FEASIBILITY OF CULTIVATION OF SUGARCANE IN AGROFORESTRY SYSTEMS

Luís Fernando Guedes Pinto[1]; Marcos Silveira Bernardes[2]*; Gerd Sparovek[3]

[1]*Instituto de Manejo e Certificação Florestal e Agrícola, C.P. 411 - 13400-970 - Piracicaba, SP - Brasil*
[2]*USP/ESALQ - Depto. de Produção Vegetal, C.P. 9 -13418-900 - Piracicaba, SP - Brasil.*
[3]*USP/ESALQ - Depto. de Solos e Nutrição de Plantas.*
**Corresponding author <msbernar@esalq.usp.br>*

ABSTRACT: Brazil is the world's main sugarcane producer and the production system has changed abiding to legal and technical recommendation. In Piracicaba many smallholders grow sugarcane in steep areas. Under such situation, mechanization at harvest makes cultivation impossible. This work assess the viability of agroforestry systems on joining crop production and conservation of natural resources. Soils at 12-20% slope class were identified, tree species which could be cultivated along with sugarcane were selected, and the design of the systems to be adopted was evaluated. Identified area occupies 11,556 ha and the most representative soil types are Typic Kandiuldult and Lithic Hapludoll. The exotic species coconut, eucalyptus, pejibaye and rubber, and eight native species have potential to be grown in contourhedgerows with sugarcane. Initial planting of exotic, domesticated trees is recommended, and gradual introduction of native, non-domesticated species, can be set according to their ecological requirements.
Key words*:* contourhedgerows, erosion, exotic trees, native trees

VIABILIDADE DO CULTIVO DE CANA-DE-AÇÚCAR E SISTEMAS AGROFLORESTAIS

RESUMO: O Brasil é o principal produtor mundial de cana-de-açúcar e seu sistema de produção tem sofrido mudanças devido a aspectos legais e técnicos. Na região de Piracicaba, grande parte dos pequenos produtores cultiva cana-de-açúcar em áreas de grande declividade, mas a mecanização da colheita tem inviabilizado seu cultivo nesta condição. Assim, foram identificados e selecionados terras e árvores visando compatibilizar a produção da cultura e a conservação de recursos naturais em sistemas agroflorestais. Os solos presentes no intervalo de 12-20% de declividade foram identificados, selecionamos árvores com potencial para serem cultivadas com cana-de-açúcar foram selecionados e os desenhos dos sistemas a serem adotados foram avaliados. A classe de declive identificada ocupa área de 11.556 ha e Argissolo Vermelho-Amarelo e Neossolo Litólico são os solos mais representativos. As espécies arbóreas exóticas coco-anão-verde, eucalipto, pupunheira, seringueira e outras oito espécies nativas têm potencial para serem cultivadas com cana-de-açúcar em sistemas agroflorestais de aléias em contorno. Sugere-se o plantio inicial de árvores exóticas domesticadas e a introdução gradual de espécies nativas não domesticadas, de acordo com suas exigências ecológicas.
Palavras-chave*:* aléias, árvores nativas, árvores exóticas, erosão

INTRODUCTION

Recent technological changes and the improvement of the environmental legislation, have driven sugarcane (*Saccharum officinarum* L.) sector through significant changes in the State of São Paulo, Brazil. The driving forces are the restriction of pre-harvest crop burning and the consequent need for mechanical harvest. Improving environmental quality brought new challenges for sugarcane farmers. In the region of Piracicaba the crop occupies 86,000 ha (49.3% of the total area) predominantly managed by smallholders, and 37% of the currently cultivated area is not suited for mechanization (Sparovek et al., 1997). Monocropping of sugarcane has also impacted the biodiversity of the Atlantic Forest, an ecosystem considered as of high conservation priorities by international studies (Myers et al., 2000).

