EVALUATING WITHIN-FIELD RICE GROWTH VARIABILITY USING QUICKBIRD AND IKONOS IMAGES IN NORTHEAST CHINA

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Measuring within-field variability is essential for precision farming, and remote sensing is an important tool to obtain the needed information. The objective of this study was to evaluate rice (Oryza sativa L., irrigated lowland rice) growth variability in Qixing farm considering different fields, management practice and cultivars using high resolution optical satellite image data. Based on the spectral dataset of 2007 and 2008, vegetation indices were calculated to quantify the rice growth variability. The vegetation indices were statistically evaluated and were joined with the spatial field data. The results of the spatial analyses show that growth variability was influenced by field conditions (Coefficient of Variation from 1.3 % to 19.8 %) and the farmer's management, mainly dominated by cultivar differences.

Keywords: within-field variability, multispectral, remote sensing, vegetation indices, rice growth, Northeast China

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1. INTRODUCTION

Measuring within-field growth variability is very important for precision farming. Farmers and scientists generally recognize that soil properties and crop growth are not uniform within a field (Yamagishi et al., 2003). In addition to that, fields show a temporal and spatial variability in crop growth. Washmon et al. (2002) e.g. reports a temporal within-field variability for wheat canopy based on a nine years study in Oklahoma. The within-field variability is caused by many parameters such as soil, nutrition, water availability, slope, local microclimate, and farmer's management (amount and type of fertilizer input, choice of cultivars, etc.). These accumulated factors vary from year to year in the same field and influence the growth and finally the yield. Due to the spatial variability, a uniform nitrogen (N) application without consideration of variable crop growth and N nutrition status in a rice field may result in over-fertilization in some locations (Nguyen et al., 2006). If the causes of this spatial variability can be identified, then site-specific management practices can reduce costs e.g. for fertilizer, increase yield and reduce negative environmental impacts, e.g. caused by over-fertilization (Roel & Plant, 2004).

Usually, the within-field variability is quantified by agronomic parameters (Cavero et al., 2001; Robertson et al., 2008) such as biomass, plant height, plant and soil nitrogen and vegetation indices (VIs) (Encloda et al., 2004; Zarco-Tejada et al., 2005), calculated from satellite or airborne images or field spectrometer data. The present generation of high spatial resolution data from sensors such as Ikonos and Quickbird offers the most advanced spatial, temporal and radiometric resolution to meet the requirements of precision farming. By applying methods of geostatistics combined with traditional statistics, the spatial crop variability of different agronomic parameters can be measured by distribution maps (Jiang et al., 2006).

This paper proposes an approach how to interpret the growth variability using Quickbird and Ikonos image data for rice (*Oryza sativa L., irrigated lowland rice*). The plant growth was quantified by VIs such as NDVI, GNDVI, RGNVI, RVI and GVI, extracted from the image data (2007 and 2008). It is aimed to prove the spatial growth variability in the same fields during a two years study considering (i) each field, (ii) each farmer´s management, and (iii) each cultivar. Additionally, this study was done to show which of these three factors (field conditions, management, cultivar) has the highest or lowest impact on within-field variability.

2. MATERIALS AND METHODS

2.1 Study area

The study area Qixing farm is located in the Sanjiang Plain (47.2 N°, 132.8° E), at the lower stretch of Songhua River (Songhua Jiang), approx. 60 km south of the Amur River (Heilong Jiang) and 450 km west of the Pacific ocean in the Northeast of Heilongjiang Province, being bordered by Siberia in the North and East. This study region belongs to the temperate zone and is characterized by a sub-humid continental monsoon climate. The mean annual air temperature is about 1.9 °C and the mean yearly precipitation ranges from 500 mm to 600 mm (Wang & Yang, 2001). Average temperatures reach -18 °C in January and 21-22 °C in July. The frost-free period is only about 120-140 days long (Zhang et al., 2009). The maximum values of temperature and precipitation are both observed in July and August. The rainfall from June to September covers about 72 % of the annual amount, with 59 % of the yearly precipitation occurring from June to August (Yan et al., 2002).

