Índice de potencial productivo del suelo aplicado a tres fincas ganaderas de ladera en el Valle del Cauca, Colombia

Index of potential soil productivity applied to hillside dairy farming in the Cauca Valley ,Colombia

Adriana Rojas Palomino[1], Edgar Madero Morales [1], Luís Miguel Ramírez Nader[1], Orlando Zúñiga Escobar[2]

1 Facultad de Ciencias Agropecuarias, Universidad Nacional de Colombia. AA 237, Palmira, Valle del Cauca, Colombia. ² Universidad del Valle. AA 25360, Cali, Colombia. Authors for correspondence: emadero@palmira.unal.edu.co; arojasp@palmira.unal.edu.co; agrophysik@telesat.com.co

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RESUMEN

Se evaluó el potencial productivo-PPS en suelos volcánicos de ladera de tres fincas lecheras (Nogales, Refugio y Horizonte) en Bolívar, Valle del Cauca, utilizando un indicador mixto de propiedades (físicas, químicas y de actividad biológica del suelo), conductividad térmica y el efecto de manejo con los Índices de Compactación (IC) y Fertilidad (IF). Se utilizó un diseño completamente al azar con tres tratamientos y cinco repeticiones de acuerdo con zonas homogéneas de humedad edáfica. IC fue moderado en todos los casos y PPS fue medio en las tres fincas no obstante el IF fuera alto en Nogales y moderado en Refugio y Horizonte. La correlación lineal múltiple entre parámetros indicó que IC e IF influyeron aproximadamente en un 70 % sobre PPS.

Palabras clave: Compactación; fertilidad del suelo; potencial productivo del suelo.

ABSTRACT

The soil production potential (PPS) of three hillside dairy farms with volcanic soils in Bolivar, Valle del Cauca, Colombia was evaluated using a mixed indicator that assessed the soil's physical and chemical properties, as well as its biological activity, including a new characteristic - thermal conductivity sensitive to soil quality. The effect of management on soil fertility and compaction was also evaluated using two new soil indices: Compaction (IC) and fertility (IF). A completely randomized design was used, with farms corresponding to the treatments, with five replications on each farm across the homogeneous areas of soil moisture. Results for each indicator (IC and IF) agreed with the analysis of individual properties. IC was moderate in all cases, and PP was intermediate in the three farms, despite the IF being high in Nogales, and moderate in Refugio and Horizonte. The multiple linear correlation between these parameters indicated that the IC and IF influenced approximately 70% of the PP.

Key Words: Soil Compaction; Soil fertility; Potential productivity of Soil.

INTRODUCTION

Recent studies of soil quality have looked to establish productivity and conservation indicators, measuring biological, chemical and physical properties separately. With an integrated perspective of land use, the soil productive potential (PPS) is based on synthetic (electro thermal) and analytical techniques, which allow the delineation of sectors according to fertility potential (Zúñiga *et al.,* 2006).

The soil microbial activity is estimated through the production of CO_2, and is related to the physical – chemical properties of the soil (Burbano, 1989; Barea and Azcón, 1982). This measure serves to evaluate possible damage in the physiological function of the soil, caused by the presence of agrochemicals, and potentially toxic products. Equally, this measure facilitates the evaluation of rates of recuperation of soils degraded by industrial residues, or through mining activity (Anderson, 1982).

In tropical soils, livestock trampling produces a pressure of approximately 9 $kgcm^{-2}$ (depending on the origin of the soil, and the location of the profile), and 'plow foot', or 'claw foot' compaction (Russell and Russell, 1994; Cuesta, *et al*. 2005). The most widely used parameter for quantifying this phenomenon is bulk density, a useful measure in percentage terms, gained from standardized measures (Chaparro, 2005). It is related to the moisture content, and inversely correlated to porosity, and hydraulic properties of the soil.

As livestock farms in the hillside areas of the village of La Tulia (Municipality of Bolívar, Department of Valle del Cauca) are causing landscape transformation (Municipality of Bolívar, 2002), and as new indicators of the impact of land use at different territorial scales need to be adjusted, the current study aimed to validate the indices of production potential, compaction, and fertility of the soil.

