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THE EFFECTS OF FIRE IN AGRICULTURE AND FOREST ECOSYSTEMS

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Introduction

Fire has been a common phenomenon throughout the history of the world. Fire has been a constant companion of humans; we have used it to our own benefit and been threatened by it. Native Americans used fire to reduce thick brush, to improve the environment for hunting wildlife and to create openings for their crops. In the State of Florida, USA, natural fire has promoted a wide diversity of plants associated with a fire ecology (Long, 2006).

Perhaps the most common and popular idea is that fire is damaging to the environment and that it should never be tolerated in forest or field. During the Twentieth Century, there was a mindset that all fire was bad and it was an obligation to try to suppress any fire as quickly as possible and at any cost. In the United States, the policy of suppressing each and every fire resulted in an increase in combustible material on the forest floor and, as a consequence, resulted in increasing numbers of large and devastating wildfires (Walsh, 2007).

It is true that one of the main concerns of forest management is protection of the forest and natural environment against wildfires. For governments as well as for forestry companies with large investments in forests, protection against wildfires is of primary importance. On the other hand, it is important to evaluate the impact of fire on different types of vegetation. Many of those fires that were grouped together and considered as undesirable were really beneficial natural fires for certain ecosystems.

Likewise, burning practiced by farmers and foresters can also be considered beneficial in many instances. Fire can occur in the environment in different ways and have different effects:

- Natural fires in forests and wildlands,
- Burning used to convert forest and field to agricultural uses,
- Agricultural burns, such as in the case of sugarcane, or to improve pastures,
- Prescribed burns used as part of forest management,
- Prescribed burns to improve the environment for wildlife and natural flora in those ecosystems that depend on fire for their existence.

Control and prohibition of all types of fires has been the traditional fire policy of many governments. Large-scale wildfire disasters which occurred in the past years, may have been less severe and extended if national fire management capabilities had been developed. It is now being realized many of those associated with fire protection efforts that the total prohibition of fire leads to accumulations of combustible materials and this can increase the threat of large and damaging fires. To minimize the accumulation of fuels, policies are being reviewed, and in some cases, modified to allow controlled burning as a forest management tool in order to remove the accumulation of fuel loads that would otherwise lead to damaging wildfires (FAO, 2006).

During recent years, there have been some good studies conducted to evaluate the influence of fire on the environment and there is considerable literature on this subject. After having studied many cases in detail, the United States Forest Service and the National Park Service have begun to favor the employment of prescribed burns as well as leaving some fires of natural origin to burn and eliminate the excess combustible fuels in forest and field. Prescribed burns or control burns are defined as "Fire applied expertly, under specific climatic conditions, in defined locations and to obtain clearly defined objectives" (Wade & Lunsford, 1989). During the decade of the 1990's, the areas treated with prescribed burns in the National Forests of the United States averaged 367.511 ha per year. The goal of the US Forest Service is to increase prescribed burning in national forests to 1,2 million ha by the year 2010 (Haines *et al.*, 1998).

Wildfires and control burns have different impacts on different parts of the environment. For purposes of discussion, the effects of fire on the environment are separated into the following areas of impact:

- Air quality
- Wildlife
- Soil and soil biota
- Growth of crops and trees
- The exclusion of fire by legal regulation
- Natural forests

The effect of fire on air quality

In a public opinion survey in St. Louis, USA, it was found that 40% of the people associated air pollution with smoke, but just 14% thought that vehicle emissions were the cause of air pollution. In other words, "the more visible, the more dangerous" (Shusky, 1966). Measurements of air pollution show just the opposite. According to Mikell (1971) the most important cause of air pollution is vehicles (60%), followed by industry (20%), power generation (15%) and commercial and residential heating (5%), with 3% due to agricultural and forest fire (Dieterich, 1971).

According to Pierovich (1976), "When compared with other sources of air pollution, smoke can be considered of importance only at a local level of importance to the agencies that make rules governing emissions".

When considering a much broader aspect of the pollution problem, the largest source of pollution is attributed to atmospheric turbulence resulting from volcanic eruptions (Friend, 1971). The eruption of the Krakatoa volcano in Indonesia in 1893 threw more particulate and gaseous material into the atmosphere than all human activities since the beginning of human existence (Pecora, 1970). Similarly, sulfur emissions into the atmosphere come primarily from natural causes with just 11% from industry (Komarek, 1970). Sulfur dioxide is virtually absent from emissions caused by forest fires (Hall, 1972).

Another of the crucial contaminants of the air is nitrogen oxide. For its formation, nitrogen oxide requires temperatures at least 1.450°C, which are seldom reached during a forest fire (Komarek, 1970). Nitrogen oxide and carbon monoxide come primarily from industry, automobiles and urban activities (Hall, 1972).

