THE DEVELOPMENT OF A SPATIAL-TEMPORAL ANALYSIS SYSTEM PROTOTYPE FOR RICE INVENTORY DATA IN TAIWAN

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KEY WORDS: spatial-temporal analysis, rice inventory, arable lands, cropping pattern, historical change

ABSTRACT:

Rice is one of the major agricultural crops in Taiwan. The Council of Agriculture (COA) has spent millions of dollars on the creation and research of rice inventory data in the last twenty years. Although a huge volume of data archive is created, unfortunately most of the analysis has been only concentrating on overall statistical numbers. We argued in this paper that the rice inventory data actually provides both spatial and temporal perspectives toward the rice crop status, and an appropriate system design based on the spatial-temporal nature of rice inventory data can help COA to have a better control of rice production, as well as the adjustment of related agricultural policy. The proposed system prototype not only successfully fulfill spatial (single arable land or region) and temporal (single or multiple seasons) querying requirement, it also enables COA to analyze cropping patterns for the selected area. The latter is valuable to the understanding of real world phenomena and has potential to serve as reference information for such applications as nature hazard assessment and the supervised classification of remote sensing images. The major contribution of this research is spatial-temporal analysis, which were either time consuming or even impossible to complete by human operators in the past, can now be completed readily with computers. Though the efficiency of the system prototype still needs further improvement, nonetheless, the preliminary result clearly indicates the value and potential by adding spatial-temporal consideration to management and analysis of rice inventory database.

1. INTRODUCTION

In Taiwan, rice is one of the major agricultural crops and plays an indispensable role to human daily lives. To accurately control a reasonable market price, the Council of Agriculture (COA) has been monitoring rice production for more than 20 years. The result not only provides the assessment of the total rice production in a single cropping season, so that the governments can promptly and appropriately adjust production policy, it is also an important source for determining the amount of agricultural compensation for individual farmer. Though a huge amount of rice inventory data is created and accumulated, the analysis, however, has been only concentrating on the numbers on overall production statistics without taking its spatial and temporal perspective into consideration. After becoming an official member of World Trade Organization (WTO) in 2002, the local market shall be facing a tough challenge from import agricultural products. A more efficient and effective system for the management and analysis of rice inventory data at a reasonably low cost is therefore desperately necessary.

The core of the current COA approach is based on human operators' photo interpretation and manual editing. Numerous approach were proposed to improve the accuracy and efficiency of the interpretation and classification process (Tseng, 1998; Hsiao, 2001), but none of them practically dealing with issues related to the spatial-temporal management and analysis of the rice inventory data. Any query of rice crop status regarding multiple seasons either demands a huge amount of operators' works, or is even impossible to complete. We believe a spatial-temporal management and analysis system prototype is capable of at least bringing the following impacts. First, a spatial-temporal system can quickly response to users' spatial and temporal constraints and provide historical changes and spatial distribution analyzed result in map formats. The analyzed area can be as small as an arable land, or as large as the nation coverage, in comparison with the current vague statistical numbers only based on political units. Second, the land laws enforce rigorous regulations on the use or even the ownership transfer of arable lands, the land use and associated crops for most agricultural lands may follow a fixed pattern. The spatial-temporal analysis during a period of multiple seasons helps to identify arable lands with fixed patterns, e.g., arable lands constantly used for rice crops or not used anymore. This is very helpful for locating major area for rice production or arable lands that are used least frequently. Finally, the spatial-temporal system enables COA to derive knowledge about rice crops. Such information may increase the accuracy of the damage assessment if natural hazards should strike. We believe there is tons of useful information hidden in the abundant rice inventory database, only if we can have a powerful mechanism to find them. The proposed spatial-temporal system prototype would try to provide an answer to this argument.

