AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

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1. SUBJECT CLASSIFICATION

A. PRIMARY: Agriculture — AF24-0000-0000

B. SECONDARY: Soil surveys and mapping

2. TITLE AND SUBTITLE

Accelerating international agricultural development with aerospace remote sensing

3. AUTHOR(S)

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4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1970	12p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

TVA

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In Am.Soc.of Agronomy. Special pub.ser.,18: Aerospace science and agr.development, p.37-48)

9. ABSTRACT

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-RAA- 164	

12. DESCRIPTORS

Agricultural economics
Remote sensing

13. PROJECT NUMBER

14. CONTRACT NUMBER

PASA TA (QA) 6-69 GTS

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

8

Aerospace Science and Agricultural Development
ASA Special Publication Series Number 18

American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
Madison, Wisconsin - 1970

TVA 133

Accelerating International Agricultural Development With Aerospace Remote Sensing

Donald L. McCune

New technology generally is considered to have little immediate application and use for the less developed areas of the world. Remote sensing seems likely to be an exception. The recent advent of high-flying aircraft and satellites, coupled with the tremendous strides in sensing equipment and computer technology, offers for the first time the opportunity for man to survey large sections of the earth within a very limited time frame. These developments appear to have equal or even greater opportunities for the less developed areas of the world than for the more developed areas.

A word of caution is needed, however. Although remote sensing may have worldwide application, getting it accepted and used may be a difficult task. The fact that remote sensing has military and defense implications has left its stigma. This will be particularly difficult to overcome, especially if the satellites and high-flying aircraft are to be able to freely sense the earth in the detail that will be necessary to make them most useful.

Although it is not the purpose of this paper to dwell on the political aspects of remote sensing, it should continuously be kept in mind that unless remote sensing from satellites or high-flying aircraft is fully accepted, the chance for major worldwide impact may be limited. It is doubtful in my mind that this can be accomplished unilaterally. A definite division from any military use or control will have to be established. Probably ownership or control by some recognized and acceptable international body or organization, such as the United Nations, will be mandatory to the acceptance of remote sensing in order to eliminate the aura of suspicion.

For an international body to sponsor such a program, it must have a purpose. Such purposes already exist. One example, the

Food and Agriculture Organization of the United Nations recently published its "Provisional Indicative World Plan for Agricultural Development." The purpose of this report, as indicated in the title, is to estimate the resources of the less developed countries and to point out alternatives these nations have for not only feeding themselves but also to start closing the economic gap between themselves and the developed nations.

The first paragraph in the summary of this report expands upon its purpose. It states, "The IWP is both an attempt to look to the future and an attempt to influence it. As such, it contains elements of projections (e. g., population, arable land, water resources) and elements of policy proposals designed to change the course of events (e. g., rate of agricultural production)."

Such a plan in itself has utility, but the real test will be its effectiveness in changing the rate of agricultural production. Remote sensing is a tool that, if properly adopted and applied, could go a long way toward guiding and monitoring agricultural development worldwide and to pointing out where additional effort would be needed.

INTERNATIONAL CENTER FOR REMOTE SENSING

If the UN through FAO or one of its other member organizations should adopt such an approach, I can foresee this organization serving as the nucleus of a worldwide system that could develop. This center would contain the master computers where all information is fed, stored, analyzed, and fed back through regional setups to furnish timely and accurate information that will be useful in country or regional planning. Direct tie-ins by cooperating countries could also be arranged.

WORLDWIDE POTENTIALS OF AEROSPACE REMOTE SENSING

For the remainder of this paper, I propose to look at some of the potentials of worldwide remote sensing, especially as they apply to agricultural development. To do this, I am assuming that the politics of remote sensing can be overcome and that we can, through the mechanism of an acceptable international body, freely observe large areas of the earth in the detail that is desired. I further assume that the techniques and equipment, many of which are still in the conceptual or drawing board stage, will become a reality and that the earth can be scanned by a multitude of sensors that are continuously orbiting the earth. I also assume that the data are freely and immediately available to all cooperating countries.

To anticipate the potentials of remote sensing to world agriculture even after making these assumptions may prove to be naive. We know that the equipment and know-how available to the military

are much more advanced and sophisticated than that available for nonmilitary uses. In all probability, we can no better foresee the values and limitations of the new developments in remote sensing than our forefathers could foresee those of the steam engine or the airplane at similar stages of development.