MATERIALS AND METHODS

The study was carried out in three dairy and dual purpose farms (Nogales, Refugio and Horizonte) in the village of La Tulia, Municipality of Bolívar, Valle del Cauca (4º23'4.6"N, 76º14'23.9" E, 22°C, 75% relative humidity, and 1500 mm annual precipitation) (Table 1). The soils belong to the association *Andic Eutrudepts* and *Typic Hapludands* (Horizonte) of the alluvial, colluvium piedmont, of humid and medium climate, with slopes close to 25%, with parental material of volcanic ash and mud flows (IGAC-CVC, 2004).

Table 1. Characteristics of the farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca)

Farm	***Altitude (masl)***	***Grazing area (ha)***	***Load (animal / ha)***	***System***	***Slope (%)***	***Forage***
Los Nogales	1600	10	3	Dairy	24	*Cynodon mefluensis* and *Braquiaria Decumbes*
Refugio	1500	5	2	dual purpose	23	*Cynodon mefluensis*
Horizonte	1800	7	1	dual purpose	25	*Cynodon mefluensis*

On each farm, 20 geo-referenced samples were taken at a depth of 5 cm to measure soil humidity, and establish five homogenous zones for repetitions according to the experimental design. Properties measures were: bulk density, porosity, and volumetric humidity (table tension), hydraulic conductivity (constant load), aggregate stability (Yoder), and thermal conductivity (electro thermal technique, polynomial equation) (Zúñiga *et al*., 2006; Rojas *et al*., 2007); pH (potentiometer), organic matter (Wakeley and Black), exchangeable bases (Ca, Mg, K, Na) and CIC (ammonium acetate), exchangeable aluminum (KCl) and available phosphorus (Bray II); and microbial activity using the method of CO_2 liberation (Swistcher, 1999).

The index of chemical-IF fertility of Parent (1989) was adopted, and was estimated using scores derived from the sum of the chemical characteristics (Table 2). The compaction-IC index was estimated from scores derived from the sum of the physical characteristics (Porta *et al*., 1994; Reyes and Viera, 2001) (Table 3). And the soil productive potential index was used to standardize each property using a normal distribution.

As variables exist that have a direct or indirect relationship with soil quality, the PPS was defined according to the following formula:

$$PPS_T = \frac{Z_{pH} * Z_{MO} * Z_{\mathrm{Ca+Mg/K}} * Z_P * Z_{?Bases} * Z_{Macrop} * Z_{AMS} * Z_{CICA} * Z_{HUM} * Z_{Kh}}{Z_{DA} * Z\_ * Z_{DPM}}$$

Values of PPS ≤ 90.2 are considered low; those between 90.21 < PPS ≤ 102.2 moderate; and PPS > 102.2 high (Zúñiga *et al*. 2006). This index was mapped using the program ArcGis version 8.3.

The field design was completely randomized, with each farm representing a treatment, and humidity levels representing the repetitions. A multiple correlation was performed to relate the productive potential with the physical, chemical and biological properties.

Table 2. Scores for obtaining the chemical fertility of the soil.

	Score			
Characteristic	***0.5***	***1***	***2***	***3***
	Ranges			
Organic Material (%)	------	<3	3 – 6	>6
		<4,5	4,6 - 5,5	
pH (1:1)	------	>8,5	7,4 - 8,4	5,6 - 7,3
Phosphorus (ppm)	------	<5	5 – 15	>15
Al saturation(%)	>15	5 – 15	0 - 5	0
CICA (meq/100g)	------	<10	10 – 20	>20
Total bases (meq/100g)	<4	4 – 10	>10	------
Pottasium (meq/100g)	<0,1	0,1 - 0,35	>0,35	------

Sum of Scores	**Fertility**
>15	High
8 – 15	Moderate
<8	Low

Table 3. Approximate scores to categorize the compaction level in humid soils of volcanic influence.