Based on the above discussion, the key functions in the proposed system prototype include:

- query cropping status of any arable land in any cropping season,
- analyze historical cropping status of any arable land in a selected time period,
- provide analysis and production statistics of the cropping status for a selected area, and
- analyze spatial and temporal cropping patterns for a selected region

The remaining of this paper is organized as follows. Section 2 analyzes the basic property of rice inventory data, followed by sections 3 discussing the basic principles of our proposed approach. Section 4 evaluates the result by testing our system prototype and analyzes if the proposed system fulfills users requirement. Finally section 5 concludes our major work and discusses possible future research.

2. 2. DATA ANALYSIS

2.1 The Creation of Rice Inventory Data

The total area used for rice cultivation is approximately 188588 hectares in the first cropping season of the year 2001 (COA, 2001). Since most arable lands in Taiwan allow two crops in a year, two different data sets, respectively describing the status of two cropping seasons, are created every year. To fulfill COA requirements, the rice inventory data must be both complete and accurate. The completeness requirement ensures that all the arable lands are investigated, while the accuracy requirement ensures 100% of the result to be correct. The current operational procedure has gone through several major changes with the introduction of new remote sensing technologies. Although there are some impressive research on data acquisition and interpretation, unfortunately none of the proposed approach can fully satisfy the above two requirements. This is because either the cost is too high, or the accuracy is not good enough due to the typical limited sizes of arable lands in Taiwan. Consequently the current procedure still has to heavily rely on human operators' photo interpretation. Operators' loading becomes even more when operators have to further manually mark the actual boundary used for rice crops. The rice inventory data is stored in PC ArcInfo format based on the coverage of 1/5000 national topographic map systems. This framework is a grid tessellation with every map covering an area of a 1.5 x 1.5 minute latitude and longitude difference. It is likely an arable land located near the border of the map be divided into two or even more polygons in different maps. A rice inventory file is then a polygon-type geographic file that stores both the spatial and attribute components of arable lands located in its specific map coverage. Other than its original 8 digit map number, the filename of each rice inventory file is expanded to include additional 3 digits, the first two refer to the year and the last one refers to the season. For example, a file '94192038852' represents a rice inventory result of map 94192038 in the 2nd season in the year of 1996 (the calendar year 85 in Taiwan). Operators interpret whether an arable land is used for rice crop based on aerial photos, then record the result with 0 (not used), 1 (rice crops) and 2 (other crops). The combination of the first and the last cases represent arable lands not used for rice crops. Figure 1 illustrates the result of a rice inventory file by using crop status as the primary controlling factor.

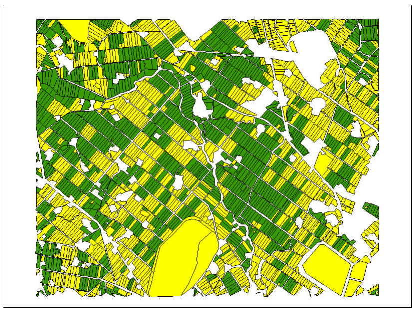

Figure 1. The illustration of rice inventory data

2.2 Basic Characteristics of Rice Inventory Data

The design of the proposed system prototype largely depends on the spatial-temporal property of rice inventory data. We'll discuss this issue from the perspectives of spatial/attribute, temporal and their integration.

□1□Spatial perspective

An arable land is recorded as a polygon and stored in the corresponding map coverage. Since only lands related to agricultural use are of interests, non-arable lands are first excluded. The interpretation result of each arable land is recorded in its associated attribute table, which include altogether 13 attributes, for example, area, land number, crop status, etc. This set of data can be directly transformed into ArcView Shape format.

