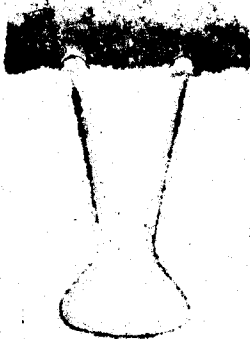


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Natural Environmental Factors Affecting
Potential Agricultural Productivity Within
Selected Arable Areas of the Linea Noroeste
Region, Dominican Republic

by

G.A. Antonini N.P. Timofeeff L. Zobler

August, 1967

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WEST INDIES LABORATORY
FAIRLEIGH DICKINSON UNIVERSITY
P.O. ANNEX BOX 4010, CHRISTIANSTED, ST. CROIX
U.S. VIRGIN ISLANDS 00820

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Natural Environmental Factors Affecting Potential
Agricultural Productivity Within Selected Arable Areas
of the Linea Noroeste Region, Dominican Republic

Report of a Special Study Team

by

Gustavo A. Antonini

Research Fellow in Geography (OAS)
Columbia University, New York
Project Coordinator

Nicolay P. Timofeeff

Assistant Professor of Geography
State University of New York
Binghamton, New York

Leonard Zobler

Professor of Geography
Barnard College and
Columbia University, New York

New York, N. Y.

August, 1967

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Barnard College

DEPARTMENT OF GEOLOGY AND GEOGRAPHY

COLUMBIA UNIVERSITY, NEW YORK 10027

August 25, 1967

Angel N. Pichardo
Executive Director
Instituto Nacional de Recursos Hidraulicos
I N D R H I
Santo Domingo, Dominican Republic

REFERENCE: Final Report - Natural Environmental Factors
Affecting Potential Agricultural Productivity
Within Selected Arable Areas of the Linea Nor-
oeste, Dominican Republic

Dear Ing. Pichardo:

It is with pleasure that the undersigned evaluatory technical team on the Linea Noroeste Region submits the attached report to you. This study, jointly sponsored by INDRHI (Instituto Nacional de Recursos Hidraulicos) and the Secretaria de Agricultura, was designed to provide the Dominican Government with information on natural environmental resources for an eight hundred and twenty square kilometer area within the northwestern sector of the Cibao Valley. Rapid, and modern statistical sampling and electronic data processing systems were developed to examine existing potential for expanded agricultural output within areas of present maximum production or potential production.

The Dominican Government's short-range developmental goals emphasize the urgent need to assimilate first-hand resource inventory decision-making knowledge in order to provide a sound base for specific regional development programs. Our study has been organized to unravel the pattern of existing natural environmental relationships, and has identified major physical elements governing agricultural productivity. The enclosed report provides the basic information needed to begin this region's agricultural planning.

Respectfully yours,

Gustavo A. Antonini
OAS Research Fellow
Dept. of Geography
Columbia University
New York

Nicolay P. Timofeeff
Assistant Professor
of Geography
State University of
New York at
Binghamton

Leonard Zobler
Professor of Geography
Barnard College and
Columbia University
New York

ACKNOWLEDGMENTS

It gives the writers great pleasure to acknowledge the role played by the Asociación Para el Desarrollo, Inc. of Santiago in sponsoring this study. Lic. Victor Espaillat M. gave unstintingly of his time for countless helpful suggestions through all stages of the program. Dr. Rafael Mirabal Rodriguez, Executive Secretary, assisted the technical study team by administering the project budget. The Asociación also provided a four-wheel drive vehicle for the projects' field operations phase.

The Dominican Government financially supported this study through the joint auspices of INDRHI (Instituto Nacional de Recursos Hidraulicos) and the Secretarías de Agricultura. Particular thanks are due to Secretary of Agriculture, Lic. Fernando Alvarez and other governmental officials who were always ready to assist the project in any way they could.

As a field study undertaken in a less developed area, the writers have depended largely on the generosity of local inhabitants for logistical arrangements. It is with great indebtedness that the following assistance be acknowledged. Vice-rector Agripino Núñez at the Universidad Católica Madre y Maestra provided our field investigator with housing for the six-month period. Field assistants were salaried by the Instituto Superior de Agricultura (ISA) at Santiago. There, particular thanks are due to Dr. G.M. Watkins, Party Chief, Dr. Leon Smith, Plant Pathologist, and Mr. Robert Cheaney, Soil Scientist, who gave encouragement and countless helpful suggestions during the study. Field assistants during the period October 1966-April 1967 were Messrs. Miguel Mauricio and Pedro Taveras of ISA.

The project staff wishes to acknowledge the participation of the rural folk and their meaningful contribution to the successful completion of an exhaustive field study. Each community, however small and seemingly insignificant, produced immediate enthusiastic response in men, material, and local agronomic information in whatever way was deemed most helpful. It can truthfully be said that the country's greatest resource is its people. A listing of principal rural contributors to the project's field phase includes the following: Alcade Ambrosio Rodriguez, Las Caobas, Santiago Rodriguez; Sr. Ramon Nicasiö, Hundidera, Valverde; Alcalde Ramon Emilio Fernandez, Higüerito Peñuela, Valverde; Alcalde Jose Antonio Almonte, Entrada de Mao, Valverde; Sr. Miguel Liriano, Martinez, Valverde; Alcalde Pedro Antonio Duran, El Cercado, Valverde; Alcalde Felix Antonio Martes, Los Quemados, Valverde; Sr. Librado Antonio Rivas and Sr. Blas Rodriguez, Santiago de la Cruz, Dajabon.

The writers also acknowledge gratefully Mrs. Ina B. Alterman, Dept. of Geology, Barnard College, Columbia University, who performed petrologic examination, identification and classification of one hundred and forty-seven rock specimens. Mr. Miklos Pinther, cartographer at the American Geographical Society, New York, gave his time and skill in preparing the maps for publication. We also wish to express our appreciation to the staff of the Columbia University Computer Center, especially to Dr. Kenneth King, director, and Mr. Michael Barrett, for facilitating the data processing under trying circumstances. Finally, grateful acknowledgment is given to Mr. Vincent Manson, Department of Geology, Columbia University, and the American Museum of Natural History, who wrote the factor analysis computer program which was used in this study.

ERRATUM

All references to sampling ~~square~~ sites should read in linear units square, as 100 meters square (100 meters by 100 meters), not 100 square meters.

SUMMARY

The agricultural potential of an eight hundred square kilometer area in the Linea Noroeste region, Dominican Republic, was assessed. Because information on the natural environmental parameters was needed urgently for economic planning, the study was conducted at a semi-reconnaissance level, utilizing new and specially designed land resource analysis techniques, applied to a reduced area of 600 square kilometers. A stratified random sample with variable proportions of 606 one-hundred-square-meter sites was used to collect data on soils, land surface, and micro-climate. The raw data consisted of nineteen variables for soils, five variables for land surface, and five variables for climate. The data for each variable set were submitted to a factor analysis by a computer. The resultant factor units were mapped and described by their respective variable loadings. The factor units were ranked according to their limiting effects on agricultural use due to the influence of their variables. The ranked factor units for soil, land surface, and climate were next areally combined and plotted on a map. The result was a multivariate factor map of site areas. Each site area is marked with a three-digit symbol that describes its agricultural quality and potential. The specific field attributes responsible for the rank of a given site may be obtained by reference to the composition of its factors. The decision to ameliorate a limiting property is left to the economic planner. The study is regarded as the initial step in a more detailed research program on the Linea Noroeste region.

INTRODUCTION

The Government of the Dominican Republic is initiating a policy of accelerated development of the country's economy. As agriculture is currently the most important economic sector, it is urgent that its resources be inventoried in order that its income-generating potential may be realized. Attainment of this potential will permit agriculture to make three essential contributions to the growth of the national economy of the Dominican Republic:

(1) The increase in productivity will directly swell the national income stream;

(2) the rise in per capita income of those employed in agriculture will stimulate demand in other sectors and encourage investment;

(3) export earnings and greater income in agriculture will be available for investment in all sectors.