	Scores			
Characteristics	***0.5***	***1***	***2***	***3***
		Ranges		
Bulk Density (g/cc)	>1.3	1.1 - 1.3	0.9 - 1.1	0.5 – 0.9
Average Diameter (DPM)	< 0.5	0.5 - 1	1 – 2	>2
Hydraulic conductivity (mm/h)	<1	1 – 5	5 – 50	>50
Macro-porosity (%)	<5	5 – 8	8 – 10	>10
Thermal Cond. (Cal/cm.s.ºC)*10 $^{-3}$	15 – 10	10 – 5	5 - 1	1 - 0.6

Sum of Scores	Compaction
□ 12	Low
9 a 12	Moderate
4 a 8	High
Š 4	Very High

RESULTS AND DISCUSSION

EVALUATION BY PROPERTY

Chemical properties of the arable layer

The farm Horizonte presented the highest fertility potential and cationic interchange capacity, as a consequence of the influence of volcanic ash, and high content of organic material resulting from its higher altitude. In contrast, the actual fertility of Nogales and Refugio was moderately high, due to the total base content (greater than 19 and 5, respectively) and minor metals (Table 4).

Table 4. Chemical properties of soil in three farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca).

PROPERTY	NOGALES 1600 masl	REFUGIO 1500 masl	HORIZONTES 1800 masl
pH (relatio 1:1)	5.68 a	5.56 a	5.18 a
M.O. (%)	6.88 b	7.4 b	15.54 a
Ca me/100	7.86 a	5.28 b	3.76 c
Mg me/100	2.18 a	1.18 a	0.74 b
K me/100	1.42 a	0.38 b	0.85 b
Na me/100	0.18 b	0.25 a	0.23 a
Al me/100	-	-	0.40
CIC me/100	15.02 b	10.36 b	21.46 a
Bases me/100	11.64 a	7.09 b	5.58 c
P ppm	8.6 a	5.6 a	10.7 a
Cu ppm	2.38 b	3.06 a	0.81 c
Zn ppm	5.04 a	5.48 a	3.36 b
Mn ppm	28.3 b	59.1 a	6.14 c
Fe ppm	272.6 a	277.2 a	174 b
B ppm	0.31 a	0.26 a	0.14 b

Means with the same letter are not significantly different (p≤0.05)

Physical properties of the arable layer

No significant differences were seen in the distribution of pores, and the proportion of macro- and micro-pores in the three soils was high. However, the density and porosity of Horizonte (p≤ 0.05) was most appropriate for rooting. The average diameter (WMD), which results from subjecting the soil to large hydro-mechanical forces, was also similar in the three cases, indicating adequate physical stability, likely due to the Andic origin of the parental material and the Al-humus complexes. (Table 5).

Water retention, which relates easily available water with total availability, was very high in all three cases, and able to maintain agriculture without irrigation. The edaphic humidity was also high in the three farms, and although there were no statistical differences between them, Nogales presented higher percentages, followed by Refugio, offering advantages for increasing production (Table 5).

The hydraulic conductivity in the three farms was high, and decayed significantly in Refugio (due to the total minor porosity) and Horizonte. For the latter, the collected information does not explain the situation, where a higher value was expected due to the concentration of organic material (Table 5).

Table 5. Physical properties of the farms, Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca).

PROPERTY	***NOGALES 1600 masl***	***REFUGIO 1500 masl***	***HORIZONTES 1800 masl***
Bulk Density (g/cm3)	1.35 a	1.28 a	1.18 b
Average Diameter DMP (mm)	0.81 a	0.79 a	0.78 a
Porosity (%)v	57.4 b	57.6 b	66.4 a
Macro-pores (%)v	24.6 a	27 a	26.8 a
Micro-pores (%)v	33 a	30.6 a	39.6 a
Hydraulic conductivity-Kh (cm / hour)	20.8 a	15.6 b	10.2 c
Volumetric humidity (%)	31.4 a	27.2 a	25.8 a
LAFA / LAA	89.7 a	89.4 a	89.5 a
Thermal conductivity λ (Cal/cm.s.ºC)*10^{-3}	4.56 a	5.3 a	2.5 a

Means in the same row with the same letter are not significantly different (p ≤0.05)
LAFA: Easily Available Water (Layer Field – Humidity at 1.5 kPa)
LAA: Avalailable water (Layer Field – Humidity at 1500 kPa)

