Using new technologies to map the suitability of forage plants

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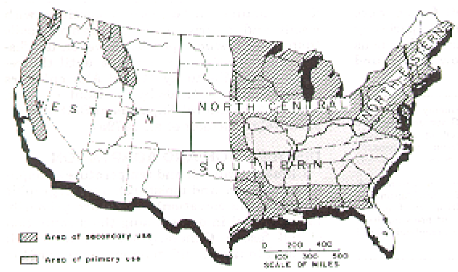
Introduction

A major focus in agriculture today is sustainability: seeking to utilise plant, animal, soil, and water resources in the most productive yet non-damaging manner. Consequently, land managers frequently request recommendations on which species and varieties would best fit into their production system (Bolte *et al.*, 1991; Hannaway *et al.*, 1992). In southern Australia, there are few sources of independent advice for farmers concerning pasture mixture recommendations, since publicly funded organisations, such as state departments of agriculture, have largely withdrawn from this type of activity. In the meantime, a wealth of knowledge and data has accumulated on the relationships between plant performance and such environmental factors as rainfall and temperature variability. The range of plant material available for farmers to use has also increased dramatically (Chapman *et al.*, 2001). To effectively deal with this problem, farmers need access to decision-support tools that (1) better capture and disseminate the collective knowledge of pasture agronomists, ecologists, GIS specialists, climatologists, soil scientists, field representatives, and other farmers and (2) facilitate individually tailored, on-farm decision-making. It is technically possible to provide this service, thereby reducing economic risks and environmental hazards when inappropriate plants are selected.

Before current sophisticated computer tools were available for generating maps, most textbooks, seed catalogues, pasture fact sheets, and technical guides included an adaptation-zone description or a map that showed general zones where the species being discussed could be grown. Typically, these maps were produced by a graphic artist working with an agronomist or agro-meteorologist and used general agricultural concepts and broad groupings of precipitation and temperature and/or soils (Figure 1).

However, these maps are of minimal value in decision-making at the individual farm level. They are inadequate since the scale is too coarse and they do not give specific locations for successful or optimal yield. Most maps do not reflect all the critical factors that govern plant survival and growth (minimum, maximum, and optimal ranges for precipitation, temperature, photoperiod, soil pH and drainage, elevation, slope, aspect, etc.). There is a clear need for maps that are more specific, consider more information, and can be adapted to reflect anticipated changes in factors. These can be linked to rules for formulating pasture mixtures to create an interactive decision-support tool to identify the best plant material for any given situation. Such a service is not currently available but could be established to provide a comprehensive source of advice for farmers and their advisors on pasture species and cultivar selection.



Source: Tall Fescue, American Society of Agronomy Monograph No. 20, 1979, p. 15.

Figure 1. Generalised tall fescue US adaptation map.

Current mapping tools

The many advances in science and technology now provide many tools that could be combined to help achieve better plant-to-site matching. Current computer-based tools include geographic information systems (GISs), expert systems, decision-support systems, and web-based delivery systems. Each of these has value individually; but together, they offer the potential to present huge amounts of information in a very user-friendly form.

GISs are a family of powerful and dynamic computer software systems that manipulate and display layers of spatially variable data (Figure 2).

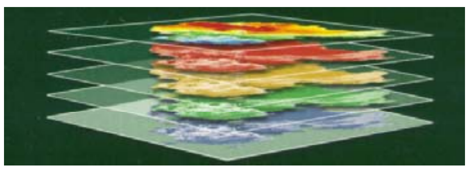


Figure 2. Graphic representation of GIS layered information.

A variety of data types is used in GISs. Layers may include climate spatial data (rainfall, temperature, radiation), geophysical features (topography, mineral and soil traits, ground and surface water), biological characteristics (plant and animal information and tolerances), and geopolitical information (political boundaries, urban centers, transport infrastructure). By integrating these individual spatial data layers in a GIS, it's possible to better understand their interrelationships and respond accordingly.

Decision-support systems and expert systems

These integrated GIS layers are even more useful when embedded in a decision-support system or expert system that permits land managers to use them as filters for identifying appropriate inputs for their properties. For example, each GIS layer can be used as a screen against which the characteristics of pasture or crop plants can be measured. The screen can automatically sort plants according to their suitability for a specific location in the GIS map. The more layers that are used, the greater the ability there will be to screen out plants that are not suited. To do this, we need to be able to write rules for all of the plants that we wish to evaluate and to connect them to the GIS. This is quite feasible, using the expert knowledge of plant scientists (e.g., Hill, 1996).

Web-based delivery

Delivering this information 24 hours a day, 7 days a week through web-based information systems can now provide the entire package of information, integration tools, and expert knowledge to make sense of a huge amount of data that has previously been unmanageable.

