Annals of Tropical Research 22[1&2]:89-104 (2000)
ViSCA, Leyte, Philippines

Soil biological parameters as indicators of sustainability of natural and agricultural land use systems

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ABSTRACT

Nagaraja M.S. and V.R. Ramakrishna Parama. 2000. Soil biological parameters as indicators of sustainability of natural and agricultural land use systems. *Ann. Trop. Res.* 22[1&2]:89-104.

Evaluating the sustainability of any land use system poses challenging methodological questions. The study conducted at the University of Agricultural Sciences, Bangalore, India revealed that management practices under different land use systems have altered soil functions and processes. The biological changes observed in man-made systems relative to the natural systems are important indicators of the impacts of management practices. Strategies based on these biological indicators and correlating them with productivity of an ecosystem would be a tool to evaluate sustainability of the land use systems. The natural systems such as grasslands and mixed forests, gave higher soil microbial biomass and enzyme activities (dehydrogenase, acid phosphatase and urease) than the agricultural systems. The results suggest that biomass turnover and disturbance through cultivation, pesticides, fire, etc. determine the nature and degree of biological activity in an ecosystem. Microbial biomass and enzyme activity can be used as indicators to evaluate land use system sustainability.

Keywords: land use systems. soil biological parameters. soil enzymes. soil microbial biomass. sustainability.

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INTRODUCTION

The sustainability of land use systems is an important issue since many agricultural systems have failed and collapsed due to various causes and one of which is land degradation. Intensive cultivation, high erosion rates, and improper nutrient management are some of the causes of land degradation. Changes in the soil which result in soil degradation could be used to evaluate the sustainability of agro-ecosystems (Mulongoy and Merckx, 1993; Woomer and Swifft, 1994). Extensive documentation has been made on the concepts of sustainability based on several strategies such as total production, economic returns, floral and faunal diversity, nutrient cycling patterns and others (FAO, 1989; Lal, 1994). Soil attributes are preferred as ecological indicators because of the vital role that soil plays in terrestrial ecosystems.

The primary function of soil in an ecosystem is related to the processes of nutrient cycling. The processes include energy exchange among the different biotic and abiotic groups, nutrient conversions, floral-faunal interactions, nutrient losses and various soil biochemical reactions. Many of the above soil processses are mediated by floral and faunal interactions with plant communities. They are also influenced to a variable extent by land management practices (Greenland and Szabolcs, 1994). Research on soil attributes among natural and manmade ecosystems would be useful in developing a holistic approach for sustainable food production.

The sustainability of different land use systems can be evaluated using several indicators. These can be broadly grouped into biomass carbon and recycling (Mulongoy and Merckx, 1993), relative size of the inorganic nutrient pool (Odum, 1969) and productivity of the system (Lal, 1994). Biological parameters appear more precise as they are very sensitive to changes in soil quality. The microbial biomass, and hence their enzyme activities, are influenced to a variable extent, by agricultural practices (Jenkinson, 1990). Variations are attributed to diversities in vegetation, cropping history, soil amendments, agricultural practices, etc. (Spier *et al*., 1979; Tabatabai, 1982). This study aimed at evaluating the sustainability of natural and agricultural land use systems based on soil biological parameters.

MATERIALS AND METHODS

The study site

All the land use systems monitored in this study were located within the campus of the University of Agricultural Sciences, Bangalore, India at a latitude of 12^0 58' N and longitude of 77^0 35' E. The climate which prevailed was cool summer and warm winter with a mean annual rainfall of 844 mm. The average maximum temperature was 30^{0}C and the average minimum temperature was 19.3^{0}C. The soils were developed from granites and gneisses and classified as fine, kaolonitic, isohyperthermic, Typic Kandiustalf. The land use systems monitored included ungrazed and grazed grasslands (dominated by *Cymbapogan* and *Heteropogan* spp.), mixed forest, teak plantation, grape and mango orchard, and irrigated dryland agricultural systems. Detailed descriptions of the experimental sites are given in Tables 1 and 2.

Soil sampling and analyses

Soil samples were collected from all land use systems in March (summer sampling). At the time of sampling, there was no addition or removal of biomass in the natural forests and the ungrazed grasslands. However, before sampling, litter had been removed from the teak plantations to prevent fire occurence. Pruning, irrigation and fertilizer application (2 months.; 25% of the total NPK) were recorded only in the grape orchard. In the case of the agricultural systems, no specific crop management practices were recorded as the crops had been harvested. Pesticide applications were not recorded in any of the land use systems at the time of sampling.

Three sites were chosen from each land use system for soil sampling purposes. Surface soil samples (0-15 cm) were collected from 3 spots in each site and made into one composite sample after air drying. The composite soil samples (in 3 replicates) were analyzed for organic C following Walkley and Black wet oxidation method (Jackson, 1973), total N by Macro-Kjedahl method (Jackson, 1973) and maximum water holding capacity by Keen's Cup method (Piper, 1966).

