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Agricultural land-use in China: a comparison of area estimates from ground-based census and satellite-borne remote sensing

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ABSTRACT

We compare estimates of total cropland area, paddy rice area, and irrigated cropland area in China from land cover maps derived from optical remote sensing in 1992–93 (1-km resolution NOAA AVHRR) and county-level agricultural census data for 1990. At national, regional, provincial, and county scales, the total cropland area estimated by remote sensing is 50–100% higher than reported in the agricultural census. For topographically flat North and Central China, there is a high correlation between county-level cropland area estimates by the two approaches. For other regions, the correlation between remote sensing and agricultural census cropland area is much weaker. Throughout China, there is only moderate to weak correlation between remote sensing-based and census-bases estimates of paddy rice area and total irrigated cropland area. It is likely that the census data underestimates and the remote sensing overestimates the actual cropland area. These uncertainties in agricultural land cover estimates will contribute to uncertainty in any large-scale biogeochemical analyses.

Key words. AVHRR, China, cropland, land-use, land-cover, paddy rice, remote sensing.

INTRODUCTION

With an ongoing goal of food self-reliance and ~1.2 billion people, China's agricultural enterprise is the largest in the world. China currently produces 20% of the global grain harvest on 9% of the earth's arable and permanent cropland, accounts for 30% of global synthetic nitrogen fertilizer use, and contains 20% of the world's irrigated land (Faostat, 1998). Agriculture on this scale must have a profound influence on planetary biogeochemical cycles (e.g. Matson *et al*., 1997; Vitousek *et al*., 1997). Quantitative analysis at this scale will require good estimates of the scale of agricultural land-use.

National, regional, and global-scale land cover maps are being developed based on 1-km resolution National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) imagery (e.g. Loveland & Belward, 1997). These land cover maps will be used for global scale analysis of biogeochemical cycling and as baseline data for evaluation of land use and land cover change (e.g. Walker & Steffen, 1996). Efforts are underway within the IGBP DISCover Program to validate these moderate resolution remote sensing products, in particular regions, with higher resolution imagery from Landsat (Belward, 1996). Additional efforts to evaluate regional landcover products are using local expert knowledge (e.g. Ojima *et al*., 1997).

We have assembled a county-scale, crop-specific, agricultural database for China in 1990 from Chinese agricultural statistical census data, atlases, and Chinese agronomy books. In this paper we compare this quasi-spatially explicit, county-scale resolution, cropland landcover database with recent estimates for China derived from NOAA AVHRR (Yang *et al*., 1997), at county, provincial, regional, and national scales. This provides a simple comparison of these two datasets,

Table 1. AC90 Database Cropland Areas

AC90 Crops	Area (km^2)
Maize	90 500
Cotton	36 300
Potato	58 300
Rape (oilseed)	34 500
Rice (single crop)	77 200
Sorghum	11 600
Soybean	38 700
Sugarbeet	5200
Sugarcane	3200
Tobacco	5700
Vegetables	135 600
Wheat (winter)	88 400
Wheat (spring)	38 600
Small grains (millet, oats, barley, etc.)	70 400
Rice (double crop)	123 900
Rice & winter wheat (double crop)	18 900
Rice & rape (oilseed) (double crop)	16 200
Maize & winter wheat (double crop)	95 000

identifies biases, and identifies those areas that are either consistent or inconsistent between the datasets.

AGRICULTURAL CENSUS DATABASE

County-level agricultural census data for China in 1990 were prepared from three sources: 1) the Eco-Environmental Database (unpublished) of the Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences; 2) Chinese agronomy books (CRTSA, 1995; Huang *et al.*, 1997); and 3) consultation with the Chinese Academy of Agricultural Sciences (Professor Qingmu Chen, personal communication). The database contains county statistics on crop acreage (Table 1) and yields for major crops, acreage of total cropland, sown area, grassland, and irrigated upland cropland, nitrogen fertilizer use, and livestock and human populations. These data are available for 2483 counties in China (excluding Taiwan, Hongkong, Macao, and the numerous small islands in the South China Sea—Xisha Qundao, Nansha Qundao, Zhongsha Qundao). The database has been used previously for an analysis of crop residue production in China (Zhuang *et al.*, 1996). Hereafter, this dataset will be called AC90.

Harvesting two crops from a single plot in a single year (double cropping) is common in much of China. The cropland area data reflects the actual land area in crops, while the sown area data double counts land that is double cropped. Some counties report sown area as nearly double-crop area (i.e. virtually all cropland is double cropped) and the AC90 total sown area for China is 27% greater than the AC90 total cropland area. Major double-cropping practices in China are rice/rice, maize/winter wheat, rice/winter wheat, and rice/rape (oilseed) (CRTSA, 1995; Huang *et al.*, 1997). We estimated areas double cropped in each of these four categories based on the difference between total cropland and sown areas, and the area of rice, maize, winter wheat and rape for each county. For this estimation, we prioritized crops in this order: rice, maize, winter wheat, and rape. The calculated areas meet the total cropland area, sown area, and each individual crop area (single plus double cropped), but the crop distribution into single and double-crop totals may be not exactly consistent with the real situation. There is still some triple cropping in southern Guangdong and Hainan Provinces, which we treated as double cropping because we consider this area to be fairly small (at a national scale) and expect that it would be difficult to classify from AVHRR remote sensing due to that region's cloudiness. The AC90 irrigation index is the irrigated fraction (excluding rice) of the total upland crop acreage in each county.