Ideas on eventual uses for remote sensing come from many disciplines. Some of these ideas may well fall in the category of wishful thinking, but there is good evidence that many of the proposed uses can be accomplished.

Probably the biggest potential for remote sensing lies in the possibilities for providing tools useful in surveying, discovering, and husbanding our natural resources and in providing a better understanding of our planet earth in order to maintain our environment so as to protect the health and welfare of our peoples and of future generations.

The increasing need for natural resources can be illustrated by considering that during the past 30 years we in the United States alone have used more fuel and minerals than the entire world used in all previous history. Further, it is estimated that we will double consumption in the next 15 to 25 years.

As population grows, we are rapidly converting much of our rich farm land into cities and transportation systems. Clean water is becoming scarce and the quality of our overall environment is deteriorating. Faced with these challenges, mankind must fully assess his total natural resources and understand the rate at which change is occurring. We must have a comprehensive and continuously updated inventory of our resources and environment and be ready to take steps to protect them.

Remote sensing techniques appear fully capable of providing much of this information. The question then becomes, "Do we have the abilities and the desire to take this information and put it to use on a timely basis?"

To those of us not directly involved in the space program, the potentials of remote sensing from satellites became meaningful only recently. The first such evidence that caught my imagination for potential in worldwide application was a mosaic of photos taken by astronauts Stafford and Cernan from Gemini 9 in June 1966 from an altitude of 150 nautical miles. Stafford and Cernan used only a hand-held camera with an 80-mm focal length and 70-mm Ektachrome film. This total mosaic of pictures was taken within a time period of only 5 minutes and, without a doubt, provides the best photographic coverage ever made available up to that time of much of Peru, northern Bolivia, and Chile (Fig. 1)

As evidence of the value of this mosaic of photos, the American Geographic Society had recently completed a map series of this same region. Upon seeing this mosaic, the director of this society noted that this time-consuming and expensive work could have been significantly enhanced by space photography. He also noted that

Fig. 1. Annotated photomosaic taken from Gemini 9 over Chile, Bolivia, and Peru.

errors in their maps, especially of the Lake Titicaca area, became apparent only upon receipt of the Gemini mosaic of photos.

This mosaic, as crude as it is by today's standards, gives information that will be useful to the planners in this region for many years to come. It gives an excellent view of the whole area. It shows geologic faults and watershed systems in detail not before known. It accurately locates many places and things that before were only estimated. It has great utility in the planning of land use

and for transportation systems through this difficult, mountainous terrain.

Now we are 4 years beyond this point in development. As previous speakers have indicated, much superior equipment is being developed. Traditional aerial photography techniques are being enhanced by the use of much improved films. By the means of folded optics, long focal lengths of up to 60 feet are achieved and used to pinpoint objects as small as a few meters across from satellites orbiting at altitudes of 100 to 200 miles.

New cameras also have multiple lenses equipped with filters that block out selected portions of the visible spectrum. This permits a number of photos to be made of the same area and the characteristics of each studied. One segment, for example, may place emphasis on vegetation, another may vividly show transportation arteries, roads, trials, and even footpaths, still others may emphasize geology or water. Also, the possibility of recombination of various parts of the spectrum gives additional information.

The role of television in sensing was vividly portrayed in the recent moon landings. We are told that television cameras are already available that give much greater detail than the home television set. Four thousand line images are possible as compared to 525 line images on home TV sets.

So far, I have mentioned only devices and capabilities within, and restricted to, the visible and near-visible portion of the spectrum. Devices are available also to detect much that the human eye cannot see and other human senses cannot detect.

Infrared sensors utilize wave lengths which lie between the visible light and the microwave regions. They detect variations in radiated energies generated by the objects being sensed.

Multispectral scanners are available that can measure radiation over the spectral range from the ultraviolet to the thermal infrared. Recorded data from such a system can be handled, processed, and analyzed only by computer methods. This, then, gives man his first opportunity to obtain earth resources data over large geographical areas, analyze the data rapidly by computer, and make useful information available on a near real-time basis. This appears to be especially useful in soil and vegetation studies--not only delineating soil, water, and vegetation, but also detecting and mapping differences in species and communities of vegetation, as well as pointing out differences within a species.

Radar also has advantages over both camera systems and infrared sensors. It provides all-weather, day-and-night observation and can penetrate cloud cover, vegetation, and even light snow cover to present a clear picture of the underlying terrain. Radar has already been used to make detailed maps of terrains such as areas in Panama that are impossible to map by other methods due to constant cloud cover (Fig. 2).