Determination of soil microbial biomass

Soil microbial activity was restored by pre-incubating air dried soils at 35 ± 2^{0}C for 10 days, after adjusting the soil moisture to field capacity (60%

Table 1. Description of the different land use systems studied

Land use systems	Vegetation	Years	System	Irrigation	External nutrients	Nutrient Removal
Ungrazed grassland*	grasses	>20 years	natural	nil	nil	nil
Grazed grassland*	grasses	>20 years	natural	nil	nil	grasses
Mixed forest	trees, brushes	>20 years	natural	nil	nil	nil
Teak plantations	teak	12 years	man-made	nil	nil	litter
Grape orchard	grapes	>20 years	man-made	irrigated	fert + FYM	fruits + cane
Mango orchard	mango	>20 years	man-made	nil	fertilizer	fruits
Irrigated agriculture (fertilizer + FYM)	FM + corn	12 years	man-made	irrigated	fert. + FYM	grain + straw
Irrigated agriculture (fertilizer only)	FM + corn	12 years	man-made	irrigated	fertilizer	grain + straw
Dryland agriculture (fertilizer + FYM)	FM	18 years	man-made	nil	fert. + FYM	grain + straw
Dryland agriculture (fertilizer only)	FM	18 years	man-made	nil	fertilizer	grain + straw

FYM - farm yard manure
FM - finger millet
* *Cymbapogan* spp and *Heteropogan* spp

Table 2. Amounts of biomass added and recycled, nutrients added and total soil organic-carbon among the different land use systems

Land use systems	Residue Biomass$ Recycled (t ha^{-1} yr^{-1})	FYM added# (t ha^{-1} yr^{-1})	Net OM Recycled+ (t ha^{-1} yr^{-1})	Soil Organic Carbon (%)	Nutrients added externally^ (kg ha^{-1} yr^{-1}) N	P_2O_5	K_2O
Ungrazed grassland	6.7	0	6.7	1.37	0	0	0
Grazed grassland	2.5	0	2.5	0.56	0	0	0
Mixed forest*	6.7	0	6.7	2.48	0	0	0
Teak plantations*	1.0	0	1.0	0.60	0	0	0
Grape orchard*	1.2	12.5	13.7	1.60	325.0	362.5	225.0
Mango orchard*	4.4	0	4.4	1.18	73.0	18.0	68.0
Irrigated agriculture (fert + FYM)	10.0	15.0	25.0	0.86	350.0	200.0	300.0
Irrigated agriculture (fertilizer only)	7.5	0	7.5	0.66	200.0	125.0	150.0
Dryland agriculture (fert + FYM)	6.6	10.0	16.6	0.58	150.0	87.5	125.0
Dryland agriculture (fertilizer only)	4.8	0	4.8	0.30	50.0	37.5	25.0

$ Residue biomass recycled including roots and stubble and only litter in perennial trees
# Farm yard manure prepared using animal excreta with plant litter and crop residues
+ Net organic matter recycled = residue biomass recycled + FYM added
* Biomass recycled only through litter biomass is considered
^ Urea, single super phosphate and muriate of potash were commonly used. In grapes, complex fertilizer was also applied

of maximum water holding capacity or WHC). Two sets of pre-incubated soil samples were used for microbial biomass estimation (one for fumigation and the other for non-fumigation). The set for fumigation received 1 ml of ethanol-free $CHCl_3$ while the other set did not. Both sets were incubated for 24 h. Fume-free soils (after fume expulsion in the fumigated samples) were extracted with 80 ml of 0.5 *M* K_2SO_4 by shaking for 30 min and then filtering through Whatman No. 42 filter paper. The difference between fumigated and non-fumigated samples was used in determining microbial biomass by quantifying ninhydrin reactive-N (NR-N) (Joergensen and Brookes, 1990). From these NR-N values Biomass-C and N were derived by multiplying them with the values 24.0 and 2.8, respectively (Carter, 1991).

Determination of enzyme activity

Pre-incubation: For enzyme analyses, the soil samples (10g for urease, 2g for phosphatase and 5g for dehydrogenase activity) were moistened to field capacity (60% of max. WHC) and incubated at 37 ± 2 ^{0}C for 10 days in a biological oxygen demand (BOD) incubator to restore normal biological activity. The pre-incubated soil samples were used for the determination of enzyme activities (Kiss *et al*., 1975). The quantity of soil sample required for enzyme analyses was predetermined by following the methodology of Basavaraj (1984).

Urease enzyme: 500ppm urea was added to pre- incubated soils as substrate for urease and the soils were incubated at 35 ± 2°C for 4 h. Unhydrolyzed urea from these incubated samples was determined colorimetrically at 430 nm by complexing it with p- methyl amino benzaldehyde solution (Watts and Crisp, 1954).

Acid phosphatase enzyme: P- nitro phenol phosphate (P-NP-P) was used as substrate for the determination of acid phosphatase activity. Pre-incubated soil samples were incubated with P-NP-P (substrate) at 35 ± 2°C for 1 h. Later, the phosphatase activity was arrested by adding 4 ml of 0.5 *N* NaOH. Para-nitro phenol (P-NP) formed during 1 h incubation, proportional to the phosphatase enzyme, was extracted and quantified colorimetrically at 420 nm by adopting the method of Tabatabai (1982).

Dehydrogenase enzyme: Pre- incubated soils received sufficient quantity of aqueous solution of 2,3,5-triphenyl tetrazolium chloride (TTC) as substrate

ensuring adequate anaerobiosis for TTC reduction (3 ml of 1% TTC solution). These samples were incubated for 24 h in a BOD incubator maintained at 35 ± 2°C. The triphenyl formazan (TPF) formed was extracted with methanol and was determined colometrically at a wavelength of 485 nm (Casida *et al.*, 1964).