CHINA LAND COVER CHARACTERISTICS DATABASE

The China Land Cover Characteristics Database was produced at the US Geological Survey EROS Data Center in co-operation with the Chinese Academy of Surveying and Mapping (Yang *et al.*, 1997). The classification of seasonal land cover regions (SLCR) was based on 1-km resolution NOAA AVHRR-derived monthly NDVI composite data from April 1992 to March 1993. Ancillary data used in the classification included atlases, regional and provincial maps published in China, Landsat data, and global ecosystem databases (Zhiliang Zhu, USGS, personal communication 1998). The 153 distinct spectral classes were mapped into 118 landcover classes. Of these, 25 classifications contain at least some agricultural cropland. We excluded plantation/horticulture classifications (e.g. tea, rubber, eucalyptus, and bamboo) from our analysis as we had no AC90 data for these crops. Fourteen of the cropland land covers were classified as a mixture of cropland and noncropland (e.g. 'grassland and cropland mosaic').

The remaining 11 were classified as 'pure' cropland. Of these, one class was 'paddy rice', one was 'irrigated cropland', two were 'irrigated and dry cropland', and seven were classified as nonirrigated crops. Only one SLCR classification specifically mentions double cropping ('double cropping irrigated and dry').

SPATIAL AND LANDCOVER AGGREGATIONS FOR ANALYSIS

To compare SLCR landcover with the agricultural statistics database, we aggregated both datasets into three separate classifications:

1 'Total cropland'—The basic measure of agricultural land use. We calculated this for SLCR as both the sum of all pure cropland pixels (SLCR-pure) and as this pure cropland total plus half the area of the mixed cropland/noncropland pixels (SLCR-mixed). SLCR-mixed will be a very rough estimate, due to the simple assumption of 50% of mixed-pixel area.
2 'Paddy rice'—Rice production is a major agricultural effort in China whose intermittent flooding could generate a distinct remote sensing signature (Malingreau, 1986; Bachelet, 1995). For AC90, 'paddy rice' includes all rice (paddy and upland). In China, approximately 93% of rice cropland is irrigated, 5% is rain-fed lowland rice, and 2% is upland (dry) rice (Hossain, 1997). We report two areas: land with single or double-cropped rice (AC90-rice), and this area plus land area with rice/wheat or rice/rape double cropping (AC90-total-rice).
3 'Total irrigated cropland'—Increasing irrigation has contributed increases in grain production in China over the last several decades (Xu, 1996), but rapid development of an industrial economy and urban expansion has generated a competition for water that has recently led to declines in irrigated area (Xu, 1996; Zuo & Xu, 1996). Non-agricultural water demands are likely to increase in the future. To calculate SLCR 'total irrigated cropland' we aggregated irrigated cropland, paddy rice, and one-half the area of the two mixed irrigated/nonirrigated cropland classes; AC90 'total irrigated cropland' equals total rice area plus all other irrigated area.

The 1:1000 000 scale, county-level template for our geographical analysis (CIESIN, 1998) represents China's national, provincial, regional and county administrative boundaries as of 31 December 1990. We re-projected the county boundary coverage (Lambert conformal conic projection) to Lambert azimuth projection (the SLCR projection), and then gridded the polygon county coverage at 1-km resolution (using ARC/INFO v.7.1.1). We overlaid the gridded county boundary map on the SLCR land cover map and counted pixels in each land cover class within each county boundary. These county-aggregate SLCR values were compared with AC90 estimates of crop and irrigated area at the county level, and both datasets were aggregated to provincial, regional, and national levels (Table 2). In 1990, China had 2833 county-level units: 1723 counties, 121 autonomous counties, 51 banners, three autonomous banners, 279 county-level cities, and 651 municipal, one industrial-agricultural, one forest, and three special districts (Institute of Geography, 1994). The agricultural census data reported crop areas for 2483 counties. The CIESIN political boundary map had 2760 polygons representing 2383 mainland counties. These two county lists were not completely consistent, so we merged those counties in either collection that corresponded to a single county in the other collection (based on county names and reported location). This resulted in a common list of 2369 county-level administrative units. There were 19 county-level units in the CIESIN map and one from AC90 that could not be mapped into a corresponding county from the other list; these were excluded from all subsequent analyses.