Field Studies and Agricultural Planning

The role of agriculture in development is well known to economic planners, but it is worth drawing the attention of the reader to the broader economic implications of the highly localized study presented in this report. Then, too, national policy-makers, though well acquainted with the principles and models of developmental theory, often have difficulty in arriving at decisions over the allocation of scarce resources to specific projects and areas. Commonly, the difficulty derives from the unavailability of the right kind of information at the right time. What is needed, then, is a means for the rapid generation of the proper data. This report is illustrative of the ways in which modern techniques of data assembly and

processing facilitate the attainment of these twin goals.

Countries in the early stages of development generally are poor in capital and are relatively rich in land or natural environmental resources and labor. Agriculture is typically the dominant economic sector. This is the situation that prevails in the Dominican Republic today. In agriculture, as contrasted to manufacturing, inputs of natural factors are inevitably high, subject to limited control, and often output determining. Thus, in an underdeveloped agricultural economy the relative importance of nature as an input is great. While capital inputs are low, labor frequently is high, as in the Dominican Republic. It is important also to appreciate that labor has embedded in it much "social capital" in the form of agricultural knowledge, skills, and technology acquired over a long period of land occupance. A key objective of the planner is to devise the means for harnessing this human capital by strategically blending with it suitable doses of modern capital and technology while coordinating both with the appropriate natural resources. Given the relative abundance and costlessness of nature in the Dominican Republic, it follows that the definition and identification of sets of natural environmental variables offer a means for conserving scarce resources if an optimum mix can be obtained. Nature may be absorptive and wasteful of capital and labor in the sense that given inputs might have yielded greater returns if invested elsewhere. In order to avoid this trap, the crucial natural resource variables must be identified and scaled. The study of other aspects of nature, while of interest in their own right, would be time-consuming and largely irrelevant to the evaluatory objectives of a given agricultural project. Again, the report is illustrative of this approach.

In the field, nature confronts the investigator with a virtual infinitude

of variables and attributes. Fortunately, these are not haphazardly arranged, but are organized into natural ecosystems in which agents, materials, and processes are intimately related in well-defined geographic patterns. Agriculture is a man-managed, eco-biologic activity that is fitted with varying degrees of conformity to the geography of nature. Departures of the agricultural system from the natural order require investments of capital and labor in the form of irrigation and water works, terracing, seed improvement, disease control, land drainage, fertilizer applications, etc. The field task is to study the subset of systemically related natural variables that are functionally involved with agriculture and which affect the viability of farm operations. National planners will then have at their disposal, the requisite information on natural environmental resources to arrive at developmental decisions.

Objectives

The objective of this report is to provide information about a portion of the Linea Noroeste Region in the northwestern part of the Cibao Valley, in order that its agricultural potential may be evaluated. (See general location map on plates in back folder.) The report does not make or recommend investment decisions, but provides data without which such decisions cannot be made rationally. These data are on the soils, land surface features, and micro-climates of the region; they provide the means for the delimitation of the region into physically homogeneous subareas in terms of agriculturally crucial variables. The areas are arranged in a land-use classification system that reflects the ecologic impact on biological productivity of the interacting variables, with each constraint suitably identified. Maps of landscape units showing land quality patterns are prepared. Modern statistical design and

electronic data-processing methods have been employed to facilitate and hasten the study.

The report, maps, and field operational scale of the study are semi-reconnaissance (1:50,000), small enough for planning decisions and large enough for field application, though more field work may be necessary for certain applied phases. For office and field study, a set of eighteen maps has been generated. These provide geographic information on cultural cartographic features, landforms and geology, soils, climate, land surface, and multi-variable land resource areas.

Study Design

The design and general approach of the study are apparent from its structural parts. These are listed below:

- (1) acquisition and rectification of base maps;
- (2) delimitation of natural landform and geologic regions and subregions;
- (3) identification and field sampling of the natural physical components;
- (4) synthesis of uniform agricultural resource areas.

Field operations and information processing were coordinated closely with the above design elements and project objectives. In addition, several conditions surrounding the project and the area under investigation dictated the development and use of a new approach to land resource analysis. These conditions were:

- (1) limitations of budget and personnel;
- (2) limitations of time; rapid generation of information was wanted and a crash program approach was developed utilizing 14 man-months of professional time;

(3) poverty of published basic scientific information about the area; only 1:50,000 Army Map Service topographic maps, 20 meter contour interval, were available;

(4) great inaccessibility of much of the area because of difficult terrain, absence of even tertiary roads or trails, and a dense and forbidding thorn-thicket vegetative cover.

Each natural environmental parameter is treated separately according to its geographic variation within the Linea Noroeste. Subsequently, joint areal distributions are plotted. A discussion of the major physical impediments to agricultural development and some suggestions for further investigation conclude the study.

In April, 1966, the National Geographic Institute of Guatemala issued its comprehensive broad-gage report on the Dominican Republic, "An Approach for Planning the Integral Development of the Dominican Republic." The work, done at the request of the Texas Agricultural and Mechanical University/ Dominican Republic Program, emphasized the urgent need for conducting detailed field studies to rapidly enlarge the sphere of knowledge about the natural resources of the country. Though independently designed and prosecuted, this report is an implementation of that request and provides basic information about the Linea Noroeste Region without which efficient agricultural planning cannot proceed.

II

SURFACE MORPHOLOGY AND GEOLOGY

The three study areas examined in this report are situated contiguously within the Linea Noroeste region, which comprises portions of the north-central and northwestern provinces of the Dominican Republic. For convenience they have been designated as Regions I and II, the Entrada de Mao Lowland and the Santiago Rodriguez Inner Lowland respectively, both within the Cibao Valley. Region III, the Lower Massacre River Basin, is situated along the Dominican-Haitian frontier and includes portions of the Cibao Valley and the Cordillera Central. The outer boundaries of the study area were set according to topography to limit the dimensions of the project to land of highest agricultural potential. Internally, further subdivisions were made based on lithology, structure, drainage, and topography.

Little detailed previous knowledge of the project area was available at the start of the study. No large-scale surface geological or morphological maps had been published. A search of the literature revealed that extensive detailed paleontological studies, reconnaissance geologic traverses, and reconnaissance soil maps cover portions of the study regions. However, these studies perforce, are either detailed stratigraphic descriptions along isolated river traverses, or highly generalized reconnaissance level reports. The paucity of geologic information is most striking from Santiago Rodriguez to the Haitian frontier--an area that until the 1930's was the habitat of revolutionary groups and bandits. Thus, the detailed 1:50,000 scale surface geologic, morphologic, and soil maps presented herein represent original, agriculturally oriented material for a previously unmapped area.