The Sanjiang Plain is an alluvial plain of the three rivers Heilongjiang, Songhua and Wusuli and covers about 108,900 km². The main part (~60 %) is plain (50-70 m above sea level) whereas the remaining part is hilly and mountainous (Wang & Yang, 2001), with elevations reaching up to 1,000 m. Originally the Sanjiang Plain was dominated by marshes. The most abundant soils are wet black clays with a general thickness of more than 20 cm. The soils offer high concentrations of organic matter and nutrients, being most favorable for agricultural productivity (Zhou & Liu, 2005). The four soil types meadow soil, lessive, swamp soil and black soil comprise more than 95 % of the area (Wang et al., 2006). The climate allows one yield per year.

The main crops in Qixing farm (~1,200 km²) are rice, maize, soybean and winter wheat. The rice cultivation began in the late 1980s and belongs to the northernmost cropping rice system in China.

2.2 Field design

Rice fields, being in neighbourhood to each other, were selected in Qixing farm in village Qixing 37. The fields, their number and the total field size were similar in 2007 and 2008 (Tab. 1). Soil characteristics were homogeneous and the altitude of the fields was similar (58-61 m). Management information was provided by the farmers. Their rice fields were managed with different fertilizer applications and cultivars such as *Fuer2008, Fuer7202, Kendao12,* and *Kongyu131*. The cultivars were only recorded in 2007. The seeds were sown in greenhouses in mid April. The rice plants were transplanted to the fields at the end of May (around 20th to 25th) and harvested around mid to end of September. The field size ranged from 12 to 27 ha (Tab. 1). Within a field, numerous plots were conducted: 223 for farmer "S", 170 for farmer "L", 99 for farmer "F", 90 for farmer "X", and 70 for farmer "Z". Every plot was bordered by 30-50 cm narrow and 30-50 cm high field banks which kept the water. The size of the plot ranged from 100 to 6,000 m², showing the same cultivar. Furthermore, the field management was done similarly. Totally, 652 plots were available for analysis. Some plots had a mixed cultivar design and were considered separately. The fields were irrigated during the whole growing season from transplanting to heading stage.

Table 1. Summary of the farmer's field design

Farmer	Number of plots	Cultivars	Total field size [ha]
F	99	2, 4	12.3
L	170	2, 4	20.2
S	223	1, 2, 4	27.4
X	90	2, 4, 5	12.2
Z	86	3, 4, 5	22.6

1 = Fuer2008, 2 = Fuer7202, 3 = Kendao131, 4 Kongyu131, 5 = mixed

To analyze within-field variability, field boundaries were measured with a Trimble GPS Pro XT (Trimble Navigation Ltd. Sunnyvale, CA, USA) with an averaged accuracy of 1 m to 2 m. The GPS data were imported into ArcGIS (ESRI, Inc., Redland, CA, USA). According to the GPS measurements, landuse data were collected for the farmers' fields and clipped in ArcGIS. Hence, only fields cultivated with rice were considered in this study.

2.3 Satellite data

Two multispectral high resolution satellite images, using Blue (B), Green (G), Red (R) and Near Infrared (NIR) bands, were acquired for the field study in 2007 and 2008: One Quickbird image on July 5th in 2007 (tillering stage, leaf age 8.5) and one Ikonos image on June 26th in 2008 (tillering stage, leaf age 8). Quickbird images come with four spectral bands (B: 450-520 nm, G: 520-600 nm, R: 630-690 nm, NIR: 760-900 nm) and a spatial resolution of 2.88 m at off-nadir acquisition. The single area of interest is 8 km by 8 km and the image's radiometric resolution is 16 bit. Ikonos data is also collected in four bands (B: 445-516 nm, G: 506-545 nm, R: 632-698 nm and NIR: 757-853 nm) with a spatial resolution of 4 m. Its swath range is 10 km and its radiometric resolution is 16 bit.

2.4 Spectral and statistical analysis

Three normalized difference vegetation indices (VIs) (NDVI, GNDVI and RGNVI) and two ratio vegetation indices (RVI and GVI) were calculated using the G, R and NIR bands from the Quickbird and Ikonos satellite data to quantify the rice growth within the field. The formulas of the VIs are listed in Tab. 2.