RESULTS

National and regional scales

Cropland

The SLCR-pure estimate of China's cropland area is around 50% higher than the agricultural census, and the SLCR-mixed estimate is about 100% higher (Table 2). At the regional level this pattern of lower estimates by AC90, higher estimates for SLCR-pure pixels, and highest estimates for SLCR-mixed is repeated, except for South China where the SLCR-pure area estimate was the lowest (Fig. 1a, Table 2). For North, North-east, and Central China, the SLCR-mixed cropland is about 5–55% higher than SLCR-pure cropland area, while for the other three regions the SLCR-mixed estimate is 75–550% higher (Table 2). These regional differences are primarily topographical, as agriculture in North, North-east and Central China mostly occupies broad, relatively flat plains, while the

Table 2. Cropland areas (km^2) in China by province and region from the Agricultural Census of 1990 (AC90) and derived from 1992–1993 AVHRR signals (SLCR)

		Cropland			Rice			Irrigated	
Region	Land area*	AC90	SLCR pure†	SLCR mixed‡	AC90 pure rice**	AC90 total rice††	SLCR	AC90‡‡	SLCR§
Total China	9102 749	950 810	1402 968	1941 652	200 976	236 091	315 936	433 657	780 371
North China	669 102	250 761	420 639	473 687	3976	6774	31 609	139 145	313 178
Beijing	16 261	4447	5425	6854	243	352	477	3147	4463
Tianjin	11 212	3983	8581	9073	295	382	17	1399	5153
Hebei	181 554	65 434	103 719	120 058	707	1373	5069	39 509	75, 346
Shanxi	151 390	37 516	54 140	74 690	32	85	4742	11 594	35 299
Shandong	147 530	68 842	122 026	132 708	86	529	4332	47 188	103 719
Henan	161 154	70 540	126 748	130 305	2612	4052	16 972	36 307	89 067
North-east China	787 577	141 832	310 306	325 821	13 254	14 813	3682	21 394	12 008
Liaoning	151 257	36 741	81 707	88 466	4586	4942	1913	7542	8266
Jilin	187 337	37 907	81 254	84 165	3509	4019	607	8481	1228
Heilongjiang	452 311	68 785	150 033	155 879	5322	6027	1162	5873	2515
Central China	880 752	198 497	284 789	353 165	95 748	113 382	1944 341	116 483	267 504
Shanghai	6744	3357	5217	5450	1569	2021	1758	2117	4796
Jiangsu	98 276	45 442	80 156	83 391	15 439	23 022	43 895	23 202	76 105
Zhejiang	100 954	18 921	13 215	21 565	13 367	15 019	9852	14 783	12 710
Anhui	133 363	42 487	744 329	82 203	11 905	15 820	43 407	16 010	70 700
Jiangxi	164 214	23 067	24 469	50 344	16 667	17 388	21 893	18 063	21 893
Hubei	167 870	32 080	59 910	69 804	12 124	14 773	48 790	16 714	48 790
Hunan	209 599	33 222	27 576	40 497	24 679	25 338	24 825	25 899	24 825
South China	573 398	93 981	26 197	142 676	56 643	57 284	7710	57 659	9272
Fujian	119 588	12 266	3841	31 656	8945	9072	766	9090	1204
Guangdong	182 742	25 767	11 743	59 167	16 117	16 225	2224	15 721	2675
Guangxi	233 252	51 238	9373	47 227	29 109	29 494	4422	30 477	4758
Hainan	36 891	4465	1156	4209	2262	2284	288	2318	624
South-west China	1108 562	109 401	143 770	260 064	29 939	40 664	57 061	41 694	80 678
Sichuan	550 617	62 442	105 071	168 317	19 167	26 237	45 542	26 381	53 225
Guizhou	174 028	18 514	144 331	42 432	2948	6047	9230	6254	12 280
Yunnan	383 917	28 445	244 368	49 315	7825	8380	2289	9059	15 144
North-west China	5083 358	156 338	217 267	386 240	1415	3176	21 533	57 281	97 733
Inner Mongolia	1134 179	49 658	944 305	164 033	185	672	788	13 249	26 956
Tibet	1132 299	2633	10 264	35 792	0	0	2357	607	4322
Shaanxi	198 779	35 215	39 582	64 583	767	1566	10 652	11 296	30 633
Gansu	390 503	33 693	32 440	55 258	5	42	7044	9907	15 633
Qinghai	584 455	5189	4631	10 712	0	0	552	1336	1811
Ningxia	48 405	7746	3961	7099	236	240	11	1209	1312
Xinjiang	1593 426	21 991	31 827	48 437	157	589	128	19 677	16 889

*CIESIN polygon coverage (HTTP://sedac.ciesin.org/china/admin/bnd90/bnd90.html) including only the 2369 counties used in our analysis (see text for details); †SLCR pure: includes only pixels classified as pure cropland (excludes woody crops). SLCR data developed by Yang *et al.*, 1997; ‡SLCR mixed: includes pure pixels plus half the area of the pixels classified as mixed cropland and noncropland (excludes woody crops); **AC90 pure rice: land area with single or double-cropped rice only; ††AC90 total rice: land area with single or double-cropped rice plus land area with rice/wheat, rice/maize, or rice/rape double cropping; ‡‡AC90 irrigated: includes all rice and other irrigated crops; §SLCR irrigated: includes all paddy rice and irrigated cropland pixels, plus half the area of the mixed irrigated and dry cropland pixels.