This scenario creates new opportunities for agricultural systems that meet both the crop production and the conservation of the natural resources. Agroforestry Systems (AFS) are suited for that because in tropical regions, there may be complementary use of light, water and nutrients by crops and trees, resulting in higher biological production than monocropping (Ong et al., 1991). AFS contribute to soil conservation hence the presence of trees significantly controls soil erosion, specially in moderate slope conditions (Young, 1988); AFS are adapted to small properties and familiar agriculture, combining market-oriented production with consumption-driven products, such as fruits, staple food, firewood, green manure, fodder and shelter to animals (Nair, 1989); AFS support relatively high biodiversity compared to monocultures and the quality and connectivity of the agricultural matrix maintenance, and recover biodiversity (Poiani et al., 2000; Perfecto & Vandermeer, 2002; Pimentel et al., 1992; Vandermeer et al., 1998; Moguel & Toledo, 1999); there is reduction of pests in AFS compared to intensive land use and AFS contribute to the survival of functional insects, like pollinators and pest predators (Klein et al., 2002 a, b).

This paper aims to identify areas in the region of Piracicaba where AFS and sugarcane production could improve soil conservation, select tree species which can be potentially cultivated in AFS with sugarcane, and identify AFS designs for the cultivation of sugarcane in areas with moderate slope.

MATERIAL AND METHODS

Central coordinates of Piracicaba are 22°42’30’’S and 47°38’01’’W; the mean altitude is 554 m (BSL). Region’s climate according to Koeppen’s classification is Cwa or wet sub-tropical, with rainy summer and dry winter (Sentelhas et al., 1998). The county occupies 137,134 ha and is representative of larger surrounding area with similar soil, climate and socioeconomic conditions.

The identification of suited areas for AFS was based on a digital, 1:100,000 soil map (IAC, Instituto Agronômico de Campinas) and a topography contour, 1:50,000 map (IBGE, Insituto Brasileiro de Geografia e Estatística). Sampling embodied the region of the Piracicaba River Basin, which occupies 104,915 ha, or 76% of the county’s area. Criteria for suitability of mechanization was slope, which is the main variable for operation efficiency and for soil erosion susceptibility. The inferior limit was 12% - maximum slope for mechanization in the conventional system of cultivation - and the superior 20%, where the efficiency for soil conservation in contourhedgerows decreases drastically (Young, 1997).

The digital soil and slope maps were analyzed through the Geographical Information System Idrisi (Eastman, 1992). The overlaying slope and the soil maps allowed identification of suitable soils for cultivation in AFS.

Trees were selected according to the multipurpose concept based on the adaptation to the local soil and climate conditions; potential to contribute for soil conservation; profitability; acceptance by local farmers; local processing and conditions for commercialization and contribution to biodiversity (Wood, 1990). Selection of AFS designs was based on literature, in a search for agroforestry practices compatible with the crop farming (Raintree, 1990).

RESULTS AND DISCUSSION

Suited areas

The 12-20% slope interval covers an area of 11,556 ha of the sampled region, which represents 8.4% of the total area. Total and relative soil classes area in the slope of 12-20% were: Typic Kandiudult 5,406 ha or 3.9%; Lithic Hapludoll 2,931 ha or 2.1%; Typic Quartzpsamment 1,182 ha or 0.9%; Typic Hapludox 718 ha or 0.5%; Rhodic Eutrudox 295 ha or 0.2%, and others 1,022 ha or 0.8%. Soils are spread out instead of grouped (Figure 1), what increases the possibility of the occurrence of high diversity in socio-economic conditions and management practices.

Predominant soils (Typic Kandiudult and Lithic Hapludoll) presented variable fertility, an attribute that, if necessary, can be amended for the agroforestry production. Susceptibility to erosion is high because of the small soil depth, and clay increase in the deeper soil horizons and is moderate at steep slopes. These soils do not present limitations for water availability neither for sugarcane nor for the intercropped trees.

Tree selection

From the 103,790 ha cultivated in Piracicaba, 50,981 ha are occupied with sugarcane and 45,974 ha with pasture (Cati, 1997). There are also 1,494 ha of eucalyptus, 1,920 ha of fruit trees and 18 ha of other perennials, in a total of 888 properties with different land uses. Despite the predominance of sugarcane and pasture, trees play an important role in the diversification of small areas, which is an important factor towards adoption of AFS. Therefore the potential of 5 tree species suitable for AFS with sugarcane was initially analyzed. Table 1 summarizes the species and presents relevant information for cultivation.