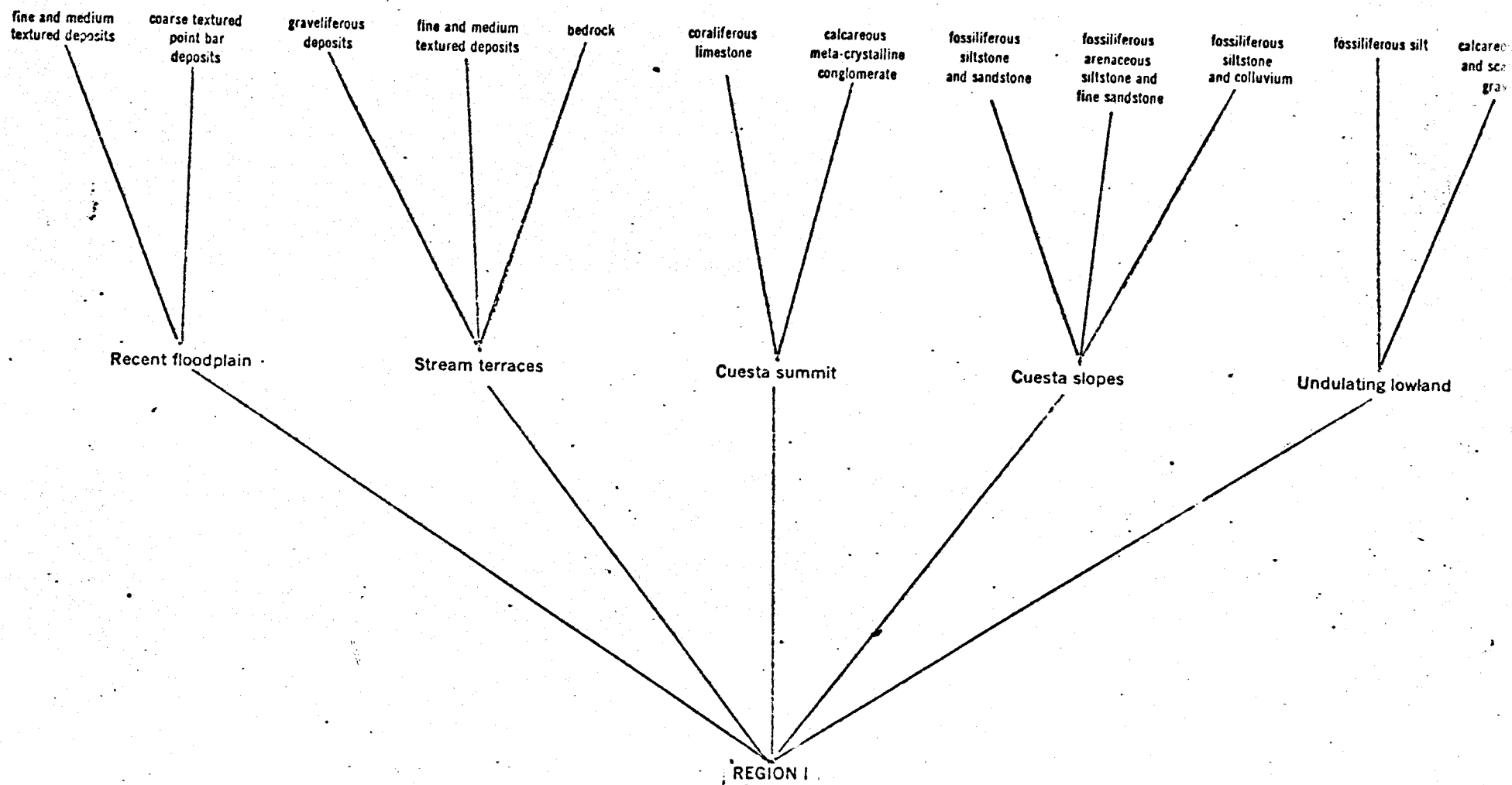


FIG. 1

Tree diagram of Entrada de Mao Lowland, showing relations of natural subregions and surficial geology

REGION I: THE ENTRADA DE MAO LOWLAND

Region I, termed the Entrada de Mao Lowland after the major community located within its confines, is found in a semi-arid region of the horizontal rock structure. The municipality Mao, Valverde Province, lies eight kilometers from the central portion of Region I.

Originally a coastal plain during the Miocene geologic epoch, subsequent uplift and development of the Cordillera Septentrional to the north has transformed this area into an interior plateau, now remote from the sea. Limestone-capped cuestras, striking WNW/ESE with a slight northward dip, delineate the northern and southern boundaries of this region. Drainage divides have been used as the eastern and western regional limits. Plate 1a shows natural subregional units, while Plate 2a is a map of surficial geology. Figure 1 (tree-diagram) illustrates the interrelationship of geology and surface morphology at the regional level.

The northernmost cuesta, termed from east to west, Sierra de Boruca, Loma de los Pozos, La Loma, presents solely a steep inface to the study area. These cuesta slopes are underlain by fossiliferous siltstone, a light brown/yellow, soft, highly calcareous material. Many stratigraphic units examined in the field contain either calcareous concretions or are highly fossiliferous. However, in some beds fossils are scarce or lacking. Photo I-1 illustrates the morphological unit, while Photo I-2 shows a closeup of surface lithology.

Intermediate on the cuesta inface, between the summit and lowland, and in the area from Mao Adentro to Gurabo Adentro, one finds a limited area underlain by calcareous meta-crystalline conglomerate and limestone. The material found in Region I is quite similar to an indurated conglomeratic lens interstratified with limestone found at Jiramagao Arriba to the northeast. This

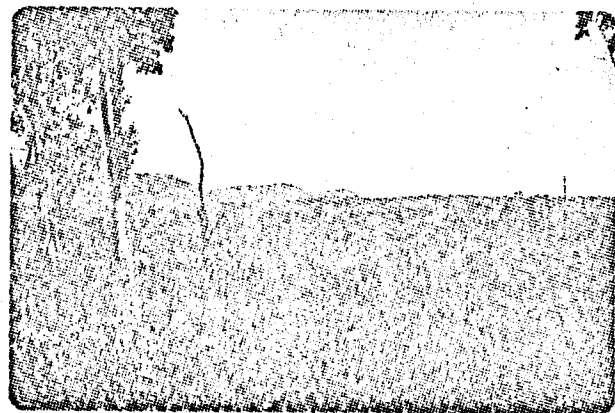


Photo I-1, Entrada de Mao Lowland, foreground-older terrace;
mid-ground-undulating lowland; background-cuesta
slopes and summit.

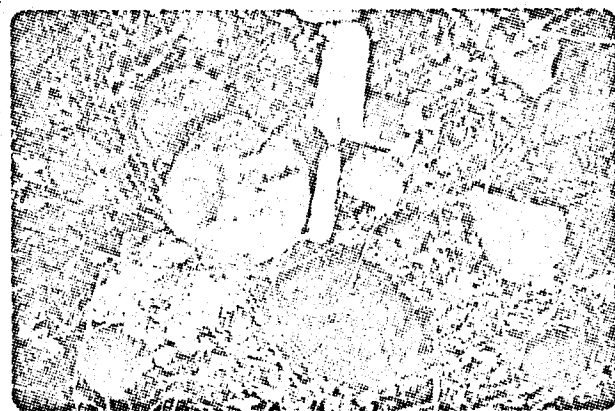


Photo I-2, Entrada de Mao Lowland, close-up of cobbles
on surface of cuesta slopes.

unit of conglomerate/limestone caps lobate hills lying adjacent to but at a slightly lower elevation than the cuesta summit.

The next geomorphological unit found to the south is the undulating lowland. This natural subregion has developed on relatively weak fossiliferous silt. Sheet wash and accelerated erosion characterize this unit; gullying is also well developed. Surface lithology may be defined as pale olive in color, soft, somewhat argillaceous calcareous silt, with and without fossils. One small, isolated area to the east of the Mao River, and within the undulating lowland subregion showed calcareous silt and scattered loose gravel. This surficial material consisted of fluviially rounded cobbles and boulders of igneous and metamorphic composition. The underlying material was a yellow-brown, argillaceous calcareous silt.

Cuesta summit and slopes found along the region's southern boundary are more complex in their interrelationships. Their locations are noted from east to west. From Jaiqui Picado to the Guanajuma Creeks indurated fossiliferous siltstone overlies fossiliferous arenaceous siltstone and fine sandstone. This latter surficial geologic unit is found on the lower portion of the cuesta slopes at Loma de Naranjo, and forms a highly dissected topographic feature. The unit contains indurated fossiliferous lens, profuse in mollusks. Photo I-3 illustrates the landscape developed here.

West of Guanajuma Creeks fossiliferous siltstone with calcareous colluvium appears on the lower slopes of Loma de los Helechos and Loma Sierrecita. Surface gravity flows of loose calcareous silt with scattered fossiliferous material can be traced from their source area, the cuesta/mesa line delimiting our southern boundary, northward into the valley. Between the Guanajuma Creek and the Mao River, surface colluvium occupies a considerable portion of the



Photo I-3, Entrada de Mao Lowland, lower cuesta slope materials, fossiliferous siltstone, and colluvial wash.