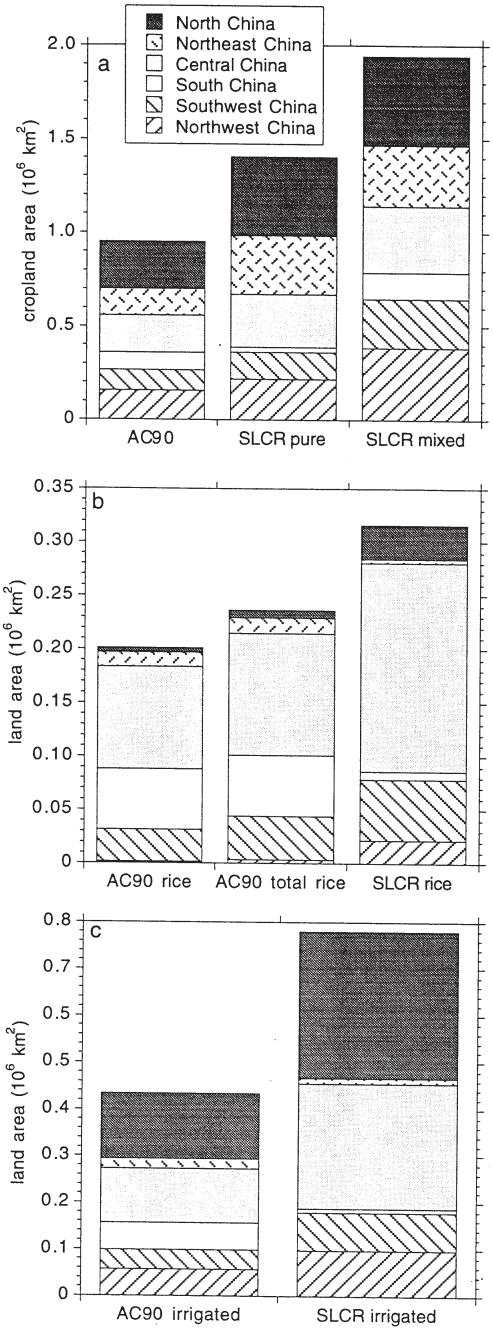

Fig. 1. Regional land area totals, based on 1990 agricultural census data (AC90) and 1992–93 remote sensing land cover classification (SLCR) for (a) cropland (b) paddy rice, and (c) irrigated cropland in China. SLCR-pure includes only pixels classified as pure cropland; SLCR-mixed includes pure pixel area plus half the area of the mixed crop/noncrop pixels. AC90-rice is single and double-cropped rice; AC90-total-rice adds to this the area of rice/wheat and rice/rape (oilseed) double cropping. Irrigated land includes paddy rice in all regions. See Table 2 for a list of the provinces in each region.

landscape of southern and south-western China is much hillier, leading to generally smaller field sizes and a more heterogeneous landscape. Both AC90 and SLCR have similar distributions of cropland area across China (Fig. 1a), and their differences at this scale are primarily in magnitude. Provincial patterns for total cropland are similar to the regional patterns (Table 2).

Rice

The SLCR-pure estimate of China's paddy rice area is also about 50% higher than that for AC90-rice (Table 2, Fig. 1b). At the regional scale, however, the discrepancies are generally larger, with SLCR estimates of rice area many times larger than those for AC90 for North and North-west China, and many times lower for North-east and South China (Table 2, Fig. 1b). Both datasets locate the largest rice area in Central China.

Irrigated land

The SLCR-pure estimated area of irrigated cropland is about 75% higher than the AC90 estimate (Table 2, Fig. 1c). SLCR estimates were roughly double AC90 values for North, Central, South-west, and North-west China, half the AC90 value in North-east China, and about 15% of the AC90 value in South China. These relationships are very similar to those for paddy rice.

County scale

To develop a meaningful comparison between ground census and remote sensing estimates, we limited the county-scale comparison between SLCR and AC90 to those counties with significant agricultural land use and relatively homogeneous land cover. We included only those counties in which: 1) at least 25% of the total county land area was cropland according to AC90 (Fig. 2a) and; 2) SLCR-pure cropland area accounted for at least 75% of the SLCR-mixed cropland area (Fig. 2b). The 683 counties satisfying these criteria account for 10% of China's land area and 45% of China's cropland (based on AC90 data); 80% of these counties are in North or Central China. This subsetting excluded most of the counties in South China, where the combination of a hilly landscape and persistent cloud cover will have made the classifying of landcover by optical remote sensing more problematic (Qiu *et al.*, 1996), and most cropland pixels were mixed.