Eucalyptus (*Eucalyptus grandis* Hill ex Maiden and *Eucalyptus citriodora* Hook) and rubber (*Hevea brasiliensis* Muell. Arg.), cultivated in the region of Piracicaba, are adapted to the local soil and climate conditions (Bernardes & Fancelli, 1990; Lima, 1993). Coconut (*Cocos nucifera* L.) and pejibaye (*Bactris gasipaes* Kunth) have restrictions to be grown in areas with low temperatures and soils with low water retention capacity; these species should not be cultivated in low lands and irrigation may be necessary in some cases (Bovi, 1993; Passos, 1998). The potential of species to contribute to soil conservation depends on their runoff interception and cover effects (Young, 1997). The relative contribution to soil conservation, based on these criteria is shown in Table 1.

Economic performance was evaluated by comparing the net present value (NPV, US$ ha^{-1} y^{-1}) of the monocropping of each tree with sugarcane monocropping. All tree species presented greater or similar NPV when compared to sugarcane (Table 2). Consequently, AFS are expected to be more profitable than monocropping, and that agrees to the results of Benjamin et al. (2000).

Nevertheless, none of the previously selected species contributes to local biodiversity, because they are exotic to the Atlantic Forests. To provide high biodiversity of AFS native trees were also evaluated. Selected native species of the State of São Paulo (Ferretti et al., 1995) were compared regarding the potential of cultivation and use (Carvalho, 1994). Seven Promising Timber Species (PTS), described as highly economic value timber trees with acceptable forestry performance and suited for soil rehabilitation were selected, and are recommended for pure and mixed plantations in the southern and northern Brazil (Carvalho, 1994). The palm tree, *Euterpe edulis* Mart. (Ferreti, 1995), was also selected. Table 3 presents the selected species and some of their forestry properties.

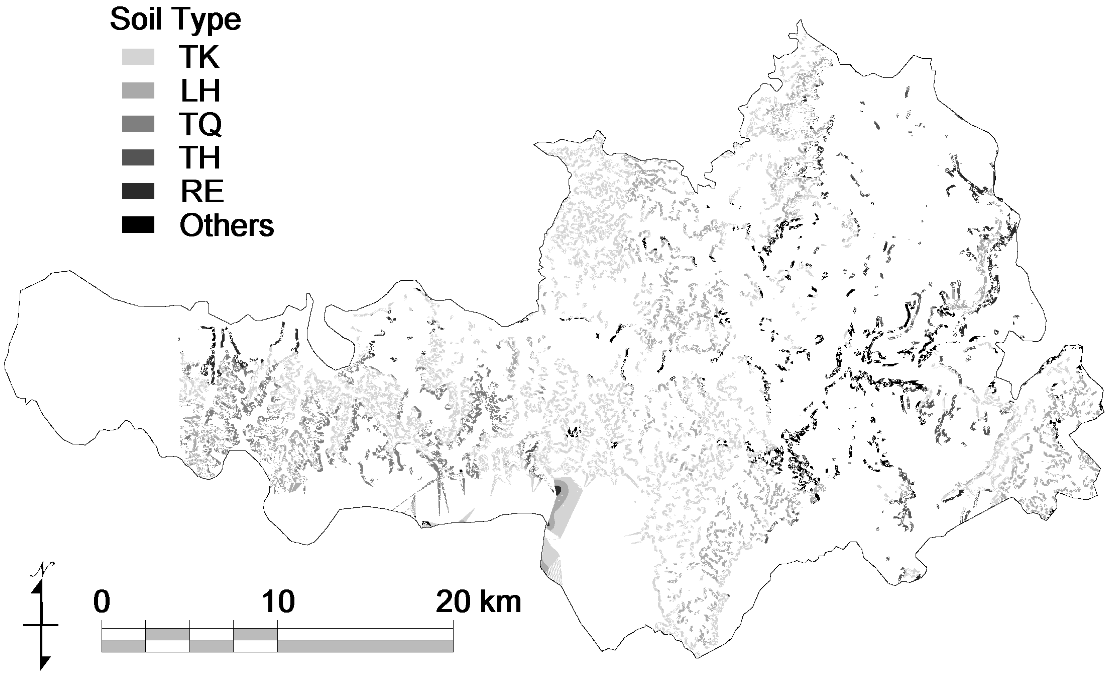

Figure 1 - Soils of the Piracicaba basin present in the county of Piracicaba in the slope range of 12-20%.*
*TK: Typic Kandiudult, LH: Lithic Hapludoll, TQ: Typic Quartzpsamment, TH: Typic Hapludox, RE: Rhodic Eutrudox.

