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FIRETOOL: an expert system for the use of prescribed fires in Brazilian savannas

V.R. PIVELLO* and G.A. NORTON†

**Dep. Ecologia, Universidade de São Paulo, Cx.P.11461, São Paulo-S.P. CEP-05422–970, Brasil; and †CRC for Tropical Pest Management, University of Queensland, Brisbane, Queensland 4072, Australia*

Summary

1. A prototype expert system, FIRETOOL, was developed to help decision makers and managers use prescribed burns for the ecological management of Brazilian savannas (*cerrado*) conservation areas.
2. The expertise necessary for producing guidelines for fire management in cerrados, that was used in FIRETOOL, came from the authors' experience, literature and an interview survey of Brazilian scientific researchers and managers of national parks and ecological reserves.
3. The knowledge was encoded in a commercial expert system shell, KnowledgePro, and auxiliary programs were used for drawing and presenting the figures.
4. FIRETOOL has four subsystems: STARTING presents the program and gives instructions on how to design a short-term burning plan; FIRERISK assesses the risk of a wildfire in the site and its likely intensity; FIREUSE estimates whether a prescribed burn is necessary and suggests the most appropriate fire regime; and PROCEDURE gives directions on basic techniques for carrying out controlled fires and for making firebreaks.
5. FIRETOOL was initially tested against the assessments of an expert on *cerrado* fire ecology. A few adjustments enabled the system to give assessments and recommendations consistent with this expert.
6. The development of FIRETOOL allowed most of the existing information on cerrado fire ecology to be assembled, analysed and used for practical problem solving. Manager's difficulties were better perceived and many knowledge gaps were identified, thus giving directions to improve decision making and research.
7. A field test of the FIRETOOL knowledge base would verify its potential use as a tool for providing information on decision making of *cerrado* management, and for training the staff of conservation areas.

Key-words: *cerrado* ecological management, controlled burns, decision making, decision support tool, fire management.

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Introduction

The Brazilian savannas, named ***cerrados***, comprise a gradient of physiognomies, from the woodland type, the *cerradão*, to the grassy field, the *campo limpo* (Fig. 1). Except for *cerradão*, the other physiognomies (*campo limpo*, *campo sujo*, *campo cerrado* and *cerrado* in the strict sense) are subjected to periodic fires; usually the more open the physiognomy, the higher the fire frequency. Fire may occur accidentally or be intentionally set by local cattle ranchers to promote the regrowth of forage and to increase its palatability.

Like many other savannas in the world, open *cerrados* are fire-adapted environments. Periodic burns have occurred since ancient times (Coutinho 1980, 1981) and are believed to have selected for fire-prone species, particularly herbs and shrubs (Coutinho 1980, 1982). Many beneficial effects of fire can be observed in the open cerrados: intense flowering, fruiting and herb resprout (Warming 1908; Coutinho 1976, 1982, 1990); increased germination (Coutinho & Jurkevics 1978); and accelerated nutrient recycling (Cavalcanti 1978; Coutinho 1978, 1982). Herbivore and frugivore can also benefit from fire, because of the more readily available food.

Burning is certainly the oldest and cheapest method of maintaining open savannas, of stimulating nutrient recycling and forage productivity, and of reducing fuel

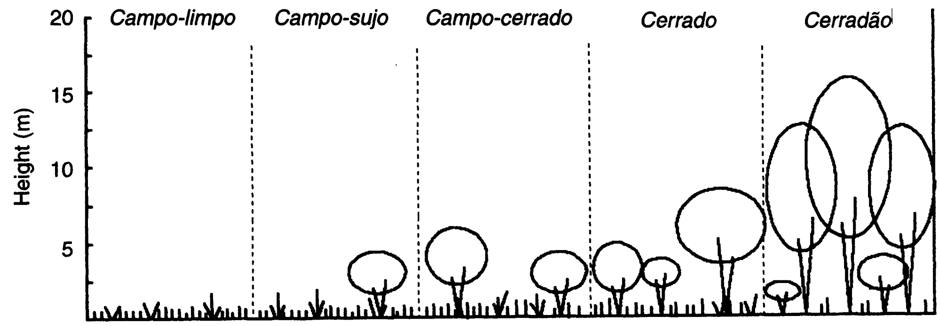

Fig. 1. A gradient of Brazilian savanna (*cerrado*) physiognomies (modified from Coutinho 1982).

and wildfire, especially over vast areas. Controlled fires have been used as a management tool in many protected savannas in the world (Edwards 1984; Kruger & Bigalke 1984; Saxon 1984; Australian National Parks & Wildlife Service 1991; Werner 1991).

