Chapter 1. LAND-SYSTEMS MAPPING FOR SEED-BASED AGROTECHNOLOGY TRANSFER

Land systems define areas of similar landscape where the same type of farming might succeed. Consequently, their careful description is fundamental to land planning and transfer of agrotechnology.

The following text presents a methodology of classifying land systems and an understanding of how they might be interpreted by agronomists in Tropical America. The case study included in this chapter emphasizes how land-systems mapping contributed to research within CIAT's Tropical Pastures Program.

A Historical Note

After the discovery of the new world, it was not long before explorers with illusions of the quest for "El Dorado" penetrated the inner recesses of the South American subcontinent. Missionaries followed; they helped stabilize settlements of indigenous peoples, stimulated agricultural production, and were mainly responsible for introducing cattle on the native savannas. Mining for gold and precious stones, and especially the rubber boom of the Amazon toward the end of the 19th century, attracted fortune seekers and resulted in further settlement. However, it wasn't until the effects of the build-up of population pressure in the Andean highlands and in the coastal strip of Brazil became felt in the 1940s that serious efforts were made to encourage colonization and agricultural development.

Colonization and bringing new land into production have proceeded apace during the past two decades, with varying success. Many new agriculture-based communities have flourished. On the other hand, a general failure to understand the nature of tropical climates and soils and a lack of germplasm adapted to the various ecosystems has often led to unnecessary hardship. The success in transforming the world's ultimate reserve of undeveloped land resources into productive agricultural lands will depend to a considerable extent on renewed efforts to understand the nature of the land resources.

Previous Knowledge of the Region

The FAO-Unesco Soil Map of the World (1971, 1974) indicates that there are extensive areas of very poor and possibly fragile soils, mainly Ferralsols (Oxisols) and Acrisols (Ultisols), supporting the lowland savannas and Amazonian forests of tropical South America. This suggests the need for understanding the nature of these land resources.

There are many, often conflicting, opinions as to the nature of these two regions. In the case of the savannas, their very existence is an enigma that has provoked considerable controversy (Goodland, 1970). Nevertheless, Eiten's (1972) review of the savannas of Central Brazil, locally called "Cerrados" (see Photo Plate 22), and many more recent studies published in the proceedings of the fourth and fifth symposiums on the Cerrados (Ferri, 1977; Marchetti and Dantas Machado, 1980) indicate that these lands are now much better understood.

Many authorities consider the Amazon forest soils (see Photo Plate 4) incapable of sustaining agriculture or livestock production after the primary vegetation is removed (Gouru, 1961; Seltzer, 1967; Reis, 1972; Tosi, 1974; Goodland and Irwin, 1975; Budowski, 1976; Schubart, 1977; Irion, 1978; Goodland et al., 1978). Yet there is ample evidence to show that agriculture and livestock production on well-drained lands is not only possible but also profitable (Falesi, 1972, 1976; Alvim, 1978, 1979; Sdnchez, 1977, 1979; Serrao et al., 1979; Toledo and Morales, 1979; Cochrane and Sdnchez, 1982).

The amount of soil-survey and land-resource inventory information available for tropical South America has increased rapidly during the past 15 years. An attempt has been made to incorporate this work into the CIAT study. Principal sources have been referenced in the bibliograhy, which is by no means exhaustive, however. As noted by McQuigg (1980):

> There is an astonishing amount of information available in most countries on climate, soils, and other factors important to agricultural success. But this information has only modest value to farmers and planners until it is organized, usually with a computer, into a system which offers capabilities for simulating, predicting results and better managing farm production.

CIAT's methodology for land-resource appraisal was designed to facilitate the speedy appraisal and systematization of the large amount of information available in tropical America.

Case Study: Using the Land Systems Map to Define Agroecosystems for Tropical Pastures

The work on a Land Systems Map for the region, presented in this book, was originally commissioned as a study of the acid-infertile savanna regions with the express purpose of selecting representative localities for testing promising grass and legume accessions (CIAT, 1978b). It is therefore fitting to provide an overview of how the region as a whole was subdivided into agroecozones for CIAT's Tropical Pastures Program and, specifically, to summarize the findings from the Land Systems Map about the major soil constraints within those ecozones (CIAT, 1981).