The primary products of agricultural and forest fires are carbon dioxide and water, with a lesser proportion of carbon monoxide and some hydrocarbons. Table 1 shows the main emissions from forest fires in the United States (Omi, 2005):

The most important pollutant of wildfires and burning is visible smoke, which is principally a mixture of particulates and water (USDA Forest Service, 1989). In a study of the origin of particulate matter in the United States, values were reported by Jones (1974) (Table 2):

Comparing hydrocarbon emission from three sources, Darley *et al*. (1966) found that vehicle emissions were ten times greater than those resulting from the burning of brush in the field. Emissions of hydrocarbons from three sources are shown in Table 3.

In 2001, Dr. Stanhill, an Israeli researcher, discovered a phenomenon that shows that the amount of sunlight penetrating to the surface of the earth is decreasing. He calculated that the intensity of sunlight is diminishing between one and two percent per year, as a global average (Sington, 2005). This phenomenon was given the name of *global dimming*. The effect appears to be the result of environmental pollution caused by humans. Other researchers in other parts of the world have found evidence that supports the theory of Dr. Stanhill. Particles of soot, ash, sulfur compounds and other compounds appear to be the cause of global dimming. The moisture in clouds condenses around microscopic particles in the air thus forming small droplets of water, a normal occurrence. However, the formation of these droplets is increasing noticeably. The result of this increase is a mirror effect, in which the clouds reflect sunlight back into space. As more contaminants with tiny particulates are thrown into the air, the global dimming effect will increase. It is important to note that global dimming, where heat from the sun is being turned back to space, acts opposite to the effect of greenhouse gases which are causing an increase in atmospheric heat. Scientists still do not have a clear idea of the interaction of these two phenomena, global dimming and global warming.

Even though control burns produce smoke, the amount of smoke produced is much less than that produced by forest fires, as has already been discussed. If control burns can reduce the risk of large fires, the net effect would be to reduce the amount of smoke in the air. Control burns are normally carried out in agriculture and forestry when material is dry, which produces much less smoke and particles than a wildfire that burns green fuels. Control burns produce one fifth the amount of smoke particles that are produced by wildfires (Dieterich 1971).

Table 1. Emissions from forest fires

Material	Percent
carbon dioxide (CO_2)	67
water (H_20)	25
carbon monoxide (MO)	6
particulates (soot, ash)	1

*/ There are minute proportions of some other chemicals including hydrocarbons, sulfur dioxide, nitrogen oxide and nitrates.

Table 2. Origen of particulate matter in smoke

Place	Millions of tons /year
Cities (transport, industry, domestic)	13,6
Forest fires	2,5
Control burns (agriculture, forestry)	0,2

Table 3. Comparison of three sources of emissions

Source of emissions*	Gasoline in autos	Burning oat stalks	Burning brush
	kg/ton	kg/ton	kg/ton
total hydrocarbons	65,0	9,1	3,4
ethanol	3,9	1,1	0,4
grease and oils	5,4	1,8	0,8
saturates and acetylenes	7,1	0,6	0,3

*/ kg of emissions per ton of fuel

Table 4. Gas emissions from burning three types of vegetation

Fuel*	C	CO	CO_2
	kg/ton	kg/ton	kg/ton
dry brush	1	35	1366
oat straw	2	42	854
green brush	7	67	764

*/ kg of emissions per ton of fuel

In one measure of the emissions from burning oat stalks, green brush and dry brush, it was found that burning of oat stalks and dry brush produced less soot and carbon monoxide than green brush, and that they produced a greater amount of carbon dioxide (Table 4, Darley *et al*., 1966).

Smoke from burning vegetation can reduce visibility within the burn area, but smoke from natural sources is not considered to be a danger to public health. In 1992 and 1993, a study was made of the health of residents of two towns in Aragua State in Venezuela, near where there were sugarcane fields (Hernandez, 1995). People living near the cane fields complained of the cane burning for health reasons. In some localities there were cases of asthma, pneumonia and bronchitis during the months of November and May, these being the months when cane burning normally occurred. In the study, local residents of the nearby towns were interviewed as well as persons living in towns where there were no cane fields. Information was also obtained from local health centers. The researchers reviewed the statistics on the number of persons with respiratory problems in health clinics in the area of the study. The purpose of the study was to determine month by month the visits by persons to health clinics with respiratory problems and to determine if there was a change in the incidence of respiratory problems during the months of cane burning. The conclusions of the study were that there was no clear connection between the health of persons living near to the cane fields and the months of cane burning (Hernandez, 1995).

In the manual "Guide to Smoke Management" published by the US Forest Service, it states that "we believe that some occasional smoke can be accepted as part of forest management (with control burning) given the benefits that burning can have for some forest ecosystems and for fire hazard reduction, which can lower the emissions from wildfires" (Mobley, 1976.

