REMOTE SENSING APPLICATION TO GRASSLAND MONITORING

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Abstract

Application of remote sensing to the management of grassland resources, the role this plays in developing sustainable grassland farming systems and opportunities for further development are outlined. Use of remote sensing technologies in grassland monitoring has a history of more than 30 years. Both fine- and coarse-grained remote sensing techniques are used to monitor and study grasslands. Fine-grained techniques are used to study landscape scale processes through the use of sensors providing spatial resolution of a few meters, whereas coarse-grained techniques are used to study catchment scale areas, and even entire biomes, using satellite-based sensors with a spatial resolution of kilometers. Remote sensing information is obtained from aerial photography, radar systems, video systems, and satellite-based sensors including the Landsat satellites' Multispectral Scanner (MSS) and Thematic mapper (TM) and the National Oceanic and Atmospheric Administration (NOAA) polar orbiters' Advanced Very High Resolution Radiometer (AVHRR). Various normalized difference vegetation indices (NDVI) have been developed and used extensively with data from the Landsat sensors (MSS and TM) and NOAA's AVHRR. The NDVI has been used for grassland classification and inventory, monitoring grassland-use change, determination of site productivity and herbivore carrying capacity, water and soil conservation, integrated management of grassland pests, and suitability for recreational use and wild life protection. Special techniques have also been developed for monitoring where fires occur on grasslands. To date the remote sensing techniques have become a powerful tool for scientists, farmers and policy makers to study and manage grassland resources. World demand for sustainable development of grasslands will increase the reliance on remote sensing as a tool in grassland management. However, the adaptation of existing remote sensing technology in grassland management will require more scientists and technicians to be trained in both remote sensing and grassland science. Additional training programs targeting scientists in developing countries will be needed. System approaches will be required that lead to better understanding of the interfacing of ground and remote sensing data sets. There is also a need for research on low cost, high resolution systems to be flown from aircraft and helicopters using narrow filters for assessing the condition of grassland health.

Keywords: grassland monitoring, grassland management, remote sensing, grassland assessment

Introduction

Grassland covers 51% of the world's land surface and is among the most prominent biogeographic regions on the earth for human welfare and economical development (WRI and IIED, 1986). Grassland provides forage to most of the world's livestock. Globally, animal products constitute about 40% of the total value of agriculture output (ILRI, 1999). As the human population increases, there is an urgent need to increase livestock productivity and the supply of livestock products. A 155% increase in livestock products over current production levels is required to meet demand by 2020 (IFPRI, 1995). As the largest terrestrial ecosystem on the earth, grassland is also associated closely with many of the most challenging environmental and ecological problems that humankind will face during the next several decades at a global scale. These include desertification, land degradation, climate change and loss of biodiversity. It is vitally important that better inventories are obtained of grassland and better monitoring with relative accuracy takes place, so that sustainable grassland management is achieved. However, due to its great expanse and diversity, rapid and low-cost evaluation and management techniques are required. For this reason, remote sensing technology provides a powerful tool for the inventory, monitoring and management of these important resources. Remote sensing has been recommended for at least 30 years for use in grassland resources management on a worldwide basis (Tueller, 1982). In his review paper Tueller (1989) gave a brief history of remote sensing for grassland management. The first black and white aerial photography became available for grassland resource investigation in 1935. As remote sensing developed into a science in the mid to late 1960 it has increasingly been used. The launch of Landsat 1 in 1972 ushered in a new era extending remote sensing beyond air photo interpretation into the realm of digital analysis of multispectral and multitemporal data. Today, remote sensing, along with Geographic Information Systems (GIS) and Global Positioning Systems (GPS) have provided a powerful and sophisticated approach to the utilization, development and management of grassland resources throughout the world. A literature survey showed that 407 papers in grassland remote sensing have been recorded by CABI information database from 1995 to 1999. The application of remote sensing technology covers land classification and grassland-use change, grassland productivity assessment, conservation and recreation valuing, detection and monitoring of stress caused by fire, drought and pests (Table 1). Based on the literature survey mentioned above and information obtained from other resources, progress in application of remote sensing in world grassland resources management during the last five years is summarized below.

