipality	Satellite-based land area (ha)	Rice area cultivated (ha) May–June	July	August–September	Total rice area	Rice area by total city or municipal area (%)	City or municipal rice area compared with provincial rice area (%)	Production (metric tons)
Aliaga	11 853	2 872	5 429	720	9 021	76.1	4.8	40 440
Bongabon	20 577	598	1 411	347	2 355	11.4	1.3	10 523
Cabanatuan City	18 608	1 162	6 008	1 514	8 684	46.7	4.6	40 227
Cabiao	13 456	3 029	2 502	1 993	7 525	55.9	4.0	34 849
Carranglan	74 598	1 391	1 145	1 403	3 939	5.3	2.1	18 219
Cuyapo	14 920	1 078	3 381	2 157	6 616	44.3	3.5	28 840
Gabaldon	25 444	213	319	193	725	2.9	0.4	3 371
Gapan City	14 512	5 717	1 742	810	8 269	57.0	4.4	36 893
General Natividad	11 235	2 634	4 636	541	7 812	69.5	4.2	34 618
General Tinio	67 115	1 256	907	521	2 684	4.0	1.4	12 108
Guimba	23 730	4 309	10 544	1 941	16 793	70.8	8.9	74 538
Jaen	8 648	498	5 375	492	6 365	73.6	3.4	30 061
Laur	23 708	886	1 421	789	3 096	13.1	1.6	14 036
Licab	4 875	1 480	1 854	478	3 812	78.2	2.0	17 320
Llanera	10 615	3 653	3 736	452	7 841	73.9	4.2	34 994
Lupao	14 986	1 787	2 211	2 001	5 999	40.0	3.2	26 865
Muñoz City	13 224	1 245	6 274	906	8 425	63.7	4.5	36 977
Nampicuan	4 854	391	1 933	1 029	3 353	69.1	1.8	14 866
Palayan City	3 261	172	175	219	565	17.3	0.3	2 444
Pantabangan	38 120	203	228	197	628	1.6	0.3	2 835
Peñaranda	6 803	868	1 844	558	3 270	48.1	1.7	15 113
Quezon	7 400	3 397	2 118	227	5 742	77.6	3.1	25 780
Rizal	16 567	2 299	5 643	723	8 665	52.3	4.6	37 993
San Antonio	16 586	1 251	4 388	4 089	9 727	58.6	5.2	42 587
San Isidro	5 167	2 762	997	192	3 950	76.4	2.1	18 970
San Jose City	16 921	978	5 186	1 691	7 855	46.4	4.2	34 371
San Leonardo	4 308	40	1 686	665	2 391	55.5	1.3	11 670
Santa Rosa	13 932	877	6 036	1 366	8 279	59.4	4.4	38 321
Santo Domingo	6 532	2 172	2 602	278	5 052	77.3	2.7	22 092
T alavera	12 015	4 012	4 306	433	8 751	72.8	4.7	38 758
T alugtug	8 529	795	1 844	1 266	3 905	45.8	2.1	17 336
Zaragoza	8 883	1 375	3 384	1 199	5 958	67.1	3.2	26 195
Total	541 981	55 400	101 262	31 388	188 050		100	844 212

cultivated in late June and July, and 17% were cultivated in August and early September. Although the start of rice cultivation covered more than 3 months, the majority of farmers planted their rice fields in June and July, which is considered the most suitable time in the wet season in terms of weather and water provisions. The earliest rice cultivation took place in the city of Gapan and the municipalities of Quezon, Jaen, and Guimba, and the latest rice cultivation was in the municipality of San Antonio. Some examples are shown in **Figures 5a–d**, where 88%-93% of the rice fields were planted in June and July.

Figure 6 and **Table 2** show the total rice area mapped in the province and the percentage of rice cultivation in all 27 municipalities and 5 cities. Based on the analysis of the radar data, the municipality of Guimba contained the most rice area during the 2008 wet season (**Figure 5a**) with 8.9% of the total provincial rice area. Conversely, Palayan, Pantabangan, and Gabaldon were among the lowest contributing city and municipalities with only 0.3%, 0.3%, and 0.4%, respectively, of the total provincial rice area (**Table 2**). The municipalities of Licab, Quezon, Santo Domingo, San Isidro, and Aliaga had more than 76% of total available land area by municipality dedicated to rice production during the 2008 wet season (**Table 2**), and among them Licab and Quazon had the highest density of rice in production by municipality, 78.2% and 77.6%, respectively, as shown in **Figure 5d**.