There have been claims in some newspapers that burning will eliminate the oxygen in the atmosphere and thus could cause a public health crisis. Charles Cooper (1971) in a conference on *The effects of fire in ecosystems* says: "The claims that oxygen in the atmosphere is in danger of being eliminated by burning are not valid". Broeker (1970) calculated that if all carbon tissues in all existing plants and living things on the planet were to be burned completely, it would require just a fraction of one percent of the oxygen available in the atmosphere.

The situation regarding carbon dioxide is not as clear. This component of the atmosphere is less abundant than oxygen and is more sensitive to human activities. Without doubt, the carbon dioxide content of air has increased during the past century, primarily due to the burning of fossil fuels (coal and oil) as well as the oxidation of organic material in the soil after extensive clearing of forests and other vegetation (C. Cooper, 1971). It is difficult to measure the effect of increased carbon dioxide in the air and its consequences in the long term. There is now convincing evidence that the total greenhouse gas content is threatening global warming.

Reforestation and afforestation are methods to capture part of the carbon from CO_2 and CO from the atmosphere. Forests are useful as carbon sinks since carbon is accumulated in them. The use of prescribed fire during plantation establishment may appear contra-dictory to carbon sequestration, but the long term result is positive, when plantations are kept growing in a continuous and sustainable manner. It is important to remember that vegetative and woody material that dies produces the same CO_2 through rotting as is produced by burning. The difference is that fires put the gas in the air quickly, whereas rotting does it more slowly. From another point of view, the more quickly that the plantations can be established, the more quickly they will accumulate carbon in living trees and vegetation.

Of the total carbon gasses currently in the atmosphere, it is estimated that 45% have been emitted during the past 150 years, since the beginning of the Industrial Revolution. Prior to the Industrial Revolution, the atmospheric concentration of CO_2 was 280 ppm (parts per million). In 1960, the concentration of CO_2 was 320 ppm, and it has reached 380 ppm today. Emissions from human activities release some 6 billion ton of CO_2 per year to the atmosphere (ILO, 2009). It is estimated that the burning of fossil fuels (oil, gas and coal) along with the destruction and burning of vegetation in forests and grasslands adds 8 billion tons of pollutants to the atmosphere annually (Cook-Anderson, 2009).

Until 1990, most scientists believed that the loss of forests was primarily a source of carbon dioxide emissions going into the atmosphere because forests are continuously being destroyed by human activities like deforestation in tropical areas, urban and suburban development, and land clearing for farming. However it has now been determined that photosynthesis is greater than decomposition on a global scale and that land vegetation is, in reality, a net sink for carbon dioxide, rather than a net source of CO_2 emissions. Oceans and forests are estimated to absorb 60% of all atmospheric carbon liberated annually by human activities (JPL, 2009). There is still uncertainty about just exactly which mechanisms are responsible for the carbon absoroption.

There are those who claim that harvesting plantations eliminates the positive effect of a carbon sink, and therefore the trees should not be harvested, just left standing permanently. This appears reasonable at first glance, but when thinking about it more thoroughly, that idea has many drawbacks. Above all, the land was initially cleared for human use. It is highly doubtful that there is interest in leaving lands to return to a natural brush and forest state again and that they are left without any economic use, especially considering that the world's human population is on the rise. In numerous cases, forests and lands covered with open woodlands or savannahs have been cleared due to fiscal incentives by governments to help create employment, food and income to its people, in order to improve the national economies. To plant trees just to leave them, without producing any kind of economic return goes against the objectives of governments that use their lands for improving their economies and the welfare of the citizens. If there are no real incentives to manage forests for economically viable products, there will not be anyone interested in managing them. The reality is that to be successful, carbon sinks must also be useful to people in a tangible way, besides simply eliminating carbon dioxide from the atmosphere.

Fast-growing trees produce wood for the pulp and paper industry, for charcoal, for sawn wood, for particle board, posts and other solid wood products. Managing plantations for such products is a process that includes the harvest and replanting of trees, the management of standing forests, their subsequent harvest and replanting again in a sustainable cycle. This results, not only in carbon sequestration in trees and wood, but also the economic utilization of trees to improve the economy. In addition, it is important to remember that when products are produced from wood which contain carbon captured from the atmosphere, such as furniture, houses, boards, books, and paper, that carbon remains in these forest products until they rot and release their CO_2 back into the atmosphere.