Table 2. Formula and references for selected VIs

Vegetation indices	Abbreviation	Formula	References
Normalized difference vegetation index	NDVI	(NIR-R)/(NIR+R)	Rouse et al. (1974)
	GNDVI	(NIR-G)/(NIR+G)	Gitelson & Merzlyak (1998)
	RGNDI	(R-G)/(R+G)	Li et al. (2008)
Ratio vegetation index	RVI	NIR/R	Jordan (1969)
	GVI	NIR/G	Li et al. (2008)

For spatial analysis, the geometric and rice cultivar information, the corresponding calculated VI and its statistical analysis are combined in one ArcGIS database. This database was used for the spatial analysis of growth variability considering each field, the management and the cultivar. To analyze the growth variability, statistical analyses were done with the software SPSS (SPSS, Inc., Chicago, IL, USA). Standard statistical parameters like Minimum (Min), Maximum (Max), Mean value (Mean), Standard Deviation (SD) and Coefficient of Variation (CV in %) were calculated.

3. RESULTS AND DISCUSSION

3.1 Growth variability influenced by fields

Generally, the within-field variability ranges from 2.2 % to 27.7 % when using different VIs and both years' data (Tab. 3). The CV values range from 2.2 % for RGNDI to 16.9 % for GNDVI in 2007 and from 3.3 % for RGNDI to 27.7 % for GNDVI in 2008. In both years the RGNDI shows the lowest and the GNDVI the highest variability. Although the satellite data were collected during approx. the same growth stage (tillering stage, leaf age 8-8.5) in both years, the range in the statistical parameters such as Min and Max is higher for 2007 (e.g. NDVI from 0.187 to 0.619; difference: 0.432) and lower for 2008 (e.g. NDVI from 0.131 to 0.540; difference: 0.409).

Table 3. Statistics for VIs in 2007 and 2008 for all farmers' fields.

	2007						2007				
VI	Min	Max	Mean	SD	CV(%)	VI	Min	Max	Mean	SD	CV(%)
NDVI	0.187	0.619	0.485	0.057	11.82	NDVI	0.131	0.540	0.378	0.049	12.84
GNDVI	0.036	0.518	0.370	0.062	16.85	GNDVI	0.034	0.343	0.167	0.046	27.72
RGNDI	0.675	0.815	0.753	0.016	2.18	RGNDI	0.565	0.811	0.631	0.021	3.28
RVI	1.459	4.256	2.932	0.412	14.05	RVI	1.301	3.346	2.237	0.249	11.11
GVI	1.074	3.147	2.207	0.300	13.61	GVI	0.935	2.045	1.408	0.133	9.43

n = 86,105 (extracted from Quickbird) n = 45,156 (extracted from Ikonos)

Fig. 1 shows two rice growth maps based on the NDVI values for 2007 and 2008. This VI was chosen because it is a very common und well known index to monitor plant crop growth or its vitality (cf. Clevers & Jongschaap, 2001). The within-field variability maps using GNDVI, RGNVI, RVI and GVI showed similar results. The highest and lowest values for these VIs were calculated for the same fields. In the following, the maps showing the NDVI values are discussed. The big trapezoidal block in the west includes the farmers' fields S, L, F and X in the east (Fig. 1). The field in the Southeast is field Z. These maps already show the disparity in growth, appearing in varied colors. The calculated NDVI values averaged 0.485 for all fields in 2007 (dark orange color) and 0.378 in 2008 (yellow color). The calculation results in higher values in 2007 because of advanced growth stage (leaf age 8.5 in 2007 and leaf age 8 in 2008). Thus the plants show higher biomass and the NDVI values were higher for 2007. In both years, the NDVI values were higher in the big trapezoidal block in the west for the fields S, L, F and X. Some NDVI values of the field Z were affected by field boundaries or non-optimal management (dark green color). These effects occurred mainly in the northern part of this field. Generally, the two maps show no similar patterns. Although the highest NDVI values (NDVI Max) were not reached in the same areas and not even in the same fields, there were fields with similar NDVI development. For field Z higher NDVI values were calculated in the southern field and lower values in the northern field in 2007 and 2008. Different growth and also within-field variability considering the two years can be explained by e.g. management or climate.

