Priorities for Worldwide Remote Sensing of Agricultural Crops

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ABSTRACT: The world's crops are ranked according to total harvested area, and comparisons are made among major world regions of differences in crops produced. The eight leading world crops are wheat, rice, corn, barley, millet, soybeans, sorghum, and cotton. Regionally, millet and sorghum are most important in Africa; wheat is the most extensively grown crop in north-central America, Europe, USSR, and Oceania; corn is the dominant crop in South America; and rice is the most extensively grown crop in Asia. Agriculture in the USA is considered in more detail to show the national economic impact of variations in value per hectare among crops. On the world scene, the cereals are the most important crops, but locally, such crops as tobacco can play a dominant role.

INTRODUCTION

REMOTE SENSING STUDIES which are directed toward design of multispectral scanners and development of algorithms for analysis of remotely sensed data require spectral reflectances of natural targets. This approach has been successful for selecting spectral channels and the evaluation of sensor responses under varying atmospheric conditions (e.g., Huck *et al.* (1982), Begni (1982), and Kiang (1982)). Data available for determining requirements are scarce, however, for many targets of interest (Kondratyev, 1982; Bauer *et al.*, 1980).

It is usually not clear just what the important natural targets are, and then it is often difficult to find representative spectral reflectances of those chosen for study. Indeed, the study is generally guided by what is available in the open literature. In this report, I review the information available for world land-use patterns in order to prioritize agricultural targets based on total harvested area. The economic value of United States crops will be used to illustrate how priorities may vary on a national level.

The data in the tables of this report were compiled from two sources: the *1976 FAO Production Yearbook*, Volume 30, published by the United Nations; and *Agricultural Statistics 1980*, by the United States Department of Agriculture. Although selected years from 1975 to 1979 are considered, the data are assumed to remain representative of current conditions. Because the reporting practices for various countries differ somewhat and influence the data, the above references should be consulted for explanations of specific reporting differences.

LAND USE

Land-use areas are summarized in Table 1 for the year 1975, for seven major regions of the world and the world total: Africa, North and Central America, South America, Asia, Europe, Oceania (which includes Australia, New Zealand, and the South Pacific Island), and the USSR. The United States, which is included in the North American data, is presented separately here to take advantage of the more detailed data available for the USA. The terrestrial area of each region is divided into five agricultural land-use categories and two total area categories as follows (FAO, 1976):

> *Total Area*—Total area of the region, including area under inland water bodies, such as the White Sea and Sea of Azov in the USSR.
> *Land Area*—Total area of the region, excluding area under inland water bodies.
> *Arable Land*—Land under temporary crops (double cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow or lying idle.
> *Permanent Crops*—Land cultivated with crops which occupy the land for long periods and need not be replanted after each harvest. Examples include cocoa, coffee, vines, shrubs, and fruit, nut, and rubber trees, but not trees for wood or timber.
> *Permanent Meadows and Pastures*—Land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).
> *Forests and Woodland*—Land under natural or planted stands of trees, whether or not productive, including cleared forest land which will be reforested in the foreseeable future.
> *Other*—Unused but potentially productive land, built-on areas (homes, buildings, parking lots, cemetaries, etc.), wasteland, parks, ornamental gardens, roads, lanes, barren land (including deserts), and any other land not specifically listed above.

The area for a given land-use category is an important parameter when considering remote sensing for any specific region of the world. When dis-

TABLE 1. TOTAL AREA OF FIVE LAND-USE CATEGORIES (THOUSANDS OF HECTARES) FOR SEVEN MAJOR REGIONS OF THE WORLD AND THE UNITED STATES. THE USA DATA ARE INCLUDED IN THE N C AMER DATA. DATA FROM FAO 1976 FOR YEAR 1975