INSERT TABLE 1 HERE

Land classification

Remote sensing technology has been most widely used in land classification at various scales. As indicated in Table 1, 188 papers (46.2% of the total number of papers published) reported on the use of remote sensing for land classification and assessment of change in use of grasslands. Most of studies employed satellite-based sensors to acquire remotely sensed data. These included the Landsat satellites' Multispectral Scanner (MSS) and Thematic mapper (TM), the Systeme Pour1'Observation de la Terre (SPOT), and the National Oceanic and Atmospheric Administration (NOAA) polar orbiters' Advanced Very High Resolution Radiometer (AVHRR). Among these NOAA-AVHRR images have been used more frequently for global and regional studies due to their low cost, suitable wavebands and high temporal resolution. Data from the AVHRR and other satellite-based sensors transformed to the normalized difference vegetation indices (NDVI) are the most common product used in land classification studies. Aerial photographs have long been an important data sources for studies of land classification and land-use changes. The literature surveyed mentioned above showed that about 11% of the studies used aerial photographs to obtain remotely sensed data. Aerial photographs still provide the highest resolution and capture the spatial and textural essence of the scene with greater fidelity than any other procedure. Disadvantages include the cost of repeated coverage for change detection and limited spectral sensitivity of conventional photography.

Land classification at global and regional scales

Land classification is a common procedure because of the increasing concerns about the environmental and ecological problems worldwide. To understand those problems is at least in part dependent on clear assessments of land-use pattern and their changes. Perhaps one of the most intensive single study on global land classification was DISCover dataset produced by the International Geosphere-Biosphere Programme Data and Information System (IGBP-DIS). DISCover is a 1 km spatial resolution land cover product from AVHRR data. It is a 17 class land classification system based on monthly NDVI composites from 1992 and 1993, which included shrubland, savanna and grasslands (Loveland and Belward, 1997). At the regional scale, Hill and his co-workers (1999) studied agricultural land classification in eastern Australia from NOAA-AVHRR and Landsat TM data. The agricultural land was grouped into 8 types: sown perennial pastures, sown perennial pastures with woodland, sown annual pastures, mixed pasture and cropping, native grasslands, native grasslands with woodland, degraded or revegetated areas, and forest.

Grassland-use change monitoring

Faced with increases of human population, grasslands are being converted into cropland, much of which ultimately becomes degraded, posing a great threat to biodiversity. This conversion is probably the major impact of humans on natural environments (Dobson, et al. 1997). The situation of Qianan county, Jilin province, China, reported by Lin (1998) is a good example. Human population and area of croplands in the county increased by 136% and 61.15%, respectively, from 1958 to 1991. During the same period, area of grassland decreased by 60.1% at the annual decrease rate of 5.06% (Figure 1). Similar land-use change also occurred at other developing countries. At Sangla, Himachal Pradesh, India, for instance, the Landsat TM and MSS data revealed that the area of crop land at the region increased by 1.5 times from 1980 to 1995, while grassland and forest decreased by 13.3% and 15.3%, respectively (Jiang, 1997).

INSERT FIGURE 1 HERE

Methodology development

The vast expanses and diversity of grasslands complicate the use of remote sensing technology. Various efforts have been made to improve the accuracy of the results derived from satellite-based or aircraft-based data. The following are some examples. Adams (1999) proposed a land classification system including 23 fundamental categories and the author believed that the system could be used at any scale, from local to global, for land mapping and monitoring. Lyon *et al* (1998) compared seven vegetation indices for their value in vegetation and land-cover change detection in Chiapas, Mexicao. Whereas Mas (1999) tested six change detection procedures for detecting areas of changes in the region of the Terminos, Mexico, using Landsat MSS. Burgess et al. (1995) studied topographic effects in NOAA-AVHRR NDVI data. Purevdorj et al. (1998) found the relationships between percent vegetation cover and various vegetation indices. Galvo et al. (1999) reported the effects of band positioning and band width on NDVI measurements of tropical savannas. Fuzzy classification of multispectral data using artificial neural networks was found to increase accuracy of land cover classification at global scale (Sucharita et al. 1999) and smaller scale (Warner and Shank, 1997). The discrimination of some targets such as bare soil and soil with low vegetation density could be improved by the combination of the spectral information obtained from both SPOT-HRV and Landsat-TM (Guyot and Gu, 1994). Application of GIS in the stage of post-processing spectral classification can improve the accuracy greatly (Palacio and Luna, 1996).