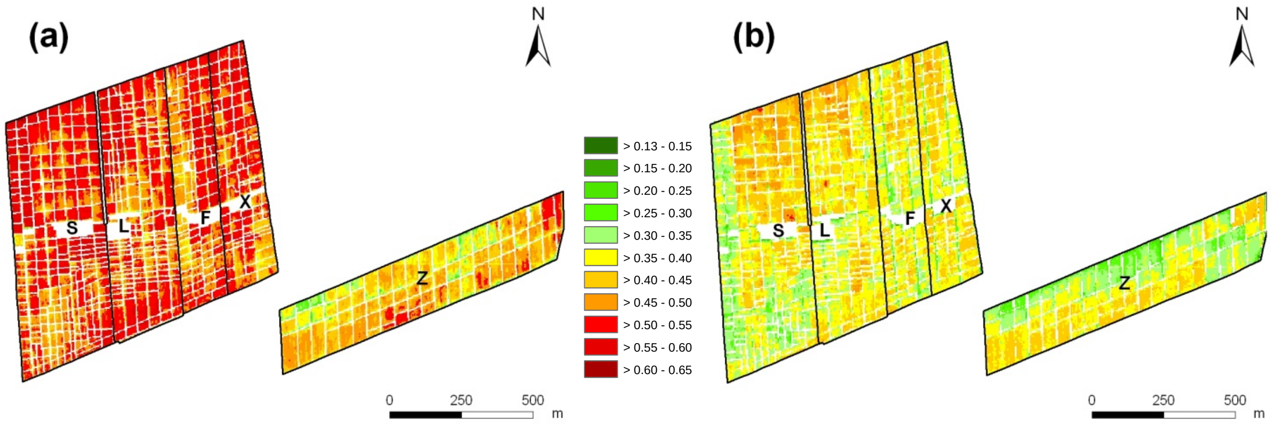

Figure 1. Within-field variability map for rice growth quantified by NDVI values. The NDVI values were interpolated by inverse distance weighted technique. (a) extracted from Quickbird data on July 5th in 2007 *(tillering stage, leaf age 8.5), n= 86,105; (b) extracted from Ikonos data on* June 26th in 2008 *(tillering stage, leaf age 8), n= 45,165.*

In order to illustrate the within-field variability, the averaged CV values for the averaged NDVI for each plot in both years are opposed in two maps (Fig. 2). Considering the within-field variability in each plot, generally lower CV values for NDVI in 2007 than in 2008 can be detected. In 2007, most plots show a CV between 0 %-5 % (for 307 cases) (Fig. 2a), and in 2008 a CV between 5 %-10 % (412 cases) (Fig. 2b). The variability increased about 5 % absolutely in 2008. On single plots, the CV increase was even more than 5 %. This effect may be caused by different transplanting dates, weather conditions or even by different spatial image resolution (2.88 m in 2007 and 4 m in 2008). Totally, the NDVI CV ranged from 1.3 % to 19.8 % in 2007 and from 2.8 % to 23.9 % in 2008 for all the 652 plots.