Yield forecasting and distribution

Figures 7 and **8** show the yield information and distribution derived from the yield prediction model described in the previous section. **Table 2** shows the rice production

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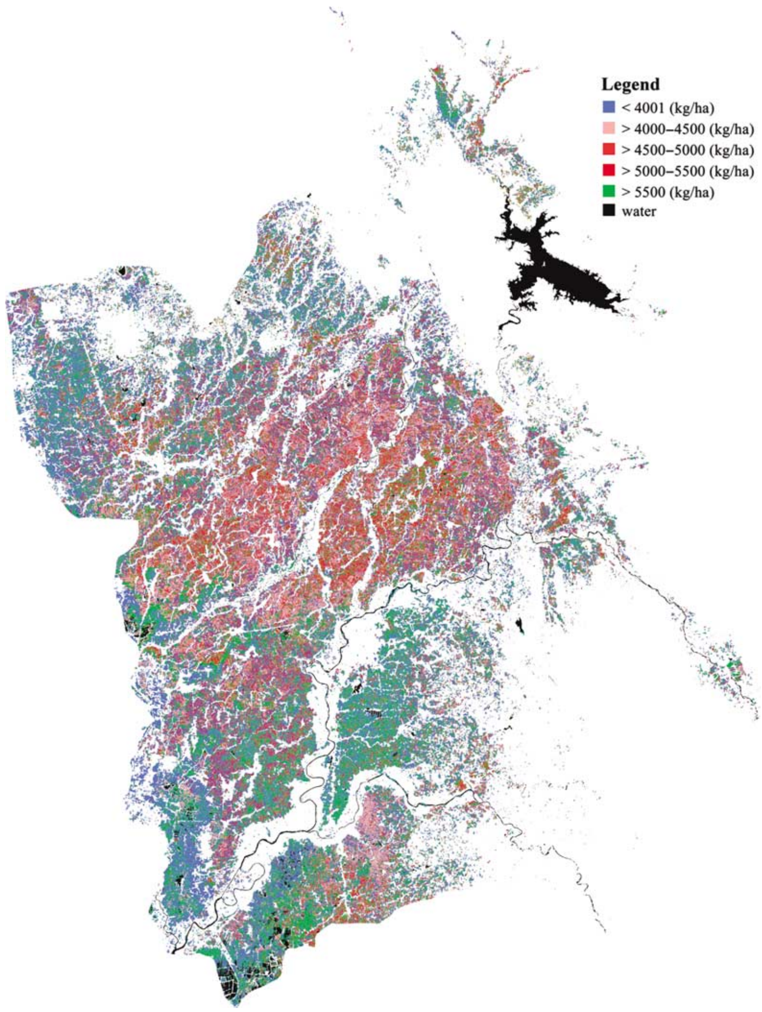

Figure 7. Yield classification of the province of Nueva Ecija during the 2008 wet season.

distribution for each city and municipality in the province. The cities and municipalities that had 40% of rice fields yielding less than 4000 kg/ha are highlighted in blue in **Figure 8**, those with yields between 4000 and 5500 kg/ha are highlighted in red, and those with 40% of the rice fields yielding more than 5500 kg/ha are highlighted in green. As shown in **Figure 8**, the cities and municipalities with higher yeilds (green), are mostly along the Pantabangan River and have the best irrigation systems. The cities and municipalities with lower yeilds (blue) were mainly in the northwest of the province where the water supply was constrained. The cities and municipalities in the center of the province (red) had moderate yields.

Comparison of remote sensing derived data with BAS data

To validate the results derived from this project, the rice cultivation area and yield data of each city and municipality in the province of Nueva Ecija for the 2008 wet season were obtained from the provincial agricultural office of Nueva Ecija (the BAS data). The BAS data and the data derived from neural network integrated approach (NNIA) are summarized in **Table 3** and plotted in **Figures 9** and **10**. **Figure 9** shows the rice area and production comparison between NNIA and BAS for all 27 municipalities and 5 cities. **Figure 10** shows the scatter plot of the paired data between NNIA derived and BAS. In general, for almost all 27 municipalities and 5 cities, the total rice area and production derived by NNIA fit well with BAS data, with correlation coefficients of 0.87 and 0.83, respectively, with a 95% confidence level. The largest variability in the points around the regression line was the municipality of San Antonio as shown in **Figure 9** and **10**. The municipality of San Antonio had more than 42% of its area in rice production in August (**Table 2**), which was the highest in the province. As described previously, the failure of the on-board recorder capability on RADARSAT-1 resulted in a critical loss of data during the month of August. By excluding the municipality of San Antonio in the comparison, the correlation coefficient improved 7% and 6% in