In Brazil the misuse of fire in primitive agriculture has created a strong feeling against its usage, especially for ecological management. This has delayed the process of developing and implementing burning programmes for *cerrado* conservation areas. In general, present regulations for conservation admit very little human intervention in the ecosystems. However, prescribed burns are now starting to be recognized as a suitable tool for managing *cerrados*.

Wildfire is one of the major problems that *cerrado* national parks and ecological reserves face today. The loss of open physiognomies and biodiversity are related to fire exclusion from the open environments. Without burning, fuel builds up and uncontrollable wildfires occur. Also, typical fire-adapted plant species tend to disappear through competition from exotic forage species or by shading under a denser canopy (Pivello 1992).

The main reason for fire misuse in early agriculture, and the existing controversy about its present use in conservation, is lack of knowledge. Often, there is a paucity of scientific information to answer practical management questions and experimental data are not available or are scattered and not interpreted for practical use. However, useful knowledge does exist in the day-to-day experience of people. Usually, this existing knowledge is poorly communicated by scientists to managers and vice-versa.

One way of assembling the existing expertise, as well as improving its delivery, is with an expert system. Expert systems are a class of computer-implemented decision support tools whose main characteristic is their ability to deal with qualitative information and heuristic knowledge, enabling specific practical problems to be diagnosed and giving advice on how to solve them (see Starfield & Bleloch 1983, 1986; Waterman 1986). The information necessary to assess the problem is obtained through a series of pre-defined questions asked in a logical sequence. According to the answers given, appropriate rules are triggered and a decision tree is followed to arrive at a final recommendation.

Expert systems have been successfully used to assist decision making on the management of natural resources in many countries: in Australia (e.g. Davis, Hoare & Nanninga 1986; Ludwig 1990), in Canada (e.g. Kourtz 1987), and in the USA (e.g. Rauscher 1987; Andrews & Chase 1989; Reinhardt, Wright & Jackson 1989). Several expert systems have also been built on the impact of fire on timber crops (e.g. Ffolliott, Guertin & Rasmussen 1988). They are a user-friendly means of disseminating knowledge and training managers.

The aim of this paper is to describe briefly FIRETOOL, a prototype expert system for the fire management of Brazilian savanna conservation areas. FIRETOOL was developed to assist managers of Brazilian savanna national parks and ecological reserves to make decisions on whether or not to use prescribed fires to meet their management objectives and, if so, how to conduct them.

The building of FIRETOOL

Building FIRETOOL involved five stages: knowledge acquisition, development of guidelines for fire management in the Brazilian cerrados, structuring of the expert system knowledge base, encoding the knowledge into expert system software (an expert system shell) and a preliminary validation.

KNOWLEDGE ACQUISITION

The knowledge necessary to develop FIRETOOL came from experiences of the authors, from a comprehensive literature review, and from an interview survey of scientific researchers and managers of savanna conservation areas. The literature review provided background information and a comparative view about the structure and dynamics of world and Brazilian savannas, their past and present management and specific details about their biotic and abiotic features.

An interview survey of scientific researchers, specialists in savanna ecology and managers of *cerrado* conservation areas was carried out in Brazil, using specific questionnaires (following Byerlee *et al.* 1980). The aim was to gain a general picture of their management problems and needs, their opinions on fire management, and to learn from their practical experience. All the information collected was analysed to ascertain the primary management goals.

FIRETOOL STRUCTURE AND THE KNOWLEDGE INVOLVED

Guidelines for the use of prescribed fires in Brazilian savannas were then defined, to serve as the FIRETOOL knowledge base, which was arranged into four subsystems: STARTING, FIRERISK, FIREUSE and PROCEDURE. Each subsystem can be accessed independently or the user can go through them in sequence (Fig. 2).