Table 1 - Domesticated exotic tree species selected for agroforestry systems with sugarcane in Piracicaba, Brazil*.

Species	Product	Contribution to soil conservation	Soil fertility requirement	Drought resistance	Level of mechanization	Labor demand
Coconut	Fruit	medium	medium	medium	Low	medium
Eucalyptus	Timber, firewood, leaves for oil	high	low, medium	medium	Medium	low, medium
Pejibaye	Palm heart	high	medium	medium	Low	high
Rubber	Latex, timber, firewood	high	low	high	Low	medium

Adapted from Bernardes & Sparovek (1998)

Table 2 - Net present value of sugarcane and the exotic domesticated tree species.

Species	NP (US$ ha^{-1} $year^{-1}$)	Longevity	Source
Sugarcane	370	7 years (6 harvests)	FNP (1998)
Coconut	2.503	30 years	FNP (1999)
Eucalyptus	301	7 years (1 harvest for paper industry)*	Rodriguez & Rodrigues (1999)
Pejibaye	715	15 years	FNP (1999)
Rubber	4.287	32 years	FNP (1999)

*It could reach higher values with production of timber for sawmill or leaves for oil production

Table 3 - Native tree species selected for agroforestry systems with sugarcane in Piracicaba, Brazil.

Species	Product	Expected growth	Maximum reported growth	Shade tolerance
			m^3 ha^{-1} $year^{-1}$	
Cariniana estrellensis (Raddi) Kuntze	timber, firewood	medium to fast	17.20	tolerant in the juvenile stage
Cariniana legalis (Mart.) Kuntze	timber, firewood	medium to fast	21.00	tolerant in the juvenile stage
Centrolobium tomentosum Benth.	timber, firewood	fast	20.0	tolerant in the juvenile stage
Cordia trichotoma (Vell) Arrabida ex Steudel	timber, firewood	slow to medium	10.70	tolerant in the juvenile stage
Didymopanax morototonii (Aubl.) Dcne et Planch.	timber, firewood	fast	21.17	non-tolerant
Euterpe edulis Mart.	palm heart	medium	-	tolerant in the juvenile stage
Peltophorum dubium (Spreng.) Taub.	timber, firewood	fast	19.60	tolerant in the juvenile stage
Zeyheria tuberculosa (Vell.) Bur.	timber, firewood	medium to fast	24.0	tolerant in the juvenile stage

Adapted from Carvalho (1994) and Ferreti et al. (1995)

It is recommended initial plantation of domesticated species to demonstrate the potential success of the adoption of trees in AFS combined with sugarcane, as they have more predictable performance, known biology, silvicultural practices and market options (Huxley, 1996). Native, non-domesticated trees should be introduced gradually according to their ecological requirements, with special attention to light use. The shade-tolerant species should be introduced below the canopy of the rows of trees, taking advantage of the microclimatic modifications that benefit their development. The non shade-tolerant species could be introduced in the edge of the rows. Finally, both exotic and native species provide products (wood, fruits, latex, leaves, palm heart) that can be processed in small scale mills, or traded by own producers or their cooperatives.

AFS design

Contourhedgerow (CH) is the main type of AFS to reduce runoff and control soil erosion on cropping in steep slope conditions (Young, 1988). Fujisaka (1997) synthesized the situations where adoption of CH is recommended, which are very similar to the Piracicaba region: a) in humid and sub-humid climates, combining erosion control with agricultural cultivation from gentle to moderate slopes; b) where the soils are relatively productive and erosion is a major problem; c) where the local population has reached a level in which extensive land use is not possible anymore.

The adoption of CH also provides benefits to the systematization of mechanized sugarcane fields. The expected gradual attenuation of the slope between tree rows (Garrity, 1996) favors mechanization in alleys of moderate slope. The presence of tree rows allows to till in parallel lines, to eliminate terraces and irregular contour lines of the crop, and to increase the length of the planting lines, favoring operational efficiency of agricultural machines (Mialhe et al., 1983). The proposed sugarcane AFS can also be adopted in slopes inferior than 12%. However, the focus of this study was to identify the most critical conditions, where monocropping is not recommended and the adoption of AFS may allow cultivation with acceptable erosion rates.