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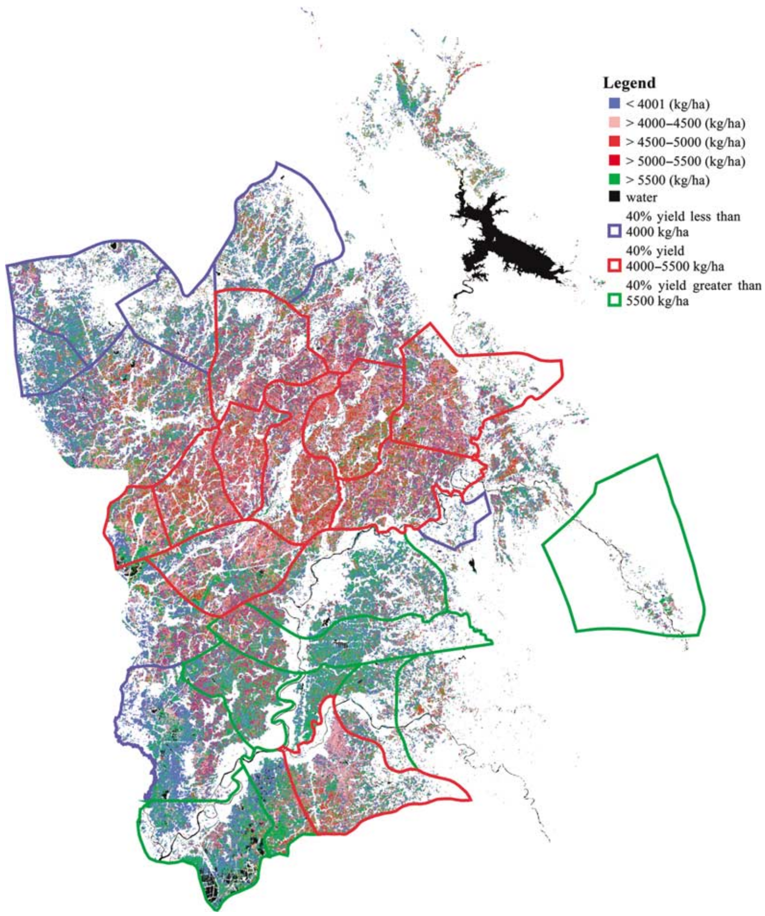

Figure 8. Yield classification and distribution of province of Nueva Ecija in the 2008 wet season where blue indicates cities and municipalities with 40% of rice fields yielding less than 4000 kg/ha; red indicates yields between 4000 and 5500 kg/ha; and green indicates 40% of rice fields yielding more than 5500 kg/ha.

the rice area and production forecast, respectively. Other municipalities, Carranglan, Cuyapo, Lupao, Nampicuan, Pantabangan, Talugtug, and Palayan city, had 30%–39% of the rice area extracted for the August imagery. However, if these areas were excluded, the correlation coefficient improved by only 1% which could indicate that the rice cultivation area in these cities did not change significantly during August in 2007 and 2008.

Table 4 summarizes the rice production and the comparison with BAS data. The NNIA-derived total rice area in the province of Nueva Ecija in the 2008 wet season was 188 050 ha with a total production of 844 212 metric tons and an average yield of 4.489 metric tons/ha. The NNIA-derived rice area, production, and average yield were 2.6%, 3.4%, and 0.7%, respectively, higher than the BAS data. **Table 4** also shows the effect of excluding the municipality of San Antonio. The NNIA-derived rice area and production were slightly lower than the data from BAS without the data of San Antonio, but the average yield increased slightly to 4.495 metric tons/ha. This result is consistent with **Figure 8** where San Antonio, located in the lower left corner (blue), had more than 40% of the rice fields yielding less than 4000 kg/ha. With this lower yielding municipality excluded, the average yield was slightly higher.