Grassland productivity assessment

Grassland degradation and productivity assessment is the second largest use of remote sensing technology. About 160 papers were published in this area (39.3% of the total), which is only surpassed by land classification (Table 1). This suggests that a most promising application of remote sensing imagery is for estimating grassland productivity across multiple geographic scales.

Net primary production assessments at global and regional scales

Terrestrial net primary production (NPP) is the central carbon-related variable summarizing the interface between plant and other processes in an ecosystem. At global and continental scales NPP is one of the ecological parameters most modeled by ecologists and environment scientists. The NOAA-AVHRR is currently the most reliable option for this type of study. Field et al. (1995) discussed the issue of combining ecology and remote sensing in global NPP assessment and concluded that NPP models driven by satellite data have many advantages over models driven only by climate and other resources. Ricotta and Avena (1998) described a method to improve the accuracy of estimate the NPP with annual cumulative AVHRR NDVI data. At the regional scale Paruelo et al. (1997) appear to be the first to attempt to calibrate a standard NDVI product for temperate perennial grasslands. They found a positive and statistically significant relationship between NDVI and annual aboveground net primary production (ANPP) for grassland areas with mean annual precipitation between 280 and 1150 mm, and mean annual temperature between 4^{o} and 20^{o}C.

Grassland herbage yields and carrying capacity predicting

Livestock in most developing countries grazes on grassland throughout the year. Animal nutrition is entirely dependent on the forage supply from grassland. Herbage dry matter yields have a great seasonal fluctuation while the needs of grazing animal is relatively constant. Ren and his team (1978) indicated that although some forage surplus existed during the plant growing season there is a big gap between forage supply from grassland and the needs of animal during a year in alpine grasslands in China, i.e. the livestock has to starve for several months every year due to shortage of feed (Figure 2). Therefore, grassland herbage dry matter yields and carrying capacity are of intensive interests to grassland scientists, pastoralists and policy makers. Using NOAA-AVHRR data Wylie et al. (1995) estimate herbage yields and grassland carrying capacity for the entire Nigerien pastoral zone. Similar studies were reported by Chen et al. (1998) and Li et al. (1998) in Xinjiang, China and by Oesterheld et al. (1998) in Argentina, respectively. To improve estimation the most important factors affecting herbage yields have been determined using Lansat TM data (Pickup, 1995; Yang et al. 1998). Effects of mosses, lichens, algae (Karnieli et al. 1996) and ferns (Hall and Gwyn, 1996), plant residue at the surface of grassland (Frank and Aase, 1994) and standing litter (Leeuwen et al. 1996) on measurement of grassland productivity were studied. The relationships between herbage biomass and grassland botanical composition (Vickery et al. 1997), the contents of leaf chlorophyll and red edge (reflectance of 690 – 740 nm) of grass, and animal grazing (Todd et al. 1998) have been established. The role of leaf, stem and standing litter in determining canopy reflectance has been studied (Asner, 1998).

INSERT FIGURE 2 HERE

Grazing management evaluation

The effects of grazing management can be monitored with the aid of remote sensing technology and with this knowledge, domestic livestock production can be improved. Thomson (1995) used airborne radiometric data to monitor sheep grazing intensities, whereas Pickup and Bastin (1997) used Landat MS data to model cattle distribution in arid rangelands. Satellite imagery (Lansat TM, SPOT and NOAA) along with other information has been used to analyse the management of livestock enterprises and grassland resources (Bastin et al. 1996; Hill et al. 1996; Wright et al. 1997).