Table 6. Average texture of the soil at the farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca) (5 repetitions)

Clay (%)			Lime (%)			Sand (%)		
Nogales	Refugio	Horizonte	Nogales	Refugio	Horizonte	Nogales	Refugio	Horizonte
2.28	4.022	1.988	35.146	33.666	35.27	43.936	41.988	43.09

Table 7. Average values of thermal conductivity of the soil in the farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca)

. λ (Cal/cm.s.ºC)*10-3	
Nogales	4,5 a
Refugio	5,3 a
Horizonte	2,8 b

The three soils were of a loam texture, for which relatively low humidity retention is expected. However, in agreement with the Andic subgroup, it is possible that, at the moment of testing, these soils do not disperse completely, and the results need to be analyzed with discretion (Table 7).

The thermal conductivity was high in all three farms (Table 7), but was significantly lower in Horizonte. This explains why this property depends inversely on the intensity and the

color purity of soil, and directly on the concentration of metals, especially the heavy metals (Baver *et al.*, 1973). In the three soils, no compaction was observed, due to the low load, and the mineral-organic nature.

Microbial Activity

Lower levels of microbial activity (moderately low) were obtained in the Horizonte farm, which can be explained by altitude, and the greater presence of exchangeable Al, which affects the microbial metabolism by reducing rates of mineralization (Porta *et al*., 1994; Sánchez de P., 2003) (Table 8). Nogales, and probably Refugio, are in better condition according to the soil productive potential, and could achieve greater agricultural productivity.

Table 8. Average values of microbial activity of the soil of the farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca)

Microbial Activity (C-CO2/g)		
Nogales 1600masl	***Refugio 1500 masl***	***Horizonte 1800 masl***
177,06 a	143,21 a	86,65 b

EVALUATION BY INDICES

Nogales presented the highest levels of the index fertility-IF, while the characteristic with the lowest score was the sum of bases (Table 9). In the index of compaction-IC, the three farms presented a moderate range. The physical characteristics that influenced negatively were bulk density, ad aggregate stability (DPM) (Table 10). In the soil productive potential (PPS), more than half of the area evaluated had values between moderate and very high, as a direct consequence of the greater IF, and the greater edaphic humidity (Figures 1, 2, 3).

The correlation established that for PPS, the indices of compaction (IC), and fertility (IF), influenced by 70%, and the model was adjusted by approximately 49%.

Table 9. Level of fertility in the soil of the farms Los Nogales, Refugio and Horizonte (Municipality of Bolívar, Valle del Cauca)

FARM	**VARIABLES SCORE***									
	MO	***pH***	***P***	***Sat Al***	***CICA***	***Total bases***	***K***	***SUM***	SCORE	
Nogales	3	2.6	2	3	2	2	2	16,6 a	H	16.
Refugio	3	2	2	3	1.6	1	1.8	14,4 b	M	14.
Horizonte	3	2	2	2.2	2.6	1	2	14,8 b	M	14.

Values followed by the same letter are not significantly different (p ≤0.05)

Table 10. Estimation of compaction (average of 5 repetitions)

FARM	SCORE PER VARIABLE					SUM	SCORE
	Da	*DPM*	*Macro*	*Kh*	*λ*		
Nogales	0.8	1	3	3	1.8	9,6 a	M
Refugio	0.8	1	3	3	1.6	9,4 a	M
Horizonte	1	1	3	3	2	10 a	M

Values followed by the same letter are not significantly different (p ≤0.05)