The areas restricted to mechanization are distributed in discontinuous small spots, indicating that the AFS should be designed in small units and in different positions in relation to solar radiation (Figure 1). As nutrients and water were not considered limiting for crop production, light can be considered the main factor for the design of the AFS (Ong et al., 1991). The exact spatial arrangement of the alleys and tree rows that provides the best resource capture and optimum land use rate, should be evaluated in field experiments driven by the previous evaluation through agroforestry models, such as HyPAR (Mobbs et al., 1998) and WaNuLCAS (Van Noordwijk & Lusiana, 1999).

ACKNOWLEDGEMENTS

To FAPESP, for a schollarship supplied to L.F.G. Pinto, through the project number 99/00797-7 and thank the Piracena Project for the use of the digital data.

REFERENCES

BENJAMIN, T.J.; HOOVER, W.L.; SEIFERT, J.R; GILLESPIE, A.R. Defining competition vectors in a temperate alley cropping system in the midwestern USA: 4. The economic return of ecological knowledge. **Agroforestry Systems**, v.48, p.79-93, 2000.

BERNARDES, M.S.; FANCELLI, A.L. Seringueira como uma possível cultura intercalar para os pomares de Citrus. In: SIMPÓSIO DA CULTURA DA SERINGUEIRA, 2., Piracicaba, 1987. **Anais**. Piracicaba: ESALQ, Depto. de Agricultura, 1990. p.223-252.

BERNARDES, M.S., SPAROVEK, G. **Sistemas de produção para áreas com restrições à colheita mecanizada de cana-de-açúcar**. Piracicaba: ESALQ, Depto. de Agricultura, 1998.

BOVI, M.L.A. Palmito pupunha: informações básicas para o cultivo. In: ENCONTRO SOBRE PRODUÇÃO DE PALMITO, 1., Piracicaba, 1993. **Anais**. Piracicaba: ESALQ, Depto de Agricultura; CALQ, 1993. p.12-23.

CARVALHO, P.E.R. **Espécies florestais brasileiras:** recomendações silviculturais, potencialidades e uso da madeira. Brasília: Embrapa, 1994. 640p.

CATI. **Levantamento subjetivo a nível de município**. Piracicaba: Secretaria de Agricultura do Estado de São Paulo, 1997.

EASTMAN, J. R. **Idrisi - user's guide.** Worcester: Clark University, 1992.

FERRETTI, A.R.; KAGEYAMA, P.Y.; ARBOEZ, G.F.; SANTOS, J.D.; BARROS, M.I.A.; LORZA, R.F.; OLIVEIRA,C. Classificação de espécies arbóreas em grupos ecológicos para revegetação com nativas no Estado de São Paulo**. Florestar Estatístico**, v.3, n.7, p.73-77, 1995.

FNP. **Agrianual 1999**. São Paulo: Argos, 1998. 535p.

FNP. **Agrianual 2000**. São Paulo: Argos, 1999. 546p.

FUJISAKA, S. Sense and nonsense: contour hedgerows for soil erosion control. **Agroforestry Forum**, v.8, p.8-11, 1997.

GARRITY, D. P. Tree-soil-crop interactions on slopes. In: ONG, C.K.; HUXLEY, P. (Ed.) **Tree-crop interactions:** a physiological approach. Wallingford: CAB & ICRAF, 1996. cap.8, p.299-318.

HUXLEY, P. Biological factors affecting form and function in woody-non-woody plant mixtures. In: ONG, C.K.; HUXLEY, P. (Ed.) **Tree-crop interactions:** a physiological approach. Wallingford: CAB & ICRAF, 1996. cap.7, p.235-298.

KLEIN, A.-M.; STEFFAN-DEWENTER, I.; TSCHARNTKE, T. Predator-prey ratios on cocoa along a land-use gradient in Indonesia. **Biodiversity and Conservation**, v.11, p.683-693, 2002a.

KLEIN, A.-M.; STEFFAN-DEWENTER, I.; BUCHORI, D.; TSCHARNTKE, T. Effects of land-use intensity in tropical agroforestry systems on coffee flower-visiting and trap-nesting bees and wasps. **Conservation Biology**, v.16, p.1003-1014, 2002b.

LIMA, W. de P. **Impacto ambiental do eucalipto**. São Paulo: Edusp, 1993. 301p.

MIALHE, L.G.; RIPOLI, T.C.; MILAN, M. Algumas considerações sobre o formato e espaçamento de plantio. **Álcool & Açúcar**. v.3, p.28-42, 1983.