Thus, the problem of suboptimal plant selection can be solved by assembling and effectively using the currently available computer and communication/delivery tools. It's still not a 'trivial' task, but it is possible by combining the collaborative efforts of talented people willing to work together for a common goal.

Creating forage suitability zone maps: a new approach

Creating GIS-based forage species adaptation maps involves integrating climate, soil, and plant information in a 'quantitative ecology' approach. Instead of using generalisations like 'moderately winter hardy,' or 'prefers acidic soils,' more specific measurements can be incorporated into layers and represented on maps that consider many factors. Quantitative ecology information can be used to define the productive range and survival limits of plants in specific terms (i.e., minimum, maximum, and optimal ranges for temperature, precipitation, pH, and drainage) (Jackson and Gaston, 1992; Hill, 1996).

This approach differs from traditional species adaptation and selection approaches because it involves developing a table of plant growth limitations (see Table 1 below) and matching these with the spatial data layers for climate, soil, and geophysical elements. This approach allows recommendations to be tailored for individual landowners based on the adaptation zones for specific plants.

The challenges

Developing integrated systems for the delivery of huge amounts of data from many different sources in a way that is understandable and easy to use presents three fundamental challenges: (1) assembling and organising the data, (2) obtaining missing data through new research or use of surrogates for unavailable data, and (3) working together in ways that are efficiently collaborative.

Scientists are often trained to work in a particular subject matter specialty. Typically, scientists are not well trained to integrate information with related or potentially related subject matter areas. And scientists are most often rewarded for individual accomplishments rather than joint efforts. Thus, developing 'web GIS expert systems' for natural resource management decision-making is a technical challenge and a social challenge to the scientists.

Steps needed

Assembling and organising the data

The required plant eco-physiology information is currently scattered throughout various research papers and isolated plant species literature so that it is not easy to find or use. Assembling this information and making it readily usable is critical for the success of decision-support systems based on plant adaptation zones (Hannaway *et al.*, 2000).

Obtaining missing data

Missing information must be being identified and obtained through cooperative sharing of existing data and by conducting applied research projects to obtain new data. Developing surrogates (relationships that can be used to reasonably predict the information required) for missing data is adequate for many purposes so long as the underlying relationships between plant performance and growth limiting factors are known. If they are not known, then this indicates that more research may be required.

Working together

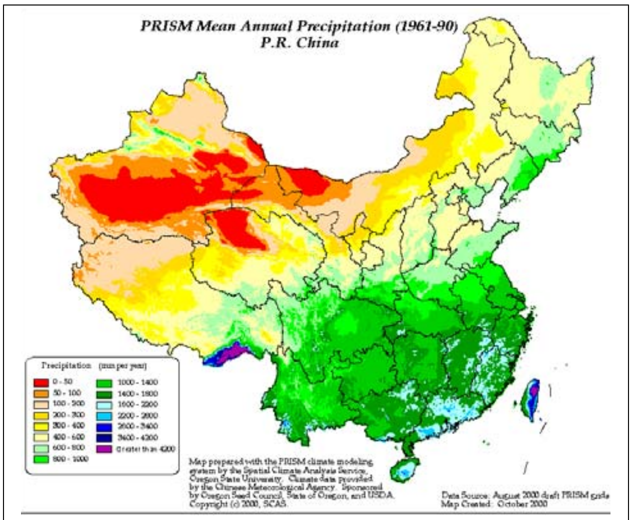
It is inefficient for scientists and technologists to duplicate work when sharing information and working cooperatively could provide much more information. Collaborative networks also provide a wonderful checks-and-balances system for research findings. It would be advantageous for scientists in specific disciplines to collaborate, and many new applications would result when experts from numerous fields and disciplines mingle their expertise.

A case study: species adaptation mapping in the People's Republic of China

For the past several years, Oregon State University has been collaborating with several Chinese organisations to produce climate, soil, and species suitability maps of China. The result has been the most detailed climate, soil, and species adaptation maps currently available.

Climate modelling

This project utilises the 'state-of-the-science' climate modeling software PRISM to produce GIS climate maps, including monthly and annual precipitation and minimum and maximum temperature (Figure 3). PRISM is an expert system that generates point estimates of climate parameters on a map grid. Papers by Daly *et al.* (1994, 2002) and an earlier web-based description (www.ocs.orst.edu/prism/amsac97.html) provide details of the model. Unlike other statistical methods in use today, PRISM was written by a meteorologist specifically to address climate. PRISM is well-suited to mountainous regions, because the effects of terrain on climate play a central role in the model's conceptual framework. It is called an expert system because it mimics the process an expert would use to map climate parameters. The user interacts with the process through a graphical interface.



Climate data provided by the Chinese Meteorological Agency. Sponsored by Oregon Seed Council, State of Oregon, and USDA. Copyright © 2000, Spatial Climate Analysis Service. Data Source: August 2000 draft PRISM grid. Map Created: October 2000.