□2□Temporal perspective

There have been some major discussions regarding the temporal modeling of geographic data (Barrera et al., 1990; Langran, 1993; Kemp and Kowalczyk, 1994). Guptill (1995) devoted a chapter discussing geographic data quality from temporal perspectives. The following discussion tries to clarify the inter-organization of rice inventory data from a temporal perspective. First, a rice inventory data represents rice crop status in 'world time' (Wachowicz and Healey, 1994), meaning its content is based on the time the data is collected. Second, a rice inventory file represents a time-slicing scenario of the real world at the chosen time. It is therefore dangerous to exaggerate any judgments other than what is stated, e.g., the situation between two crop seasons. Third, the temporality of rice inventory data for a crop season can be represented as a 'time-point', although conceptually 'interval-based' (Allen, 1983) approaches seem to be an intuitive choice. However, since the data of each season is created independently, there are only two possible temporal relationships existing in our system: disjoint and equal. The 'equal' relationship means selected rice inventory files are in the same season (note their actual world time may be different, but the difference is not important here), while the 'disjoint' relationship means selected files are corresponding to different seasons. This scenario is different from the 'meet' relationship existing in cadastre data (directly change from one state to another) so that event-based approaches (Peuquet and Duan, 1995) do not seem to be necessary here. Under such circumstance, a combination of year and season (a time point) would be sufficient to temporally distinguish two files.

□3□Spatial-temporal perspective

An arable land with explicitly stored spatial and temporal components will be defined as a 'temporal-arable' in the remaining of this paper. A rice inventory file is therefore a collection of 'temporal-arable' inside the corresponding map coverage in the same crop season. Since the crop status may be quite different from one crop season to another, the total number of temporal-arable and their respective boundaries in the same regions may be different as well. Based on this analysis, we introduced a five-level data management hierarchy (Figure 2). From the bottom to the top, the five levels respectively refer to a temporal-arable, a rice inventory file, a set of rice inventory file for local areas (e.g. political unit), a single-season rice inventory database and the historical rice inventory database (multiple seasons). The first level contains the collections of accumulated rice inventory data created in different seasons. As noted earlier, a disjoint temporal relationship exists between two rice inventory databases of different seasons (Level 2). From a spatial perspective, Level 2 to level 5 represent a spatial subdivision hierarchy, the relationships among them can be described by a 'part-of' spatial relationship. In our system, users have to first specify temporal constraints (what seasons are of interests), then issue spatial constraints to further narrow down the files to process.

When only parts of the arable land is used, a temporal-arable in a season may correspond to two or even more temporal-arable in another season. Sometimes, even the boundaries of the same arable land may be different in two seasons. Therefore, any spatial-temporal analysis must take both spatial and attribute (land number) component into consideration.

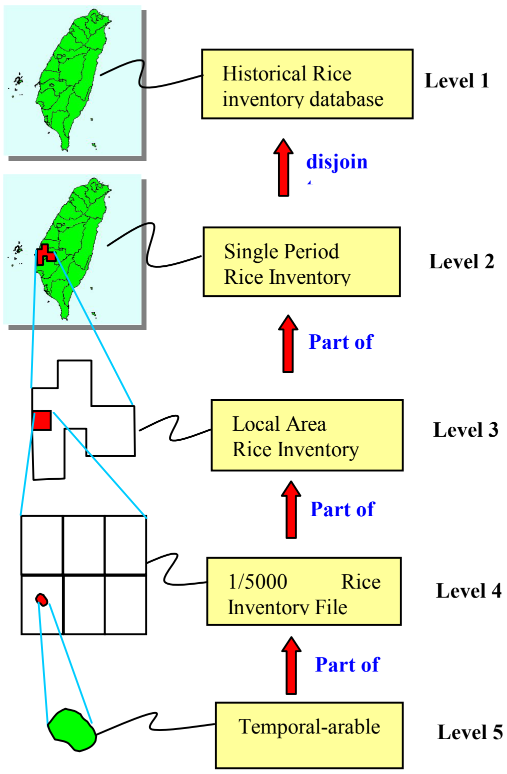

Figure 2. The five-level spatial-temporal hierarchy of the rice inventory database

3. SPATIAL-TEMPORAL ANALYSIS PROTOTYPE

3.1 Query regarding single season

With the introduced five-level hierarchy, querying the rice crop status in a particular season is fairly simple. As long as users can explicitly express temporal (what season) and spatial (location or land number) constraints, we can navigate through the hierarchy to locate appropriate rice inventory file (Level 4) in which the queried temporal-arable is stored. After the temporal constraint is determined, the remaining procedures are only spatial-related. Even for a query regarding a selected region (or even queries across a number of map coverage), related files can still be readily determined by a geometric intersection test between the boundary of selected region and the map coverage framework (Level 4). Since all of the selected rice inventory files share the same attribute schema, such query as the total area of rice crops or the percentage of area lands used can all be easily calculated with statistical tools.