After following the procedures outlined in later chapters, five agroecozones were selected to define and subdivide the humid lowlands of central tropical South America. These are shown in Map I (see Map Plates), which is based on computer printouts of land-system groupings integrating the broad climatic, topographic, and natural vegetation classes (defined in later chapters). It is a first approximation to put gross climate and landscape differences into perspective. Table 1-1 summarizes the five agroecozones in terms of their major vegetation, climatic, and topographic characteristics. (The very poorly drained forested areas indicated on the map were included within the forest subdivisions according to their climatic regime.)

The basis for the subdivision of the lowlands of tropical South America into climatic sub regions is summarized in Chapter 3. The close relationship of the wet-season potential evapotranspiration (WSPE) to the natural vegetation growingon well-drained soils (Cochrane and Jones, 1981) indicates that gross natural vegetation characteristics are a function of the amount of energy plants can use, as accorded by annual water-balance patterns. This finding was used as a first broad criterion for subdividing the region into agroecozones for perennial pasture production. The second criterion was soil drainage. In poorly drained lands, for instance, the ability of plants to withstand waterlogging is of primary importance. Consequently, the poorly drained savannas, including the picturesquely described *Pantanal* of Brazil, which are found throughout the climatic subregions b to e (defined in Table 3-4, Chapter 3), were grouped together as an "agroecozone" for pasture production because they are lands affected by a common problem of prolonged periods of annual waterlogging. The first subdivision of the region, however, was only possible through the second-grouping the vegetation classes of the well-drained soils of the land systems. Further, it is obviously necessary to study climatic characteristics in much greater depth.

It was axiomatic that the soil physical and chemical conditions within the agroecozones would have to be defined more carefully for (1) choosing representative sites for testing promising high-yielding pasture plant accessions and (2) developing reasonable criteria for both preliminary screening and advanced field testing of germplasm. By computerizing the land-resource study, an in-depth analysis of soil physical and chemical constraints within the agroecozones was facilitated. This resulted in a summary of the soils found on the mainly well-drained, not too steep slopes (less than 30%) within the predominantly well-drained agroecozones (Table 1-2, Sections a to 1).

The many factors relevant to soil physical and chemical conditions summarized on the computer formats for the land facets of the land systems, and described in detail by Cochrane et al. (1979), were examined separately within the

Table 1-1. Agroecozones determined for CIAT's Tropical Pastures Program in the central lowlands of tropical South America.

Agroecozone	Climatic parameters	Area (ha x 10⁶) in each topography class: Flat, poor drainage	< 8% slope	8-30% slope	> 30% slope	Total area (ha x 10⁶)	Percentage of total area
Poorly drained savanna	WSPE < 900 mm,< 6 mos. wet season, WSMT > 23.5°C	49	0	0	0	49	7
Isohyperthermic savanna	WSPE 900-1060 mm, 6-8 mos. wet season, WSMT < 23.5°C	17	72	12	10	111	6
Isothermic savanna	WSPE 900-1060 mm, 6-8 mos. wet season, WSMT > 23.5°C	1	25	9	7	42	6
Semi-evergreen seasonal forest	WSPE 1061-1300 mm, 8-9 mos. wet season, WSMT > 23.5°C	53	145	94	4	296	41
Tropical rain forest	WSPE > 1300 mm, > 9 mos. wet season, WSMT > 23.5°C	69	88	55	5	217	30
	Total area (ha x 10⁶)	189	330	170	26	715	
	Percentage of total area	26%	46%	24%	4%		

a. WSPE = total wet-season potential evapotranspiration.
b. WSMT = wet-season mean monthly temperature.

Table 1-2. Summary of the aereal extent of major soil constraints of importance to pasture germplasm selection for the well-drained soils of the central lowlands of tropical South America, by natural vegetation and topographic class.