Statistical analysis

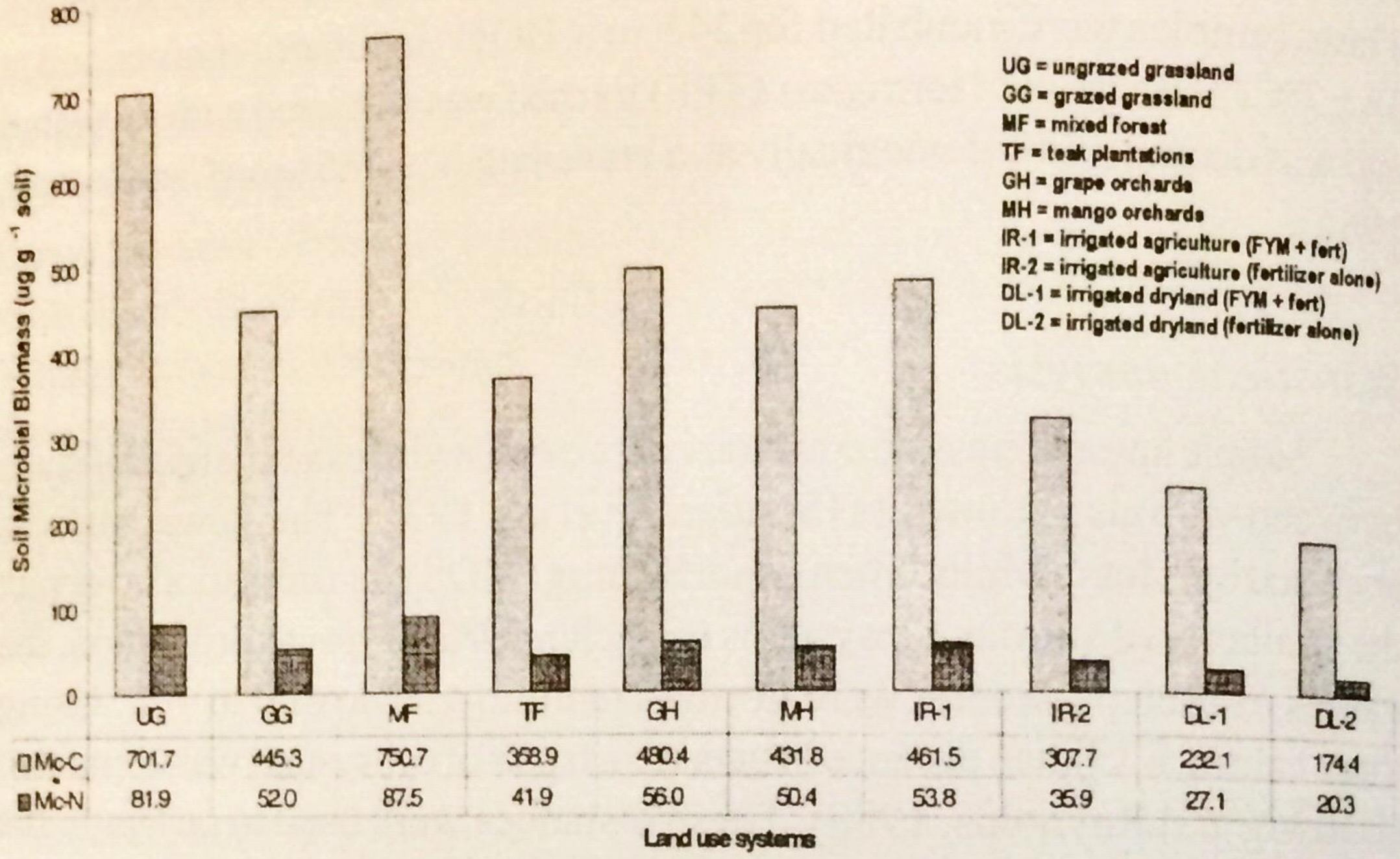
Simple linear regression equations were estimated to examine relationships between various parameters (Sundararaj *et al.*, 1977). The same data was analysed by Metric Multidimensional Scaling (MDS) for ordination to depict the similarity of various ecosystems (Gauche, 1982). Prior to ordination, the values of each parameter were normalized into a scale of 0 to 100. Using these values, Euclidian distance between each pair of ecosystem was computed (Ludwig and Reynolds, 1988). These distances were used to compute the projected values of each land use system on the first two axes of the MDS.

RESULTS AND DISCUSSION

Soil microbial carbon and nitrogen

Soil microbial biomass (SMB), indicated by its carbon (SMB-C) and nitrogen (SMB-N) levels, was higher in ungrazed grassland and mixed forest than in manmade agricultural and grazed grassland systems (Fig.1). SMB-C ranged from 174.4 μ g g^{-1} soil in the dryland agricultural systems without farm yard manure (FYM) application to 750.3 μg g^{-1} in the mixed forest. Microbial biomass in the grazed grassland was significantly lower than in the ungrazed grassland. Similarly, the teak plantation also showed lower microbial biomass compared to the mixed forest. Mango and grape orchards showed slightly lower microbial biomass than the undisturbed natural systems. The irrigated agricultural systems recorded more microbial biomass than the dryland systems. Among the man-made agricultural systems, the land use systems which received both FYM and fertilizers showed larger microbial pool than those receiving chemical fertilizers alone (Fig. 1).

The high microbial biomass in the mixed forest and the ungrazed grassland systems can be due to the high organic-carbon turnover and to the little or no disturbance in these systems (Singh *et al.*, 1989). Among the forests, the



	UG	GG	MF	TF	GH	MH	IR-1	IR-2	DL-1	DL-2
Mc-C	701.7	445.3	750.7	368.9	480.4	431.8	461.5	307.7	232.1	174.4
Mc-N	81.9	52.0	87.5	41.9	56.0	50.4	53.8	35.9	27.1	20.3

Figure 1. Soil microbial biomass carbon (SMB-C) and nitrogen (SMB-N) under different land use systems

natural mixed forest recorded higher soil microbial biomass than the teak plantation. Reduction in recyclable litter biomass in teak might have resulted in the lower microbial biomass. Similarly, reduction in the recyclable residues in the grazed grassland might have caused a decline in its microbial biomass. These observations indicate that the plant biomass carbon turnover is crucial in maintaining microbial activity. Even though the grape orchard had higher soil organic carbon (SOC), the SMB-C and N were lower compared to the natural systems which may be due to recurring disturbances (Gupta *et al.*, 1981). This may also be due to the high usage of copper fungicide in these orchards. Application of FYM in the agricultural systems appears important in maintaining moderate levels of microbial biomass in both dryland and irrigated agricultural systems. Lower microbial biomass in the dryland system compared to the irrigated agricultural systems can be attributed to the low plant biomass or residues turnover (Mulongoy and Merckx, 1993).