3.2 Query regarding multiple season

Queries regarding multiple seasons (historical query) are only meaningful when analyzing the crop status of the same region in different seasons. Users have to choose both a level to analyze (Level 2 to Level 5) and seasons of interests (Level 1). For example, when querying the historical change of an arable land, the analysis will be based on the comparison on Level 1 and Level 5. We introduced the familiar 'layer' concept here, with every layer referring to crop status of the selected region in a particular season. To query the historical change for the selected region, the system only needs to find the corresponding temporal-arable (either spatial or attribute) within all the selected layers. When the boundaries of temporal-arable in the two seasons are the same, only the comparison on land number is necessary. On the other hand, when the temporal-arable configurations of the two seasons are different (sometimes even the land number changes), an additional geometric intersection test must be included. Because the geometric test is often time-consuming, the system is default to execute only when the areas of the corresponding temporal-arable are not the same. The querying result is a list of rice crop status (with both spatial and attribute description) for the queried arable land in time dimension. This concept can be further extended for region queries related to a number of arable lands. The historical change of total area of rice crop can be easily calculated and illustrated (e.g., bar chart). In the past, the analysis basis in COA statistical report is limited to pre-selected political boundary. With the proposed approach, the selection of queried region is arbitrary and the response is almost instant.

3.3 Cropping Pattern Analysis

The goal of the cropping pattern analysis is to find arable lands that constantly follow a fixed pattern, for example, arable lands used for rice crop for a number of consecutive seasons may be regarded as the major area for rice production. One important pattern to COA is to find arable lands no longer used for rice production because more and more arable lands are losing due to the booming economics. Without the pattern analysis mechanism, COA can only control crop status in a single season. Our goal is to identify arable lands with fix pattern so that COA can have a better control of how land use change and appropriately adjust its policy. Cropping pattern analysis is again based on the layer concept. While querying lands possibly no longer used for rice production, we can first issue a 'no crop' constraint on the crop status of the selected temporal-arable and store the queried result into a temporary layer. After creating a temporary layer for each selected season, the geometric intersection of temporal-arable in these layers then represents arable not used for rice crop in the selected seasons. Figure 4 illustrates this scenario.

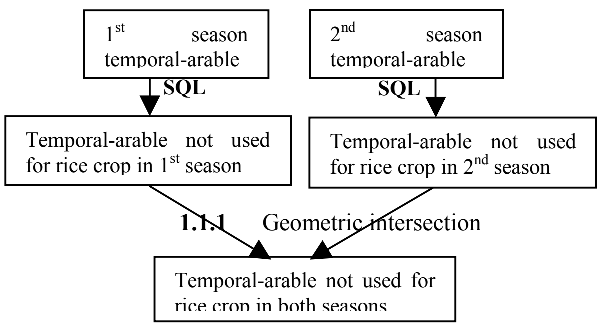

Figure 3. Basic procedure for pattern analysis

If the only concern is whether the arable lands are used for rice production or not, the addition of a season will double the number of possible combinations (either used or not used), represented as follows:

Number of patterns = 2^N

N denotes the number of seasons being analyzed. Obviously the number of possible patterns quickly increases with the increase of the number of seasons. Even with fast computers, such a dramatic increases is still not preferred. Although theoretically all possible patterns can be analyzed, nevertheless, only four patterns are practically of interests in this paper:

Arable land used for rice crops in every season (two-crop pattern)
Arable land only used for rice crops in the 1^{st} season every year (single-crop pattern)
Arable land only used for rice crop in the 2^{nd} season every year (single-crop pattern)
Arable land not used for rice crops (no crop pattern)

Figure 5 shows the analysis of no-crop pattern for rice inventory file '94193048' in the two seasons of 1996, we can easily conclude the majority of arable lands in this region are not used for rice crop in 1996. After analyzing rice inventory data for several consecutive seasons, the result can be regarded as a strong indication to arable lands no longer used for rice production.