STARTING

STARTING opens the program, briefly describing FIRETOOL's subsystems, the principles used and program limitations. It then gives instructions on the use of FIRETOOL, starting by outlining a burning plan for conservation areas. A burning plan concerns the burning scheme for a site. There are basically four steps which must be defined in the burning plan. First, the spatial distribution of the *cerrado* landscapes (including the units of the different vegetation physiognomies, the topography, the accesses, fences, water bodies, existing firebreaks and buildings) must be drawn on a detailed map (e.g. Fig. 3). Then, the firebreak strategy [e.g. patch burning (Saxon 1984) or burned strips] and the management objective must be defined. At the end, the risk of wildfire in each unit must be evaluated by running FIRERISK.

According to the management objectives for each site and wildfire risk, a prescribed fire may or may not be conducted. If fire is used, then the different fire regimes (fire type, frequency, intensity and season) and firing techniques must be determined (Vogl 1979; Wright & Bailey 1982; Werner 1991; Pivello 1992), as given by FIREUSE and PROCEDURE, respectively.

FIRERISK

FIRERISK makes an estimate of the risk of an accidental fire for a given site; also of the expected fire intensity and spread velocity. Information obtained from the user on patch physiognomy, fuel characteristics, weather conditions and human activities in the area and nearby is used to calculate the risk of accidental fires. FIRERISK determines fuel flammability (i.e. 'the capacity for vegetation to be ignited at the flash point': Phillips 1974), using the moisture content of dead and live fuels, the ratio of dead to live fuels, fuel curing status (a measure of the moisture content of the living tissue), chemical composition, particle size and shape and its compaction in the fuel bed (see Cheney 1981; Burgan & Rothermel 1984; Trollope 1984a). Some factors can be inferred directly from other *cerrado* features; for example, physiognomy already suggests fuel type. The moisture content of live and dead fuels can be estimated from the *cerrado* structure, the season, weather in the last 2 weeks (frost occurrences, number of dry days) and meteorological conditions on the day of consultation (air temperature, relative humidity, wind speed). The fuel dead-to-live ratio can be inferred from the date, which also governs plant phenology and fuel curing status, frost occurrences in the year and time since the last fire.

Once fuel flammability is estimated, fuel quantity is added to determine potential combustibility ('the capacity to sustain fire and to remain alight': Phillips 1974). In the open *cerrados*, some grass species may occur, including *Hyparrhenia rufa* (Nees) Stapf, *Tristachya leiostachya* Nees, *Panicum maximum* Jacquin, *Melinis minutiflora* Beauv., P.) that can grow 2–3 m tall, especially when flowering, increasing the amount of fuel in the area and, consequently, influencing other parameters, such as combustibility. Frost and increas-

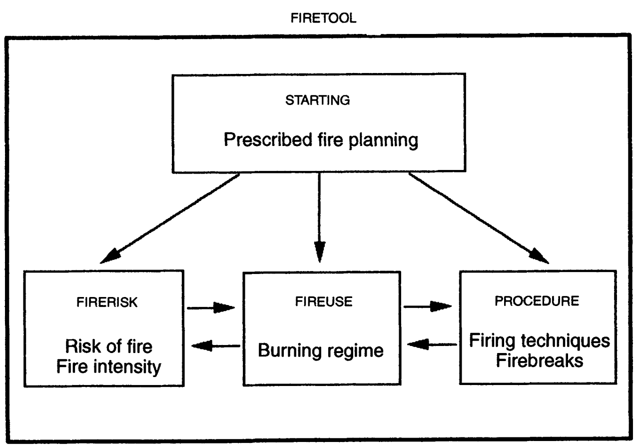

Fig. 2. FIRETOOL subsystems and their applications.