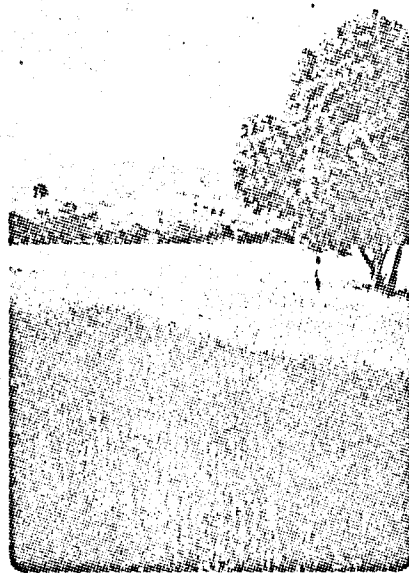


Photo I-4, Entrada de Mao Lowland, floodplain of the Amina River in rice cultivation.

valley floor.

West of the Mao River, the fossiliferous siltstone member of cuesta slopes soon disappears, its stratigraphic position taken by a structural bench underlain by coraliferous limestone. This latter unit is best observed on the road between Los Quemados and La Cacique. Yellow, yellow/brown, hard, somewhat argillaceous limestone caps the platform at 240 meters. The cuesta summit lies adjacent to this structural bench and one hundred meters higher. Both units represent true reefal deposits, containing a great number of branching corals.

Recent floodplain and stream terraces mapped are those features associated with the Amina, Mao, Gurabo rivers, and Guanajuma Creek. Photo I-4 shows floodplain of the Amina River in rice cultivation. All are exotic perennial streams, entrenched, and have extended their courses from the Cordillera Central northward through the study region. These rivers are, in fact, extended consequent streams which developed initially when the region was a newly uplifted coastal plain. The Cañada de Toñico, a dry-wash tributary of the Amina River, represents more recent stream development. This cyclical subsequent stream has developed on the belt of weaker rocks of fossiliferous silt underlying the undulating lowland.

Both fine/medium- and coarse-textured, unconsolidated, recent floodplain deposits have been mapped. Three types of stream terrace deposits are defined: (1) graveliferous; (2) fine/medium-textured; (3) bedrock. These latter deposits are found lying adjacent to the outer perimeter of the recent floodplain. Bedrock terraces may or may not have a thin veneer of alluvium on them. Essentially, they represent remnant valley flats produced in most instances through lateral erosion ^{by} streams.

REGION II: THE SANTIAGO RODRIGUEZ INNER LOWLAND

Region II, the Santiago Rodriguez Inner Lowland, extends from Las Caobas westward to the Cerro de Jacuba in Dajabon Province, a distance of 43 kilometers. The area is widest on the east, between El Guanah and Martin Garcia (18 kms.), but narrows westward between Partido and La Gorra, (8 kms.). Total area of Region II is 315 square kilometers.

The Cibao Valley/Cordillera Central geologic contact serves as the southern regional boundary. While to the northeast, from Las Caobas to Martin Garcia and Machete, the limestone cuesta of Miocene age, called Loma de las Caobas and Sierra Zamba, provides a natural limit. Northwestward, a metamorphic inlier of the Cordillera Central forms the boundary from Cabeza de Toro to Baboso, La Gorra, and Sabana Larga. This mountain mass is locally called Loma de los Garquises. The region's eastern boundary lies along the dissected Cercado sandstone upland/piedmont plain contact, while the western limit follows a drainage divide. Plate 1b shows the natural subdivisions, while Plate 2b is a map of surficial geology. Figure 2 illustrates the interrelationship of geology and surface morphology at the regional level.

Perusal of Figure 2 shows the major regional geomorphological units: (1) recent floodplain; (2) stream terraces; (3) piedmont plain; (4) piedmont upland; (5) horizontal structural plain; (6) belted metamorphics; (7) complex crystalline hills.

Recent and older fluvial deposition along the entrenched Cana, Yaguajal, Guayubin, Aminilla, Chacuey, Maguaca rivers, and Macabon Creek formed fine/medium and coarse textured, unconsolidated deposits. Photo II-1 illustrates a fine textured recent floodplain deposit along the Guayubin River. Photo II-2 shows a stream terrace graveliferous deposit.

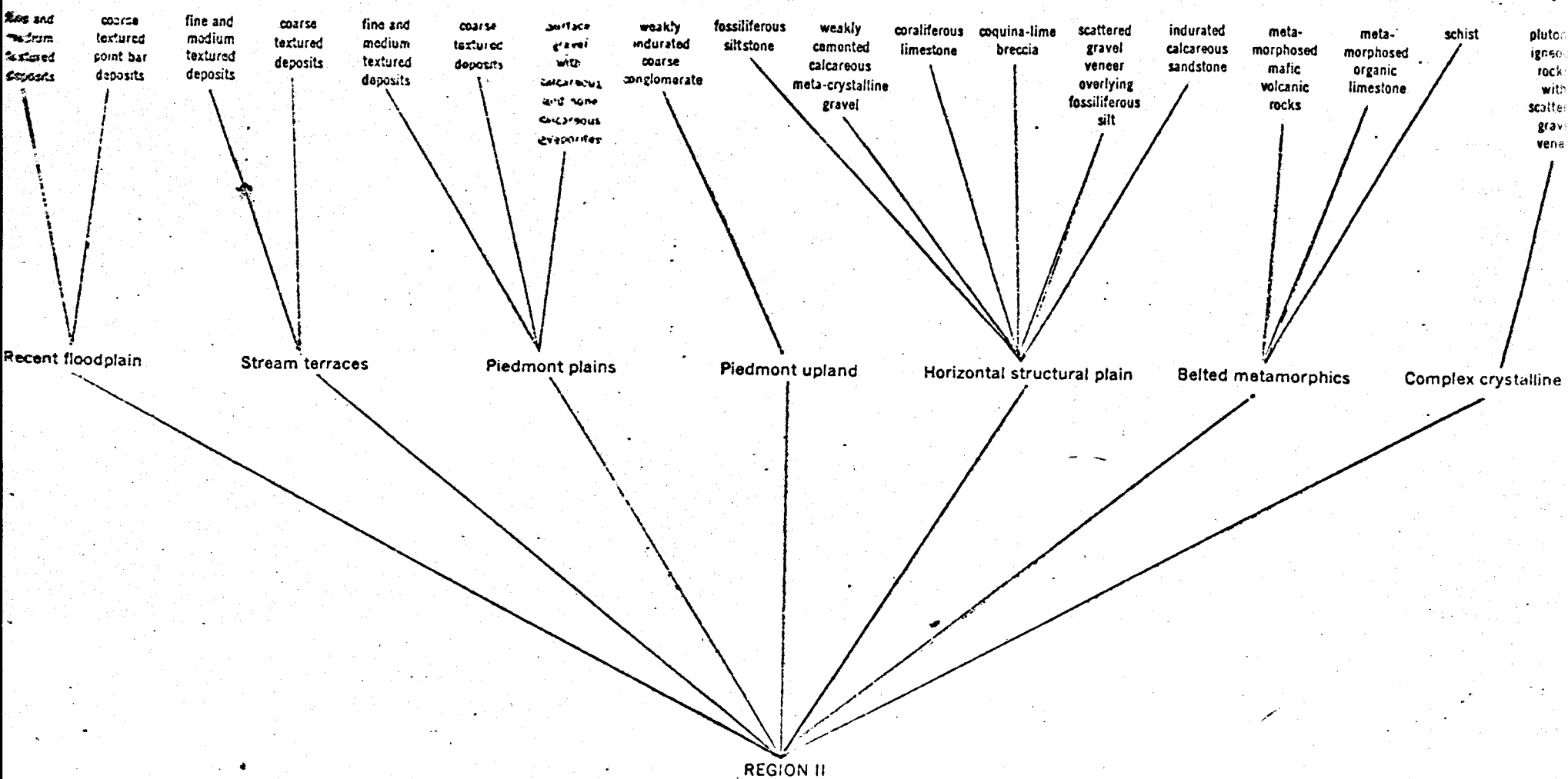


FIG. 2

Tree diagram of Santiago Rodriguez Inner Lowland, showing relations of natural subregions and surficial geology



Photo II-1, Santiago Rodriguez Inner Lowland, recent flood-
plain of Guayubin River.