Soil dehydrogenase activity

Dehydrogenase, a respiratory enzyme, is widely used as a biological activity index (Kiss *et al.*, 1975). Results showed that its activity varied

significantly among the different land use systems (Fig. 2). The TPF formed per gram of soil per hour ranged from 0.41 µg in the soils of the dryland systems without FYM to 3.91 µg in the mixed forest system. Higher dehydrogenase activity was found in soils of mixed forest, ungrazed grassland, grapes and irrigated agricultural systems with FYM. Least dehydrogenase activity was found in dryland systems applied with chemical fertilizers alone (no FYM application).

Agricultural systems with high biomass turnover recorded a higher dehydrogenase activity than those with a low biomass turnover. Less disturbance in the ungrazed grassland and the mixed forest soils might have resulted in the higher dehydrogenase activity. Intensively cultivated grape orchards with high doses of fertilizers and pesticides were anticipated to show lesser dehydrogenase (microbial) activity but the application of large quantities of manure might have enhanced soil biological processes (Greenland and Szabolcs, 1994). Recurring disturbances in the monoculture agricultural systems led to low diversity and coincided with low organic matter inputs. This might have reduced the microbial biomass and hence, the dehydrogenase activity, also (Fig.2).

Acid phosphatase activity

Phosphatase is another important soil enzyme which is involved in the release of phosphorus from its organic form. Soils of the ungrazed grassland and the mixed forest revealed a higher phosphatase activity than the other systems. (Fig. 2). Its activity was least (19.3 µg of P-NP per gram of soil per hour) in solids of the dryland agricultural system receiving no FYM but was high (52.3 µg) in the soils of mixed forests. Interestingly, phosphatase activity was relatively higher in the natural systems than in the manmade systems where phosphorus was added externally.

The role of recyclable biomass in the natural systems appears to be more prominent for efficient cycling of phosphorus. Plant biomass removal by grazing showed about 32% reduction in phosphatase activity. The agricultural systems, except irrigated systems receiving both chemical fertilizers and manure, had lower phosphatase activity than the other systems. High disturbance in the above systems might have hindered phosphatase activity. However, high biomass turnover in irrigated agricultural systems and grape orchards applied with manure might have overcome the impact of intensive cultivation. (Dick,

INTRODUCTION

The economic situation of many coconut-exporting countries, including the Philippines, has drastically been affected by the continuing fluctuation of coconut oil price in the world market for the past several years. As a result, development of new food products from coconut has been carried out to diversify its utilization through processing of coconut into high valued, non-traditional food products for domestic and export markets. One method of processing coconuts into food products is by dehydrating sweetened coconut meat at various degrees of maturity (from young to mature coconuts).

One of the dehydrated food products developed from coconut is called coco-crisps, a dried crispy product from a maturing coconut meat (9-10 month old) meat. Coco-crisps has white color, leaves no fibrous texture and has the right crispiness. Its processing involves nut husking, meat removal, meat slicing, blanching in boiling water, cooking in sugar syrup, soaking in syrup overnight, draining, drying and packaging (Truong *et al.,* 1984). The drying process of coco-crisps is a very important step in terms of both process economics and product acceptability.

Previous research showed that high drying temperatures increased drying rates of coconut meat resulting in shorter drying times (Bimbenet *et al.,* 1985; Lozada, 1978). The rate and temperature of drying have a substantial effect on the texture of foods. Heat does not only vaporizes water during drying but also causes the loss of volatile components from the food. Drying also changes the surface characteristics of the food hence, alters the reflectivity and color. In general, rapid drying, longer drying times and high temperatures cause greater changes than moderate length of drying and lower temperatures, respectively (Johnson and Peterson, 1974). Holdsworth (1971) reported that structure and composition of raw materials, shrinkage during drying and loss of volatile components and browning reaction are the important aspects determining organoleptic properties during dehydration of food products. The sensory qualities of food products dried at high temperature may be affected (Desrosier, 1970).

This study was conducted to determine the effect of temperature on the drying rates and sensory qualities of sweetened maturing coconut meat meat called coco-crisps at ambient humidity, constant air velocity and tray density.

MATERIALS AND METHODS

Coco-crisps processing

About nine-month old coconuts of the Baybay Tall cultivar were obtained from the experimental fields of the Regional Coconut Research Center (RCRC), ViSCA, Baybay, Leyte. The nuts were husked, split and shelled. The coconut meat was sliced into 0.7-1.2 mm thick slices using a mechanical slicer, blanched in boiling water for 15 minutes, drained and cooked in 50% sugar syrup for about 15 minutes and soaked in syrup overnight. The drained samples were used in the drying experiments.