3-year rice production monitoring in Muñoz and Santo Domingo

As mentioned previously, the technology used in this project was developed in 2001 using RADARSAT-1 fine beam imagery in the city of Muñoz and the municipality of Santo Domingo in Nueva Ecija, in the Philippines, and it was reevaluated in 2007 using RADARSAT-1 standard beam imagery. The 3 years of rice monitoring in Muñoz and Santo Domingo serve as a good example of vertical comparisons and trends of rice production in the region as shown in **Figures 11** and **12**. **Figure 11** shows Muñoz and Santo Domingo in 2001, 2007, and 2008, where the color images are RADARSAT-1 composites of June and July images and their corresponding rice areas which were

Table 3. Rice area and production data derived from remote sensing technology and the Bureau of Agricultural Statistics (BAS) in the 2008 wet season.

		Neural network integrated approach (NNIA)		BAS data	
City or municipality	Satellite-based land area (ha)	Total rice area (ha)	Production (metric tons)	Total rice area (ha)	Production (metric tons)
Aliaga	11 853	9 021	40 440	6 994	28 238
Bongabon	20 577	2 355	10 523	3 593	17 617
Cabanatuan City	18 608	8 684	40 227	8 413	33 869
Cabiao	13 456	7 525	34 849	5 556	26 751
Carranglan	74 598	3 939	18 219	4 500	21 494
Cuyapo	14 920	6 616	28 840	8 740	44 820
Gabaldon	25 444	725	3 371	1 897	7 648
Gapan City	14 512	8 269	36 893	8 440	40 020
General Natividad	11 235	7 812	34 618	6 512	26 759
General Tinio	67 115	2 684	12 108	2 102	8 963
Guimba	23 730	16 793	74 538	15 097	60 630
Jaen	8 648	6 365	30 061	6 108	25 339
Laur	23 708	3 096	14 036	2 573	12 561
Licab	4 875	3 812	17 320	3 031	14 034
Llanera	10 615	7 841	34 994	7 749	30 919
Lupao	14 986	5 999	26 865	6 483	26 922
Muñoz City	13 224	8 425	36 977	8 764	46 719
Nampicuan	4 854	3 353	14 866	3 876	16 892
Palayan City	3 261	565	2 444	1 936	8 286
Pantabangan	38 120	628	2 835	1 280	4 959
Peñaranda	6 803	3 270	15 113	3 608	15 011
Quezon	7 400	5 742	25 780	4 600	22 546
Rizal	16 567	8 665	37 993	7 136	31 262
San Antonio	16 586	9 727	42 587	3 147	15 057
San Isidro	5 167	3 950	18 970	4 182	23 045
San Jose City	16 921	7 855	34 371	8 850	40 266
San Leonardo	4 308	2 391	11 670	2 992	12 564
Santa Rosa	13 932	8 279	38 321	7 469	36 085
Santo Domingo	6 532	5 052	22 092	7 146	32 534
T alavera	12 015	8 751	38 758	8 717	37 793
T alugtug	8 529	3 905	17 336	6 389	27 748
Zaragoza	8 883	5 958	26 195	5 355	19 475
Total	541 981	188 050	844 212	183 234	816 827

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extracted and displayed in green. **Figure 12** shows a plot of the extracted rice area of Muñoz and Santo Domingo with the total rice area varying over the 3 years (2001, 2007, and 2008) (**Figure 12**). There was a slight decrease in rice area over the 6-year period from 2001to 2007 in both Muñoz and Santo Domingo. From 2007 to 2008, 8.9% and 5.6% increases in the rice cultivation area in Muñoz and Santo Domingo, respectively, can be seen (**Figure 12**). The increase in the rice area in 2008 can be attributed to the rice crisis experienced in the first quarter of 2008. The decrease in 2007 was due to a shift from rice to high-value crops because of the low farm gate price of rice.

Summary and conclusion

Weather conditions, availability of water, market price, and other unpredicted factors can change the amount of area used for rice cultivation, and these factors vary from year to year and from season to season. For decision makers to ensure that the country has an adequate rice supply, as defined by the Interagency Committee for Rice, it is imperative that timely and accurate information on rice area, yield forecasts, and production be regularly updated with little or no statistical response burden to producers. A process that is well suited for the integration and utilization of the methodologies for rice monitoring using radar data is described in this research paper.