Grassland degradation assessment

Remote sensing can enhance grassland degradation assessment. Most of successful degradation assessment techniques require data with a relative high spatial resolution from Landsat MSS, Landsat TM or SPOT (Pickup, 1996; Pickup et al.,1998). Videography has great potential for rapidly verifying or calibrating vegetation cover indices derived from satellite data (Pickup et al. 2000), while NOAA-AVHRR data are inappropriate for the reliable detection of grassland degradation (Bastin et al., 1995). Wang *et al* (1999) concluded that the area of grassland desertification increased at annual rate of 3120 km^2 in northern China after compared the aerial photographys taken at 1950 and 1970s, respectively. Ringrose (1996) reported that most of the degraded areas in southern Botswana are within 2 km of villages and boreholes. Similarly, Bastin et al. (1993) found a pattern of increasing cover of palatable plants with greater distance from water and decreasing cover of unpalatable shrubs after decades of grazing in central Australia. Satellite-based grazing gradient methods for grassland assessment in South Australia have been developed and are under further evaluation by the relevant agencies (Bastin et al. 1998).

Soil process monitoring

As an important component of agro-grassland ecosystem soil plays an integral role in almost all remote observations aimed at monitoring grassland productivity. Wessman (1991) presented a general review on application of remote sensing to soil process. Todd and Hoffer (1998) reported the responses of NDVI, green vegetation index (GVI), brightness index (BI) and wetness index (WI) to different combinations of vegetation and soil type and moisture content using Landsat TM image, and concluded that GVI values were least affected by soil background variation. Using special sensor microwave/imager (SSM/I) Jackson (1997) found that soil moisture in grassland in Oklahoma, USA, could be estimated with an error of 5.3%. Morrow and Friedl (1998) reported that good correlations between observed and modeled soil temperature derived from helicopter mounted multi-spectral sensor.

Satisfactory results on interaction of soil temperature, moisture and other factors were achieved by use of NOAA-AVHRR (Yang et al. 1997) or aircraft boarded sensor (Chen et al. 1997). Data derived from NOAA-AVHRR are comparable with Landsat TM and SPOT-HRV data for measuring grassland surface temperature and other biophysical variables (Goetz, 1997).

Conservation and recreation site valuing

As humans enter the 21st century it is apparent they value grasslands for many reasons other than livestock production. Grassland is important natural habitat for much of the world's flora and fauna. National parks are invaluable resources of biodiversity and conservation, and unreplacable sites for recreation and tourism. According to Ren (1995) a modern grassland agricultural production system consists of four production levels i.e. pre-plant production (conservation, tourism and recreation), plant production, animal production and post-biological production (preliminary processing of plant and animal products and marketing). As stated in previous sections, remote sensing technology has been applied frequently to the plant production and animal production levels. The technology is also becoming more actively involved in Ren's pre-plant production level i.e. conservation, wildlife and recreation. During the last 5 years, at least 30 papers (7.4%) were published in this area (Table 1).

Watershed and national park investigation

Watershed studies and protection can be enhanced by remote sensing technology. Surendra and Singh (1995) investigated the geomorphological characteristics of 13 watersheds in India using remote sensing and the data was used to determine the priorities for development. Courault *et al* (1996) estimated the evapotranspiration over a watershed in north-west France using an infrared camera aboard a small aircraft.

With the aid of remote sensing technology some changes in national parks and conservation areas can be detected and monitored, and land-use maps can be updated, so that environmental planning and management of national parks can be facilitated.

Most reports in this area employed Landsat TM, Landsat MSS data or integrated satellite data and GIS. Laba et al. (1997) found that 77.3% and 81.3% accuracy was achieved, respectively, by use of Landsat MSS and Landsat TM image for land-use classification in Los Haitises National Park in the Dominican Republic. After study of the distribution and composition of successional vegetation of glaciers in Norway, Eckardt and Milton (1999) concluded that ground, airborne or spaceborn remotely sensed data can be used to satisfactorally resolve the spatial determination of glacial recession. Other studies include analysis of disturbance regimes in the northern Chihuahuan Desert (Yool, 1998), monitoring the change of vegetation and botanical composition in environmentally sensitive areas in England (Peter et al. 1996), and evaluation the current extent of the Dorset heathlands in southern England (Veitch et al. 1995).