In a feasibility study for a carbon sequestration project, the author calculated the carbon dioxide debits and credits for a 10,000 ha eucalypt plantation project. The study used a 21 year eucalypt rotation with clear-cuts each 7 years and coppice management of the stump sprouts after each harvest. A mean annual growth rate of 35 m^3/ha/year for eucalypts was used for the calculations, which is a normal average for industrial plantations in many parts of the tropics. The study included CO_2 production from machinery used for forest management (vehicles for site preparation, planting, and harvesting, as well as administrative vehicles). The amount of carbon was calculated for all tree parts, including crowns, boles, bark and roots. Losses of carbon dioxide to the atmosphere were calculated for the rotting of detritus left during harvesting. Losses of carbon to the atmosphere were also calculated for eventual rotting of all products made from the wood (wood pulp, paper, sawn lumber, sawdust, bark, etc.). After 21 years, the project had reached a level of 1,2 million tons of carbon sequestration for 10.000 ha of plantations and this level was maintained during the subsequent years. This is equivalent to eliminating 4.5 million tons of CO_2 from the atmosphere on a permanent and sustainable basis.

Similarly, natural forests are valuable as a carbon sink and have value to a nation and its people. A primary reason that natural forests are eliminated is that, after harvesting the wood of commercial tree species, the value of the forests is severely reduced and there is little or no incentive to maintain them. Human nature is such that anything that does not have value of some sort will be treated carelessly and without consideration. Cleared land has greater value to squatters and farmers for food crops than does the remnant natural forest. One way to protect natural forests is to increase their value by generating public use of the forests. An important alternative is to develop the recreational benefits of the forest and to develop tourist sites within the forests. When the forest and natural areas become destinations for the public, there is the potential to generate values in the form of recreation and tourism as well as income from associated activities such as lodging, food services and the travel industry. In Costa Rica, natural tourism is among the most important sources of revenue to the gross national product.

The effect of fire on wildlife

A very hot wildfire that destroys extensive areas of natural forest or burns up natural prairies can have a negative effect on wildlife. However, this does not imply that any burning by agriculture or forestry has the same negative effect. To the contrary, wildlife researchers have shown that there must be equilibrium between fire and certain species of animals.

Cattle ranchers practice burning and this has been shown to improve the forage on their grasslands. Biologists who are specialists on wildlife ecology also make prescribed burns to improve the habitat for fauna (Mobley, 1976). In one study, it was found that herbaceous plants that are eaten by wildlife were ten times more abundant in areas that had been burned than in areas without fire (R. Cooper, 1971). In Southeastern United States, plantations of slash pine (*Pinus elliottii*) have more forage and food for cattle and deer where the pines are periodically subjected to prescribed fires (Mobley, 1976).

In South Africa it was found that in an open brush land without burning there was little wildlife, but after making prescribed burns, many herbivore mammals were attracted to the site (Bigalke, 1974). Burning of Japanese honeysuckle (*Lonicera japonica*) is recommended to increase the nutrient content of its foliage for deer (Stransky *et al.*, 1976). Worms of the genus *Diplocardia* require periodic fires for their survival; many other species of invertebrates live in areas of North America where fires occur naturally (Komarek, 1971).

According to Mobley *et al*. (1973), "The primary effects of control burns for wildlife are indirectly beneficial insofar as improvements in the available food supply and cover." Fire can be an essential need to maintain the necessary conditions for the survival of some species of geese, ducks and other large birds (Vogl, 1970). In North America, the original native habitants maintained ideal conditions for game birds and mammals by periodic burning, but regulations that prohibited open burning in the Twentieth Century resulted in a severe reduction in wildlife populations (Thompson & Smith, 1970).

Frequent burns of rangeland and natural prairies improve the quality and quantity of forage available for wildlife and cattle and are less damaging than infrequent fires that burn hotter. Prescribed burns at intervals of two to four years are used to improve the diversity of animals, to improve cover and to improve visibility (Long, 2006). Herbaceous growth, brush and grasses capture soil nutrients after burns and the sprouts are more succulent and edible for grazing and browsing animals than the vegetation that existed prior to the burn. Fire also improves flowering, seed and fruit production, increasing the availability of these foods for wildlife.

According to James Kennamer, Vice-president of the National Association of Wild Turkeys (2006), "Prescribed burns (in Southeastern USA) improve the habitat for wild turkeys (*Meleagris gallo pavo*) by reducing the amount of understory fuel, by creating openings in the underbrush in the forest and by promoting the growth of herbaceous plants and grass seed which are food for wild turkeys".

In a study of field mice in areas where the forest had been cut, it was found that populations were high one year after burning the residual debris after harvesting but returned to the original population levels after two years (Fala, 1975). In South Africa prescribed burns are recommended for blocks of veldt and grassland that are a couple of hundred hectares in size, so as to form a mosaic that favors populations of two important game birds, the greywing francolin (*Francolinus africanus)* and the redwing francolin (*Francolinus levaillantii*) (Mentis y Bigalke 1974).

In Colombia and Venezuela, numerous birds have been observed that are attracted to agricultural or forest fires. When there is a fire, many flying insects jump into the air to escape the fire and the birds search these out for food. Rodents have also been seen to escape from a fire and hawks and other predatory birds search them out as they run from the fire.