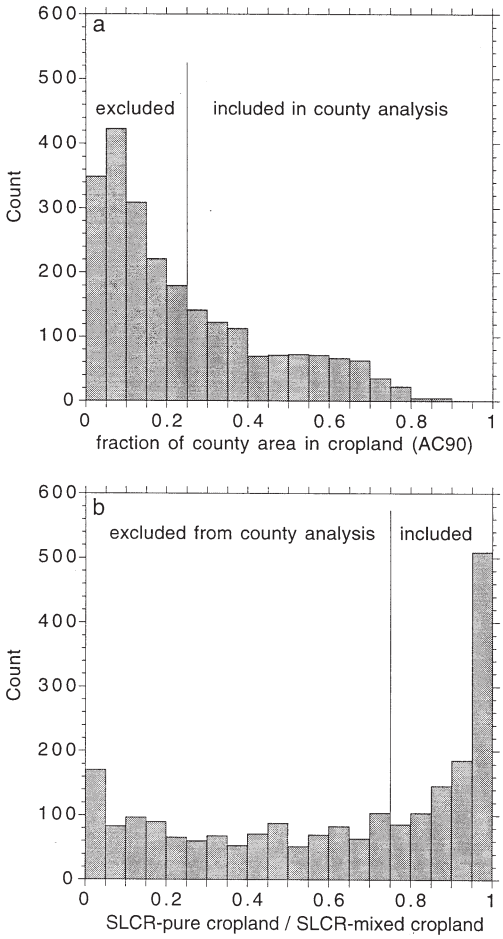

Fig. 2. (a) Frequency distribution of fraction of 1990 county land area in cropland (AC90 data); (b) Frequency distribution of ratio of SLCR-pure (SLCR estimate of cropland area in pure pixels) to SLCR-mixed (SLCR estimate of cropland in pure pixels plus half the area in mixed cropland/noncropland pixels for 1992–93). For the county level analysis we considered only those counties with greater than 25% of the land area in crops, and with an SLCR-pure:SLCR-mixed ratio greater than 0.75, i.e. those counties that fell in the 'included' portions of both panel (a) and panel (b). The 683 counties satisfying these criteria account for 10% of China's land area and 45% of China's cropland (based on AC90 data); 80% of these counties are in North or Central China.

Cropland

There was a strong correlation ($r^2 = 0.82$) at the county scale between the AC90 and SLCR-pure estimates of cropland area, with SLCR-pure estimates averaging

about 70% higher than AC90 (Fig. 3a). The SLCR-mixed dataset gives a very similar result (not shown) because the cropland in this subset of counties is dominated by pure pixels.

Rice

There was a moderate correlation ($r^2 = 0.45$) at the county scale between AC90-total-rice and SLCR-pure estimates of paddy rice area (Fig. 3b). The AC90-rice and SLCR-pure paddy rice areas had poorer correlation ($r^2 = 0.32$; not shown). The 683 county database subset had 119 counties with SLCR paddy rice area greater than 10 km^2 for which AC90 reported no rice, and 57 counties with AC90-rice area greater than 10 km^2 for which SLCR detected no paddy rice.

Irrigated land

There was a weak correlation ($r^2 = 0.23$) at the county scale between AC90 and SLCR estimates of irrigated area (Fig. 3c). The 683 county database subset had 43 counties with SLCR irrigated area greater than 10 km^2 for which AC90 reported none, and 30 counties with AC90 irrigated area greater than 10 km^2 for which SLCR detected no irrigation.

DISCUSSION AND CONCLUSIONS

The AC90 cropland area estimate (950 810 km^2) is within 1% of the national total provided by China's State Statistical Bureau (SSB) in their annual report (e.g. SSB, 1994). Remote sensing-based estimates of 1992/1993 cropland area in China are 48% higher (SLCR-pure) and 104% higher (SLCR-mixed) than the agriculture census estimate of 1990 cropland area (AC90). Other cropland area estimates are also higher than the AC90 and SSB totals. Fischer *et al*., (1998) summarize ground census data reported by China's State Land Administration, estimating the 1990 total arable land area at 1225 100 km^2, 29% greater than the AC90 estimate. The Food and Agricultural Organization of the United Nations reports a comparable total arable land area for China in 1990, 1 236 780 km^2 (Faostat, 1998). Researchers at the Institute of Geography, Chinese Academy of Sciences have developed a 1:1 000 000 land use map of China, based on satellite images (1:500 000–1:1 000 000) and large-scale aerial photographs from the 1980s (Wu 1990; Wu & Guo, 1994). They estimate the cultivated land area of China at 1 364 000 km^2 (including cropland area in Taiwan, Hongkong, and Macao, which contain < 1% of China's total cropland area in the SLCR-mixed estimate), 43% greater than the AC90 estimate.