Photo II-2, Santiago Rodriguez Inner Lowland, graveliferous
stream terrace deposit.

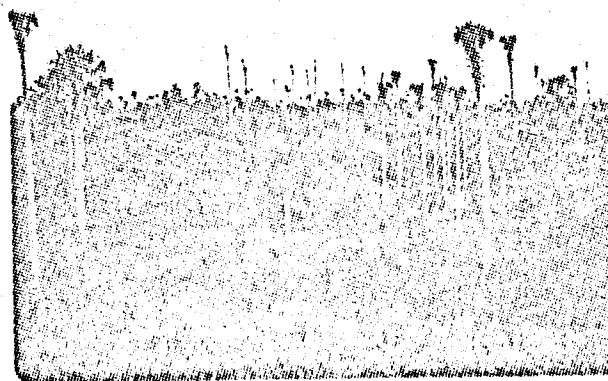


Photo II-3, Santiago Rodriguez Inner Lowland, dissected piedmont
upland.

The Piedmont Plain natural subregion, the largest areal unit in Region II, extends from Las Caobas to Gavilán on the extreme west. At Sánchez, 2 kilometers south of Las Caobas, piedmont plain gravels are found interstratified with the fossiliferous silt of Miocene age. Here, they lie within interstream areas of rolling plains developed on marine horizontal sediments. Westward, a series of piedmont fans extend for several kilometers away from the mountain front. At Alto de Cana and Mata de Jobo, weakly indurated, coarse conglomerate underlies a dissected piedmont upland (see Photo II-3). This yellow-colored conglomerate is interbedded with sand and contains poorly sorted pebbles, cobbles, and subangular boulders of diorite, granite, schists, and other rocks of the basal complex, ranging from 1 cm. to 30 cm. in diameter. At Lázaro, Agua Clara, Estancita, and farther west at La Breña de Campeche, lag gravel deposits are found. These deposits, located at the northern base of the mountain range are in fact gravel plugs, similar in morphology and composition to alluvial fan systems developed elsewhere. They occur where sudden change in gradient at the foot of the mountains causes rapid deposition of coarser debris. These piedmont coarse-textured deposits consist of rounded to subangular weathered gravel, composed of varying amounts of metamorphic mafic volcanics, calcareous metasediments, schists, and plutonic igneous rocks. Photo II-4 shows a typical landscape developed on this material. The land surface is illustrated in Photo II-5.

Fine- to medium-textured deposits are found north of the Piedmont Upland. They are yellow-red/yellow/yellow-brown, non-calcareous, predominantly silts, interstratified with sand and clay. Note the land surface which characterizes this geologic unit in Photo II-6.



Photo II-4, Santiago Rodriguez Inner Lowland, piedmont
upland on coarse conglomerate.



Photo II-5, Santiago Rodriguez Inner Lowland, close-up
of coarse material of piedmont upland.

Another surficial unit mapped within the Piedmont Plain is surface gravel with calcareous and noncalcareous evaporites. Most outcrops associated with this deposit are found within the dissected interfluvies of the creeks and dry washes of the western area. In this semi-arid environment, calcium carbonate is deposited chemically in the solum. Lime-bearing water evaporates instead of finding its way to the water table. Here, concretionary masses are found in the subsoil and at times, as masses or layers close to the surface. Photo II-7 shows a badlands topography developed on caliche with a surficial gravel veneer in Baboso parish.

Northwest/southeast-trending inliers of metasediments project through the piedmont plain in Region II. These monadnock-like features of resistant rock with their associated pediments are found at Cerro Chino, located along the banks of the Guayubin River. Here, sheared schistose rock and quartzite lens outcrop. At Cordero to the southwest, intensely sheared organic limestone lies in contact with massive greenstone. This organic limestone unit outcrops also farther west, as at Cerro del Llano, one kilometer northeast of Chaquey, and at Cerro de Jacuba on Region II's western limit.

Plutonic igneous rocks in contact with the Piedmont Plain define the region's southwestern boundary from Sangre Linda to Chaquey with a portion of these complex crystalline hills occurring within the study area. Here, quartz diorite is found, and also quartz keratophyre, which is fine-grained, and contains albite, and also some quartz phenocrysts.

The Horizontal Structural Plain subregion is located northeast of the piedmont plain. This marine unit is actually a continuation of those rocks of Miocene age examined in Region I. Fossiliferous silt underlies the gently undulating plain from Las Caobas to Zamba. This unit has a gentle

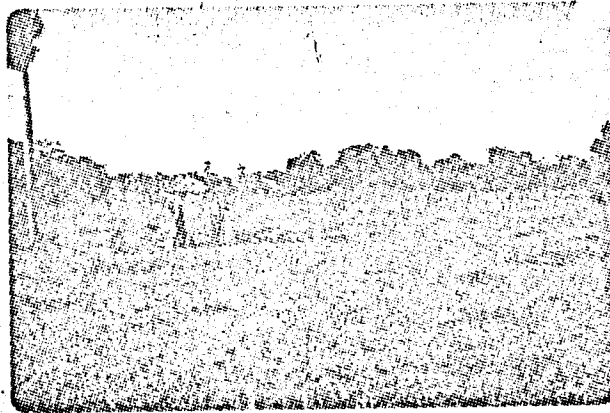


Photo II-6, Santiago Rodriguez Inner Lowland, piedmont plain on fine material.



Photo II-7, Santiago Rodriguez Inner Lowland, piedmont plains with "badlands" topography.



Photo II-8, Santiago Rodriguez Inner Lowland, horizontal structural plain.

dip northward toward the Sierra Zamba. The material exposed here is pale olive, soft, somewhat argilliferous. Fossil pectins are found in places, such as in the Los Guanos Creek, northwest of Las Caobas. Photo II-8 shows the plain.

Small, scattered deposits of weakly cemented calcareous metacrystalline gravel lie superficially on the fossiliferous silt. This material is oxidized, fragmented, and of pebble/cobble size. A gravel pit, located on the road between Santiago Rodriguez and Zamba exposes this surficial material.

Isolated reefal deposits of fossiliferous limestone and coquina occur between Zamba and Martin Garcia. The limestone is yellow/yellow-brown, hard, and somewhat argillaceous. Coquina is found at the distal end of the limestone deposits and consists of unconsolidated small shells and shell fragments in a cal-lime matrix. Photo II-9 shows the shell deposits.

A scattered surficial veneer of lag gravel was seen overlying fossiliferous silt along the west bank of the Guayubin River at Boca de Aminilla, and west of the Macabon Creek at Detrás de la Sierra. The gravel here may represent fluvial deposition of coarse fragments beyond the outer perimeter of the alluvial plain during some past pluvial stage.

REGION III: THE LOWER MASSACRE RIVER BASIN

Region III, the Lower Massacre River Basin, extends in a north-south direction along the eastern border of the Dominican-Haitian frontier, from Manzanillo to Loma de Cabrera and Capotillo, a distance of 31 kilometers. Total area studied here is 170 square kilometers.

The political boundary served as this region's western limit. On the

north and northeast, the drainage divide was used as the regional boundary. The metacrystalline/piedmont plain contact was then taken to form the limit from Clavellina west and south to Buena Vista. While the base of the mountains, La Traversada, Cerro de la Mercedes, and Loma de las Palomas, defined the southeast and southern boundary. Plate 1c shows the natural subregions, while Plate 2c is a map of surficial geology. Figure 3 illustrates the interrelationship between geology and surface morphology at the regional level.

Perusal of Figure 3 shows the major regional geomorphological units: (1) recent floodplain; (2) younger piedmont plain; (3) older piedmont plain; (4) horizontal structural plain; (5) complex crystalline hills; (6) belted metamorphics.