The significant increase in radar backscatter over the short vegetation phase of paddy rice growth optimizes SAR for rice crop monitoring. The multiple incident angles of RADARSAT-1 and RADARSAT-2 provide tremendous flexibility in image acquisition. In this project, the relationship between rice growth and radar backscatter was utilized in an integrated approach of change detection and neural

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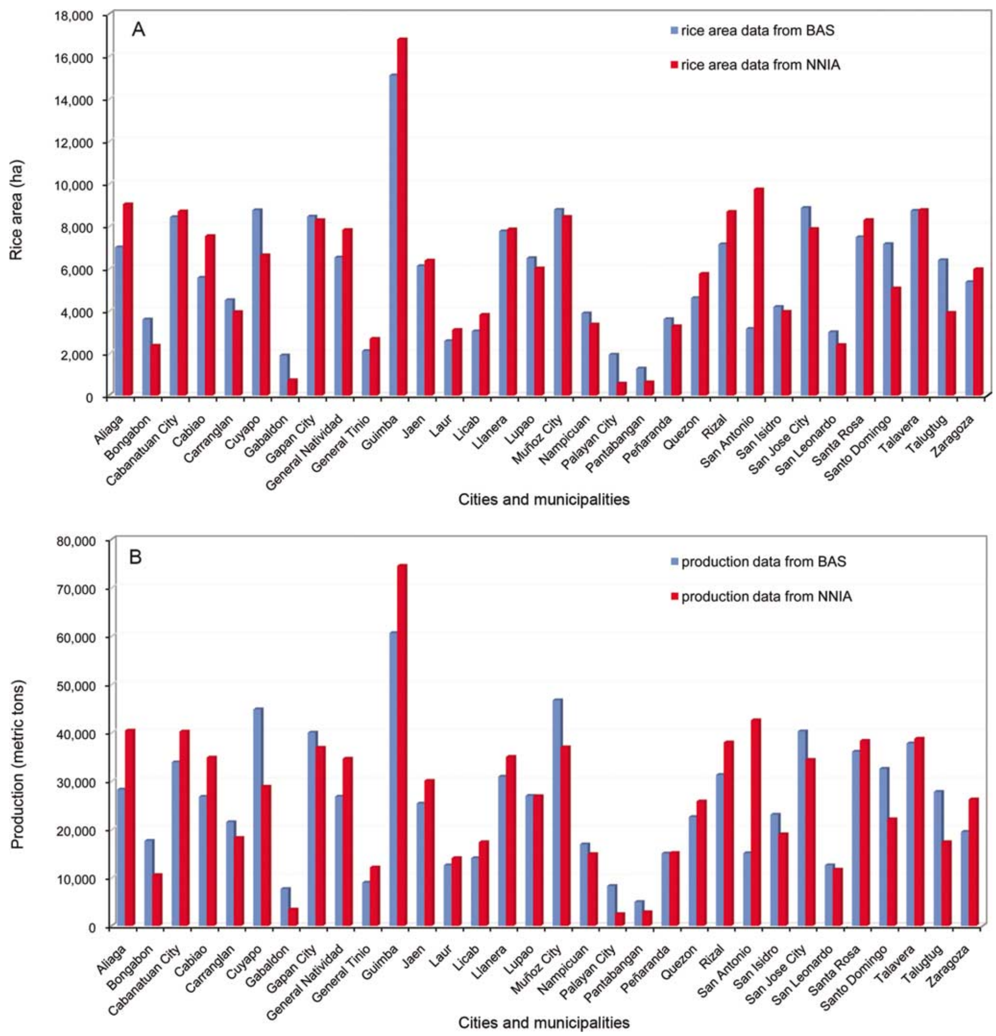

Figure 9. Comparison of NNIA-derived (A) rice area and (B) production with BAS data for all 27 municipalities and 5 cities.