MOGUEL, P.; TOLEDO, V.M. Biodiversity conservation in traditional coffee systems of Mexico. **Conservation Biology**. v.13, p.11-21, 1999.

MOBBS, D.C.; CANNELL, M.G.R.; CROUT, N.M.J.; LAWSON, G.J. Complementarity of light and water use in tropical agroforests. I. Theoretical model outline, performance and sensitivity. **Forest Ecology and Management**, v.102, p.259-274, 1998.

MYERS, N.; MITTERMEIER, R.A.; MITTERMEIER, C.G.; FONSECA, G.A.B., KENT, J. Biodiversity hotsposts for conservation priorities. **Nature**, v.403, p.853-858, 2000.

NAIR, P.K.R. **Agroforestry systems in the tropics**. London: Kluwer, 1989. 664p.

ONG, C.K.; CORLETT, J.E.; SINGH, R.P.; BLACK, C.R. Above and below ground interactions in agroforestry systems. **Forest Ecology and Management**, v.45, p.45-57, 1991.

PASSOS, E.E.M. Ecofisiologia do coqueiro. In: FERREIRA, J.M.S.; WARWICK, D.R.N.; SIQUEIRA, L.A. (Ed.) **A cultura do coqueiro no Brasil**. Brasília: Embrapa, 1998. cap.3, p.65-72.

PERFECTO, I.; VANDERMEER, J. Quality of agroecological matrix in a tropical montane landscape: ants in coffee plantations in southern Mexico. **Conservation Biology**, v.16, p.174-182, 2002.

PIMENTEL, D.; STACHOW, U.; TAKACS, D.A.; BRUBAKER, H.W; DUMAS, A.R.; MEANEY, J.J.; O'NEIL, J.A.S.; ONSI, D.E.; CORZILIUS, D.B. Conserving biological diversity in agricultural/ forestry systems. **BioScience**, v.42, p.354-362, 1992.

POIANI, K.A.; RICHTER, B.D.; ANDERSON, M.G.; RICHTER, H.E. Biodiversity conservation at multiple scales: functional sites, landscapes and networks. **BioScience**, v.50, p.133-146, 2000.

RAINTREE, J.B. Theory and practice of agroforestry diagnosis and design. In: Macdicken, K.G., Vergara, N.T. (Ed.) **Agroforestry**: classification and management. New York: John Wiley & Sons, 1990. p.58-97.

RODRIGUEZ, L.C.E.; RODRIGUES. F.A. Plantações florestais: rentabilidade e visão de longo prazo. **Preços Agrícolas**, v.14, p.10-12, 1999.

SENTELHAS, P.C.; MARIN, F.R.; PEREIRA, A.R.; ANGELOCCI, L.R.; VILLA-NOVA, N.A. BARBIERI, V. **Análise dos dados climáticos e do balanço hídrico climatológico de Piracicaba (1917-1997)**. Piracicaba: ESALQ, Depto. de Ciências Exatas, 1998. 81p.

SPAROVEK, G.; PEREIRA, J.C.; ALLEONI, L.R.F.; ROSSETTO, R. Aptidão das terras de Piracicaba (SP) para o corte mecanizado de cana-de-açúcar. **Stab**, v.15, p.6-9, 1997.

VANDERMEER, J.; VAN NOORDWIJK, M; ANDERSON, J.; ONG, C.; PERFECTO, I. Global change and multi-species agroecosystems: Concepts and issues. **Agriculture, Ecosystems and Environment**, v.67, p.1-22, 1998.

VAN NOORDWIJK, M.; LUSIANA, B.; WaNuLCAS, a model of water, nutrrient and light capture in agroforestry systems. **Agroforestry Systems**, v.43, p.217-242, 1999.

WOOD, P.J. Principles of species selection for agroforestry In: MACDICKEN, K.G.; VERGARA, N.T., (Ed.) **Agroforestry:** classification and management. New York: John Wiley, 1990. p.290-309.

YOUNG, A. The effectiveness of contour hedgerows for soil and water conservation. **Agroforestry Forum**, v.8, p.2-4, 1997.

YOUNG, A. Agroforestry in the control of soil erosion by water. **Agroforestry Abstract**, v.1, p.39-48, 1988.

Received September 27, 2002
Accepted April 28, 2003