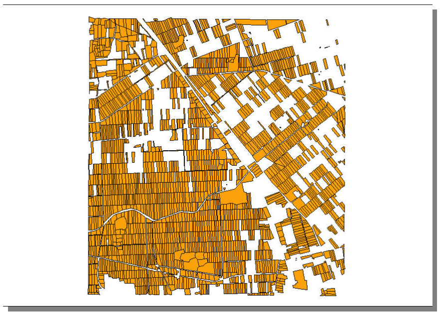

Figure 4. No-crop pattern analysis for rice inventory file '94193048' for the two seasons in 1996.

One major bottleneck in this approach is the cost of geometric intersection. Since each layer may contain thousands of polygons, the volume of calculation is sometimes still unbearable even with the introduction of the equal-area rule. For just a rice inventory file, its pattern analysis involving a number of seasons may take minutes to complete. We introduce a filter-refining strategy, based on the Minimum Bounding Rectangle concept, to reduce the number of possible intersection test. Though the efficiency did indeed improve, a more powerful strategy is still needed. We proposed a layer-difference model in (Tseng and Hong, 2001) and will do more tests in the future research.

Another property is the total area of arable lands fulfilling a certain pattern decreases with the increase of analyzed seasons. This is not surprising as the intersection of two polygons always yields a polygon that is equal to the original polygons (if the two are the same), or parts of the original polygons (the common part of the two polygons) or none at all (two polygons do not intersect). The analyzed result may dramatically change when an abnormal incident happens. For example, a drought may cause fallow in a particular season and lead to a conclusion that no arable lands fulfilling two-crop pattern in all the analyzed seasons, regardless of the fact that these arable lands may actually be used for rice crops in all the other seasons. It is certainly preferred to be able to flexibly express a query like 'find arable lands that are used for rice crops for at least 5 times in the 10 analyzed seasons'. The process is however very time-consuming because it will require altogether 638 patterns to test and may take hours or even days to complete with current system configurations.

4. TEST RESULT ANALYSIS

4.1 Test sites

We select three test sites respectively located in northern, central and southern Taiwan, each site contains either 15 or 18 maps. Most of the arable lands in northern and central test sites are two-crops pattern, while those in the southern test site are either one-crop or no-crop pattern. Under our request, COA provides ten seasons (from 1996 to 2000) of rice inventory data for the selected test sites. Some of requested files were unavailable and totally 453 files were acquired and processed. After converting from its original ArcInfo format to ArcView shapefile format, the files are organized into spatial-temporal rice inventory databases according to the five-level hierarchy discussed in section 2. The system prototype is developed in ArcView 3.2 environment with Avenue.

4.2 Single-season query

For queries regarding only a season, system will prompt users to first specify the season of interests. Users then have the choice to either use land number or create a queried region in the visual map interface. The land number constraint allows only single temporal-arable query, while the map interface constraint determines all the temporal-arable that intersect with the queried region and prompt users a list to make further selection. After selecting a temporal-arable from the list, its associated attributes are shown accordingly for users inspection. Figure 5 shows a queried region simultaneously intersecting three arable lands. Note all three of them are selected. Meanwhile, the use of visual able 'hue' further enhances the thematic display of rice inventory data (Robinson et al., 1996). Figure 6 shows the analyzed result to a query regarding the total area statistics of rice crop for arable lands located in the prefecture of Tainan. Note the file on the top-right corner in the selected season is missing, suggesting a possible crisis in the future multiple-season analysis.