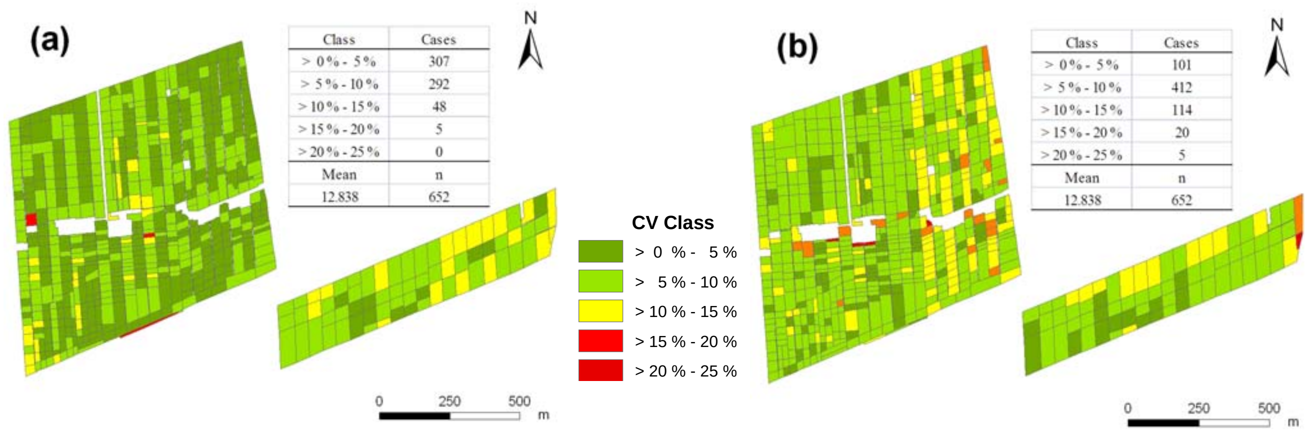

Figure 2. Averaged NDVI CV values for each plot for 2007(a) and 2008 (b).

The mean NDVI CV amounted to 11.8 % in 2007 and 12.8 % in 2008. Similar results were reached for GNDVI and RGNDI. Lower CV values were observed for RVI and GVI (Tab. 3). Smaller fields in neighborhood to other crops like maize or soybean were affected by their reflectance or resulted in mixed pixels, although a 4 m buffer was created around the field boundaries.

Table 4. Comparison of the VI statistics for each of the farmers' fields

NDVI 2007							NDVI 2008						
Field	Min	Max	Mean	SD	n	CV (%)	Field	Min	Max	Mean	SD	n	CV (%)
F	0.294	0.615	0.497	0.044	9,760	8.87	F	0.199	0.504	0.376	0.043	5,720	11.55
L	0.213	0.608	0.504	0.043	15,569	8.53	L	0.155	0.540	0.393	0.039	9,434	10.01
S	0.201	0.619	0.505	0.046	29,473	9.05	S	0.167	0.536	0.384	0.053	12,975	13.77
X	0.278	0.618	0.502	0.043	11,330	8.60	X	0.155	0.483	0.385	0.045	5,766	11.65
Z	0.187	0.569	0.427	0.057	19,973	13.23	Z	0.131	0.470	0.358	0.048	11,261	13.46
all	0.187	0.619	0.485	0.057	86,105	11.82	all	0.131	0.540	0.378	0.049	45,156	12.84

GNDVI 2007							GNDVI 2008						
Field	Min	Max	Mean	SD	n	CV (%)	Field	Min	Max	Mean	SD	n	CV (%)
F	0.159	0.509	0.384	0.047	9,760	12.38	F	0.018	0.322	0.163	0.039	5,720	24.13
L	0.036	0.509	0.391	0.047	15,569	12.02	L	0.015	0.343	0.183	0.037	9,434	20.35
S	0.050	0.518	0.392	0.050	29,473	12.74	S	0.013	0.327	0.167	0.052	12,975	31.06
X	0.155	0.517	0.390	0.048	11,330	12.38	X	0.029	0.272	0.173	0.04	5,766	23.12
Z	0.049	0.460	0.305	0.059	19,973	19.23	Z	0.034	0.258	0.152	0.048	11,261	31.26
all	0.036	0.518	0.370	0.062	86,105	16.85	all	0.034	0.343	0.167	0.046	45,156	27.72

RGNDI 2007							RGNDI 2008						
Field	Min	Max	Mean	SD	n	CV (%)	Field	Min	Max	Mean	SD	n	CV (%)
F	0.695	0.811	0.753	0.016	9,760	2.18	F	0.583	0.811	0.630	0.022	5,720	3.43
L	0.675	0.815	0.752	0.018	15,569	2.40	L	0.571	0.787	0.630	0.019	9,434	2.95
S	0.676	0.814	0.752	0.016	29,473	2.11	S	0.565	0.794	0.623	0.021	12,975	3.32
X	0.695	0.813	0.755	0.017	11,330	2.19	X	0.581	0.781	0.63	0.021	5,766	3.31
Z	0.684	0.805	0.754	0.016	19,973	2.09	Z	0.596	0.809	0.642	0.017	11,261	2.64
all	0.675	0.815	0.753	0.016	86,105	2.18	all	0.565	0.811	0.631	0.021	45,156	3.28