Habitat assessment for wildlife and biodiversity

Remote sensing has become increasingly important in the evaluation and management of wildlife habitats during the last five years. Using Landsat TM and ancillary data Joria and Jorgenson (1996) evaluated the accuracy of supervised, unsupervised and modeling approaches for investigating land cover types of Arctic National Wildlife Refuge. Verlinden and Masogo (1997) used NOAA-AVHRR data to successfully evaluate habitat suitability for ungulates and ostrich (*Struthio camelus*) in the Kalahari of Botswana. Roseberry and Woolf (1998), using classified satellite imagery and a proximity-based habitat model, studied the relationships between habitat and white-tailed deer (*Odocoileus virginianus*) population density in Illinois. Remote sensing is also a useful tool in biodiversity assessment. Examples include Fuller et al. (1998) who generated biodiversity ratings to help plan conservation in the Sango Bay area in Uganda by integration of field survey and remote sensing, and Wuyunna and Li (2000) who used Landsat MSS and TM data to study change in landscape diversity in Inner Mongolia, China, from 1978 to 1992.

Recreational site valuing

Grassland and turf are an integral part of people's daily life and they provide space, solitude and beauty. Remote sensing technology can be used to understand and monitor grassland and turf more rationally. For instance, the combination of remotely sensed and ground data, Spronken and Oke (1998) found the air temperature in grassland parks, savannas, golf courses and gardens was 5-7 ^{o}C cooler than surrounding urban areas in summer in both Vancouver and Sacramento cities. Quattrochi et al. (1998) used airborne Thermal Infrared Multispectral Scanner (TIMS) sensor to measure thermal energy response for different vegetation classes in Salt Lake City, Utah and concluded that vegetation has a significant influence on reducing the amount of absorbed radiation across the city.

Stresses detection and monitoring

The role of remote sensing technology in detection and monitoring both biotic and abiotic stresses in grassland ecosystems has increased during the last five years. Twenty nine papers (7.1% of the total) have been recorded by the CABI database. Among these 18 papers dealt with fire management and only five papers reported the use of remote sensing in pest detection and monitoring.

Fire detection and monitoring

Fire is a natural phenomenon in grasslands and causes problems for humans. In some grassland ecosystems fire damages vegetation and causes economical losses. Remote sensing can be used in fire detection and monitoring (Adams, 1995; Eva et al. 1998), and estimation of fire damage (Pant et al. 1996; Ehrlich et al. 1997). The technology has also been used to study fire history in Kakadu National Park in Australia (Russell-Smith et al. 1997), and the relationships between landscape and fire in heathlands in France (Morvan et al. 1995). NOAA-AVHRR data is widely used in fire studies although aerial photographs and other satellite data have also been useful. After examining the spatial and temporal distribution of fires over 4 major ecosystems in south America using AVHRR Global Area Coverage Land Pathfinder (AGLP) Christopher and Chou (1997) concluded that AGLP can be used to determine the fire distribution along with vegetation characteristics. Razafimpanilo et al., (1995) discussed the usefulness of linear method employing Channel 2 reflectance of AVHRR and nonlinear method employing both Channels 1 and 2 for estimating burned areas. They concluded that neither method can be used when the pixel contains low reflectance background (e.g. water). Roy et al. (1999) presented a burn scar detection algorithm which provided the basis for operational burn scar monitoring using the AVHRR and MODIS. Pereira and Setzer (1996) provided a regression equation between the areas of the AVHRR fire pixels and of TM fire scars after comparison of fire detection in savannas in central Brazil using AVHRR and Landsat TM images.

Drought evaluation

Remote sensing has monitored effects of drought on grassland vegetation. Examples included Lozano (1995) using data obtained from NOAA-AVHRR to assess successfully the development of native grassland under the drought conditions, and Pei and Ao (1996) generated a soil drought map for the Inner Mongolian grasslands in China using NOAA-AVHR data.