Three factors probably contribute to these cropland area discrepancies. First, the SSB states, 'Figures for the cultivated areas are underestimated and must be further verified' (SSB, 1994; p. 329); this under-reporting is probably also true for AC90 (Zhuang *et al*., 1996). Recent estimates are that actual cropland is 15–50% greater than reported by the SSB, with regional and crop type variations (Crook, 1993; Fu *et al*., 1993). Second, these estimates may not be counting exactly the same things. For example, the AC90 and SSB databases refer to planted cropland, while the FAO definition of arable land includes 'temporary meadows for mowing or pasture' and 'land temporarily fallow (less than 5 years)' (Faostat, 1998). This broader cropland definition may also apply to estimates by Fischer *et al*., (1998) and Wu & Guo, (1994). A third factor is the inherent overestimate in our remote-sensing analysis. If a pixel is classified as pure cropland, we allocate the entire area of that pixel to crops, with no land area for infrastructure (e.g. roads, dwellings, other buildings, idle land). The amount of noncropland area in each pure cropland pixel may vary from 10 to 40% (e.g. Okamoto & Fukuhara, 1996; Fang, 1998; Gonzalez-Alonso *et al*., 1998). In the Jianghan Plain, a flat region with widespread rice cultivation in southern Hubei Province, ~10–20% of the landscape is agricultural infrastructure which would be identified as crop lands by moderate to coarse resolution remote-sensing analysis (Fang *et al*., 1998). This problem probably also occurred to a lesser degree for the cropland polygons in the 1:1 000 000 Land-Use Map of China of Wu (1990). Applying a 20% infrastructure area to the pure pixels reduces the SLCR-pure cropland area 1 122 000 km^2, 18% greater than the AC90 estimate. If mixed cropland/noncropland pixels (total area to 1 077 000 km^2) are only ~10–20% cropland, then the SLCR-mixed cropland area is similar to estimates of the FAO (Faostat, 1998), Fischer *et al*., (1998), and Wu & Guo, (1994). Two independent groups estimate cropland area loss from 1990 to 1993 at about 1% (SSB, 1994; Fischer *et al*., 1998), so land use change is not the source of the discrepancy.

Discrepancies between AC90 and SLCR-pure estimates of total cropland area at the regional and provincial scales are generally greater than for the national total, because the large underestimate by SLCR-pure for South China compensates likely

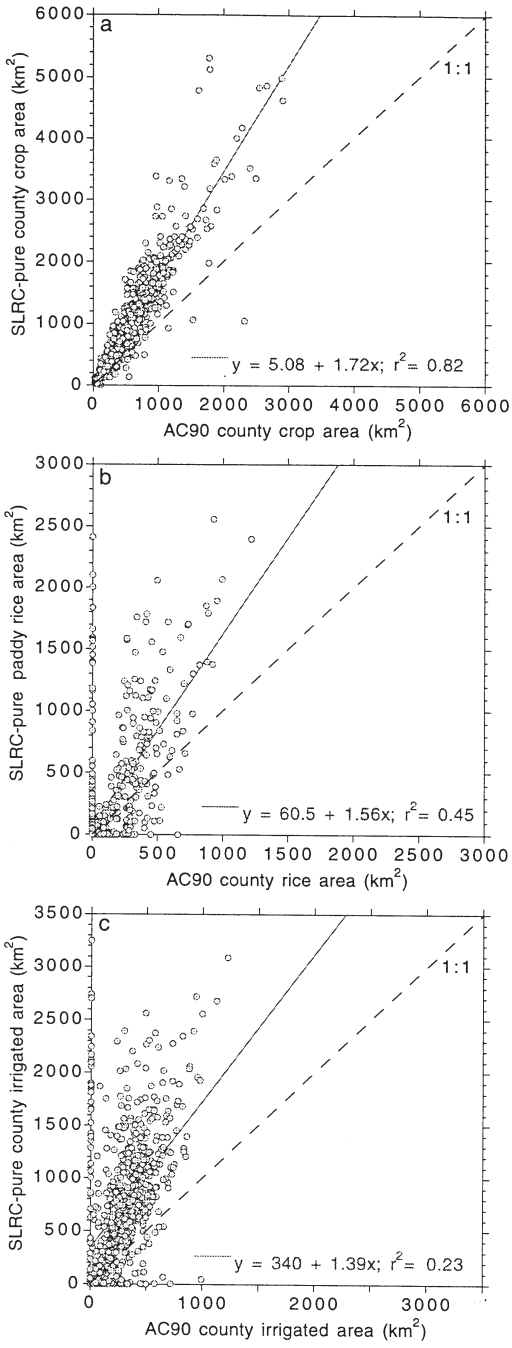

Fig. 3. AC90 vs. SLCR-pure estimates of county land area totals for (a) cropland (b) paddy rice, and (c) irrigated cropland in 683 counties in China. These counties were selected for having more than 25% of their total land area in cropland in the AC90 database (1990 land-use) and at least 50% more pure than mixed cropland pixels in the SLCR database (1992–93 land-use) (see Fig. 2). The AC90 rice area is 'total rice', including that land in rice/wheat or rice/rape (oilseed) double cropping. All SLCR totals are based on pixels classified as pure cropland. Irrigated land includes paddy rice in all counties.