Small animals such as small mammals, amphibians and reptiles can find it more difficult to find hiding places after a fire and predatory birds search for them after a fire (Long, 2006). In low wet areas in the north of Colombia, near natural lakes, the grass and cane grow thick and provide good cover to small rodents. After a fire, these sites are free of vegetation and hawks and falcons perch in nearby palmettos waiting for a small rodent or lizard to scurry over the ashes, making it an easy target for the predators.

Although a fire can cause the loss of nests of some ground nesting birds, the adults normally rebuild their nets with the advantage of having a greater abundance of insects, seeds and other foods that grow after a fire (Long, 2006).

Research has shown that fire is an integral part of some ecosystems and the elimination of fire would modify the habitat to the point that some of the resident fauna would disappear. The grouse (*Tympanuchus cupido*) was eliminated in the State of Massachusetts, USA, due to the exclusion of fire in its habitat, when laws were made to prohibit burning. The savannahs that were maintained by fire disappeared, along with the plants and insects that were the food for the grouse: thus the bird also disappeared due to a lack of food (Komarek, 1971). This same author states that the elimination of burning in the fields where the North American quail (*Colinus virginianus)* thrives would change the ecology to such a degree that within three to four years the birds could no longer live and reproduce in significant numbers.

Before formulating restrictions as to the practice of burning, it is important to study in detail the impact of fire in the environment and the consequences of its elimination. Restrictions on burning in the Twentieth Century resulted in changes in many ecosystems, with an increase in brush land, along with the accumulation of ground fuels, both green and dry, which increased the risk of large and damaging wildfires out of control (Long, 2006).

Ecologists at the National Wildlife Refuge (USA) are using prescribed burns in the South to restore the habitat for a species in danger of extinction, the Mississippi heron (*Grus canadensis pulla*). This bird requires open grasslands to nest and sleep. In the wildlife refuges, burning is showing benefits for other migratory birds that spend the winters in the delta of the Mississippi River, including other species of herons, egrets, songbirds, the bluebird (*Sialia sialis*) and the Henslow bird (*Ammadroamus henslowii*) that are found in those same grasslands (National Wetlands Research Center, 2000).

The effect of fire on the soil and the soil biota

The soil is the basic natural resource of agriculture and silviculture. The way soil is managed determines in large part its productivity for human purposes. Unfortunately, immediate needs take priority over long term soil conservation and what is convenient today could be damaging in the long term, especially with reference to burning. Nonetheless, fire is not always damaging and its effects on the soil depend on certain specific factors.

The principal factor to consider with regard to fire is the slope of the land. The possibility of physical soil damage increases as the slope increases (Smith, 1962). Burning should not be practiced on steep or long slopes that have a risk of soil erosion. On moderate slopes, soil displacement after a fire or burn is insignificant (R. Cooper, 1971). On level land, fire presents little danger of soil erosion (Mobley *et al*., 1973).

Repetition of fire is another important factor. In Canada, Strang (1970) reported that repeated burning degraded soils in rocky areas in the western part of the Province of Nova Scotia. Repeated burning on slopes also caused erosion (Scotter, 1972). On level sites of the Atlantic Coastal Plain of North America, annual burning does not appear to have a negative effect on the soil. Annual burning practiced during a period of 20 years did not reduce the organic material or the nitrogen content of the soils (Stone, 1971). After 12 years of biannual burning there were no differences found in the growth or composition of herbaceous plants growing under a coniferous forest in the state of Louisiana (Grelen, 1975).

The effect of fire on the erodability of a soil is also determined in large part by the soil texture. Sandy soils are highly erodable during heavy rains, even on slight slopes, once they have been uncovered by plowing or by burning. On level or gently sloping soils there is little to no damage from normal rains because the sands allow for the quick penetration of rain water into the soil (Smith, 1962). Clay soils, especially those compacted by cattle grazing are susceptible to superficial erosion after rains due to their reduced capacity for water infiltration and due to a greater amount of surface runoff. Agricultural burning on clay soils on slopes tends to cause soil erosion (Mobley *et al*., 1973). The effect of water runoff on some types of clay soil on slopes is to produce gullies.

Contrary to popular opinion, soil heating produced by fires is only superficial and slight (Heyword, 1938; Stone, 1971). In a study of sugarcane burning in Cuba, temperatures of the flames were measured at between 600°C and 750°C, whereas the soil temperate at a depth of 2 cm was never more than 34°C (Velazco *et al*., 1968). Similarly in Venezuela, when burning sugarcane, the increase in the soil temperate was a maximum of 6°C at 2 cm depth, which was maintained for only 20 minutes (Arnal, 1976). At a depth of 5 cm, the soil temperature only increased by 1,5°C while burning sugarcane.