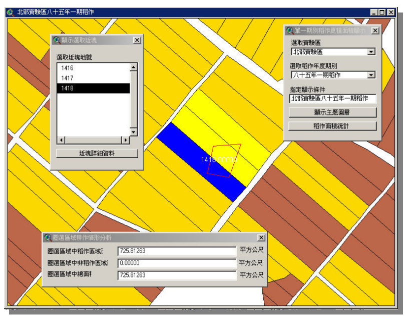

Figure 5. Query for the crop status in single season

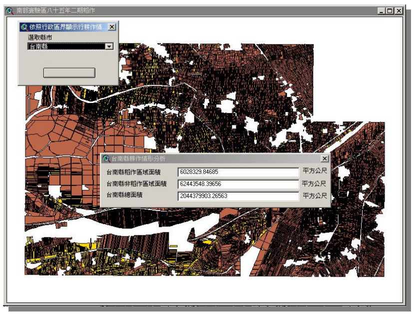

Figure 6. Rice crop statistics for selected region.

4.3 Multiple-season query

Multiple-season queries deal with the historical change of a selected arable land or region. Depending on the number of seasons of interests, the interface consists of the same number of map window, respectively displaying the rice crop status of the selected seasons. Figure 7 demonstrates the result after selecting 10 seasons of rice inventory data. Spatially speaking, these map windows are 'dynamically' linked with each other, such that whenever users zoom in/our or pan the content of a map window, the content and coverage of the other windows adjust correspondingly and automatically. This provides a great advantage that users can visualize the same area simultaneously and can create an overall impression easily. The selection of queried region can be easily completed with the index map locating at the left of the map windows. By overlaying 1/25000 scale topographic maps as reference maps, the index map provides users a convenient tool to select area of interests. After creating spatial constraints in the index map window, the rice crop status of the selected seasons automatically appears in the map windows. Note the contents of these map windows are slightly different in Figure 7, as some arable lands not categorized as arable lands were later identified as arable lands not used for rice crop. A possible reason is the change of interpretation standard from COA or misjudgment by human operators. Whatever the reason may be, this suggests a possible crisis regarding the correct analysis of the proposed spatial-temporal system.

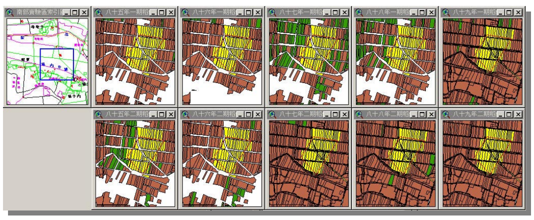

Figure 7. Map interface for the illustration of rice inventory data in multiple seasons.

Figure 8 shows the spatial-temporal analysis for a selected temporal-arable (land number 1300). Note there are two cases in the attribute table recording '1300' twice, meaning the corresponding polygons are divided into two polygons in these two seasons and their land numbers remain unchanged. A possible reason is only parts of the arable lands are used for rice crops in these two seasons.

Figure 9 shows a bar chart based on the total area of arable lands used for rice crop (vertical axis) and selected seasons (horizontal axis). After users create queried region, system automatically searches the same area coverage in other temporary layers and calculate the total area for every season. The pattern in Figure 9 appears to be either all arable lands are used for rice crop or not at all, likely a scenario for area that totally rely on irrigation water. When irrigation water supply is insufficient, farmer within the regions are forced to leave their arable lands fallow under current regulations.

Figure 8. Historical query regarding temporal-arable.

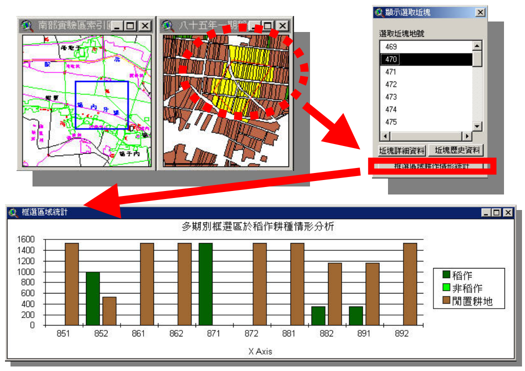

Figure 9. The bar chart of the total area statistics in different seasons.