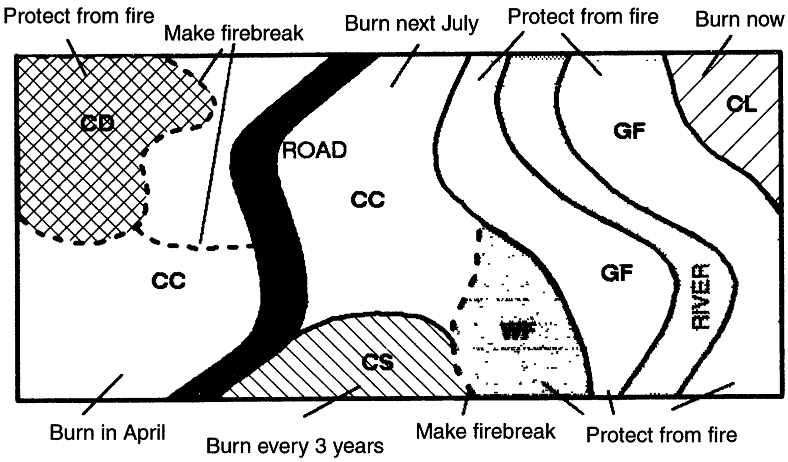

Fig. 3. An example of a burning plan map with notes. CD, *cerradão*; CC, *campo cerrado*; CS, *campo sujo*; CL, *campo limpo*; WF, wet field; GF, gallery forest.

ing time since the last fire also enhance the amount of dead fuel.

The current risk of an accidental fire is assessed on the basis of potential combustibility, local meteorological conditions (air temperature, relative humidity and wind speed) and hazardous activities that can take place within the conservation area or in its vicinity. These human risks are related to agriculture (such as cattle ranching, grain crop farming, pine silviculture), urbanization or activity by fishermen and hunters in the area. The probability of wildfires caused by lightning is estimated from the date.

Fire intensity is estimated from fuel type, moisture and amount, its curing status and weather conditions. Also, an assessment of fire spread is obtained from fuel flammability, weather conditions (particularly wind speed), fuel amount, its distribution (uniformly or irregularly) and terrain slope (Cheney 1981; Wright & Bailey 1982; Burgan & Rothermel 1984). At the end of a consultation, FIRETOOL presents justification for the assessments given.

FIREUSE

FIREUSE estimates whether a prescribed fire is needed on a site by analysing vegetation structure, management objectives, current fuel condition, the presence of key species and season. The management objectives considered in recommending a prescribed fire include:

1 fuel reduction; **2** wildfire prevention; **3** increase in the food supply for herbivores; **4** maintenance of open cerrado patches and their typical species; **5** weed control; **6** reduction of tree density; **7** maintenance or promotion of dense *cerrados*. Some of these objectives are closely related and follow the same decision-tree path in FIRETOOL; some others do not apply to all *cerrado* physiognomies. These seven objectives were identified as management needs by scientists and managers.

If a burn is necessary, the program estimates the appropriate fire regime, i.e. the fire type (surface or crown fire), intensity (mild or moderate), the firing strategy (headfire or backfire), the best season for burning and the recommended interval before the next burn (fire frequency), according to the management objective for the site.

To establish whether to reduce fuel and avoid wildfires (Objectives 1 and 2), FIREUSE first checks the amount of dead fuel on the site. If there is little fuel or if the current month is rainy (summer), then a prescribed burn must be postponed, otherwise, a mild winter burn (between July and September) is recommended. Mild surface fires do not damage the soil or adult trees, and research has shown that winter burns reduce dead fuel more efficiently than autumn or summer fires (Griffin & Friedel 1984; Faulkner, Clebsch & Saunders 1989). If fuel amount is high, a controlled fire early in the dry season is recommended. Fire frequency should vary between 4 and 6 years in *cerrados sensu stricto*, not less than 3 years in *campos cerrados*, and not less than 2 years in *campos sujos* and *campos limpos*. However, FIREUSE also checks for erosion susceptibility and, in this case, fire interval may be increased: late winter or early spring burnings being recommended to achieve a quicker vegetation recovery after the first spring rains.