Soil			Area covered	Area with chemical constraints[a] (ha x 10)							Area with physical constraints[b] (ha x 10⁶)	
				Toxicity		Deficiency						
Order	Percentage within class	Great Group	(ha x 10⁶)	Al	Al (sat)	K	Ca	Mg	P	P fixation	MH	S
				ISOHYPERTHERMIC SAVANNA								
a) Topographic class 0-8%												
Oxisol	66.5	Haplustox	19.24	7.53	7.72	14.07	11.93	8.04	13.40	9.89	9.48	4.80
		Acrustox	17.57	14.64	6.44	17.57	17.57	5.31	17.38		9.83	16.50
		Haplorthox	6.02	1.94	1.68	5.65	3.45	4.99	4.28	3.46	5.67	
		Eutrustox	5.03	0.76	1.01	0.76		0.46	0.30	0.30	1.01	
		Subtotal	47.86	24.87	16.85	38.05	32.95	18.8	35.36	23.48	32.66	4.80
		% with constraint		51.9%	35.2%	79.5%	68.8%	39.2%	73.8%	49.0%	68.2%	10.0%
Entisol	23.1	Quartzipsamments	12.71	0.28	4.60	12.71	12.71	11.23	12.63		12.71	12.71
		Tropofluvents	1.88									
		Ustipsamments	1.49			1.49	1.49	1.49			1.49	1.49
		Ustifluvents	0.51									
		Subtotal	16.59	0.28	4.60	14.20	14.20	12.72	12.63		14.2	14.2
		% with constraint		1.6%	27.7%	88.8%	85.5%	76.6%	76.1%		85.5%	85.5%
Alfisol	6.7	Rhodustalfs	2.44									
		Haplustalfs	2.43			0.17	0.17	0.17	0.17			
		Subtotal	4.87			0.17	0.17	0.17	0.17			
		% with constraint				3.5%	3.5%	3.5%	3.5%			
Ultisol	2.0	Plinthudults	1.48	1.48		1.48	1.48	1.48	1.48			1.46
		% with constraint		100.0%		100.0%	100.0%	100.0%	100.0%			98.6%
Inceptisol	1.0	Dystropepts	0.66			0.66					0.66	0.66
		Eutropepts	0.14									
		Subtotal	0.80			0.66					0.66	0.66
		% with constraint				82.5%					82.5%	82.5%
Mollisol	1.0	Haplustolls	0.32									
		TOTAL	71.92	26.63	21.45	54.56	48.80	33.17	49.64	23.48	47.52	21.12
		% of topographic class		37.0%	29.8%	75.8%	67.8%	46.1%	69.0%	32.6%	66.0%	29.3%
		Rank order of importance[c]		2	2	1	1	2	1	2	1	2
b) Topographic class 8-30%												
Oxisol	78.0	Haplustox	7.51	2.26	0.48	5.18	4.95	2.48	4.95	2.34	4.58	0.19
		Eutrustox	1.64		0.11	0.11						
		Acrustox	0.05			0.05	0.05		0.05			
		Subtotal	9.20	2.26	0.59	5.34	5.00	2.48	5.0	2.34	4.58	0.19
		% with constraint		24.6%	6.4%	58.0%	54.3%	27.0%	54.3%	25.4%	49.8%	2.1%
Entisol	11.0	Troporthents	0.77	0.77	0.77	0.77	0.77	0.77	0.77		0.77	
		Quartzipsamments	0.56			0.56	0.56	0.30	0.26		0.56	0.56
		Subtotal	1.33	0.77	0.77	1.33	1.33	1.07	1.03		1.33	0.56
		% with constraint		57.9%	57.9%	100.0%	100.0%	80.4%	77.4%		100.0%	42.1%

Continued

Table 1-2. Continued.