4.4 Cropping pattern analysis

Figure 10 and Figure 11 demonstrate two cropping pattern analysis of the rice inventory file '94202038' (in central test site) from the two seasons in 1996. Figure 10 shows the arable lands used for rice crops in both seasons, while figure 11 shows arable lands not used for rice crops in both seasons. It is clear that the majority of arable lands in this region fulfill the two-crop pattern and those not used mainly locate in the northern part of the map. The combination of arable lands with two-crop and no-crop pattern is close to the total area of the arable lands in the map coverage. Further analysis on the single-crop pattern supports this conclusion because only a few arable lands fulfill the constraint. It is therefore reasonable to conclude the analyzed region is a major area for rice production. A natural hazard striking this region has a better chance to cause more damage to the rice production. On the contrary, a similar case would not bring too much damage to arable lands with 'no crop' patterns (please refer to Figure 4.).

We also conducted several tests on the crop status of the southern test site, the result indicated most of the arable lands are single-crop or no-crop pattern. Nevertheless, how many patterns there are or what pattern is found within what region are not really the major concerns of this paper, what we would really like to demonstrate is users' loading is simplified to be just a few mouse clicks for creating spatial and temporal constraints, in comparison with the possibly tremendous operator loeading in the past.

Figure 10. Arable lands with two-crop pattern for rice inventory file '94202038' in 1996.

Figure 11. Arable lands with no-crop pattern for rice inventory file '94202038' in 1996.

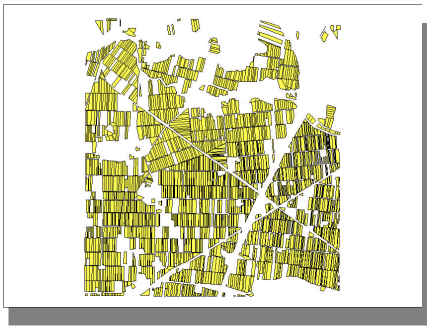

Figure 12. Arable land with two-crop pattern for rice inventory file '94202038' in the period of year 1996~1998.

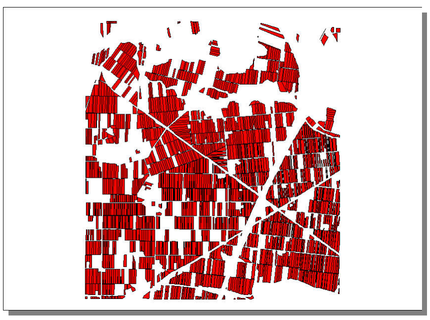

Figure 13. Arable lands with two-crop pattern for rice inventory file '94202038' in the period of year 1996~2000.

Figure 12 and Figure 13 further illustrate the analysis of the same region with two-crop pattern during the period of year 1996~1998 (6 seasons) and 1996~2000 (10 seasons). Although both visual inspection and total area statistics show a decreasing trend on the arable lands (as discussed in section 3.3), it is still safe to support the above 'major production area' conclusion because the trend does not drop dramatically with the addition of analyzed seasons. Such a quantitative analysis was almost impossible to COA in the past, but it is no longer a problem from now on.

5. CONCLUSION

In the past, COA has to rely sorely on the statistic numbers to monitor and control rice production. The proposed system prototype successfully encompasses spatial and temporal nature of rice inventory data, and is capable of providing an effective spatial-temporal analysis capability to the quickly increasing rice inventory database. The five-level hierarchy enables users to efficiently narrow down the required data with given spatial and temporal constraints. By analyzing arable lands with fixed patterns from the historical rice inventory database, COA can not only query the historical change of rice crop for any region, but also accumulate spatial-temporal knowledge about rice production, for example, a better understanding to major rice production area or area no longer used for rice production. By introducing the spatial-temporal concept, this system prototype has great potential to improve the current analysis procedure and even open a new dimensionality for the use of rice inventory data in the future.

Acknowledgement

This result of this paper is supported by the Council of Agriculture, under research grant 90 Agriculture Science-4.1.3-Food-Z1(4).

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