The logical sequence of this subject of soils is to evaluate the effect of fire on the soil flora and fauna. In the Atlantic Coast of South Carolina (USA) some forested sites were subjected to annual and periodic burns under the pine canopy during a period of 20 years, whereas others in the same locations were not. When observing species of mycorrhizal fungi in the soil, there were no significant differences in the amount of fungi at depths of 0 to 5 cm or at 13 to 18 cm (Jorgensen & Hodges, 1971). In that same study, populations of bacteria and actinomycetes at those same depths were 51 million/gm in soils without burning, 28 million/gm in soils burned annually and 71 million/gm in soils that were burned every three or four years.

At the same time that the above study was underway, two other researchers measured the population of soil mesofauna, i.e. chiggers, ticks, worms, insects, and others. In that sampling, it was found that the populations of mesofauna were greater in the areas that had been burned annually than in the areas with periodic burning or no burning (Metz & Farrier, 1971). The conclusion of this research was that control burns did not produce any significant changes in the quality or the composition of microbes or soil fauna (Stone, 1971).

The last question regarding soils is the effect of burning on nutrient levels. In the Amazon region of Peru, a study was conducted regarding migratory agriculture and the effect of burning of brush on the soil productivity (Seubert, 1974). Traditional slash and burn was compared with clearing of the site with a bulldozer. The results of the study were as follows:

- The amount of bases in the soil increased markedly with burning.
- The content of exchangeable calcium, magnesium and potassium tripled after burning whereas in the area cleared with a bulldozer there was no change.
- Available phosphorus increased dramatically after burning.
- The organic matter content of the soil did not decrease with burning, but organic carbon and nitrogen did decrease in the area cleared with the bulldozer since the blade scraped off the upper soil layer (humus layer) and pushed it into windrows.

Other authors discussing control burns in coniferous forests of the United States have concluded the prescribed burning in the South normally causes little or no change in the organic content of surface soils (Mobley *et al.*, 1973). Control burning under a pine forest cover does not appear to affect the quantities of bases or mineral nutrients (Stone, 1971). Several studies have shown that control burning that is well planned has no significant impact on water quality (Douglass & Van Lear, 1983).

The effect of fire on the growth of trees and crops

A study of migratory agriculture was mentioned in the previous section. Besides the soils study, tests were conducted with crops on the same site, including upland rice, corn, cassava and soybeans (Seubert, 1974). After two years, the yields of the crops in the burned site were triple those harvested in the area that had been bulldozed. According to Seubert, “The results of this study notably favor the traditional slash and burn agricultural system” to that of mechanical clearing.

In tree plantations, control burning does not appear to have a negative impact on tree growth. In a study of burning under a stand of pines in the United States, Grelen (1976) reported that treatments with control burns had no negative effects on tree survival or on tree growth after thirteen years. In Zambia, where control burning in forest plantations is done, Ross (1976) did not find any reports of significant changes in tree growth after four years.

In a study of burning of wheat straw, there were no differences in grain productivity on the site after twelve years of burning (Stone, 1971).

In the Lower Mississippi River Delta, there have been many wildfires in the lowland hardwood (broadleaf) forests. Toole (1957) reported that more than three fourths of the trees had rot in the base of the trees and that fungi entered into the wounds produced by fire. This substantially reduced the commercial value of the wood in the affected trees. In forests such as these, any type of fire can cause damage to the quality of the trees.

Control burning does not appear to affect the growth of trees in forest plantations if the species are resistant to fire and the fire is light. However, a forest fire that is very hot can cause damage to a forest or, at a minimum, damage the base of the trees and allow rot fungi to enter and reduce the quality and value of the standing timber. When brush and woodland is converted to migratory agriculture, burning gives better results than clearing with mechanical machinery. The burning of crop residues in the field does not appear to affect the site quality.

The effect of exclusion of fire from the environment

The concept of control burning is not new. Farmers have burned their fields prior to replanting them ever since humankind began managing crops. Prescribed burns have been used to preparing land to plant trees since the beginning of silviculture. On the other hand, the concept of using fire for hazard reduction is a relative new idea, but of great utility.

In the region of Landes, France, control burning was practiced in pine stands between 1922 and 1940. During this period, wildfires burned an average of 750 ha per year. During World War II, when control burning was suspended, the amount of fuel accumulation under the pine stands increased and, from 1941 to 1949, forest fires burned over an average of 11,300 ha per year (McArthur, 1967).

Control burns have reduced the number and extension of forest fires in all parts of the world (Hall, 1972). Since its beginning in 1908, the United States Forest Service maintained a policy of exclusion of all fire from the national forests. In 1977, that policy of total fire exclusion was lifted and, starting in 1978, there has been a new policy of control burning to reduce the fuel load on the forest floor in natural forests, especially in the conifer forests in the western part of the country (Chandler *et al*., 1983; Wuerthner, 2006).