Soil			Area covered	Area with chemical constraints[a] (ha x 10⁶)							Area with physical constraints[b] (ha x 10⁶)	
				Toxicity		Deficiency						
Order	Percentage within class	Great Group	(ha x 10⁶)	Al	Al (sat)	K	Ca	Mg	P	P fixation	MH	S
Alfisol	7.1	Paleustalfs	0.84						0.84			
		% with constraint							100.0%			
Ultisol	3.2	Haplustults	0.38						0.38			
		% with constraint							100.0%			
Inceptisol	1.0	Dystropepts	0.11			0.11			0.05			
		% with constraint				100.0%			45.4%			
		TOTAL	11.86	3.03	1.36	6.78	6.33	3.55	7.3	2.34	5.91	0.75
		% of topographic class		25.5%	11.5%	57.1%	53.4%	29.9%	61.5%	19.7%	49.8%	6.3%
		Rank order of importance[c]		2	3	1	1	2	1	3	1	1
c) Combined topographic classes 0-8 and 8-30%			83.78	29.66	22.81	61.34	55.13	36.72	56.94	25.82	53.43	21.87
% of combined area with constraint				35.4%	27.2%	73.2%	65.8%	43.8%	67.9%	30.8%	63.7%	26.1%
Rank order of importance[c]				2	2	1	1	2	1	2	1	2
				ISOTHERMIC SAVANNA								
d) Topographic class 0-8%												
Oxisol	95.6	Acrustox	9.75	9.75	3.03	9.75	9.75	2.86	9.75	8.37	6.52	
		Eutrustox	7.62	3.07	0.38	3.07	1.38		2.69	4.07	3.29	
		Haplustox	6.74	3.73	1.64	6.74	6.74	4.02	6.74	1.91	6.74	
		Subtotal	24.11	16.55	5.05	19.56	17.87	6.88	19.18	14.35	16.55	
		% with constraint		68.6%	20.9%	81.1%	74.1%	28.5%	79.5%	59.5%	68.6%	
Ultisol	3.5	Rhodustults	0.87									
Alfisol	0.9	Rhodustalfs	0.23			0.23						
		% with constraint				100.0%						
Entisol	0.1	Ustifluvents	0.02									
		TOTAL	25.21	16.55	5.05	19.79	17.87	6.88	19.18	14.35	16.55	
		% of topographic class		65.6%	20.0%	78.5%	70.8%	27.2%	76.0%	56.9%	65.6%	
		Rank order of importance[c]		1	3	1	1	2	1	1	1	
e) Topographic class 8-30%												
Oxisol	96.9	Haplustox	5.57	1.98	1.05	5.57	3.39	1.61	4.57		5.57	
		Acrustox	3.01	3.01			3.01		3.01	2.01	2.01	
		Eutrustox	0.35	0.13	0.13	3.01					0.13	
		Subtotal	8.93	5.12	1.18	8.58	6.40	1.61	7.58	2.01	7.71	
		% with constraint		57.3%	13.2%	96.1%	71.7%	18.0%	84.9%	22.5%	86.3%	
Alfisol	3.1	Rhodustalfs	0.29									
		% with constraint										
		TOTAL	9.22	5.12	1.18	8.58	6.40	1.61	7.58	2.01	7.71	
		% of topographic class		55.5%	12.8%	93.0%	69.4%	17.4%	82.2%	21.8%	83.6%	
		Rank order of importance[c]		1	3	1	1	3	1	3	1	
f) Combined topographic classes 0-8% and 8-30%			34.43	21.67	6.23	28.37	24.27	8.49	26.76	16.36	24.26	
% of area with constraint				62.9%	18.1%	82.4%	70.5%	24.6%	77.7%	47.5%	70.4%	
Rank order of importance[c]				1	3	1	1	3	1	2	1	

SEMI-EVERGREEN SEASONAL FOREST (UNDER NATIVE VEGETATION)