Recent fluvial deposition along the Massacre River has laid down fine/medium-textured, unconsolidated sediments. This area, located north-northwest of Dajabon and extending to Sanchez is extremely level land, crossed by many distributaries by which the river funnels its discharge. Recurrent annual flooding has handicapped agricultural development here. Test borings at six locations showed recent stratified silts and clays to more than a six-foot depth. Photo III-1 shows the landscape developed here. Note that a small stream terrace of the Massacre River is included within this sub-regional unit. Located at Dajabon, this one-quarter square kilometer area is normally not subjected to recurrent flooding.

The Piedmont Plain geomorphic unit in Region III is subdivided into younger and older plains on the basis of air photo interpretation and field observation. The older unit is actually the westward continuation of Region II's piedmont plain and retains essentially the same characteristics. Fine/medium, coarse, and evaporite deposits are also found here.

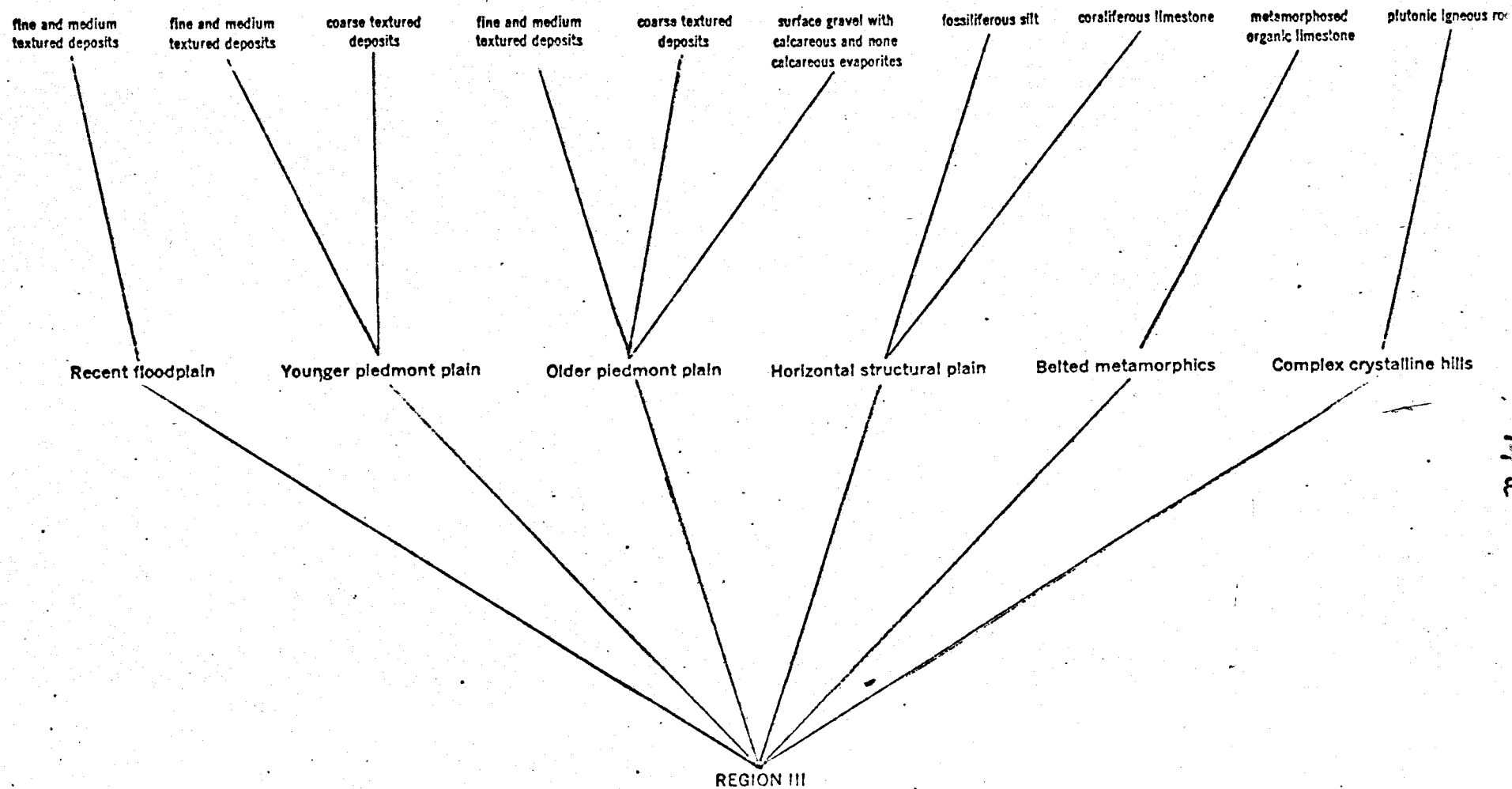


FIG-3

Tree diagram of Lower Massacre River Basin showing relations of natural subregions and surficial geology

The Younger Piedmont Plain overlies the older unit west of the 218°00m.E. grid coordinate. This contact is identifiable on overlapping aerial photographs viewed in stereoscopy. The piedmont fan originates at Juan Calvo where the diameter of its apex is two kilometers. Lateral spread of fine/medium-textured materials in lobate form occurs northward to its Cañongo/Sánchez terminus. Gravel plugs occur just north of Juan Calvo, at La Vigia, and between El Cercado and Sánchez.

Two small inliers of organic limestone outcrop at Sánchez and Cañongo. These units, trending northwest/southeast are the westward extension of the unit mapped in Region II.

A large pluton of tonalite underlies the region from Juan Calvo south to Loma de Cabrera and Capotillo. The topography of this area is generally much less rugged and of lower elevation than the surrounding mountain system. (Photo III-2). This complex crystalline hills subregion may correlate with a tonalite zone mapped between Jarabacoa and Moncion and a quartz diorite region mapped in northern Haiti. It would therefore represent a portion of one large batholith of over 100 kilometers in extent, trending in an east/west direction.

While the tonalite (quartz diorite) group appears to be the country rock within this subregion, volcanic and metavolcanic rocks have also been observed and hand specimens examined. Several basaltic rocks were found in the Don Miguel, Juan Calvo, La Piña area.

Local shearing has produced in places contact metamorphism. This phenomena was observed near the juncture of Arenoso Creek and the Massacre River at La Hoya. The basaltic-amphibolite rock found had a schistose structure. Silvery metallic ore was found here. Two kilometers west-southwest at Pueblo Nuevo, contact metamorphism was again observed with the occurrence of the metallic ore.



Photo II-9, Santiago Rodriguez Inner Lowland, horizontal structural plain with shell fragments on surface.



Photo III-1, Lower Massacre River Basin, recent floodplain of Massacre River.

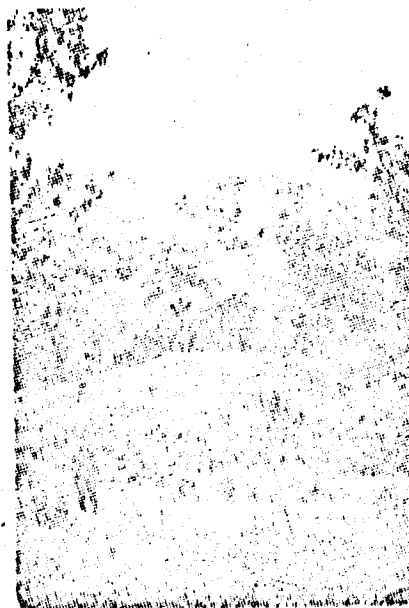


Photo III-2, Lower Massacre River Basin, complex crystalline hills.

III

CARTOGRAPHY

Operational and logistical problems in the field early centered on the fact that the Army Map Service Series 1:50,000 topographic and photo-maps had not been field checked to verify all existing cultural data. Frequently, the actual site of a village occurred kilometers from its map location over intransitive roads. In addition, most drainage features were expressed cartographically as intermittent streams (arroyos) when in actuality they were cyclical features or washes (cañadas). The need for field-verified drainage, and other cartographically expressible cultural map data was immediately realized and incorporated into the field work phase. Hence, the following statements can be made regarding our base map data for Regions I, II, and III.