	World	Africa	N C Amer	(USA)	S Amer	Asia	Europe	Oceania	USSR
					(Thousands of Hectares)				
Total Area	13,392,015	3,031,168	2,246,475	936,312	1,782,980	2,753,206	487,032	850,934	2,240,220
Land Area	13,075,336	2,964,616	2,140,747	912,689	1,754,691	2,672,388	472,816	842,878	2,227,200
Arable	1,415,467	196,744	285,590	207,376	79,521	451,599	127,707	47,006	227,300
Perm Crops	90,672	14,146	6,549	1,860	22,003	27,165	14,988	914	4,907
Perm Pasture	3,046,404	798,105	320,725	215,000	446,822	552,466	87,138	469,148	372,000
Forest & Wood	4,156,355	640,918	729,245	304,400	926,701	600,696	152,787	186,008	920,000
Other Land	4,366,428	1,314,703	798,629	184,053	279,644	1,040,462	90,195	139,802	702,993

cussing the differences between regions, however, it is perhaps more instructive to compare the relative percentages of land area in each category. Table 2 presents the land-use areas for each category in Table 1 as a percentage of the land area for each region.

The large percentage of arable land in the USA and Europe undoubtedly accounts for the importance of agriculture in the economics of these two regions. The slightly above average percentages of permanent crops in South America and Europe are related to coffee and grapes, respectively. It is noted that permanent meadows and pastures are over twice as prevalent in Oceania as in the other regions. South America and the USSR are dominated by forests and woodlands, while Africa has its largest areas devoted to deserts and barren lands.

Although arable land and permanent crops account for only 11.5 percent of the world land areas, they are of primary importance to remote sensing for their economic value and variety of targets. The following section will discuss how these lands are being used.

MAJOR AGRICULTURAL CROPS

Table 3 gives the total harvested area for each region for 13 leading world crops. The data were taken from "Agricultural Statistics, 1980," for the year 1979, and the table lists only those crops for which world data were given. The total area for these crops within each region was ratioed to the arable land entries in Table 1 to obtain the percent of arable land that was harvested. The difference of four years between the land-use and agricultural data will affect the percentages by a small but unknown amount. For instance, the world's arable land increased by only 2.5 percent from 1970 to 1975.

Wheat, the leading world crop, was the focus for the Large Area Crop Inventory Experiment (LACIE) program. Other crops are being investigated as well by the joint NASA-USDA effort, AGRISTARS (NASA JSC, 1983). Regionally, however, wheat is the leader only in Europe, Oceania, and the USSR. Rice is dominant in Asia, and corn (maize) in the remaining regions. Three of the agricultural crops are not foods: cotton, flax, and tobacco.

The total area, worldwide, of the 13 harvested crops accounts for just over half of the available arable land. The remaining arable land was either planted in other crops, not harvested, or left lying fallow. The next table gives additional detail on the other crops.

Table 4, compiled from 1976 FAO data, lists the total harvested area within each region for 25 major crops, for the year 1976. The two crops ranked fifth and seventh-millet and sorghum, respectively-are grown chiefly as feed for livestock and poultry in Europe and North America, but are also used as

TABLE 2. PERCENTAGE OF LAND AREA WITHIN EACH LAND-USE CATEGORY FOR THE SEVEN MAJOR REGIONS OF THE WORLD AND THE UNITED STATES

	World	Africa	N C Amer	(USA)	S Amer	Asia	Europe	Oceania	USSR
					(Percent)				
Arable	10.8	6.6	13.3	22.7	4.5	16.9	27.0	5.6	10.2
Perm Crops	0.7	0.5	0.3	0.2	1.3	1.0	3.2	0.1	0.2
Perm Pasture	23.3	26.9	15.0	23.6	25.5	20.7	18.4	55.6	16.7
Forest & Wood	31.8	21.6	34.1	33.3	52.8	22.5	32.3	22.1	41.3
Other Land	33.4	44.4	37.3	20.2	15.9	38.9	19.1	16.6	31.6

TABLE 3. THIRTEEN MAJOR WORLD CROPS RANKED ACCORDING TO TOTAL HARVESTED AREA. DATA FROM AGRICULTURAL STATISTICS 1980 FOR YEAR 1979