Electric cabinet dryer

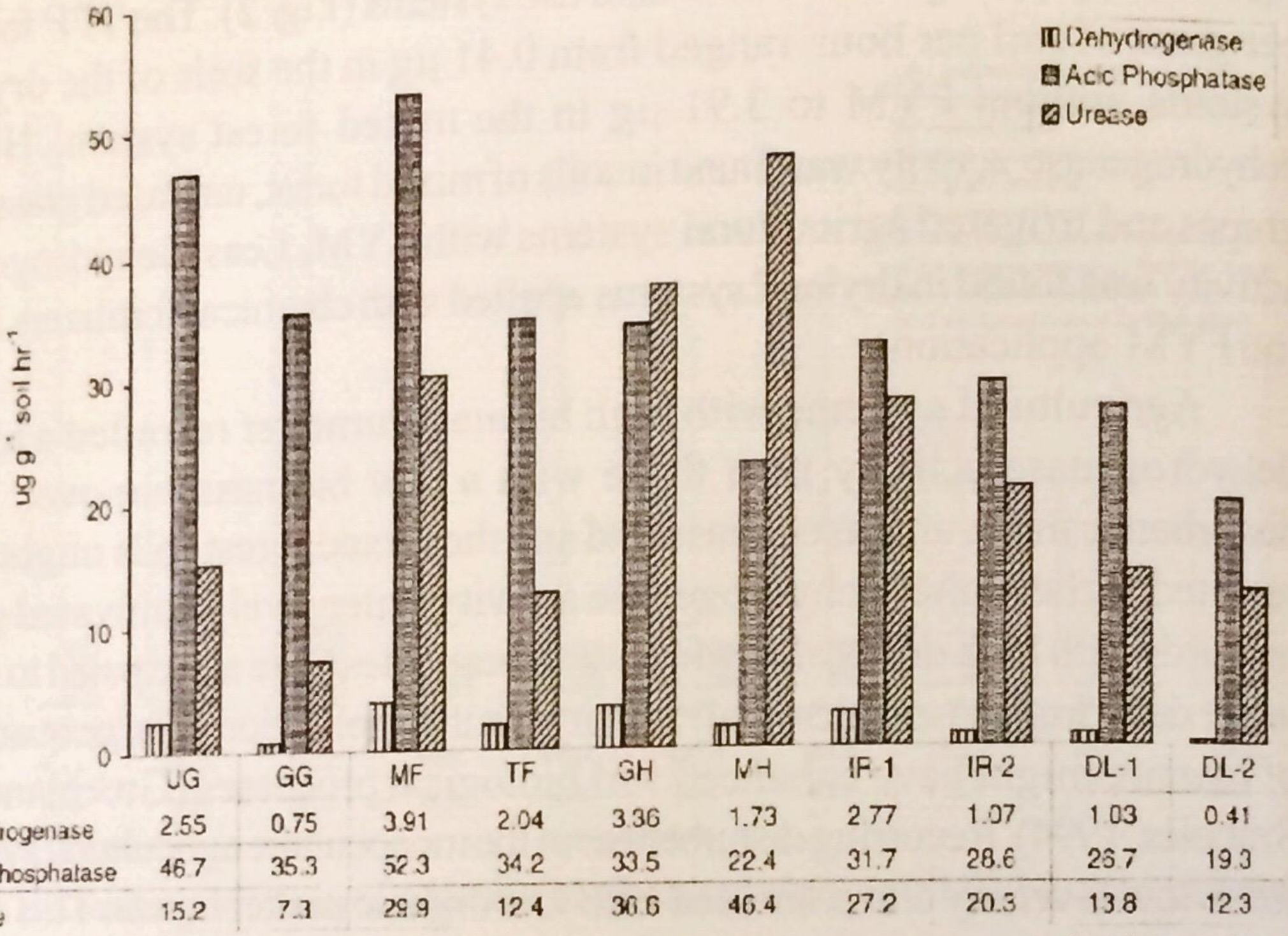
The electric cabinet dryer used in the study is shown in Fig.1. The dryer consists of a blowing section, heating section, flow straightening and mixing section and drying chamber. The blowing section consists of a centrifugal fan driven by a 0.377 kw (½ hp) motor. The amount of air flow admitted into the dryer can be varied by using air baffles at the inlet section. The heating section consists of four 1.5 kw heaters with variable controls. The flow straightening and mixing section consists of 0.30 m long, 0.025m by 0.025 m square channels made of GI sheet. The drying tray is connected to an electronic weighing balance and suspended inside the drying chamber. During the drying experiments, the upper exhaust window was fully opened while the bottom window was fully closed.

Moisture content determination

The moisture content of the samples were determined using the air oven method at 105 ± 3°C for at least 15 hours without grinding the samples. The dried samples were cooled in a desiccator with selica gel before weighing. An electronic weighing balance with an accuracy of 0.0001 g was used for all measurements (Mettler AE 200). Moisture content determination was done at least in triplicate. The moisture content of the samples was calculated on a percent dry basis.

Drying curve determination

The dryer was stabilized for one hour at the required conditions. The air velocity of the drying air was fixed at the lower air velocity of 0.25 m/s in



	UG	GG	MF	TF	GH	MH	IR 1	IR 2	DL-1	DL-2
Dehydrogenase	2.55	0.75	3.91	2.04	3.36	1.73	2.77	1.07	1.03	0.41
Acid Phosphatase	46.7	35.3	52.3	34.2	33.5	22.4	31.7	28.6	26.7	19.3
Urease	15.2	7.3	29.9	12.4	30.6	46.4	27.2	20.3	13.8	12.3

Figure 2. Soil enzyme activity under different land use systems

1994). Higher phosphatase activityin FYM-treated agricultural plots compared to those systems without FYM (fertilizers only) also indicate the importance of recyclable biomass carbon in maintaining phosphatase activity. The cause for the low activity of acid phosphatase in the teak plantations was not known.

Urease activity

Urease activity was significantly different in the various land use systems (Fig.2). Soil urease activity ranged from 7.3 (µg of urea hydrolyzed per gram of soil per hour) in grazed grassland to 46.4 in the mixed forest.