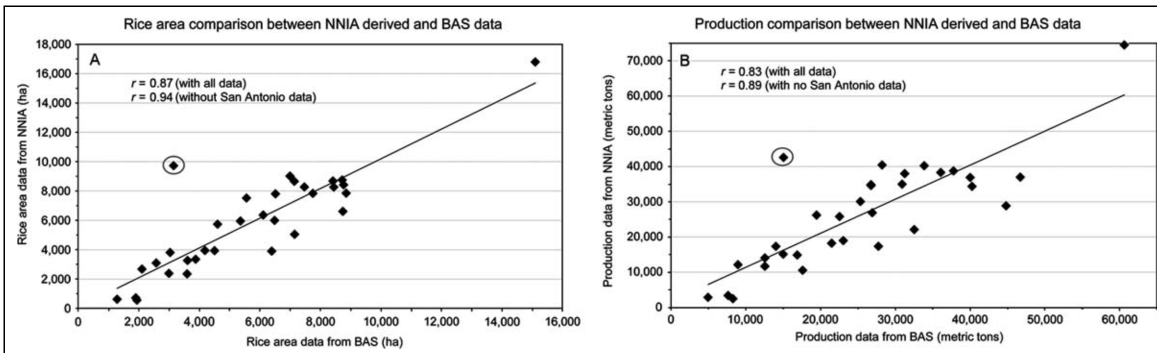

Figure 10. Scatter plot of NNIA-derived and BAS data with (A) rice area and (B) production, where data inside the circle were derived from the municipality of San Antonio.

network to identify rice fields and to assess the yield of the province of Nueva Ecija. The total cultivated rice area was extracted after all the rice fields were established, and the yield was predicted well in advance of the rice harvest, a critical component of an integrated, operational forecasting system. Detailed statistics at different levels, municipal, regional, or provincial, were evaluated and were used at the local or provincial levels for rice production management.

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Table 4. Comparison of the 2008 wet season rice area, yield data, and production derived from remote sensing technology and the Philippine Bureau of Agricultural Statistics (BAS).

	Rice area (ha)			
	BAS	NNIA derived	Difference	% difference from BAS data
All 27 municipalities and 5 cities	183 234	188 050	4 816	2.6%
Without municipality of San Antonio	180 087	178 323	−1 764	−1.0%
	Average yield (metric tons/ha)			
	BAS	NNIA derived	Difference	% difference from BAS data
All 27 municipalities and 5 cities	4.46	4.49	0.03	0.7%
Without municipality of San Antonio	4.45	4.50	0.05	1.0%
	Production (metric tons)			
	BAS	NNIA derived	Difference	% difference from BAS data
All 27 municipalities and 5 cities	816 827	844 212	27 385	3.4%
Without municipality of San Antonio	801 770	801 624	−145	0.0%