RVI 2007							RVI 2008						
Field	Min	Max	Mean	SD	n	CV (%)	Field	Min	Max	Mean	SD	n	CV (%)
F	1.833	4.200	3.009	0.346	9,760	11.49	F	1.498	3.031	2.220	0.217	5,720	9.80
L	1.541	4.100	3.064	0.327	15,569	10.69	L	1.367	3.346	2.308	0.213	9,434	9.24
S	1.502	4.256	3.073	0.362	29,473	11.79	S	1.401	3.310	2.268	0.282	12,975	12.43
X	1.772	4.233	3.041	0.337	11,330	11.10	X	1.366	2.868	2.268	0.222	5,766	9.79
Z	1.459	3.643	2.523	0.335	19,973	13.28	Z	1.301	2.774	2.133	0.228	11,261	10.69
all	1.459	4.256	2.932	0.412	86,105	14.05	all	1.301	3.346	2.237	0.249	45,156	11.11

GVI 2007							GVI 2008						
Field	Min	Max	Mean	SD	N	CV (%)	Field	Min	Max	Mean	SD	n	CV (%)
F	1.377	3.073	2.263	0.247	9,760	10.93	F	1.036	1.950	1.396	0.113	5,720	8.08
L	1.074	3.070	2.303	0.235	15,569	10.20	L	1.030	2.045	1.452	0.113	9,434	7.76
S	1.106	3.147	2.310	0.261	29,473	11.29	S	0.975	1.971	1.409	0.151	12,975	10.75
X	1.367	3.141	2.297	0.253	11,330	11.01	X	0.944	1.749	1.425	0.114	5,766	7.98
Z	1.103	2.701	1.899	0.236	19,973	12.44	Z	0.935	1.694	1.367	0.130	11,261	9.54
all	1.074	3.147	2.207	0.300	86,105	13.61	all	0.935	2.045	1.408	0.133	45,156	9.43

3.2 Growth variability influenced by farmers

The farmers can influence the growth variability by their management or choice of cultivars. The management includes dates, amounts and types of fertilizer input, irrigation techniques or soil improvement. These cultivation practices were similar for all five fields S, L, F, X and Z. This chapter is divided into two parts, because some results could be only explained by management (3.2.1) and others by choice of cultivars (3.2.2).

3.2.1 MANAGEMENT

The analysis showed that the farmer's management influences the within-field variability. The NDVI CV values for the farmers' fields ranged from 8.5 % for field L to 13.2 % for field Z in 2007 (Tab. 4). The CV values were evidently higher in 2008. In 2007 as well as in 2008, the results showed relative high CV values for field Z compared with the other four fields. The lowest CV values were reached for field L (CV = 8.5 % in 2007; CV = 10.0 % in 2008). The results for 2007 and 2008 evidently show the influence of management on within-field variability. There are differences between these fields which can be only explained by the management practice. Climate influence can be excluded. Regarding the RGNDI CV, the highest CV values were detected for field L (CV = 2.4 %) in 2007 and for field F (CV = 3.4 %) in 2008. The lowest CV values were calculated for field Z (CV = 2.1 % in 2007; CV = 2.6 % in 2008). The values are relatively low across all the five fields, also for both years. The values range from 2.1 % to 2.4 % in 2007 and from 2.6 % to 3.4 % in 2008. The RGNDI CV range is very small for both years (CV values from 2.1 % for field Z to 2.4 % for field F in 2007 and CV values from 2.6 % for field Z to 3.4 % for field F in 2008). Very high CV values were calculated using GNDVI in 2008 (CV values from 20.3 % to 31.3 %). The ratio vegetation indices (RVI and GVI) showed the lowest CV values in 2008 and the highest in 2007. In contrast to the statistic results and due to the VI formula (Tab. 2), the normalized ratio indices show the highest CV values in 2008 and the lowest in 2007.