Urease activity was low in the soils of grasslands, teak and dryland agricultural systems applied with chemical fertilizer alone but high in the mixed forest. Larger biomass turnover might have influenced the system to utilize the amide form of N from soil organic matter (Kiss *et al*, 1975). The total nitrogen pool and high soil organic matter (SOM) may also indicate the importance of ureolytic organisms. Among the man-made agricultural and horticultural systems, the fertilized plots with no FYM recorded higher urease activity.

Relationships between soil organic carbon and soil biological parameters

Soil biological processes are determined by recyclable quantity of organic matter within a system. Several authors have reported a direct relationship among SMB-C, recyclable biomass carbon and soil organic–C (Lovell *et al*, 1985; Srivastava and Singh, 1989). The soils of mixed forest, ungrazed grassland and grape orchard showed higher levels of the above parameters (Table 2 and Fig.3). Systems with high biomass turnover maintained higher microbial biomass while man-made systems with low biomass turnover recorded less SMB indicating the influence of agriculture and other disturbances on soil microbial biomass (Fig. 3).

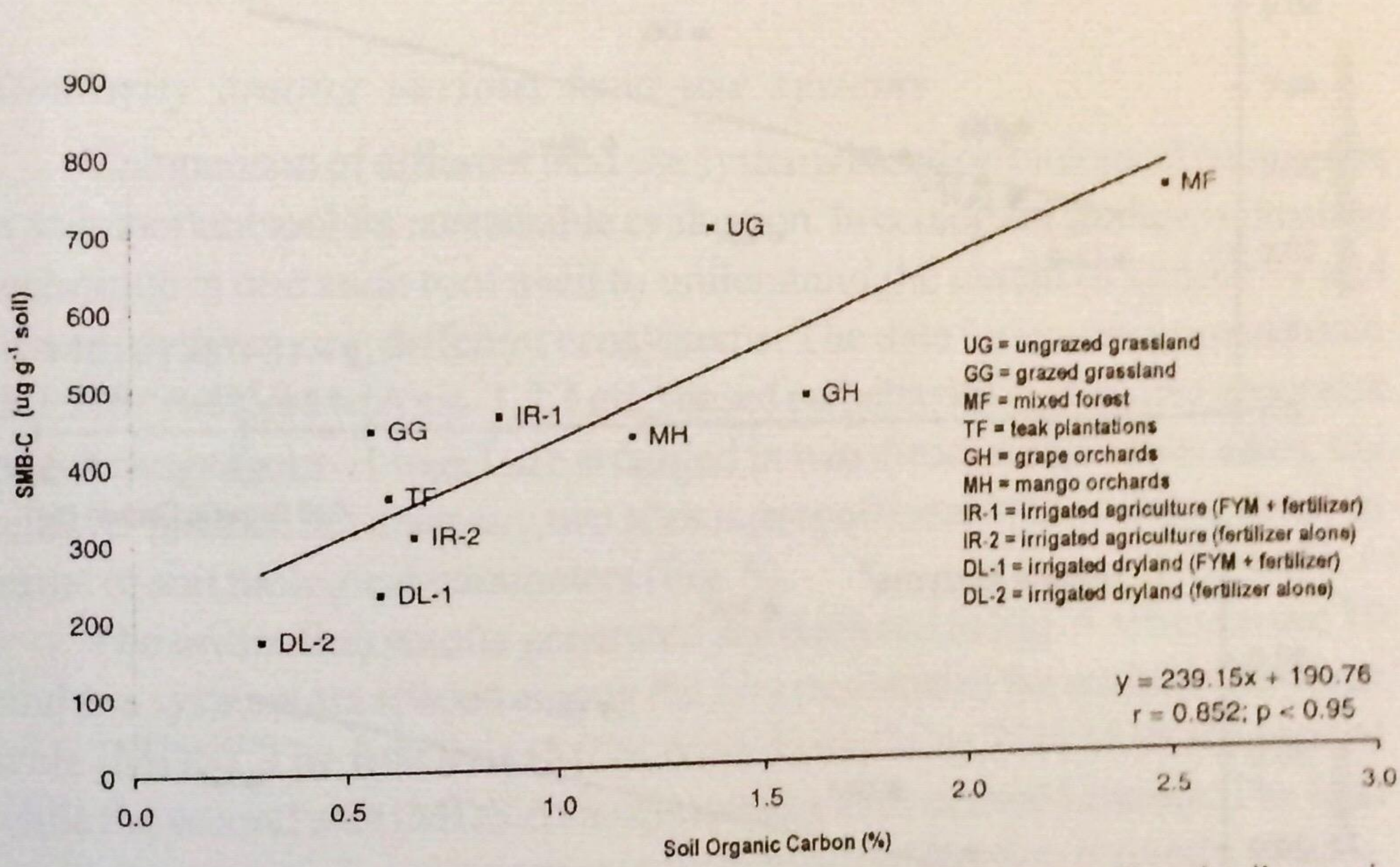


Figure 3. Relationship between soil microbial biomass carbon (SMB-C) and soil organic carbon (SOC)

Figure 4a indicates that dehydrogenase activity increased with an increase in SOC. The observed dehydrogenase activity was higher in the undisturbed natural system and irrigated agricultural system (applied with FYM). Least disturbance among the natural systems and better moisture availability in the irrigated agricultural systems might have induced higher biological activity.