	World	Africa	N C Amer	(USA)	S Amer	Asia	Europe	Oceania	USSR
					(Thousands of Hectares)				
1. Wheat	226,016	8,646	36,372	25,172	9,621	77,582	24,433	11,862	57,500
2. Rice	140,198	4,523	2,037	1,221	7,331	125,207	390	110	600
3. Corn	127,179	17,743	38,839	28,126	17,730	37,537	12,452	78	2,800
4. Barley	89,418	5,015	7,058	2,995	1,035	15,071	20,759	2,680	37,800
5. Soybeans	52,990	68	29,266	28,543	10,856	10,500	295	1,142	840
6. Cotton	32,126	3,273	5,943	5,247	3,193	16,312	252	66	3,087
7. Oats	27,423	531	5,668	4,047	587	1,616	5,304	1,317	12,400
8. Peanuts	18,662	5,690	724	617	692	11,518	12	36	—
9. Potatoes	15,651	149	699	519	1,015	960	5,792	36	7,000
10. Rye	13,283	33	709	379	205	460	5,350	26	6,500
11. Sugarbeets	8,146	—	477	453	34	369	3,616	—	3,650
12. Flax	6,111	29	1,350	412	1,040	2,162	203	15	1,300
13. Tobacco	4,340	311	522	337	430	2,355	527	10	185
Total Area: (percent of arable land)	53.8	23.4	45.4	47.4	67.6	66.8	62.2	37.0	58.8

Note: Only those crops for which world data are given are listed. Sorghum, an important crop in Tables 4 and 5, is not included here.

TABLE 4. TWENTY-FIVE MAJOR WORLD CROPS RANKED ON A WORLD BASIS ACCORDING TO TOTAL HARVESTED AREA. DATA FROM FAO 1976 FOR YEAR 1976

	World	Africa	N C Amer	(USA)	S Amer	Asia	Europe	Oceania	USSR
	(Thousands of Hectares)								
1. Wheat	235,302	8,932	40,636	28,661	12,308	78,229	26,735	9,000	59,462
2. Rice	142,248	4,581	1,760	1,012	7,767	127,158	371	87	524
3. Corn	118,054	19,654	38,304	28,767	16,503	28,498	11,704	88	3,303
4. Barley	93,446	4,895	8,061	3,407	1,054	24,363	18,627	2,387	34,258
5. Millet[a]	72,808	16,325	—	—	241	53,191	27	25	2,999
6. Soybeans	44,885	209	20,309	20,009	7,106	16,171	300	28	762
7. Sorghum	43,929	13,939	7,760	6,020	2,421	18,956	151	506	196
8. Cotton	31,363	4,387	4,983	4,411	2,893	15,851	266	33	2,949
9. Oats	30,244	390	7,571	5,015	594	3,291	6,066	1,094	11,237
10. Beans	24,121	2,007	2,984	601	4,577	12,458	2,063	5	26
11. Potatoes	21,097	485	767	569	1,040	5,480	6,295	44	7,087
12. Peanuts	19,311	6,896	759	616	761	10,855	10	30	—
13. Rye	16,431	22	649	325	468	570	5,659	28	9,035
14. Sweet Potatoes	14,930	843	166	48	286	13,524	6	105	—
15. Sugarcane	12,732	846	2,672	307	3,365	5,500	5	343	—
16. Cassava	11,617	6,067	112	—	2,611	2,808	—	19	—
17. Chick Peas	10,784	402	190	—	15	9,975	202	—	—
18. Peas	9,966	471	96	66	135	5,462	308	42	3,453
19. Sunflower Seed	9,436	549	310	284	1,406	619	1,870	148	4,534
20. Sugarbeets	9,376	78	635	599	91	810	4,008	—	3,754
21. Rape Seed	8,997	50	810	1	61	6,753	1,297	14	13
22. Sesame Seed	6,384	1,607	270	1	182	4,316	9	—	—
23. Flax	5,727	128	745	386	816	2,327	288	19	1,403
24. Broad Beans	5,483	709	69	—	252	3,952	501	—	—
25. Tobacco	4,477	284	665	473	438	2,326	570	12	183
Total Area: (percent of arable land)	70.9	48.2	49.5	49.0	84.7	100	68.4	29.9	63.9

[a] Includes sorghum for those countries that do not distinguish the two.

food in Asia, Africa, and the USSR. Many countries make no distinction between the two grains; when combined figures are given, they are listed as millet.