Weeds detection

Pests including insects, pathogens and weeds cause significant biotic stress to grasslands. Diseases of pasture crops, for instance, have been estimated to cause 310 million US dollars annually in China (Nan, 2000). Remote sensing is becoming an integral part of integrated pest management system in grassland production.

The technology provides a powerful tool to assess the extent of infection, develop management strategies and evaluate control measures on noxious plant populations in grasslands. Aerial photography, videography and satellite sensor are used to remotely detect noxious plants over large and inaccessible grassland areas. More recently, remote sensing, GIS and global positioning system (GPS) technologies have been integrated for mapping the distribution of noxious plants in grasslands. Everitt et al. (1995) comprehensively reviewed the progress in this area. Lass et al. (1996) reported that yellow starthistle (*Centaurea solstitialis*) and common St. Johnswort (*Hypericum perforatum*) could be detected with multispectral digital imagery in semi-arid grassland in Idaho. Eve and Peters (1996) used meteorological satellite imagery to assess mesquite (*Prosopis glandulosa*) control effectiveness in southern New Mexico.

Detection and monitoring diseases, insects and rodents

Aerial photography has been the major techniques used to remotely detect plant diseases. Although the technology has been used to study incidence, distribution and severity of plant diseases since 1956 (Jackson, 1986), it has not been widely used in plant pathological studies due to the high resolution required and the high cost. Most studies reported involve crops other than 'pasture' grassland. The only work on forages is the one reported by Basu et al. (1978) who studied lucerne (*Medicago sativa*) stand decline in eastern Ontario, Canada, by the combination of aerial photography and ground survey. The possibility of using satellite multispectral scanner data to detect and monitor plant disease has been studied using Landsat MSS and Jackson (1986) suggested that it can be used to quantitatively assess disease damage. Recently, Nelson et al. (1999) described the application of GIS, GPS and Geostatistics in plant disease epidemiology and management and indicated that the techniques are particularly useful in identifying recurring patterns of plant disease, as well as other problems such as insect and weed infestation.

Insects cause plant stress by interrupting the transpiration stream and by ingesting plant leaves and stems. Tucker et al. (1985) demonstrated that satellite data could be used to monitor ecological conditions conducive to the population explosion of the desert locust (*Schistocrca gregaria*). Power et al. (1996) also reported use of NOAA –AVHRR data in desert locust control in Algeria. These suggested that satellite data can be used to monitor the desert locust populations.

Rodents including *Myospalax baileyi, Ochotona curzoniae* and *Marmeta himalayana* are major pests of alpine grassland in China (Zhang and Jiang, 1998). Zhou et al. (1999)

reported that the rodent damaged areas were identified by use of NOAA-AVHRR data, which will improve the efficiency of rodent control.

Limiting factors of grassland remote sensing application

As reviewed above, remote sensing has been increasingly used for grassland monitoring since Landsat 1 was launched in 1972. However, it will take some time for the technology to be routinely used in grassland management and livestock production. From a grassland scientist point of view, the following have been identified as the major limiting factors for the application of the technology.

Shortage of skillful personnel

There are not enough experienced and skillful personnel who have knowledge both in remote sensing and grassland science. This is one of the main impediments for rapid application of remote sensing technology to grassland resource management. For example, very few grassland scientists or extension officers receive training in remote sensing in China. Recently, remote sensing has been taught to grassland students as a subject in some universities. Postgraduate students with grassland science backgrounds have studied remote sensing, or *vice versa*, at both Master and PhD levels. However, the number of students graduating each year are far too few compared with the demand. On the other hand, those who have dual training often persue other interests for various reasons, rather than working on grassland remote sensing. More active training programs in remote sensing that target scientists with grassland science background are needed.