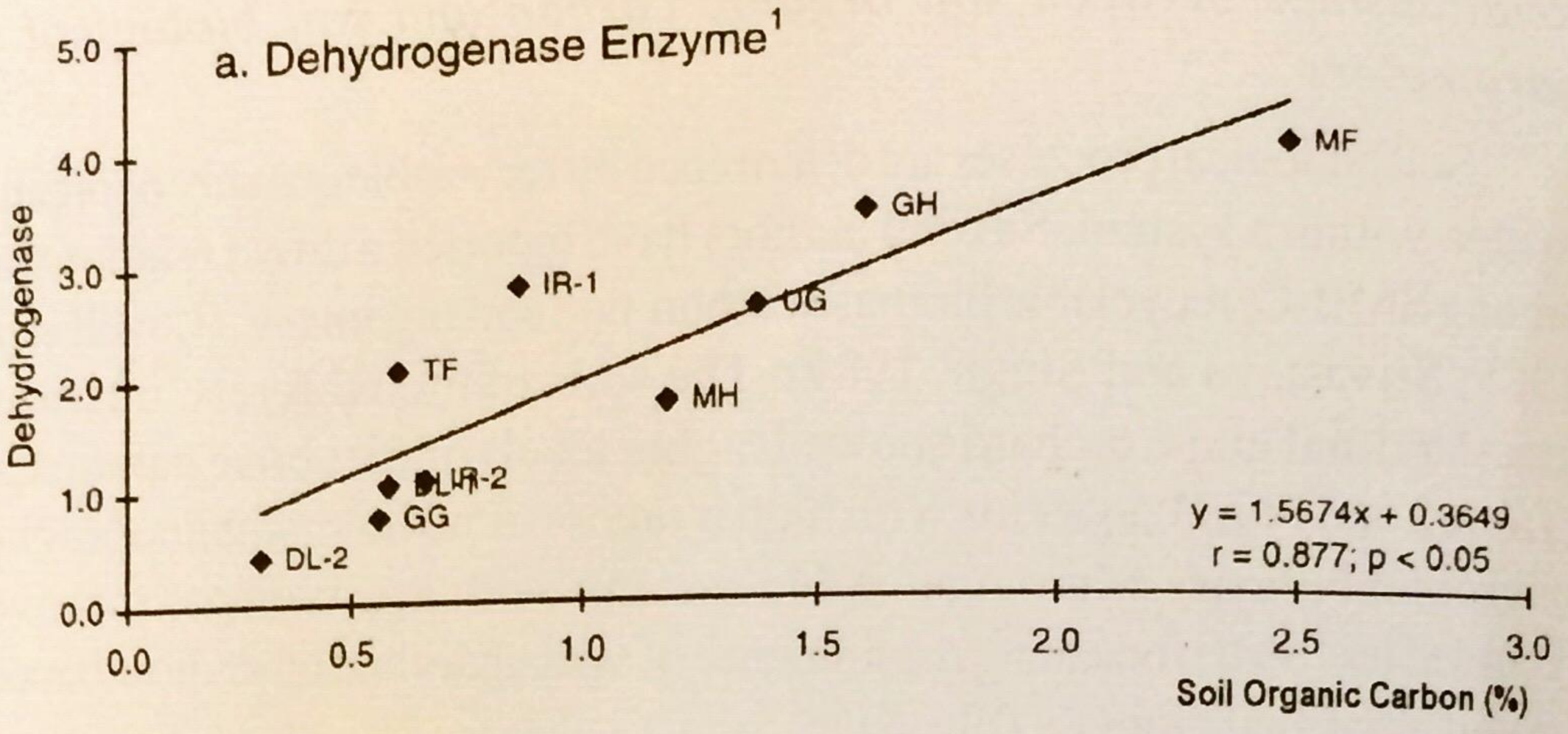


Figure 4. Relationship between soil enzymes and soil organic carbon (SOC) *(1)*µg of TPF formed g^{-1} soil hr^{-1} *(2)* µg of P-NP formed g^{-1} soil hr^{-1} *(3)* µg of urea-N hydrolyzed g^{-1} soil hr^{-1}

Microbial activity is known to be sensitive to disturbances such as fire, cultivation, etc (Tabatabai, 1982; Greenland and Szabolcs, 1994). The acid phosphatase activity also increased with SOC among the systems. (Fig. 4b). However, the natural systems maintained higher phosphatase activity than the other systems. Non- application of phosphorus in these systems might have compelled them to depend more on natural phosphorus recycling processes. The microbes responsible for P-release may decline due to P-application as in the case of N-fixers on addition of N- fertilizers and the proposed hypothesis needs to be tested in both laboratory and at field level. Urease activity increased with SOC and its activity was high in the agricultural system and in the mixed forest systems (Fig. 4c) while the natural systems maintained lower levels of the enzyme. Higher urease activity in mixed forest might be due to high C and N in the system (Fig. 4).

Similarity among various land use systems

Comparison of different land use systems based on biological parameters is an important tool for sustainable evaluation. In ecological studies, ordination technique is one such tool used to understand the extent of similarity and dissimilarity among different ecosystems. The data inputs are grouped into different categories (Axis- 1,2,3 etc.) based on behavior. The scores generated which range from –1 to + 1 are arranged in two dimensional scale. Thus, the relative distance between any two sites is proportional to their dissimilarity in terms of soil biological parameters (Fig. 5).