The crops in Table 3 are ranked in the same approximate order as in Table 4 except that sugarbeets, flax, and tobacco are now less important on the world scene. Table 3 considered only those crops most important in the USA economy. Thus, the two tables are in good agreement, even with a three-year difference between the dates.

When the 25 crops are considered, the total harvested area is about 71 percent of the world's arable land. This increase over that in Table 3 is due largely to millet and sorghum. The two regions where these crops are the most important, Africa and Asia, showed the greatest increase in percent arable land harvested.

VALUE OF USA CROPS

While total area is certainly one of the most important parameters in the remote sensing of crops, the economic value of the crops should also be considered. Table 5 lists 24 crops harvested in the USA for 1979, ranked according to total crop dollar value. Crops grown for silage or forage are not included. Value is derived by multiplying production by the estimated season average price received by farmers for that portion of the crop actually sold. Value/area ratio is also a useful variable here.

Three new items show up near the top of the list: hay, fruit and nuts, and commercial vegetables. When the permanent crops are excluded, the arable land area accounted for is about 65 percent of the total. The major crops for the USA from Table 3—wheat, corn, soybeans, and cotton—are still at the top of the list while most of the other crops have dropped slightly, particularly oats and rye. The one exception, tobacco, has jumped from thirteenth place to eighth place (fifth place when the multiple crops, hay, fruit and nuts, and commercial vegetables are excluded). Tobacco has the highest value/area ratio. Other crops with high value/area ratios are hops, potatoes, peanuts, rice, and sugarbeets. The two multiple crops, fruit and nuts and commercial vegetables, also rank high. Corn, soybeans, and wheat, three of the major areal crops, are ranked in the lower half of the table when value per unit area is considered.

An additional consideration for each crop in the national economy is its export value. Table 6 ranks seven of the most important crops according to export value for 1979. There is a minor shift in the ranking of the major crops; otherwise, Table 6 has about the same ranking as Table 5.

PRODUCTIVITY OF USA FORESTS

Table 7 gives the total area of forest lands and commercial timberlands in the USA (forest land is being considered here because of its dominance in land-use and its relative importance in remote sensing). Forest land is defined as land that is at least 10 percent stocked by forest trees of any size and includes land that formerly had such cover and which will be naturally or artificially regenerated. Included are transition zones between heavily forested and non-forested lands (when at least 10 percent stocked with forest trees) and forest trees adjacent to urban and built-up land. The minimum area for classification is one acre.

Commercial timberland is forest land which is producing or is capable of producing crops of industrial wood, and which has not been withdrawn from timber utilization by statute or administrative regulation. It should be capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Areas that are currently inaccessible and inoperable are included in this category.

Timber resources for commercial timberland are given in Table 7 as net volume of sawtimber for the major species of softwoods and hardwoods. The evergreens, or softwoods, contain over three times more volume than the hardwoods. It is not known how the timber volume for each species relates to land area.

CONCLUDING REMARKS

The objective of this report was to rank agricultural crops for remote sensing studies. After selection of the most important crops, however, it is important to define their spectral reflectances. A survey of available data from the literature has been given by Bowker et al. (1985). Unfortunately, data are not available for all crops. In addition, Collins (1978) has shown that subtle variations in the spectral reflectance of vegetation throughout the growing season can be used for crop identification and separation of similar crops. Thus, a high spectral resolution reflectance curve for each crop for several stages of growth is desired. Vane et al. (1982) have summarized the spectral channels available to various researchers that have been used successfully for remote sensing of agriculture, but they do not necessarily represent an optimum selection.

Another important point which has not been treated thus far is the average size of the field for each crop. According to a study of the Thematic Mapper, 60 pixels are required to properly measure a target radiometrically (Park, 1981). This requirement results from the fact that the point spread function will cause adjacent scenes to affect the target two pixels inside the border, and the inherent inhomogeneity of the average target will increase the total number of required pixels to 60. The median field area for cereal crops in the USA varies from 8 to 32 hectares (Park, 1981). Placing 60 pixels within these areas requires a sensor resolution between 37 and 73 metres. The Thematic Mapper,