3.2.1 CHOICE OF CULTIVAR

The rice cultivar seems to have the highest influence on crop growth variability. The lowest variability was calculated for cultivar *Fuer2008* (CV = 7.7 %) and the highest for cultivar *Kendao12* (CV = 13.0 %). The cultivar *Kendao12* was only planted in field Z (Tab. 5) and covered approx. half of this field. It seems that the variability within field Z is mainly caused by the cultivar *Kendao12*. Different cultivars always show a different reflectance and consequently also different VI values during the tillering and panicle elongation growth stage. This matter of fact agrees with many studies conducted for other crops such as wheat (Babar et al., 2006) or maize (Mauser & Oppelt, 2004). When reaching the heading growth stage, the reflectance of the different cultivars is almost the same.

Table 5. Statistics for cultivar influence on rice growth variability in 2007 using NDVI data

Cultivar	Farmer	Min	Max	Mean	SD	N	CV (%)
Fuer2008	S	0.256	0.600	0.516	0.040	8,099	7.69
	Total	0.256	0.600	0.516	0.040	8,099	7.69
Fuer7202	F	0.294	0.615	0.508	0.045	5,728	8.80
	L	0.213	0.608	0.512	0.044	9,343	8.52
	S	0.201	0.619	0.514	0.052	8,049	10.05
	X	0.306	0.618	0.506	0.040	4,206	7.93
	Total	0.201	0.619	0.511	0.046	28,326	9.04
Kendao12	Z	0.187	0.551	0.427	0.056	10,620	13.03
	Total	0.187	0.551	0.427	0.056	10,620	13.03
Kongyu131	F	0.322	0.588	0.482	0.038	4,032	7.94
	L	0.260	0.568	0.493	0.040	6,226	8.02
	S	0.271	0.589	0.490	0.040	12,325	8.22
	X	0.278	0.602	0.512	0.035	5,774	6.75
	Z	0.203	0.543	0.416	0.053	7,026	12.72
	Total	0.203	0.602	0.479	0.053	35,383	11.09
mixed	X	0.316	0.538	0.441	0.035	1,350	7.96
	Z	0.206	0.569	0.461	0.057	2,327	12.38
	Total	0.206	0.569	0.454	0.051	3,677	11.27

Regarding each cultivar separately for each field, reveals a large difference in CV. Especially, for cultivar *Kongyu131* the CV values range from 6.8 % for field X to 12.7 % for field Z. So the CV value is approx. twice as high for field Z. The other statistical parameters such as Min, Max or Mean also show a high variability (Tab. 5). Lower differences in CV were found for cultivar *Fuer7202*, reaching from 7.9 % to 10.1 % for four of the five fields. Fields with mixed cultivars are not studied separately, because not all cultivars were known. High CV values (on average 11.3 %) were observed because of mixed pixel information.

4. SUMMARY AND CONCLUSION

Results presented in this study showed the potential of VIs, extracted from multispectral image data, to quantify rice growth variability. All studied VIs could capture the rice growth variability, their CV values varied between 2 % to 24 % during the two years. The highest influence on growth variability was found within the fields. The NDVI CV ranged from 1.4 % to 19.9 % in 2007 and from 2.8 % to 23.9 % in 2008. The spatial within-field variability was high and cannot be explained by cultivars, but by factors like microclimate, management practice or soil. The cultivars were the same in each field except for fields with mixed cultivars. The choice of cultivar evidently influenced growth variability. The multiyear comparison showed an increase in CV values for all normalized difference vegetation indices and a decrease in CV values for ratio vegetation indices. The second highest influence was detected in overall management practice, including choice of cultivar (NDVI CV = 7.6 % to 13.0 % in 2007).

Combining remote sensing data with GIS geostatistics tools demonstrated the significance of these methods to map rice growth variability: spatial and temporal variations could be detected. Nevertheless, more studies are needed to identify factors and relationships among the factors influencing the within-field crop growth variability. Factors such as soil, nutrition availability and microclimate within the fields should be studied. Understanding these factors is the key to diagnose causes of poor growth, and to improve the management of site-specific farming.

ACKNOWLEDGEMENTS

This study was financially supported by the National Science and Technology Support Project (**2008BADA4B02**), the International Bureau of the German Federal Ministry of Research and Technology BMBF (Project number **CHN 08/051**), the Sino-German Cooperative Nitrogen Management Project (MOST **2007DFA30850**), the GIS & RS group of the University of Cologne, and the Qixing Research and Development Center in Heilongjiang.

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