First, drainage features have been classified as follows:

1. Perennial features, i.e., rio (river), contain water during most of the year.
2. Intermittent features, i.e., arroyo (creek), contain water during only part of the year.
3. Dry or cyclical features, i.e., cañada (wash), are usually dry most of the year.

Second, road and trails have been classified as follows:

1. Hard-surface, all-weather two-lane roads. These roads can carry fairly heavy truck loads in all weather. Construction is usually bituminous macadam, surface-treated oiled gravel, or light tar-bound macadam.

2. Loose-surface, all-weather roads. These roads carry light loads in all weather. The roads generally are drained and graded. Construction is usually of gravel, stone, or some stable material such as sand-clay, on a light foundation.
3. Loose-surface, fair or dry weather roads. These roads carry light loads in dry weather only. The roads may or may not be graded or drained. Any surfacing consists of gravel, or sand-clay with a poor foundation.
4. Tracks. These are natural roadways, here in the Linea Noroeste termed callejones, that can accommodate very light vehicles with four-wheel drive in dry weather.
5. Trails. These include important foot trails, paths, and pack trails. Note that both the drainage classification and trafficability categories follow those outlined in the following reference: U. S. Dept. of the Army. Field Manual FM 21-31 (Topographic Symbols). June, 1961.

The site of each rural settlement occurring in the study regions has been verified and its actual location on the base map plotted. These communities have in addition been classified as a parish, section, or municipality using the following map notation:

Parish	Santa Maria
Section	SANTA MARIA
Municipality	SANTA MARIA

All spelling has been checked with reference to:

Republica Dominicana. Direccion General de Estadistica y Censos.
Division Territorial de la Republica Dominicana. 1961.

IV

NATURAL COMPONENTS OF THE AGRICULTURAL ENVIRONMENT

General Design of Study

With insufficient knowledge of the physical environment available for planning purposes, a primary objective of the study was to uncover the needed information as quickly as possible. The three major interacting site environmental variables affecting the biological productivity and agricultural potential of the region are soils, climate, and land surface. These features co-vary through space. Hence, it is necessary to delineate their joint areal distributions in order to assess the quality of the region, since any one may be limiting for agriculture. In other words, unit areas of land in the Linea Noroeste region were examined and their soil, climatic, and land surface properties were simultaneously characterized. In all, forty-one soil attributes, five climatic attributes, and four land surface attributes were initially scored and recorded in the field. By the use of appropriate statistical methods, the data were processed through an electronic computer. These permitted the sampled sites to be compared with each other and ultimately to be collapsed into typical sites and uniform areas. The process was applied to the sites for each of the three main variables: soil; climate; and land surface; separately and jointly. Thus, the major physical impediments to agricultural development in the Linea Noroeste region were identified by kind and geographic location.

The initial step in the analysis was to devise a field-sampling procedure which would insure that the sites examined would provide the needed information on soil, climatic, and land surface properties and would be

representative of the conditions that prevail in the Linea Noroeste region. In other words, the sample population had to be randomly selected and of sufficient size to provide unbiased information about the whole region. Considering the limitations of time, budget, and geographic scale, it was decided that six hundred and six sites would be adequate. After the initial eight hundred and twenty square kilometer area had been reduced because approximately two hundred square kilometers along the periphery were unsuited for cultivation, one member of the team, Mr. Gustavo A. Antonini, examined each site in the field.

The specific location of each field site was selected according to a stratified random areal sampling with variable proportion method. According to this procedure, the total sample population was numerically distributed among the regions and subregions described in the previous section, proportionate to the size of their areas. Thus, each region was assigned its fair share of the total. Within each subregion, the specific location of each site was selected by randomly designated geographic coordinates generated by an electronic computer. These sites were then visited in the field and their properties recorded, generalized, and projected to the whole region. The method permitted the identification of the categories of soils, climates, and land surfaces, as well as reliable estimates of the areal proportion of each category for the different variables. By reference to air photos and topographic maps, projected geographic patterns were recognized and represented on maps.

SOILS

Because of the wide range of soil-forming factors present in the region,

the pattern of soil development can be expected to be varied and reveal a complex geographic distribution. The local pedogenic regimes are the result of the interaction of parent materials, climate and microclimate, and land surface. From the tree diagrams showing the relations of the natural subregions and the surficial geology, it is apparent that a wide variety of rock materials, differing both lithologically and physically, are available for transformation into soil. These include consolidated and unconsolidated materials, various textural sediments, calcareous and non-calcareous deposits, and sedimentary, igneous, and metamorphic rocks of contrasting mineralogy and age.

Superimposed on the parent materials are the influences of climate and land surface. The climatic differences of greatest significance derive from the effectiveness and availability of soil moisture. These may be reduced to three components, the first independent of the soil itself, and the second and third dependent in part upon the properties of the very soil whose formation they are affecting. They are: (1) annual and seasonal distribution of rainfall, the former ranging from an approximate mean annual maximum of 2200 millimeters to an approximate mean annual minimum of 850 millimeters. The variation in annual and seasonal precipitation would have pedogenic effects even if the land surface of the Linea Noroeste were perfectly flat and composed of uniform surficial material. Because it is not, two other moisture components are superimposed on rainfall. These are the different infiltration rates, permeabilities, and moisture-holding capacities of the materials, and the water runoff received ⁱⁿ by depressions and lowlands from uplands. These two components are responsible for local pedogenic transformations; (2) the ^{amount} depth of moisture that the soil is capable of retaining at field capacity, against gravity from a given rainfall

receipt, expresses the total effective soil forming water, and separates the moisture that remains in the soil from the free water passing through the profile and running over its surface; (3) addition of water to the soil body from above or below may result from its topographic position relative to the surrounding area. Runoff water from higher surfaces may accumulate in local depressions or low surfaces and significantly increase the entrance of water into the profile. A similar phenomenon may occur on alluvial surfaces when streams are in flood stage and inundate their plains. This may occur more than once a year or as little as once in fifty years. Flooding from beneath takes place when the unconfined water table rises and lies within the profile or at the surface.

The influence of the land surface on soil formation is, of course, very much involved in the third climatic variable treated above. In addition, it affects the depth and age of the soil. Water moving downslope over surfaces carries eroded soil material in suspension which it deposits at the foot of the slope where its velocity becomes insufficient to carry the material further. The removal of weathered material from the upland surface reduces the soil depth and continually exposes rock at the surface so that the soil is young and immature. On the other hand, the lower surfaces continually receive deposits of fresh material so that the soil body again remains young and immature, and, in addition, open and unconsolidated.

In brief, then, the pedogenic environment of the study area has the properties and variabilities that encourage a complex pattern of soil formation. It is the purpose of the study design and analysis to uncover this pattern as rapidly as feasible. The method employed is described briefly in the next several paragraphs.

Field Methods and Data Analysis

Within each randomly selected 100-square meter sampling site, the soil was examined at a point regarded as representative by the field investigator. A 10.16 centimeter (four inch) diameter bucket auger able to reach a depth of 103 centimeters was employed. Forty-one soil properties were determined initially; these included texture, color, depth, horizons, consistency, effervescence, acidity, and many others. However, only nineteen properties were used in the analysis. Because the samples were taken with an auger, only soil variables and attributes that were not destroyed by this method were used in the study. Except for pH, no chemical or mineralogic determinations were used.

Data on the variables were recorded at each sampling site on field sheets. The information was scaled numerically and punched on IBM (International Business Machine) data cards for computer processing. The location of each sampling site was noted on the field sheet and on the IBM card by an appropriate identification number.

Because of the limitations of the information uncovered and the way in which the samples were collected, the findings and maps presented are not identical with traditional soil maps or soil classifications. Nonetheless, the information gathered is valid for the purposes of the study, that is, the recognition of the soil properties affecting the potential agricultural productivity of the Linea Noroeste region. Together with some additional study, these data can provide the basis for a more comprehensive classification of the soils, if needed.