g) Topographic class 0–8%											
Oxisol	48.5	Acrorthox	38.80	22.07	28.31	30.06	30.06	4.04	28.52	7.99	22.07
		Haplorthox	26.62	18.42	21.81	17.42	5.61	4.78	16.46	4.36	23.49
		Umbriorthox	4.31	4.31	4.31	4.31	4.31	4.31			4.31
		Eutrorthox	0.35						0.35		0.35
		Subtotal	70.08	44.80	54.43	51.79	39.98	13.13	45.33	12.35	50.22
		% with constraint		63.9%	77.6%	73.9%	57.0%	18.7%	64.7%	17.6%	71.6%
Ultisol	40.5	Tropudults	41.75	26.09	41.68	30.10	30.73	11.67	34.77	9.78	
		Paleudults	15.47	14.11	14.11	6.00	15.47	14.11	4.07	0.22	
		Haplustults	0.89		0.69	0.89	0.07		0.69		0.21
		Plinthudults	0.35	0.35	0.35	0.07		0.07	0.07		
		Subtotal	58.46	40.55	56.83	37.06	46.27	25.85	39.60	10.0	0.21
		% with constraint		69.3%	97.2%	63.4%	79.1%	44.2%	67.7%	17.1%	0.4%
Entisol	6.6	Quartzipsamments	4.79	4.35	4.58	0.55	4.52	4.33	4.53		4.79
		Tropofluvents	3.13			1.30	0.37	0.37	0.25		0.63
		Ustipsamments	1.21	0.71	0.71	0.21	0.18	0.18	0.71		1.11
		Ustifluvents	0.26								
		Tropopsamments	0.16			0.06					0.14
		Subtotal	9.55	5.06	5.29	2.12	5.07	4.88	5.49		6.67
		% with constraint		52.9%	55.4%	22.2%	53.0%	51.1%	57.4%		69.8%
Alfisol	3.5	Hapludalfs	4.55			2.12			0.89		
		Haplustalfs	0.47			0.47			0.47		
		Subtotal	5.02			2.59			1.36		
		% with constraint				51.6%			27.1%		
Inceptisol	0.9	Eutropepts	0.75								
		Ustropepts	0.37								
		Dystropepts	0.24	0.24	0.24	0.24	0.24				
		Subtotal	1.36	0.24	0.24	0.24	0.24				
		% with constraint		17.6%	17.6%	17.6%	17.6%				
Mollisol	0.1	Argiudolls	0.01						0.02		
		% with constraint							100.0%		
		TOTAL	144.48	90.65	116.79	93.80	91.56	43.86	91.78	22.35	57.10
		% of topographic class		62.7%	80.8%	64.9%	63.3%	30.3%	63.5%	15.5%	39.5%
		Rank order of importance[c]		1	1	1	1	2	1	3	2
h) Topographic class 8–30%											
Oxisol	56.6	Haplorthox	38.49	36.32	31.92	28.36	23.15	28.05	30.19	6.18	36.65
		Acrorthox	14.39	12.85		12.85	3.17	2.59	12.27		3.17
		Haplustox	0.07		0.07				0.07	0.07	
		Subtotal	52.95	49.17	31.99	41.21	26.32	30.64	42.53	6.25	39.82
		% with constraint		92.8%	60.4%	77.8%	49.7%	57.8%	80.3%	11.8%	75.2%
Ultisol	36.5	Tropudults	27.08	3.05	15.63	12.87	12.53	2.77	12.23	0.91	
		Rhodudults	4.43								
		Paleudults	2.54		2.44						
		Haplustults	0.14			0.04			0.10		0.01
		Subtotal	34.19	3.05	18.07	12.91	12.53	2.77	12.33	0.91	0.01
		% with constraint		8.9%	52.9%	37.8%	36.6%	8.10%	36.1%	2.7%	0.03%
Entisol	4.1	Troporthents	3.82			0.34	0.34	0.34	3.82		3.82
		Quartzipsamments	0.02			0.02		0.02	0.02		0.02
		Subtotal	3.84			0.36	0.34	0.36	3.84		3.84
		% with constraint				9.4%	8.8%	9.4%	100.0%		100.0%

Continued

Table 1-2. Continued.