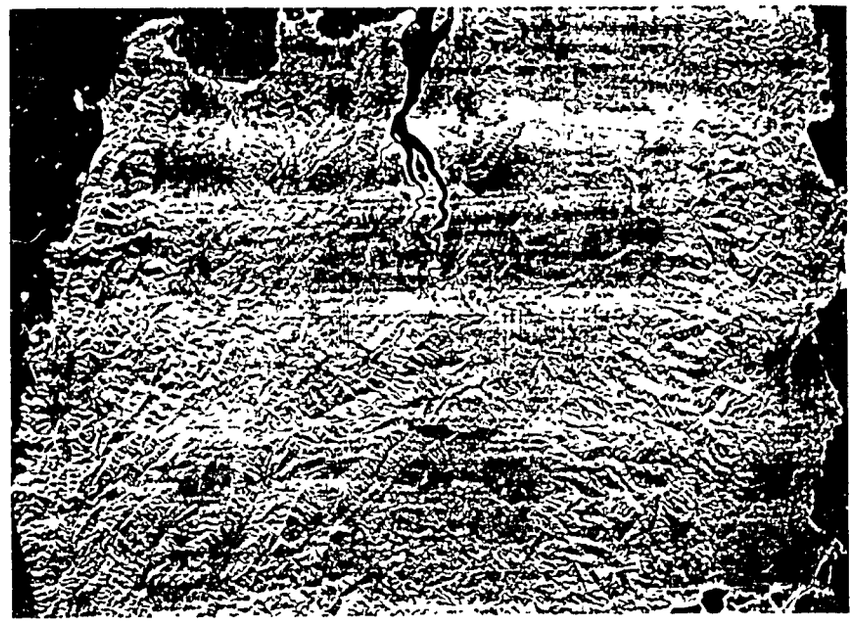

Fig. 2. Radar map of Panama; continuous cloud cover has rendered aerial photography useless for mapping this area.

A GLOBAL SYSTEM

To take full advantage of remote sensing, a global system must be established. Eventually, a worldwide remote sensing system can be visualized that will carry a number of different sensors and can have a repeatability for any part of the world of about once every 3 weeks from satellite. Due to the volume of data that will be generated, this system must be based on computers for storage, retrieval, and analysis and be operated in conjunction with the individual country and probably, as suggested earlier, through an acceptable international organization. It must be flexible and adjustable to developing as well as developed world conditions.

There is little doubt that before a global system will become operational, the feasibility must be further established through a functioning localized program such as Dr. Army and his co-workers have suggested in the previous paper. Once a localized program is developed, it can be easily and cheaply extended to other parts of the world and could become a valuable adjunct to all foreign aid programs.

Probably the most advanced segment of remote sensing application from a worldwide standpoint is meteorological sensing. Weather satellites are already furnishing worldwide pictorial coverage (Fig. 3). Crossing of national boundaries has already been

Fig. 3. An ESSA-V satellite records the weather with a TV camera some 850 miles above the North Pole.

accomplished as some 100 nations are now freely interchanging information and data on weather. For the first time it is possible to detect and study weather, hurricanes, tornadoes, frontal systems, and the movement and nature of winds over water as well as over land. Storms can now be studied from their origin and throughout their existence.

The ability to study weather globally has spurred many to attempt to construct theoretical weather models which, if fully developed, may result in some significant practical breakthroughs in weather management, such as storm control through seeding and dissipation of fog and smog. Since evidence indicates that other countries including the USSR are making great advances and may well be ahead of us in this field, even closer between-country cooperation may be beneficial.

As we all know, progress already made in meteorological remote sensing enables earlier-than-usual recognition, tracking, and

warning of hurricanes. Much more precise warnings have become possible in the last few years. Although the warnings are not heeded to the extent desirable, there is little doubt that much human suffering, as well as loss of human life and property, has already been averted.

Weather Forecasting

It appears that many additional breakthroughs in weather forecasting may be on the horizon. Some feel that weather models already exist and, if the necessary data and adequate computer capacity were now available, weather could be accurately predicted for any part of the world for as much as 2 weeks in advance. It is predicted that the day will soon come when farmers as well as agribusinessmen will have much greater confidence in weather forecasting and will make much greater use of these forecasts in planning such activities as seeding, fertilizing, harvesting, storage, and in marketing operations. As communications through radio and television improve, the less developed countries can also take greater advantage of this to improve and assure their yields and to avert disaster.