Costs

Cost is another major factor limiting wide use of remote sensing technology in grassland management. Aerial photography, video images, radar systems, airborne scanners and satellite-based images including NOAA-AVHRR, Landsat-TM and MSS, and SPOT are major costs to any management program. Aerial photography has been the most fruitful approach in grassland remote sensing. Video images acquired from aircraft offer a number of advantages over conventional small format aerial photography (Pickup et al. 1995). This technology is becoming the most useful single new technology for grassland applications. However, due to economical limitations the data from NOAA are still the most important source of new or up to date information on grassland resources in China and other developing countries. It will cost about 600 US dollars to purchase one TM image covering the area about 180 x 180 km in China. Two or three images will be normally needed to cover a county in the pastoral region, The information will need to be obtained repeatedly during the growing season of a year (four or five times) and two or three years' data will be required for study grassland dynamics. The costs will rise to about 9000 US dollars per year (Liang Tiangang, personal communication). For this reason, NOAA data is still the most important resource for remote sensing although pixel size is approximately 1 km a side from AVHRR. More cost effective systems are needed to make remote sensing technology available for general assessment of grassland livestock production and management. There is also a need for research on low cost, high resolution systems to be flown from aircraft and helicopters using narrow filters for assessing vegetation vigour and detecting biotic stress of pasture crops caused by plant pathogens.

Requirement of multidisciplinary teamwork

The more efficient and successful application of the technology results from teamwork. Grassland perhaps is the most complicate ecosystems with much variability within and among ecosystems on the earth. They differ in species present, forage productivity, soils, climate, species of grazing animal and human activities and management. Multidisciplinary and interdisciplinary approaches will be needed in grassland remote sensing to gain a better understanding of the interfacing of ground and remote sensing data sets, so that more acceptable results of the soil-plant-animal-atmosphere system can be achieved.

The future

Remote sensing technology will become an integral part of grassland resource management in the future. As the major feed resources of livestock, grasslands have played a key role in the development of civilization. Grasslands are also used as multi-functional natural resources on the earth in the modern society. The multi-functions of grasslands will be developed continuously as societal demands and new technologies become available in the next millennium. These include the continuous need of livestock products to meet human needs and increasing requirements for environmental quality and recreational use of grasslands. Remote sensing and other new technologies monitoring impact of livestock and human activities on the grassland resources will be critical for sustainable management of grasslands. As more grassland scientists and extension officers obtain knowledge of remote sensing, and more remote sensing systems are developed and become cost effective, the high technology of remote sensing will have come of age to the grassland resource management.

Acknowledgment

I thank Dr Ken Hogkinsion for critically review the manuscript, Dr Liang Tiangang and Mr Gary Bastin for providing valuable references and Dr Hou Fujiang for computer generating the figures. I also like to thank Professor Sila da Silva for the patience and encouragement

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Table 1 - Number of papers in grassland remote sensing recorded in CABI database from 1995 to 1999

Applied to	No. papers	% of total
Land classification	188	46.2
Productivity assessment	160	39.3
Conservation and recreation valuing	30	7.4
Stress detection and monitoring	29	7.1
Total	407	100