Soil			Area covered (ha x 10[6])	Area with chemical constraints[a] (ha x 10[6])							Area with physical constraints[b] (ha x 10[6])	
				Toxicity		Deficiency						
Order	Percentage within class	Great Group		Al	Al (sat)	K	Ca	Mg	P	P fixation	MH	S
Inceptisol	1.8	Dystropepts	1.65	1.65	1.65	1.65	1.65	1.65	1.65		1.65	
		% with constraint		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%		100.0%	
Alfisol	1.0	Hapludalfs	0.86						0.28			
		Haplustalfs	0.06								0.02	
		Subtotal	0.92						0.28		0.02	
		% with constraint							30.4%		2.2%	
		TOTAL	93.55	53.87	51.71	56.13	40.84	35.42	60.63	7.16	45.34	
		% of topographic class		57.6%	55.3%	60.0%	43.6%	37.9%	64.8%	7.6%	48.5%	
		Rank order of importance[c]		1	1	1	2	2	1	3	2	
i) Combined topographic classes 0-8 and 8-30%			238.03	144.52	168.50	149.93	132.40	79.28	152.41	29.51	102.44	
% of area with constraint				60.7%	70.8%	62.9%	55.6%	33.3%	64.0%	12.4%	43.0%	
Rank order of importance[c]				1	1	1	1	2	1	3	2	
TROPICAL RAIN FOREST (UNDER NATIVE VEGETATION)												
j) Topographic class 0-8%												
Ultisol	56.5	Paleudults	26.05	26.05	26.05	26.05	22.56	25.16	8.42			
		Plinthudults	21.47	21.47	21.47	21.47			6.87			
		Tropudults	10.83	10.21	10.21	10.27	1.79	1.80	8.42			
		Subtotal	58.35	57.73	57.73	57.79	24.35	26.96	23.71			
		% with constraint		98.9%	98.9%	99.0%	41.7%	46.2%	40.6%			
Inceptisol	14.3	Dystropepts	6.72	6.72	6.72	0.92			6.11			
		Eutropepts	4.26			4.26						
		Dystrandepts	1.58	0.45	0.45	1.39	0.61	0.45	0.94	1.13		
		Subtotal	12.56	7.17	7.17	6.57	0.61	0.45	7.05	1.13		
		% with constraint		57.1%	57.1%	52.3%	4.9%	3.6%	56.1%	9.0%		
Alfisol	10.7	Hapludalfs	9.41			9.41			9.41			
		% with constraint				100.0%			100.0%			
Oxisol	4.3	Acrothox	2.76	2.76	1.27	2.76	2.76	2.76	1.27	0.45		
		Haplorthox	1.01	1.01	1.01	1.01	1.01	1.01				
		Subtotal	3.77	3.77	2.28	3.77	3.77	3.77	1.27	0.45		
		% with constraint		100.0%	60.5%	100.0%	100.0%	100.0%	33.7%	11.9%		
Entisol		Tropofluvents	3.63			3.13						
		% with constraint				86.2%						
		TOTAL	87.72	68.67	67.18	80.67	28.73	31.18	41.44	1.58		
		% of topographic class		78.3%	76.6%	92.0%	32.7%	35.5%	47.2%	1.8%		
		Rank order of importance[c]		1	1	1	2	2	2	3		
k) Topographic class 8-30%												
Oxisol	74.7	Haplorthox	33.53	31.42	31.42	33.53	13.60	13.20	32.68	11.48		
		Acrorthox	7.47			7.47	7.47	7.47				
		Subtotal	41.00	31.42	31.42	41.00	21.07	20.67	32.68	11.48		
		% with constraint		76.6%	76.6%	100.0%	51.4%	50.4%	79.7%	28.0%		

Ultisol	6.6	Paleudults	2.14	2.14	1.88	2.14		1.88		
		Tropudults	1.51	1.51	1.51	1.51		1.51		
		Subtotal	3.65	3.65	3.39	3.65		3.39		
		% with constraint		100.0%	92.9%	100.0%		92.9%		
Inceptisol	13.3	Dystropepts	7.32	6.40	4.79	7.32		6.40	1.61	1.61
		% with constraint		87.4%	65.4%	100.0%		87.4%	22.0%	22.0%
Alfisol	5.4	Hapludalfs	2.96		0.23	2.96			2.73	
		% with constraint			7.8%	100.0%			92.2%	
		TOTAL	54.93	41.47	39.83	54.93	21.07	30.46	37.02	13.09
		% of topographic class		72.5%	72.5%	100.0%	38.3%	55.4%	67.4%	23.8%
		Rank order of importance		1	1	1	2	2	1	3
I) Combined topographic classes 0-8 and 8-30%			142.65	110.14	107.01	135.60	49.80	61.64	78.46	14.67
% of area with constraint				77.2%	75.0%	95.0%	35.0%	43.2%	55.0%	10.3%
Rank order of importance				1	1	1	2	2	2	3

a. Refers to topsoil, except for Al (sat) = % Al saturation in subsoil.
Al = Al saturation>70%; K = <0.15 meq/100 g soil; Ca = <0.4 meq/100 g soil; Mg = <0.2 meq/100 g soil; P = <3 ppm; P fixation = high P fixation.
For details see: Cochrane et al., 1979.

b. MH = low moisture holding capacity, <75 mm/100 cm soil; S = sandy topsoils.

c. 1 = >50% of area, 2 = 25-50% of area, 3 = < 25% of area.

Great Group soil subdivisions of the topographical classes for each agroecozone. In Table 1-2, Sections c, f, i, and l, the topographical classes 0-8% and 8-30% are grouped together to summarize the major soil constraints. The specification of soils in terms of Great Groups clearly helps with the appraisal of soil conditions, but, as can be seen from Table 1-2, it is not always sufficient to describe specific soil constraints, let alone judge their relative importance in geographical perspective for the determination of desirable germplasm traits.

The following ecosystems were determined for CIAT's Tropical Pastures Program.