overestimates in other regions (Table 2). However, provincial area estimates are generally consistent with the finer-scale county estimates for the dense agricultural regions, where it appears that there is good correlation between the two estimates. The real area likely lies between the AC90 and SLCR totals. In many regions of China, however, the correlation between county-level cropland estimates of AC90 and SLCR was weak (e.g. $r^2 \sim 0.14$ for all counties in South, South-west, and North-west China). These regions probably have higher levels of under-reporting to AC90 (Crook, 1993; Fischer *et al*., 1998), and are a challenge to optical remote-sensing analysis because of frequent cloud cover in the south (Qiu *et al*., 1996) and a high percentage of mixed pixels with unknown fractional cropland areas. Cropland estimates in these regions may not be well-constrained by these databases.

Correlations between AC90 and SLCR estimates of paddy rice area or total irrigated agriculture were weaker (Table 2, Figs 3a, 3b). Even in the highly agricultural regions of North and Central China, more than 25% of the counties were identified as having significant paddy rice area by one analysis and none by the other (Fig. 3b). Identification of paddy rice with AVHRR NDVI data requires a cloud-free image during the period of initial flooding (NDVI very low) and subsequent cloud-free images during peak growing season (high NDVI). This is difficult to achieve with significant cloud contamination of the NDVI signals (Qiu *et al*., 1996). Estimating irrigated area will also be difficult, as the seasonal remote sensing signal, based on 1 year of AVHRR data, may not be strong. AC90 irrigated area data are probably based on reports of areas where some irrigation infrastructure existed (i.e. potential irrigation if everything was working), but may not be a good estimate of actual irrigation.

County scale evaluation of national and regional remote sensing products can provide an important ground-level test at a resolution intermediate between field observation at the pixel scale and regional and national scale statistics commonly reported in almanacs and on-line databases. Analysis at this scale can help identify regions where land cover classifications are more and less successful, and also point out probable discrepancies in census and almanac data sets. We believe that SLCR and AC90 put a realistic constraint on cropland area in North and Central China. For the rest of China, and for paddy rice and irrigated areas, there are large and as yet unresolved discrepancies between AC90 and SLCR estimates. The new generation of optical sensors due for launch in 1999/2000 (MODIS, MISR, ASTER on EOS-AM1, and ETM on Landsat 7) have been designed for studying vegetation and landcover, and should substantially improve remote-sensing mapping and monitoring of vegetation and land cover types (Kaufman *et al*., 1998). Improved ground-based datasets also need to be developed.

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REFERENCES

Bachelet, D. (1995) Rice paddy inventory in a few provinces of China, using AVHRR data. *Geocarto Int*. **10,** 23–38.

Belward, A.S. (1996) The IGBP-DIS global 1 km land cover data set (DISCover): Proposal and implementation plans. IGBP-DIS Working Paper. IGBP-DIS Office, Meteo-France, 42 Av. G. Coriolis, F-31057 Toulouse, France.

CIESIN (Consortium for International Earth Science Information Network) (1998) *The China Time Series Administrative Regions GIS Data: 1:1M, County Level*, prepared by CIESIN, the Chinese Academy of Surveying and Mapping, and China in Time and Space (University of Washington), available on the World Wide Web at http://sedac.ciesin.org/china/admin/bnd90/bnd90.html.

CRTSA (Central Radio and Television School of Agriculture) (1995). *Textbooks for Primary Agricultural Technology Training*, Volumes. I-VI. China Agricultural Publishing House, Beijing (in Chinese).

Crook, F. (1993) Underreporting of China's cultivated land area: Implications for world agricultural trade. *China International Agricultural and Trade Report*, pp. 33–39. 1993 Situation and Outlook Series RS–93–4. US Department of Agriculture, Washington, DC.

Fang, H., Wu, B., Liu, H. & Huang, X. (1998) Using NOAA AVHRR and Landsat TM to estimate rice area year-by-year. *Int. J. Remote Sens.* **19,** 512–525.

Fang, H. (1998) Rice crop area estimation of an administrative division in China using remote sensing. *Int. J. Remote Sens.* **19,** 3411–3419.

Faostat (1998) *Statistical Database of the Food and Agricultural Organization of the United Nations*, available on the World Wide Web at http://apps.fao.org.