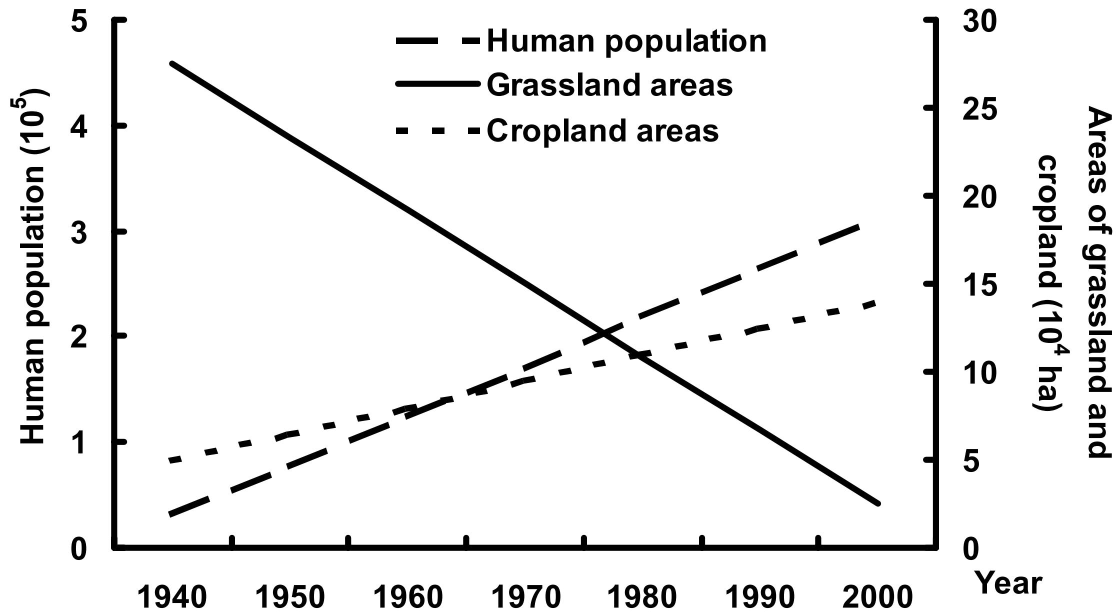

Figure 1 - Human population, grassland area and cropland area of Qianan county, Jilin Province, China, from 1958 to 1991 (From Lin, 1998).

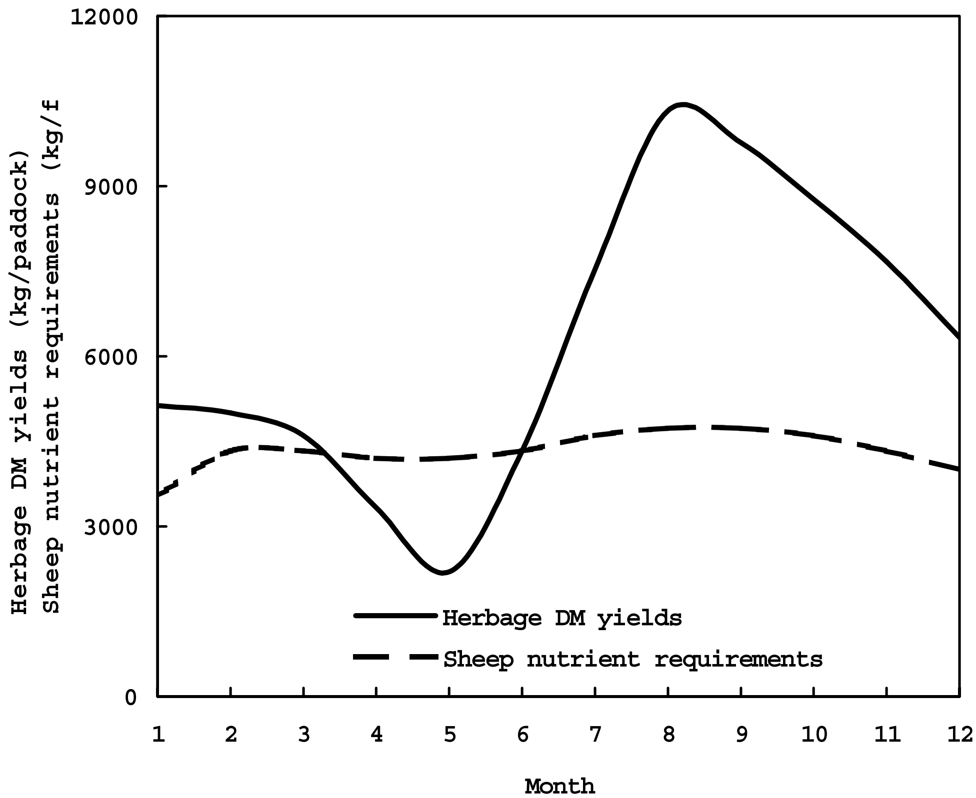

Figure 2 - The amount of herbage required monthly by a flock of sheep and the monthly herbage dry matter yields produced on a paddock at alpine grassland, China (From Ren, 1978).