Survey of World Crops

Worldwide coverage of the proposed earth resources satellites opens many additional vistas that will be helpful to world agriculture. The fact that the world can be sensed both rapidly and inexpensively and that the sensing can be periodically repeated, presents the distinct possibility for a worldwide crop reporting service with all of the ramifications of balancing supply and demand on a timely basis. Impending crop failures due to drouths or other causes in one area can be recognized in time for production emphasis to be shifted to other areas to avert food shortages.

National and Regional Planning

The fact that photos can be provided both rapidly and cheaply for all parts of the world provides new tools for country or regional planning. Most developing countries have very little accurate resource data available on a timely basis for effective resource planning, development, and management. With adequate detailed maps, river systems can be better understood and managed. More logical transportation systems can be laid out to serve agriculture and industry, and the opening up of frontiers for those countries that have sizeable areas of agricultural and forest land yet to be exploited can be enhanced.

Vegetation Mapping

Most developing countries have, at best, only very general maps. The Earth Resources Satellites or high-flying aircraft will contain equipment capable of making maps of vegetation and of broad land use potential. Crop, soil, and forestry information systems in themselves will not solve the world food problems. Nevertheless, efficient agriculture and forestry practices in the modern sense cannot proceed without such information. Depending on the equipment and the detail decided upon, information from these satellites may be capable of actually identifying plant species and making possible species mapping. There is good evidence that disease and/or insect damage can be detected, often at an earlier stage than is possible with ground- or low-level aerial surveillance with the result that more effective corrective measures can be applied (Plate 2).*

The U. S. Forest Service already utilizes remote sensing from aircraft to pinpoint individual trees that are infested by disease or insects. The infected trees are then harvested or destroyed, helping to eliminate further infestation. In reality, this is done by taking the tree's temperature much as would be done on a person that is ill. A "sick" tree may, during the heat of the day, have a temperature 5 to 10 degrees or more over healthy trees. Perhaps physiological changes leading to decline in vigor and yields of fruit and nut trees can be detected, and failing trees can be eliminated in advance of their decline in production.

Remote sensing techniques are also being used to detect and map forest fires even under dense canopy and through smoke that preclude conventional procedures. This helps fire fighting crews to detect and accurately locate fires for faster and safer action.

Physiological stresses of many kinds in plants, due to moisture, saline conditions, fertility, or disease, can be spotted. Ground checking can determine the cause and timely corrective measures may be applied.

Characterization and Mapping of Soils

In soils, there is good evidence that aerial photos produced by remote sensing can be more rapidly and cheaply provided than by existing methods (Plate 3). It also appears that many characteristics that may take years to determine by present methods can be quickly determined by remote sensing. Those of us who have worked in the developing countries know how much the lack of good soil information has hindered our work.

There is evidence that certain characteristics, such as soil moisture, soil temperature, and organic matter contents, may be

*The four-color plates, numbered in one series for all chapters, are shown inside the front and back covers.

determined easily and with a high degree of accuracy from remote sensing data once proper correlations have been developed. This will be important not only for these factors themselves but also for the many inferences that can be made from them. It has been demonstrated that soil boundaries can be effectively determined. Remote sensing may be the tool that can help close the gap in the knowledge of soils between developed and developing countries.

Inventory of Water Resources

Remote sensing techniques appear to be especially applicable to inventorying water resources (Plate 5). River and lake sources can be inventoried, and the fact that it may be possible to reinventory them every few weeks from satellites and supplement these data as desirable from aircraft will make possible good predictions of seasonal patterns of flow and availability. Indications are that snowfall and snow accumulation can be accurately determined, giving rise to a better estimate of seasonal melt for irrigation and for flooding danger. The extent of flooding, flood damage, and hail damage can be rapidly assessed. Rapid evaluation of indivi-ual rainfalls (quantities and coverage) can be made and used by agribusinesses in planning distribution and sales emphasis. Even water quality of rivers as affected by heat or other pollution, as well as the sources of pollution, can be detected easily by sensing techniques, and the extent of this pollution can be mapped. Salt water intrusions in estuaries and actual salt water-fresh water interfaces have already been detected by remote sensing.