To achieve an increase in food supply for herbivores and maintain open savanna (Objectives 3 and 4), a mild surface winter burn (June to September) is recommended, unless a frost has occurred recently or *Melinis minutiflora* or *Tristachya leiostachya* occur at high densities. Winter fires favour grass regrowth, control tree and shrub encroachment and are the least harmful to animals. However, when these two grass species are dominant it is better to burn in April or May, before they release their seeds. Also, if a frost has occurred and there is a reasonable risk of wildfire, a mild burn is recommended at any time from May to September. The burning interval for Objectives 3 and 4 will usually be the same for Objectives 1 and 2, but when *Melinis minutiflora* or *Tristachya leiostachya* are dominant, more frequent burns will be necessary to control them (Objective 5).

Objective 5 concerns weed control in cerrados. According to the survey, the main weeds that invade cerrado conservation areas are *Pteridium aquilinum* (L.) Kuhn, *Cuscuta* sp., *Melinis minutiflora*, *Hyparrhenia rufa*, *Panicum maximum*, *Paspalum notatum* Fluegge, *Andropogon* spp., and *Brachiaria* spp. Apart from *Melinis minutiflora*, the remaining grasses are shade-sensitive and fire-resistant species (Aronovich & Rocha 1985; Zuniga 1985; Costa & Brandão 1988; Filgueiras 1990). Thus, burning of invaded areas must be avoided. Alternative control treatments are manual clipping of the tufts near the soil (Zuniga 1985), or use of herbicides (Faulkner *et al.* 1989). Burnings must also be avoided where bracken (*Pteridium*) has established. It can be controlled by mechanical methods, such as cutting, crushing and ploughing in early summer, or by chemical substances (where the level of infestation is high), or by biological control (Kirkwood 1990; Lawton 1990a, 1990b; McElwee, Irvine & Burge 1990; Taylor 1990a, 1990b; Tolhurst 1990; Veitch 1990). *Cuscuta* sp. is an epiphytic parasite that can be killed by fire (Dias, B.S.F. and Meca, M., personal communication), with moderate crown burns being most effective. In *cerradão* and *cerrado sensu stricto*, the best season to burn is between May and July, which causes the least damage to trees. In *campo*, the burn can be made from May to September since damage to trees is less relevant. Fire frequency will depend on the burn efficacy.

Although there is some controversy in the literature regarding fire adaptation of *Melinis minutiflora* (molasses-grass: Aronovich & Rocha 1985; Costa & Brandão 1988; Filgueiras 1990), observations have shown that it can be greatly reduced by serial surface burns. In the open *cerrados*, moderate burns in early winter (April to early June) or summer burns in the '*veranico*' period (dry period in the middle of the wet summer) are recommended. Two consecutive annual burns are likely significantly to reduce *Melinis minutiflora* but, if not, another burn may be conducted in the same season, or a herbicide treatment may be applied. In dense *cerrados*, fire is not recommended for *Melinis* control. The area must then be protected from fire, enabling the vegetation to grow more dense, when *Melinis* will disappear because of shading. At high infestation levels, frequent manual clipping may be applied (Zuniga 1985).

When tree reduction is desired (Objective 6) with an increase in grasses and herbs, one or two consecutive moderate surface burns are advised in late winter or early spring (from September to early October). Although hot fires are also effective in reducing tree and shrub encroachment, they are not recommended by FIREUSE because of the difficulty of controlling such fires and the unacceptable harm to fauna that can result.

If the purpose is to maintain or promote a dense savanna (Objective 7), the physiognomies that are already relatively dense (*cerrado sensu stricto* and *cerradão*) must be protected from fire. Firebreaks or open patches with little fuel can be created, and vigilance in the dry season or in '*veranico*' periods is needed. In open *cerrados*, however, mild fires in early winter (April or May) can stimulate tree development, if the interval between them is not less than 3 years.

The site and environmental conditions required to recommend mild and moderate burns are summarized in Table 1, which also indicates when burns are not recommended, either for safety reasons or because conditions will not allow a proper burn. In the latter case, the program advises the user to postpone the burn until conditions are suitable.

The firing techniques recommended by FIRETOOL will be examined next together with the use of fire for making firebreaks.