In southern United States, there were large and destructive wildfires due to the accumulation of fuel on the forest floor when prescribed burns were not used (R. Cooper, 1975). From 1950 to 1975, control burns were used on more than one million ha of forests on private land. The objective was to eliminate fuels in the forests and reduce the hazard of forest fires (Mobley, 1976). The ecological need for fire in some types of forests and the reduction of the fire hazard by control burns are solid arguments for its use (Mobley, 1976; Pierovich, 1976).

In general terms, the laws established in the Twentieth Century tended to group all types of burning with wildfire and to consider any type of fire an infraction of the law. In Australia, the exclusion of fire from the eucalypt forests resulted in forest fires with the associated loss of property and life. Total exclusion of fire from those forests defeated its own purpose (Crane, 1972). In Zambia, Ross (1976) commented that "there is no doubt that control burns reduce the risk of forest fires and provide greater opportunities for fire suppression by fire fighters". In

Venezuela, Arnal (1976) commented that: "control burning of sugar cane has the great advantage of reducing the risk wildfire in cane fields and in neighboring areas."

Besides the reduction in the risk of a wildfire, the use of control burns has proven important for the health of tree plantations. "The practice of fire exclusion from 1920 to 1970 increased the risk of wildfires and the levels of diseases in the forests of California (Alexander & Hawksworth, 1976).

Many of the problems with insects in forests as well as in agriculture are related to or stimulated by policies of exclusion of prescribed fire (Komarek, 1971). Forest pathologists recognize that burning is a safety measure in some cases (Pierovich, 1976). There is no ecological alternative to a control burn due to its many and important uses for forest management as well as in the agriculture and cattle sector and also for wildlife management (Darley *et al*., 1966). Fire plays an important role in the recycling of nutrients, the energy flow and the food chain (Scotter, 1972).

After the increase in areas that were burned by wildfires in the Unites States, the new policy starting in the later part of the Twenty-first Century is to increase the use of control burns to reduce the danger of wildfires and to improve the ecosystems that depend on fire (Mutch 1994). In the State of Florida, USA, prescribed burns are applied to between 600.000 and 1.400.000 ha per year in forests, in the agricultural sector and for the restoration of forest and grassland ecologies.

It must be understood that the smoke that accompanies burns is a problem in municipal areas as well as on highways. Landowners and the public must understand the value of fire as a forest management tool as well as its negative implications (Long, 2006). The Florida Division of Forestry does not permit burning during very dry and hot weather, or when there is the risk of a fire getting out of control and burning onto adjacent lands. Similarly, prescribed fires are started only when the wind direction moves the smoke away from delicate areas, such as roads, population centers or other sensitive areas (Long, 2006).

The incidence of forest fires in natural forests

Overall, the humid as well as the temperate regions of the tropics have relatively low fire dangers, when compared with the fires that occur on dry sites in the temperate latitudes of the world during the summer months. Nonetheless, due to a general lack of preparation of the forest fire protection organizations in many tropical countries, the infrequent fires in humid and temperate tropical regions can take the fire protection organizations by surprise and can result in large areas being burned with severe damages to natural forests as well as to plantations (McArthur, 1967). In many tropical countries the periodic use of prescribed fire could be the only economic and practical alternative for forest fire protection. The reduction of the fire hazard is of primordial importance for any fire protection system in plantations (McArthur, 1967).

According to Linton (2004), the actual damages caused by forest fires are often exaggerated in official reports by 10% to 50%. The over-estimation of the areas that are affected by forest fires are often made by measuring the perimeter of a burned area and calculating the total area, without considering that there are many islands of vegetation within that perimeter that did not burn. Likewise, there are over-estimations of damage by wildfires in some locations, but where there is little or any lasting or significant effect of the fire on the vegetation.

Between 1982 and 1983, there were many large fires in Borneo that burned over more than three million hectares of humid tropical forest reserve. Between September, 1997, and May, 1998, there were between 6 and 7 million ha of land burned in Indonesia, including 800,000 ha of natural forests. Those fires were mostly on the Islands of Sumatra and Borneo.

In 1995, there were 6,8 million ha burned in Canada (Forestry Source, 2000). Some of the worst forest fires in the United States since the data recording began in 1960, occurred between 2000 and 2007.

Forest fires have varied causes, but the majority are due to human influences, while few are due to natural causes such as lightening. In the Twentieth Century, between 25% and 30% of the fires in the United States were intentional, caused by maliciousness or pyromaniacs (Moore, 1975). Many other fires around the world have been caused by negligence and carelessness of those people who permit agricultural burns to get out of hand or where control burns in forests have escaped from the burn area.