There are already some incidents of discovery of usable ground water sources that have not been known before. Surveys for this purpose may be especially useful for such areas as the west coast of South America, Pakistan, India, North Africa, or other agricultural areas that now or in the future may depend on ground water sources. Probably the best known case to date was the location of a good source of ground water in water-short Hawaii. This source was found by sensing of the ocean and finding an area that was 12 degrees cooler than the surrounding areas. Investigation showed that this was caused by large springs of fresh water that were emptying into the sea under the level of the ocean. It has been estimated that at least 5% of the world's runoff water enters the ocean below sea level and is wasted. This may be a fruitful field of investigation for many of the water-short coastal areas of the world.

Monitoring Irrigation Agriculture

The extraordinary growth of the world's population and the need to face up to its demands for food by progressively intensifying the production of plants and animals have brought to the fore in

every continent the expansion of irrigation as one of the main factors that can help in this general production increase. According to FAO, there are now some 130 million hectares under irrigation in the world. It is foreseen that by the year 2000 the irrigated hectares will number something like 600 million, almost a five-fold increase This would be about 5% of the world's cultivated area.

To accomplish this will, at best, be costly. Studies to determine the amounts, quality, and needs for water, in themselves, will be a major undertaking. To map properly such areas will require many topographic and soils maps; in this area alone remote sensing techniques can make contributions. Once the irrigation projects are established, remote sensing can play its role by determining plant stress and the time for additional irrigation. There are indications that problems of salinity can be recognized earlier by remote sensing than by any other method presently used, thereby permitting the use of such corrective measures as improved drainage and leaching and eliminating the need for more costly corrective measures later on.

Energy-poor and mineral-poor countries may be able to utilize remote sensing to help overcome these deficits. Petroleum companies are already utilizing remote sensing as an aid in exploration and drilling. Geological mapping can also be enhanced. Minerals occur in distinctive geologic formations, so such things as phoshate rocks, sulfur-bearing minerals, potassium deposits as well as liming material may be found with greater ease and at less expense by using remote sensing techniques that are evolving.

Animal Agriculture

Animal agriculture can also utilize certain aspects of remote sensing. Under range conditions, forage availability and quality (through species identification) can be determined and this would lead to better pasture management. Also, the possibility exists for spotting sick animals by temperature differences, at least from airborne sensors, and outbreaks of disease can be detected before they run rampant.

From aircraft, wild animal populations have been monitored and their habits studied. Overpopulation or underpopulation of certain species can be detected in time for measures to be taken to bring them back into balance.

Migration of waterfowl has already been monitored by sensing methods. Again, a better understanding of their habits and needs can go a long way toward improving conservation measures.

One of the greatest needs in the less developed countries is improvement in marketing. Remote sensing can aid in the establishment of infrastructure as well as in information systems. Monitoring of production in relation to need may make it possible to

utilize better the limited transportation systems and, at the same time, improve distribution systems so that local surpluses may not occur, causing market disasters, while other areas are in deficit.

TRAINING AND PROGRAM IMPLEMENTATION

Of the things mentioned, practically all are applicable to the developed as well as the developing countries. Applicability is a matter of degree, however, and I feel that these techniques have more application to the less developed countries. Most developing countries have a very limited amount of accurate resource data available on a timely basis. If, as part of the contribution to the less developed countries, the benefits of remote sensing could be made available as an aid in closing the gap, what better kind of aid could be given? If we develop this for our own use, we could, comparatively cheaply and with much of the same basic equipment and know-how, extend these same benefits to other countries. This suggests the immediate need for training technicians and possibly an international center dedicated to the preparation of technicians who can use these techniques.

Should this become our goal, now is the time to be searching out this cooperation. To be successful, there must be trained technicians in all countries where remote sensing has application, and we should be taking into account the sensing needs and priorities of the less developed countries as well as our own. The question may then become one of funding and balance of payment. Would not this be a good use to which we could put some of our "blocked" currencies? There is little doubt that with proper cooperation and direction both we and the countries in which this currency exists would benefit. Much tedious work on ground truths could be ferreted out in this way, which is very costly and sometimes impossible in the United States.

In my brief study of remote sensing, I am convinced more than ever that it will, in time, become recognized as a real payoff by-product of our space programs; and the economic fallout from our space efforts that we have heard about may become a reality. It is a program that will be developed and useful for United States agriculture, and it can become a comparatively cheap and effective adjunct to our AID programs. It is time that we, as agronomists, become better acquainted with the techniques and potentials of remote sensing to assure that it is developed to fit our needs as well as those of other disciplines. It is also time that we who are dedicating our careers to the development of world agriculture do the same.