PROCEDURE

PROCEDURE gives basic techniques for carrying out controlled fires and making firebreak based on objectives, weather, fuel load and susceptibility to soil erosion. Weather conditions are first checked and, if not appropriate for a safe burn, PROCEDURE advises

Table 1. Recommended types of prescribed burns given different site and environmental conditions

Site and environmental conditions	Fire intensity		Firing technique		Burn not advisable
	Mild	Moderate	Headfire	Backfire	
Cerrado structure	Open	Open	Open	Open	*Cerradão**
Wind velocity (km h^{-1})	< 10	10–30	< 10	< 30	> 30
Air temperature (°C)	18–30	> 18	> 18	> 18	< 18
Relative humidity (%)	40–65	25–40	40–65	25–65	< 25; > 65
Days since last rain	2–3†/3–5‡	4–8†/6–10‡	2–8†/3–10‡	2–8†/3–10‡	0–1†; > 8†/ 0–2‡; > 10‡
Fuel moisture	Med	Med; low	Med; low	Med; low	High
Fuel load	Low; med	Med; high	Low; med	High	Very low; very high
Susceptibility to soil erosion	Low; med	Low	Low; med	Low	High

*Unless in special circumstances; †open *cerrados*; ‡*cerradão*; DFM, dead fuel moisture; LFM, live fuel moisture.

postponement of the burn for some hours or to the next day. When weather conditions are suitable, PROCEDURE provides instructions on how to prepare the site and how to conduct the burn, including estimates of personnel and equipment needed.

There are basically two firing strategies, headfires (following the wind direction) and backfires (travelling against the wind). Both can be used for conducting a mild or a moderate burn. The choice depends on weather conditions (Table 1) and objectives. Headfires pass quickly, are not very hot and produce tall flames, which damage plants high above the ground but not near the soil. Backfires, on the other hand, are hotter at the soil surface and are thus more damaging to ground-level plants and soil properties. However, they are safer to conduct (Coutinho 1978; Trollope 1984a; Walker 1985; Frost & Robertson 1987; Miranda, Dias & Miranda 1989). Headfires are recommended by FIREUSE to meet Objectives 3, 4, 6, and Objectives 1 and 2 when erosion problems occur in the site. Because they are safer, backfires are usually recommended for making firebreaks, as well as to meet Objectives 5, 7 and Objectives 1 and 2 when erosion is not a problem.

In order to determine the firebreak type and width, PROCEDURE checks the objective and the vegetation type. Whenever possible, existing tracks or roads, rivers and lakes, or patches of recently burned vegetation should be used as firebreaks. Man-made firebreaks can take the form of bulldozed, ploughed, burned or watered strips. Firebreak width may vary from between 1 and 2 m to between 60 and 70 m, depending on the objective. Schematic figures are also used to illustrate PROCEDURE instructions.

THE EXPERT SYSTEM DESIGN

FIRETOOL was constructed using a commercial expert system shell, KnowledgePro (Knowledge Garden Inc., Naussau, NY 12123). A shell is software which contains the programming to make the system run, initially with an empty knowledge base which is filled by experts. One of the advantages of the shell used is its ability to provide explanations through hypertext. Hypertext consist of blocks of information (usually presented as text) which are linked and can be retrieved at various levels (Rauscher & Host 1990; Warwick, Mumford & Norton 1992).

KnowledgePro uses the **IF** – (AND/OR) – **THEN** – (ELSE) rule structure, where one or more conditions result in one or more consequences, for example:

IF the vegetation is moist
AND the weather is cold
THEN fire will not spread
ELSE a wildfire can occur.

This shell also requires structured 'topics' which contain specific information on a given situation, either as questions or rules. Rules or procedural commands (such as 'do', 'reset', 'remove') relate the topics to each other and determine the path to be followed in the decision tree. Information, such as instructions for running the program, recommendations, or hypertext explanations, is supplied as text. Explanatory figures used in FIRETOOL were drawn using a drawing program, PaintBrush, and are called to KnowledgePro through an auxiliary program, PICEM.

SYSTEM REQUIREMENTS

FIRETOOL was developed using an IBM PC/AT compatible computer but it can also run on XT or PS/2 or compatible computers with at least 640K of RAM and a hard disk. Because of the drawings, an EGA or VGA colour monitor is required. FIRETOOL is composed of 12 individual knowledge bases (the main one and 11 subknowledge bases) and three auxiliary files. The main knowledge base occupies about 300 Kb of memory. The duration of a consultation depends on the complexity of the situation (which will demand more or fewer steps), on the number of assessments the user needs and on the amount of help or background information accessed.