Isohyperthermic Savannas

From Table 1-2, Sections a, b, and c, it can be seen that the predominant soil physical constraint throughout this agroecozone is low moisture-holding capacity. This is particularly evident in the Haplustox, Acrustox, and Haplorthox soil Great Groups within the Oxisol order, and in the Quartzipsamments and Ustipsamments of the Entisols; soils with low moisture-holding capacities within these Great Groups account for over 60% of the soils found in the agroecozone as a whole. The tendency for rainfall patterns to be somewhat erratic in some parts of the ecozone suggests a need for plants - capable of withstanding moisture stresses, perhaps beyond that indicated by the length and intensity of the dry season.

Soil mineral deficiencies, principally P, K, and Ca, are of primary importance; pasture plants capable of producing satisfactorily in soils with low levels of these elements should be sought. The ability of plants to tolerate high levels of Al and low Mg is of importance over about 30% of the area. Further, . the percentage of Al saturation in the subsoil does not tend to be as high as in the topsoil. Phosphorus fixation is likely to be a problem in 30% of the soils. In short, the geographical extent of soils with potential Al toxicity and P-fixation problems is not as large as might be inferred from small-scale, generalized soil maps.

Isothermic Savannas

Table 1-2, Sections d, e, and f, indicate that in isothermic, as in isohyperthermic, savannas, low soil moisture-holding capacity is a serious problem. Over 70% of the soils, virtually all of them Oxisols, have low moisture-holding capacities. This problem is demonstrated by the exaggerated effect the *veranicos* (erratically occurring periods with little rainfall during the "wet season" in Central Brazil) have on crop growth and, to a lesser extent, on pasture production. Pasture plants for this ecozone must be adapted, not only to survive a prolonged dry season of 4 to 6 months but also to resist lesser periods of moisture stress during the wet season. Perhaps the best way to ensure this is to find plants that will grow deep roots under the poor chemical conditions of these soils, coupled with more efficient soil amendments and fertilizers to promote deeper rooting.

In the isothermic savannas, in contrast to the iso-hyperthermic savannas, both soil deficiency and toxicity problems are of primary concern. Pasture plants should be selected to give satisfactory yields in soils with high levels of the percentage of Al saturation and low levels of P, K, and Ca. Phosphorus fixation also appears to be a potential and widespread problem, so emphasis should be put on choosing germplasm adapted to very low P availability.

The Al saturation percentage levels tend to diminish with depth; this is very important insofar as root penetration is concerned. It also means that the correction of Al toxicities through minimal lime applications, as calculated by the improved liming equation of Cochrane et al. (1980), would provide an alternative, relatively low-cost way of overcoming a serious problem throughout this agroecozone.

Tropical Semi-Evergreen Seasonal Forest

The analytical data of soil samples, taken mainly from soil profiles describing soils under native vegetation, would suggest that potential P, K, and Ca deficiencies could be widespread problems, and that soil Al levels are often high in the tropical semi-evergreen seasonal forest areas (Table 1-2, Sections g, h, i). However, as illustrated by the work of Falesi (1972, 1976) and Serrao et al. (1979), soils under forest vegetation may be changed completely if the vegetation is burned and the resulting ash returned to the soil. In other words, the potential fertility of soils in this eco-zone under forest cover is a function not only of the soil's fertility but also of the fertility "stored" in the biomass. Analytical figures can only provide a satisfactory guide to fertility if the vegetation is completely removed by clearing lands by bulldozers. After an adequate burning of vegetation, the fertility of these soils may be restored. If followed up by careful management using - deep-rooted pastures, this restored fertility might be maintained for many years.

The phenomenon of "fertility" being stored in biomass would indicate that, provided adequate management techniques are used, pastures not so well adapted to very low soil-fertility conditions for the semi-evergreen seasonal forest agroecozone might be cultivated. On the other hand, there is clearly a lot more to be understood about pasture management in these areas, and the search for pastures better adapted to the ecosystem should continue.

Tropical Rain Forest

Owing to the inherent difficulty of burning forests in very wet areas, the analytical figures indicating chemical constraints or the tropical rain forest agroecozone (Table 1-2, Sections j, k, 1) probably serve as a more useful guide for selection criteria for pasture plants than is the case for the semievergreen seasonal forests. The percentage of Al saturation levels are often high, and K levels are almost universally low. The P, Ca, and Mg figures appear, on the average, to be slightly higher than those of the other agroecozones, but they clearly reflect the higher proportion of inherently more fertile soils, especially the Inceptisols, Alfisols, and Entisols. These three soils alone account for about 25% of the well-drained soils of the region; their presence indicates that the development of pasture germplasm specifically adapted to acid, infertile soils for this ecozone is not so high a priority as in the other ecosystems.