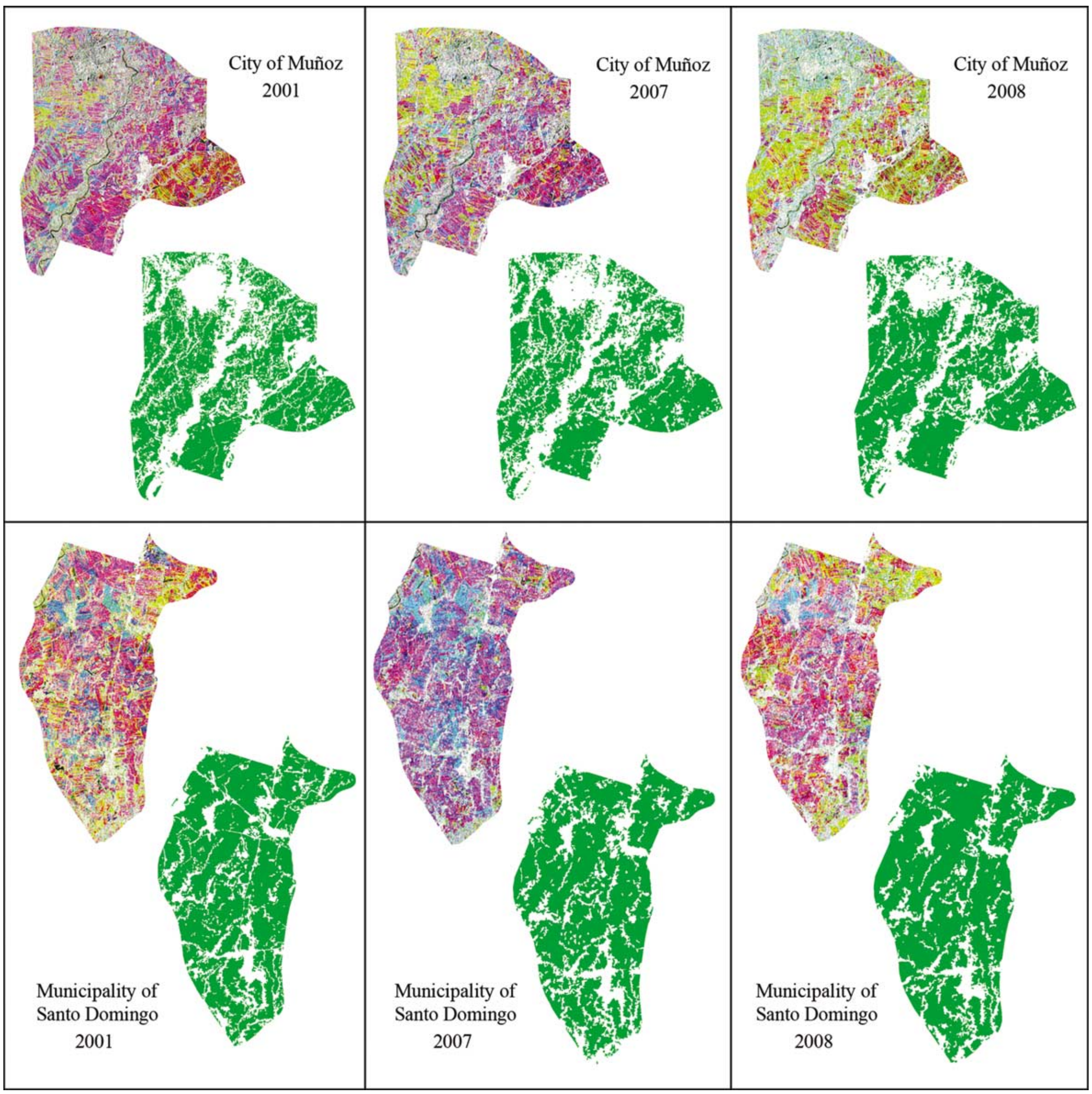

Figure 11. Rice area of Muñoz and Santo Domingo in the province of Neuva Ecija in 2001, 2007, and 2008. Color images are RADARSAT-1 composite images and green images are extracted rice fields.

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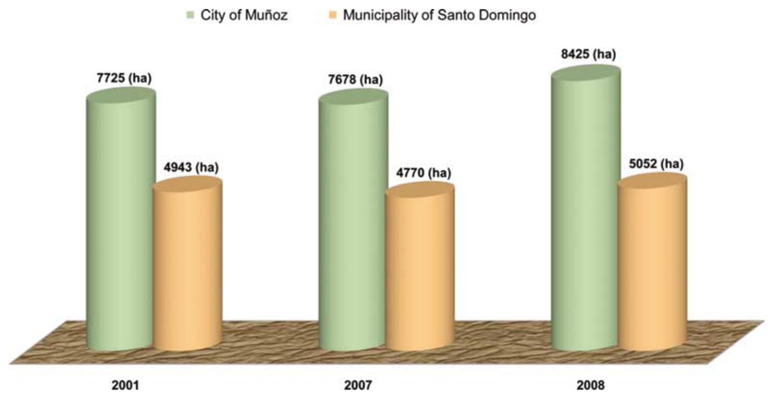

Figure 12. Comparison of rice areas using radar data for the city of Muñoz and the municipality of Santo Domingo in 2001, 2007, and 2008.

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During the 2008 wet season of rice production in the province of Nueva Ecija, 29% of rice fields were cultivated in late May and early June, 54% in late June and July, and 17% in August and early September. Although more than 3 months of rice cultivation time was observed, the majority of farmers had their rice fields prepared in June and July. Based on the NNIA analysis, the total rice area planted during the 2008 wet season was 188 050 ha with a total production of 844 212 metric tons and an average yield of 4.489 metric tons/ha. The high-yielding cities and municipalities were mostly located along the Pantabangan River and the lowest yielding cities and municipalities were mainly in the northwestern part of the province.

This project achieved 97.4% and 96.6% agreement with the BAS provincial level data in rice area and production forecasting, respectively. When the results of rice area mapping were presented to the Philippine Department of Agriculture and the Philippine Rice Institute in November 2008, it was recommended that the technology be applied to the whole country or at least to the top ten rice production provinces.

To cope with wider dynamic variations in local rice cultivation practices and to maintain a high monitoring accuracy, this project relied on a considerable amount of imagery which affects the application extensively. As more and more SAR imagery, such as RADARSAT-2, ASAR, and especially the new Sentinel series (launch scheduled for 2011), becomes available and is coupled with new or refined methodologies that are focused on providing an integrated solution that is based on the needs of the user community, it is without a doubt that this technology will be utilized in broader areas.

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