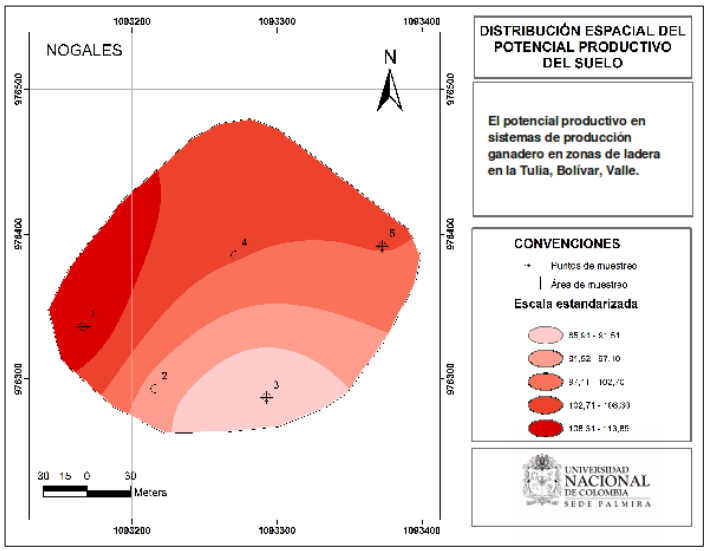

Figure 1. Map of PPS in the farm Nogales

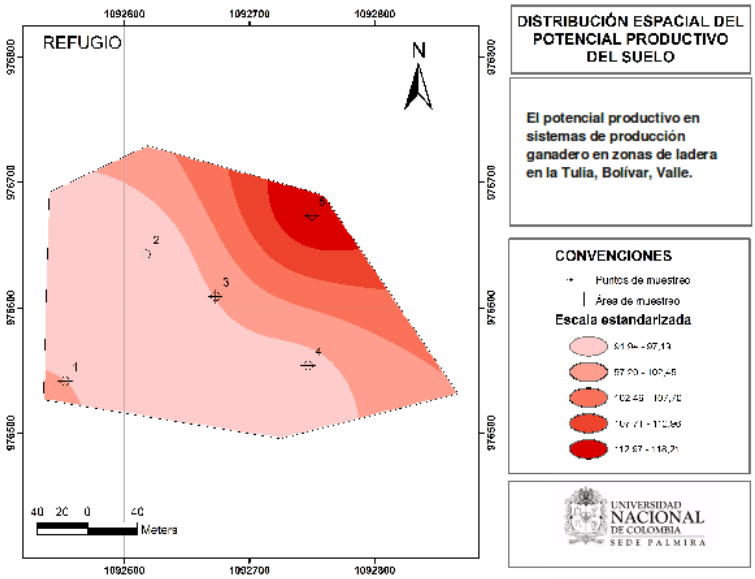

Figure 2. Map of PPS in the farm Refugio

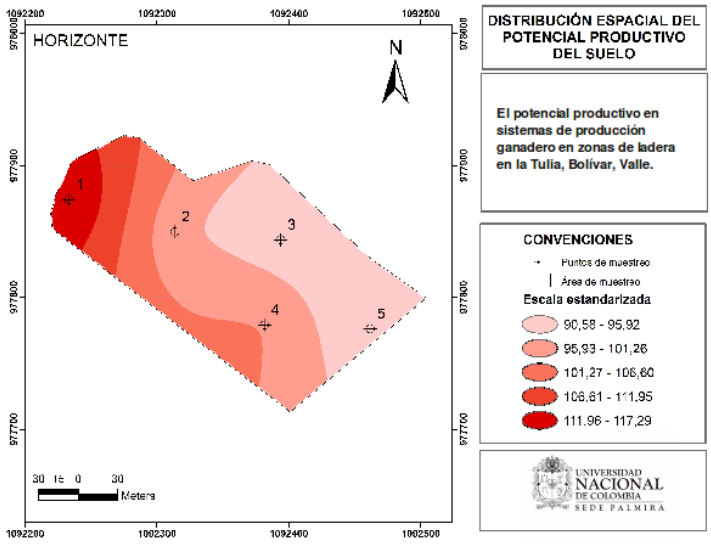

Figure 3. Map of PPS in the farm Horizonte

CONCLUSIONS

The indices of fertility, compaction, and production potential were reliable. The farm Nogales stood out with the highest PPS.

The index of compaction overestimated this phenomenon.

Modest changes in fertility and humidity influenced the productive potential of the soil.
The thermal conductivity was sensitive to changes in soil fertility.
The indirect measure of the microbial activity coincided with the fertility index of the soil.

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