Figure 3. Annual precipitation of China as modelled by PRISM. Map prepared with the PRISM climate modeling system by the Spatial Climate Analysis Section, Oregon State University.

Although PRISM was originally developed for precipitation mapping, it was quickly recognised that the approach could be extended to other climate parameters. PRISM has since been used to map temperature, snowfall, weather generator statistics, and others.

The PRISM methodology and output products underwent extensive evaluation early in a project with the US Department of Agriculture's National Resources Conservation Service to develop state-of-the-science maps of monthly and annual precipitation for all 50 states in the United States. A panel of state climatologists from several western states, plus additional experts, critically reviewed PRISM methods and maps of precipitation in their areas of interest. The panel concluded that PRISM produced precipitation maps that equalled or exceeded the quality of the best hand-drawn maps available.

Assistance in the People's Republic of China with climate modeling efforts is being provided by a large group of cooperators as this project attempts to work in a new mode of collaboration. Cooperators include the National Meteorological Center; Chinese Academy of Agricultural Sciences (CAAS) Institutes of Agrometeorology and Remote Sensing and Soil & Fertilizer Institute; China Agricultural University, Agrometeorology Department; Nanjing Agricultural University, Physiological Ecology Department; Inner Mongolia Institute of Meteorology; Chinese Academy of Sciences (CAS), Institute of Geography and Natural Resources and Institute of Remote Sensing Applications; Jiangsu Academy of Agricultural Sciences, Agrometeorology Department; Wuhan University (formerly Wuhan Technical University of Surveying and Mapping); Hubei Province Soil and Water Resources Bureau; Yunnan Province Institute of Geography; Yunnan Province Pasture Research Center; and Yunnan Agricultural University.

Soils mapping

Soil characteristics have been mapped with the help of the CAAS Soil & Fertilizer Institute, Yunnan Province Institute of Geography, and Jiangsu Academy of Agricultural Sciences. These maps include national and provincial maps for soil type, texture, drainage, pH, salinity, and alkalinity (Figure 4).

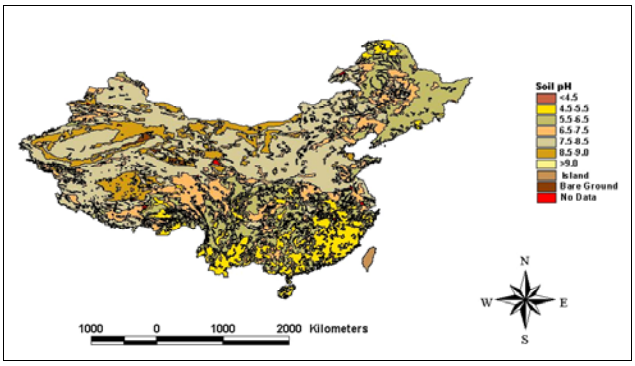


Figure 4. Soil pH values in China.

Species tolerances

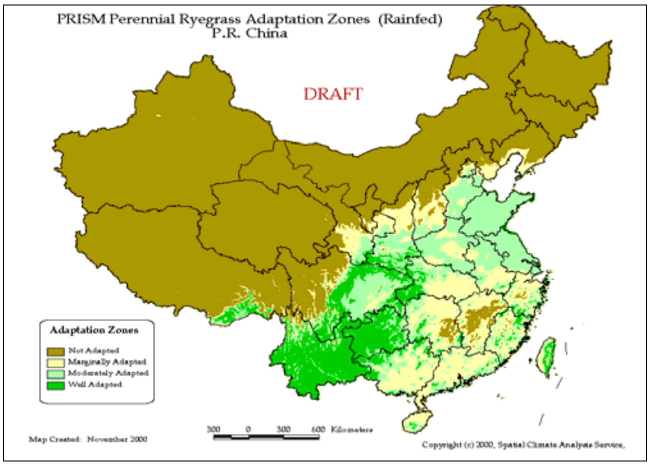
Initial draft quantitative species tolerances for climate factors have been defined for three example species (Table 1). These values are being refined and soil tolerances are being added with the help of global cooperators using web-mapping tools.

Table 1. Climatic tolerances for tall fescue, cocksfoot (orchardgrass), and perennial ryegrass.

Species	Max. temp (°C)	Min. temp. (°C)	Annual precipitation (mm)
Well-adapted			
Tall fescue	22 - 32	≥ -10	≥ 625
Cocksfoot	22 - 31	≥ -7.5	≥ 625
Perennial ryegrass	22 - 30	≥ -5	≥ 625
Moderately adapted			
Tall fescue	20 - 34	≥ -15	≥ 450
Cocksfoot	20 - 33	≥ -12.5	≥ 490
Perennial ryegrass	20 - 32	≥ -10	≥ 525
Marginally adapted			
Tall fescue	18 - 36	≥ -20	≥ 300
Cocksfoot	18 – 35	≥ -17.5	≥ 375
Perennial ryegrass	18 - 34	≥ -15	≥ 450

Species suitability mapping

Using the three components (climate, soils, and species tolerances), GIS-based maps can be produced for species adaptation (Figure 5). Project design allows for refinement of the maps by subject experts via an online dynamic map server, as well as the creation of additional layers for other environmental and economic data.