Discussion

These summaries of the major soil constraints in the agroecozones of CIAT's Tropical Pastures Program take what is known into account. Unfortunately, the recorded soil survey and fertility work rarely includes S, Mn, or minor element assays, because of past analytical and interpretative problems. It is thus possible that germplasm tolerant to low S levels or toxic Mn levels may be required for some regions.

The picture that has emerged from this land-system evaluation of the major soil constraints, and, by inference, the priorities for desired genetic traits in tropical pastures for the acid soils of tropical America's hinterlands, is considerably different from what was previously inferred from generalized small-scale maps.

A first major finding is that P fixation is not a potential problem over much of the area, but is mainly confined to the isothermic agroecozone. This calls for a different emphasir on work designed to tackle P problems. Phosphate rock seems an attractive, low-cost solution for correcting P deficiencies for pasture production over much of the region. We still need to learn about the behavior of rock phosphate in the context of overall crop growth, however. There is also a need for more study on the ability of P and other minerals to move down the soil profile and stimulate deeper rooting and, consequently, tap more extensive water and mineral supplies. There is evidence, for instance, that single superphosphate does this task more effectively than triple superphosphate (E. Wagner, CPAC, pers. comm.). Nevertheless, at this point, it is certain that pasture plants should be selected for tolerance to soils with low P levels. This is particularly important in the case of plants for the isothermic savannas.

The second major finding is that potential Al toxicity is not as widespread as previously thought; however, it is an important consideration in the isothermic savanna agroecozone. Fortunately, in this ecozone, the percentage of Al saturation in many soils diminishes with depth, and, thus, the strategic use of minimal lime applications will provide a lowcost solution to many toxicity problems. Pasture plants tolerant to high Al saturation in soils are still highly desirable for the isothermic savanna agroecozone, although this tolerance need not be as great as previously thought. Pasture germplasm need not all be screened for tolerance to very high soil-solution Al levels, as has been the practice in the past.

The third major finding is that soil Ca and K levels are low on a very high proportion of the soils. Low Mg levels are also common. This would suggest that a desirable "trait" in pasture plant germplasm would be tolerance to low available K, Ca, and Mg. (Clearly, deficiency problems of Ca and Mg can be overcome by modest applications of dolomitic limestone; however, the cost of such is a function of distance from suitable and commercially exploited deposits.)

A fourth finding is that the substantial fertility reserves in arboreal biomass infers that care must be taken in interpreting the relative importance of soil chemical constraints for the semi-evergreen seasonal forest agroecozone. It is evident that by burning the forest cover many of these soils will undergo major changes in their nutrient properties. Further, the restored fertility can be maintained for many years under adequate pasture management. This would involve only a minimal input of chemical fertilizers. As a consequence, the search for germplasm adapted to extremely poor soil-fertility conditions need not necessarily be a priority for the semievergreen seasonal forest regions. In the tropical rain forest ecosystem, also, the high proportion of inherently fertile soils suggests that the search for pasture germplasm adapted to low soil fertility need not be a top priority.

A fifth finding concerns soil chemical restraints over the entire area. Although germplasm testing sites can now be more carefully located to take advantage of the known soil constraints, these trials should be monitored for the complete gamut of potential nutrient problems. A careful monitoring of nutrient problems using foliar analytical techniques could lead to a wealth of knowledge about potential soil problems over the area. If only one trace element problem is identified in an area, its solution could lead to significant socioeconomic benefits.

Finally, it was found that varying moisture-holding capacities in many of the savanna soils emphasizes the need to maintain perspective in testing pasture plant accessions adapted to the acid soil hinterlands. Climate, especially in the sense of the annual energy available for plant growth as accorded by the soil moisture regimes, is of great importance in determining the adaptability of germplasm to any agroecozone, always pro viding that soil physical conditions are taken into account and that the germplasm is adapted to acid-infertile soils. It is therefore necessary that germplasm be tested in representative soil sites within the major agroecozones, and over a period of several years, to accurately assess the influences of climate and soil moisture conditions.