The ordination results generated are depicted in Fig. 5 wherein the 10 land use systems are spaced among the first two axes of the multidimensional scale (MDS). The first axis (MDS Axis-1) explains 75% of total variance while the second axis (MDS Axis-2) explains 19% of total variance. The land use systems, which were similar in biological properties, formed a cluster. Comparative analysis of the similarity/dissimilarity of the different land use systems resulted in the three broad groups. The first group consisted of less disturbed natural ecosystems (ungrazed grassland and mixed forest), the second group comprised of manmade systems with high biomass turnover (mango and grape orchards and manure applied irrigated agricultural systems, and the third group comprised of disturbed natural systems (grazed grassland and teak plantations) and manmade agricultural systems (IR-2, DL-1 and DL-2) with low biomass turnover. The above inference may have low precision as the microbial –C and microbial-N are computed from the same ninhydrin

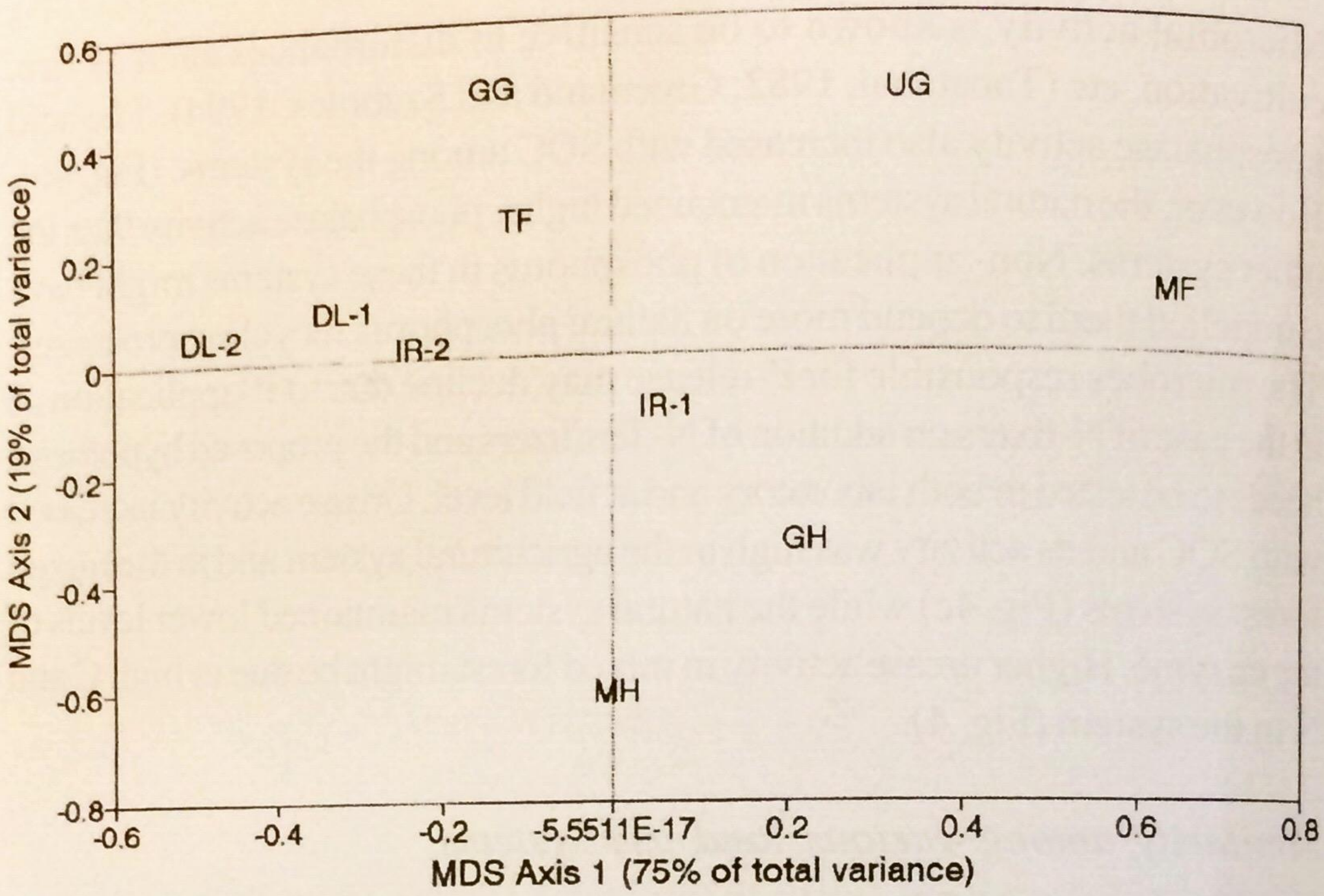


Figure 5. Multidimensional scaling of ecosystems based on soil biological parameters

reactive –N. However, these results suggest that soil biological features in different land use systems are a result of biomass turnover, disturbance and management practices. Hence, the biological parameters monitored in this study could be used as indices of ecosystem sustainability.

CONCLUSION

Soil microbial biomass and microbial processes vary greatly with land management practices. Biological changes in the soil over time are attributed to cropping history, soil amendments, environmental factors and other factors. Biological activity was substantially higher in the soils of undisturbed natural systems (ungrazed grassland and mixed forest) compared to the other systems. Perturbations, such as fire, cultivation, grazing, pesticide and fertilizer application etc, could have altered the soil biological processes in manmade ecosystems. Comparison of the natural land use systems and the existing agricultural land use systems based on soil biological properties is useful in the assessment of the impacts of management practices. Thus, there is a great potential for soil biological parameters particularly soil microbial biomass and soil enzymes, as indicators of the sustainability of various natural and man-made ecosystems.

ACKNOWLEDGMENTS

We acknowledge the Department of Soil Science, University of Agricultural Science, Bangalore, for providing the facility for the conduct of this research. We thank Prof. R. Siddaramappa, Prof. K. Shivashankar, Dr. Viswanath, Prof. M. Uday Kumar, Prof. L. Suseela Devi, Dr. Sudhir, Dr. Mukunda, Dr. S. Jaganath and Dr. Thirtha Prasad for their valuable suggestions. We also thank ICAR for recognizing this work for the Jawaharlal Nehru Award for best PG Research in Agriculture for the year 1998.

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