TABLE 5.　TOTAL CROP VALUE AND HARVESTED AREA, AND VALUE/AREA RATIO OF TWENTY-FOUR MAJOR CROPS IN THE UNITED STATES, RANKED ACCORDING TO VALUE. DATA FROM AGRICULTURAL STATISTICS 1980 FOR YEAR 1979

	Value (Thousands of Dollars)	Area (Thousands of Hectares)	Value/Area (Dollars/ Hectare)
1. Corn	18,618,461	28,799	646
2. Soybeans	14,039,171	28,543	492
3. Wheat	8,175,467	25,334	323
4. Hay, all	7,324,470	24,752	296
5. Fruit & Nuts[a]	6,254,645	1,427	4383
6. Cotton	5,097,579	5,188	983
7. Comm. Vegetables	4,127,315	1,374	3004
8. Tobacco	2,160,138	334	6467
9. Sorghum	1,884,604	5,240	360
10. Rice	1,503,337	1,206	1247
11. Potatoes	1,326,979	569	2332
12. Barley	865,691	3,022	286
13. Peanuts	822,356	617	1333
14. Oats	716,783	3,979	180
15. Sunflower	645,256	2,190	295
16. Sugarbeets	554,257	453	1224
17. Beans	475,949	547	870
18. Sugarcane	374,266	301	1243
19. Seed crops	264,074	643	411
20. Flax	80,708	412	196
21. Hops	53,614	13	4124
22. Rye	51,330	384	134
23. Peas	20,531	55	373
24. Coffee[b]	2,610	1	2610

[a] Includes all fruit and tree nuts, such as oranges, grapes, walnuts, etc.
[b] Grown in Hawaii

with a resolution of 30 metres, could satisfy these requirements. However, the median field area for tobacco is 1 hectare, which requires a resolution as small as 13 metres. Because farming practices differ substantially on the local level, it may be necessary to improve upon the 30-metre resolution of the Thematic Mapper in future missions.

From an analysis of total harvested area, the cereals are certainly the most important world crops, with soybeans, cotton, beans, potatoes, and peanuts

TABLE 6.　SEVEN MAJOR CROPS OF THE UNITED STATES RANKED ACCORDING TO EXPORT VALUE, WITH TOTAL CROP VALUE GIVEN FOR COMPARISON. DATA FROM AGRICULTURAL STATISTICS 1980 FOR YEAR 1979

	Export Value	Total Crop Value
	(Millions of Dollars)	
1. Soybeans	6,157.0	14,039.2
2. Corn	6,078.5	18,618.5
3. Wheat	4,859.5	8,175.5
4. Cotton	1,896.2	5,097.6
5. Tobacco	1,292.2	2,160.1
6. Rice	884.2	1,503.3
7. Sorghum	575.4	1,884.6

TABLE 7.　TOTAL FOREST LAND AND COMMERCIAL TIMBERLAND IN THE UNITED STATES, WITH MAJOR SOFTWOOD AND HARDWOOD SPECIES LISTED ACCORDING TO NET BOARD FEET OF GROWING STOCK AND SAWTIMBER ON COMMERCIAL TIMBERLAND. DATA FROM AGRICULTURAL STATISTICS 1980 FOR YEAR 1977

	(Thousands of Hectares)	(Million Board Feet)
Total Forest Land	298,074	
Commercial Timberland	195,255	
Softwood Sawtimber		1,985,408
Fir		742,324
Pine		665,903
Hemlock		276,571
Spruce		142,418
Cedar		56,529
Other		101,663
Hardwood Sawtimber		593,532
Oak		228,953
Gum		59,400
Maple		57,216
Cot'wood & Aspen		35,218
Yellow Poplar		34,111
Hickory		33,645
Red Alder		21,559
Ash		17,801
Beech		16,780
Other		88,849

completing the list of the top 13 crops, as shown in Table 4. Other crops can be more important on a regional level, such as sweet potatoes, sugarcane, cassava, peas, sunflower seeds, and sugarbeets. For individual countries, the importance of various crops can vary considerably. For instance, in the USA, tobacco ranks thirteenth in harvested area, and as high as fifth when economic value is considered. Thus, it is clear that priorities will vary somewhat as the remote sensing program is tailored to the individual needs of local areas.

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