Map Created: November 2000. Copyright © 2000, Spatial Climate Analysis Service.

Figure 5. Perennial ryegrass (*Lolium perenne* L.) suitability map.

Dynamic mapping

One of the most exciting developments of the China project work has been the development of the capability to develop dynamic maps via an Internet map server application. 'Dynamic' in this context means the maps can be changed to reflect new data almost instantaneously. This allows refinement of the adaptation maps by subject experts located anywhere in the world. Experts can translate their 'mental map' of what they know to be true from experience in the field into quantitative tolerance-based digital maps. With the Internet map server presented on the web with drop-down menus and easy-to-use forms, an expert can adjust the measurements to be reflected in a map. Then, with the computer making thousands of calculations 'on demand', the revised map appears. Maps generated in this manner are completely different from old, static maps that were out of date as soon as they were published. Dynamic maps are more current but also can depict so many more factors and handle the changes that elevation creates. This dynamic mapping software application, like PRISM, is a one-of-a kind system that could be applied to any other similar type project.

Validation

Scientists would be remiss to rely on computer calculations alone to determine the validity of maps when there are many experts and techniques that can add to the picture. 'Ground truthing' will be accomplished with the help of collaborators in collecting data from applied research trials, including those developed specifically for this project and those adapted from other projects to include the data needed by this validation effort. With the maps tested 'on the ground' by many experts, adjustments can be made and measurements can be refined, resulting in the most accurate and useful maps ever.

Current progress

For China, initial countrywide climate maps have been developed for precipitation, maximum temperature, and minimum temperature. These maps are based on 1961 to 1990 monthly means from approximately 2,600 weather stations. National soil maps have been developed from the most current soil survey data. Crop characteristic data drafts have been developed and applied to the climate maps. The soils data may now be added to the tolerances for species through the Internet map server application. A website is being developed to provide links to the climate, soil, and crop characteristics maps. Maps are being developed using ArcInfo (commercial GIS software), GRASS (public-sector software), and PRISM (Daly *et al.*, 2002; Taylor, 2000). Maps are posted to the website as they are developed and verified. Economists and marketing and transportation specialists will provide additional overlays. Other social factors are being considered and will be added as the concepts are developed with collaborators with that expertise.

Relevance to Australia: future developments in information systems

Significant improvements in computer processing power, inexpensive storage devices, and spatial-data layer-integration tools currently offer computer programmers powerful resources for developing simulation models, information systems, and decision aids. Web-based GIS decision-support systems (and their future generation improvements) will be developed for natural resource management, including pastureland, cropland, rangeland, and forestland areas. They will enable us to capture and use the new information that is accumulating every day about our environment and the way agricultural plants respond to the environment. The result will be the capacity for farmers to make better, and more responsive, management decisions in their businesses. This capacity is critical to the future development of the agricultural industries in Australia, as in other parts of the world. As with other technologies, if we do not adopt them while our competitors do, then we lose competitive advantage and industry development may suffer.

These applications for integrating soil, plant, animal, and atmosphere systems will be developed. The question at this point is how fast we will get there. There is a very good foundation of spatial datasets and pasture plant information available in Australia. Technology is no longer the limiting factor in bringing these building blocks together. The way we work, our sociology and psychology of work, is the current roadblock. The speed at which we change the way we work—from individual, competition-based models to group-based, collaborative models—will determine the speed of our progress.

Seamless integration of scale and resolution

The future vision is to model and map at national, state, and local levels (depending on the decision information needed) and provide that information in ‘real time’ to natural resource managers, decision makers, scientists, educators, and students. The new, ‘dynamic mapping’ technologies being developed will allow scientists and farmers and ranchers to create their own maps based on ‘mental models’ developed over years of experience. These techniques are being developed, refined, and applied to species adaptation mapping work in China and the United States (Figures 3 to 5; Hannaway *et al.*, 2001).

Sharing data and expertise: the need to work together globally

Clearly, a new age of information technologies is upon us for managing agricultural and natural resources. The potential power of these technologies is discussed further by Henry (2002).

To most effectively and efficiently identify, develop, and apply these opportunities, we must work together globally. Mutually beneficial research, education, and outreach activities are needed more than ever. The tools for collaborative work are available (e-mail, web, fax, phone, overnight courier services, etc.). What’s needed is the mindset to work together. This paper is one small example of the desire to do that. And, hopefully, it also demonstrates the benefit of doing so.

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