PRELIMINARY TEST OF THE SYSTEM

FIRETOOL was tested against the appraisal of an independent expert on *cerrado* fire ecology, Dr Bráulio F.S. Dias, from the University of Brasília (Brazil). Ten hypothetical situations were presented to this expert. For each situation, the expert was asked to estimate the risk of fire and to recommend prescribed fire procedures according to different management objectives. The same situations were then run using FIRETOOL and the assessments and recommendations given by the expert and by FIRETOOL were then compared. The initial level of coinciding answers on the risk of wildfires was around 70%. Some assessments given by FIRERISK were underestimated in comparison with the expert's opinion. Thus, some of the intermediate steps and weighted values used by the system were adjusted to generate assessments more consistent with those of the expert. In FIREUSE, the recommendations were very similar to the ones given by the expert and no modifications were required. Other parts of FIRETOOL, such as making firebreaks and the burning plan, were also checked by the expert.

Discussion

Lack of scientific data and knowledge is a common limitation faced by managers of natural resources, who use their own or another expert's practical experiences to solve problems. By means of expert systems, the expertise of several experts, as well as data, can be collected, organized and interpreted to supply information and advice to decision makers. Expert systems are very useful for training managers, since they can consistently explain decision rules in a systematic way. Expert systems provide easy access to technical information, improve communication among decision makers and therefore improve decisions. Another role for expert systems is design. They can help to structure complex problems through identifying main components, manager's requirements and gaps in knowledge.

The development of FIRETOOL revealed gaps in information at different levels; for example, the collection of data, management-directed analysis and synthesis of the available information, the dissemination of knowledge, and information reception and training. A number of priorities for future research were identified (Table 2), which can be used to improve FIRETOOL.

Some improvements in FIRETOOL are related to software (debugging and refinements in screen presentation), others to hardware (increasing memory and running speed). Making improvements to FIRETOOL's knowledge base will involve laboratory and field tests to confirm assumptions and to provide data on tree mortality, rate of fire spread, incidence of spotting (i.e. the frequency with which new areas can be ignited by sparks), size and shape of the area burned. All these improvements will be valuable for assessing vegetation recovery and for preparing fire-fighting operations.

Problems related to spatial considerations were also revealed during the design of FIRETOOL. Spatial information is difficult to handle in most conventional expert system shells. An approach to solving such spatial aspects could be made by attaching a Geographical Information System (GIS) to the expert system (see Coulson *et al.* 1988; Davis, Whigham & Grant 1988; Brown & Smith 1991; Wilkerson, Luzar & Nye 1991). This is being considered as a future improvement for FIRETOOL.

Table 2. Knowledge gaps on *cerrado* management identified by developing and using FIRETOOL

Knowledge gaps	Priority
Surveys	
Flora in the conservation areas	2
Fauna in the conservation areas	2
Historical data	
Successional processess in cerrados and mesophylous forests	2
Fire occurrences in cerrados and within conservation areas	2
Fire management practiced by indigenous peoples	1
Basic biological information	
Cerrado plants phenology	2
Reproduction, dissemination, recruitment strategies, longevity of cerrado, gallery forest and mesophylous forest plants	2
Habitats, feeding preferences and biological cycles of *cerrado* fauna	1
Field data	
Cerrado fire behaviour: flame height and length, fire intensity and rate of spread, spotting rate	2
Flammability of *cerrado* fuels	1
Environmental constraints for burning	1
Procedures for prescribed burns: firing techniques, firebreak types and widths	2
Methods for weed control, including fire, cutting, ploughing, and herbicide treatment	2
Methods for controlling *Tristachya leiostachya* and *Sorghastrum* sp.	2
Effects of fire regimes on:	
soil erosion	2
soil fertilty	2
soil micro-organisms	1
soil plant cover	1
plant reproduction, regeneration and species composition	2
fauna survival and behaviour	1
fauna nutrition and diseases	2

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