Fischer, G., Chen, Y.F. & Sun, L.X. (1998) The balance of cultivated land in China during 1988–95. Internat. Inst. Appl. Syst. Analysis (IIASA) Interim Report IR-98–047, Laxenburg, Austria.

Fu, L.Q., Zhang, S.W., Liu, D.W. & Wan, E.P. (1993) Image processing for maize yield estimation by remote sensing. *Remote Sensing Technique for Wheat, Maize, and Rice Yield Estimation* (ed. by B.S. Chen), pp. 8–15. China Science and Technology Press, Beijing (in Chinese).

Gonzalez-Alonso, F., Cuevas, J.M., Arbiol, R. & Baulies, X. (1998) Remote sensing and agricultural statistics: crop area estimation in north-eastern Spain through diachronic Landsat TM and ground sample data. *Int. J. Remote Sens.* **18,** 467–470.

Hossain, M. (1997) Rice supply and demand in Asia: A socioeconomic and biophysical analysis. *Applications of Systems Approaches at the Farm and Regional Levels* (ed. by P.S. Teng, P.S.M.J. Kropff, H.F.M. ten Berge, *et al.*). Kluwer Academic Publishers, Dordrecht, Germany.

Huang, G., Zhang, Z. & Zhao, Q. (1997). *Crop Practice in Southern China*. China Agricultural Publishing House, Beijing (in Chinese).

Institute of Geography & Chinese Academy of Science, State Planning Committee, State Economic Information Center, and Institute of Statistics, State Statistical Bureau. (1994) *National Economic Atlas of China*, p. 314. Oxford University Press, Oxford UK.

Kaufman, Y.J., Herring, D.D., Ranson, K.J. & Collatz, G.J. (1998) Earth Observing System AM-1 mission to Earth. *IEEE Trans. Geosci. Remote Sens.* **4,** 1045–1055.

Loveland, T.R. & Belward, A.S. (1997) The IGBP-DIS global 1 km land cover data set, DISCover: first results. *Int. J. Remote Sensing.* **18,** 3289–3295.

Malingreau, J.-P. (1986) Global vegetation dynamics: satellite observations over Asia. *Int. J. Remote Sens.* **7,** 1121–1146.

Matson, P.A., Parton, W.J., Power, A.G. & Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science*, **277,** 504–509.

Ojima, D.S., Stretch, L., Chuluun, T., *et al.* (1997) Development of the temperate east Asia land-cover (TEAL) database. *Proceedings of the IGU-LUCC '97 Meeting on Information Bases for Land Use/Cover Change Research* (ed. by Y. Himiyama & L. Crissman), pp. 77–83. International Geogr. Union, Asahikawa, Japan.

Okamoto, K. & Fukuhara, M. (1996) Estimation of paddy field area using the area ratio of categories in each pixel of Landsat TM. *Int. J. Remote Sens.* **17,** 1735–1749.

Qiu, Z., Yang, L. & Loveland, T.R. (1996) Recent experiences in mapping land cover from AVHRR data: People's Republic of China test sites. *Proc. IGARSS 96,* 2318–2320.

SSB (State Statistical Bureau) (1994). *Statistical Yearbook of China 1994*, p. 795. China Statistical Publishers House, Beijing.

Vitousek, P.M., Mooney, H.A., Lubchenco, J. & Melillo, J.M. (1997) Human domination of earth's ecosystems. *Science*, **277,** 494–499.

Walker, B. & Steffen, W., eds. (1996) *Global Change and Terrestrial Ecosystems*, p. 619. Cambridge University of Press, Cambridge, UK.

Wu, C. (ed.) (1990) *Land-Use Map of China* (1:1 000 000 scale). Science Press, Beijing (in Chinese).

Wu, C. & Guo, H. (1994). *Land-Use in China*, p. 442. Science Press, Beijing (in Chinese).

Xu, Y. (1996) Irrigated farming of the North China Plain. *Experimental Studies on Water and Energy Balance in Agricultural Lands* (ed. by D. Tang, & X. Xie), pp. 151–160. China Meteorological Press, Beijing.

Yang, L., Zhu, Z., Li, J. & Qiu, Z. (1997) Seasonal land cover characteristics database of China for global change research. Proceedings: 1997 ASPRS/ACSM Annual Convention & Exposition, ASPRS technical papers, 2, pp. 82–86. Bethesda, MD, USA.

Zhuang, Y.H., Cao, M., Wang, X. & Yao, H. (1996) Spatial distribution of trace-gas emissions from burning crop residue in China. *Biomass Burning and Global Change*, Vol. 2 (ed. by J.S. Levine), pp. 764–770. MIT Press, Cambridge, MA.

Zuo, D. & Xu, Y. (1996) The shortage of water resources in the Northern Territory of China and its mitigation countermeasures. *Experimental Studies on Water and Energy Balance in Agricultural Lands* (ed. by D. Tang & X. Xie), pp. 1–12. China Meteorological Press, Beijing.