In Zambia, the cost of wildfire control was estimated to be five percent of the total cost of plantation establishment (Ross, 1976). Firebreaks five meters wide are established around plantations to reduce the risk of a fire within the plantation. The cost of control burning in that period, using 8 persons and two vehicles was calculated at US$0.50/ha with a capacity to burn up to 80 ha per day (Ross, 1976). Because of the winds and dry months that occur in Zambia, control burns are made at night, whenever possible. The burning is initiated at the end of the rainy season when there is a minimal risk of a wildfire and when the flames are relatively low. As a general rule, the control burns under pine plantations cause scorching of foliage up to five times the height of the flames. Before burning under pine plantations for hazard reduction, it is always useful to prune the lower branches of the trees to avoid flames running up into the tree tops. In Zambia, an initial pruning is made to 2.2 m when the trees reach 10 m, in order to make a gap between the fuel on the forest floor and the tree crowns.

Pruning for fire prevention is also used in Australia. Pruning to 2.5 m is normal for reducing the risk of fire going into the crowns of the trees (McArthur, 1967). The velocity of a crown fire is more than double the velocity of a wildfire that remains on the ground in a pruned plantation (McArthur, 1967). Fire lines around Australian plantations are generally five to seven meters wide. The cost of fire hazard reduction in 1967 was US$4.20/ha (McArthur, 1967). This total amount can be broken down into the following values: Firebreaks, roads, control burns and personnel training (US$3,08/ha), fire suppression activities (US$0,15/ha), and capital cost of fire equipment (US$0,97/ha) (McArthur, 1967). A fire danger index based on meteorological information is essential for planning the detection and suppression of fires.

In the United States the control burns are more economical for wildfire hazard reduction than any other control method. In the South, the cost of control burns in 1975 averaged US$2.50/ha and in the West in mountainous terrain it varied between US$2.50 and US125/ha, depending on the local conditions (R. Cooper, 1975). Mechanical and chemical fire suppression methods in 1975 averaged between US$65/ha and US$750/ha. In the State of Virginia, the cost of control burns was US$5/ha (Ladrach, 1978). In a financial study in the State of Mississippi, it was shown that a maximum investment of US$172/ha could be justified for fire prevention during the life of a forestry plantation whereas the real cost of fire prevention was just US$15/ha (Moak, 1976).

Night time burns are safer than daytime burns with regards to controlling the fire and keeping it within the designated area. However, nighttime burns present a greater problem with smoke on highways and the reduced visibility of drivers at night where smoke crosses a road. The smoke problem is greater when there are temperature inversions that trap the smoke near the surface of the land. Under such conditions, there are great risks for highway traffic that must be taken into account (Mobley *et al*., 1973).

Conclusions

This literature review of the impact of fire on the environment shows that when there is fire on erodable soils and slopes it can lead to accelerated erosion. Wildfires that are very hot can destroy the commercial value of wood in forests, either natural or plantations.

On the other hand, control burns carried out at the right time and that do not generate high heat do not affect the growth of trees or of agricultural crops established afterwards. Such fires do not cause soil damage, they cause minimal air pollution when compared with other sources of pollution, and they do not cause untoward damage to wildlife. Fine air borne particles such as those produced by smoke are necessary for the formation of water droplets and rain (Darley *et al*., 1966), but high concentrations of smoke particles in the atmosphere can cause excess condensation in the clouds and result in greater refraction of sunlight and a reduction of the amount of light reaching the surface. Although much of the formation of these particles is due to the burning of fossil fuels (coal and oil), smoke from wildfires and control burns can also contribute to a reduction in sunlight reaching the surface. Wildfires produce much more smoke in the air than do control burns when the burns are carried out under optimum conditions. The use of control burns can minimize the risk of wildfires as well as the extent of land area burned by wildfires. This is a solid argument for the use of control burns as a method for reducing smoke particles in the air.

Prescribed burns play an important role in the reduction of the risk of forest and agricultural fires, and are an economic method of land management. In many parts of the world it has been shown that the incidence of wildfires increases when control burns are not utilized.

The danger of wildfires is generally considered to be less in the tropics than in temperate regions of the world. Nonetheless, infrequent wildfires in the tropics can cause very significant damages due to the size of the areas affected during extended droughts and due the general lack of preparation of personnel and the availability of equipment for fire suppression.

There is a need to form crews of fire fighters that are well trained for fire suppression. This requires the use of classroom training courses as to the behavior of wildfire and the methods to combat fires, as well as field practices of burning as a tool for training in fire suppression methods.

It is important to promote and create legislation that permits and also regulates the use of control burning based on the conclusions of the research carried out as to the effect of fire on the environment. It has been clearly shown that by prohibiting all classes of fire in the environment, there will be an increase in the number and severity of wildfires in the forests. Fire, correctly managed, is an effective tool and it is beneficial to forestry, to agriculture and pasture management and for the environment.

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