Treating the main regions jointly, each sampling site characterized by nineteen scored soil variables was compared to every other site in order to

set up uniform types whose geographic location could be shown on maps. Thus, uniform soil regions were established. The work was done by an IBM 7094 electronic computer. A factor analytical technique was employed following a special machine program.*

Factor analysis is a statistical technique by which the relationships among a large number of variables may be reduced to a smaller number of variables or common factors. Thus, the essential variables that are responsible for the distinctive properties of the soil samples can be identified and aggregated into independent soil groups whose geographic distribution can be plotted. A study of the variables contributing to each factor composing the soil groups and the geographic patterns of distribution for the groups, exposes the nature and quality of the soils in the Linea Noroeste.

The soil units that are described and mapped are soil factor categories, not soil groups as the term is used traditionally. A factor category consists of the nineteen variables which have been used to describe all the soil samples. The variables are synthesized into factor categories whose variable structure reflects the behavior or composition of the samples. Several factor categories are generated by the analysis in the most efficient manner; that is, so as to explain the maximum amount of information in the system. After the factors have been generated with their respective variable loadings, the soil at each sampling site is matched to the closest factor or factors. Hence, the soil descriptions are given in terms of their factor affinities, and, the program acts to cluster the sample.

Six factors or groups of variables were generated by the analysis. The composition of each factor in terms of the nineteen variables permitted

* The program called "MUST" was written by Mr. Vincent Manson, American Museum of Natural History and Columbia University, both in New York, N.Y.

the soils to be identified. That is to say, the soil of each sampling site could be fitted to a factor, which may be regarded as a synthetic soil. All of the factors taken together describe the compositional variations for all the soils observed at all the sampling sites by the nineteen selected variables. For each factor, an actual soil was located that closely fitted the factor; this is the reference soil for that factor to which the composition of other soils was compared. Some soils departed from a "close fit" to a single factor. Their compositional variation was partitioned among two or three factors. The identification and location of these soils led to the setting up of additional soil units and areas.

The soil factor units of each subregion are described below:

Factor Soil Units of Region I, Entrada de Mao Lowland

1. Factor 1 soils are derived from fossiliferous siltstone, and are deep but moderately developed. They are medium-textured, typically, loams, silt loams, and silts, but have silty clay and clayey subsoils. They are highly plastic and sticky when moist, and tend to suffer from poor internal drainage. The profiles may be stone free or contain some fossiliferous fragments. The pH of the surface and subsoil ranges from 7.6 to 8.0 and they contain considerable free lime. Their surface color varies from dark brown to dark gray-brown and their subsoils are olive to olive-brown in color.

These soils occupy the largest area within the region and are the core of the undulating lowland. Good examples of the group and the reference site may be observed approximately one kilometer east of Potrero at coordinates 958 and 542, sheet 6074 III (Moncion, D.R.), U. S. Army Map Service, Corps of Engineers, 1:50,000.

2. Factor 2 soils are shallow stony phases of factor 1 soils. They are less than 183 centimeters to hardpan or hard rock, and contain coarse fragments, generally calcareous, but occasionally are associated with a veneer of gravel. Colors of the two soil groups are similar, though subsoil colors of this unit are more apparent at the surface. Factor 2 soils commonly occupy a belt between the higher limy rocks along the margins of the region and the lower lying factor 1 soils.

An accessible good example of this soil factor may be observed along the main north-south highway in the vicinity of Los Quemados at coordinates 734 and 560, sheet 5974 II (Moncion, D.R.), U. S. Army Map Service, 1:50,000. The reference site, however, is located at coordinates 842-546 on the same sheet.

3. Factor 3 soils are composed of young alluvial floodplain materials that are subject to periodic stream overflow unless protected by dikes. The texture of the deposits are medium to coarse, and, in places the soil may contain gravel and coarse fragments, surficial and scattered in the profile. Profiles are deep and generally well drained internally, but external drainage is poor to very poor because of flooding. Color of these soils varies from dark brown to dark gray-brown in the surface, while subsoils vary from dark gray-brown to yellow-brown and olive-gray. (One sample had a reddish-brown subsoil.) The pH ranges from slightly acid to slightly alkaline (6.8-7.2), with subsoils tending to be on the alkaline side. One sample, however, had a pH of 8.0 at a depth of 75 centimeters.

Good examples of this factor may be observed east of the village of El Cercado near the intersection of coordinates 806-557, sheet 5974 II (Moncion, D.R.), U. S. Army Map Service, 1:50,000.

Factor Soil Units of Region II, Santiago Rodriguez Inner Lowland

1. Factor 1 soils are also found in a large area of Region II, having developed from similar parent material, a pale olive fossiliferous silt.

Also present in Region II, occupying large areas, is a variant of the factor 1 soil group, designated as 1a. In these soils the pH's tend to be somewhat lower and free lime is less pronounced. The brownish color is more strongly developed and the pale olive color of the subsoil is absent. Coarse fragments tend to be more common. A reference site for factor 1 in Region II is at coordinates 518-580, sheet 5974 IV, Martin Garcia sheet; a reference site for factor 1a is at 555-564, northeast of Santiago Rodriguez, on the Santiago Rodriguez sheet.

2. Factor 2 soils also are found in Region II occupying a belt developed on outcrops of various kinds of limy rock materials and fragments with inter-mixtures and overlays of gravel. Hence, these soils are shallow, medium to coarse-textured like their counterpart in Region I. A reference site may be seen at coordinates 496-646, sheet 5974 III, Santiago Rodriguez sheet.
3. Factor 3 soils, as described for Region I, are also found in Region II along stream courses. In addition, there is a substantial area of intermittently distributed factor 3 soils throughout the Piedmont Plains subregion associated with the narrow, shallow valleys and floodplains that ramify the landscape in a dendritic pattern. Not all of these sites have been shown, but sufficient detail has been mapped to indicate their areal distribution. A reference site may be seen at coordinates 488-693, sheet 5974 IV, Martin Garcia sheet.

4. Factor 4 soils are found in the southeastern part of Region II, on an upland piedmont surface composed of a weakly indurated mixed conglomerate. The soil is coarse-textured containing a varied assortment of rounded igneous pebbles and cobbles. In places, an indurated layer may be reached, but more commonly the profile is open and permeable. As a result, internal drainage and external drainage are excessive, the latter being due to steeply sloping surfaces. Texture grades from stony silt loams to coarse and fine sandy clay loam subsoils. The pH of the soil is slightly acid to neutral. The colors range from a dark reddish brown to reddish brown surface soil and from a yellowish brown to light olive brown subsoil. A reference site is located at coordinates 595-506, sheet 5974 III, Santiago Rodriguez.
5. Factor 6 soils are upland soils developed on igneous crystalline rocks. They are light-textured, shallow and stony, and tend to be excessively drained. These soils are on the acid side, but the subsoils may be slightly alkaline. Surface color is typically dark brown and the subsoil is a strong brown. A reference site is located at coordinates 339-572, sheet 5874 II, Lomade Cabrera.
6. Factor 7 soils are developed from mixed metamorphic rocks, including schists, meta limestone, and greenstone. These soils are not of large areal extent. They have medium-textured surfaces and heavy-textured subsoils with considerable coarse fragments of residual material on the surface and in the soil body. Profiles are shallow. The soil material exhibits a surprising degree of stickiness and plasticity when moist. The pH of these soils ranges from slightly acid to slightly alkaline. Surface colors are dark brown grading into a light yellowish brown with increasing depth. The reference site is at coordinates 438-571, sheet 5974 III, Santiago Rodriguez sheet.

000654

Factor Soil Units of Region III, Lower Massacre River Basin

1. Factor 1 and 1a soils are also found in this region, where they have developed from materials similar to their counterparts in Regions I and II. In Region III, however, toward the west, because the elevation declines to sea level and the surface relief diminishes, the profiles exhibit the effects of imperfect drainage. While surface colors remain unaltered, the subsoil takes on a definite grayish cast. In other aspects, factor 1 and 1a soil groups are similar to their respective sites in Regions I and II. A reference site for factor 1 may be obtained at coordinates 191-735, sheet 5874 I, Dajabon sheet; a reference site for factor 1a is at coordinates 193-694, sheet 5874 I, Dajabon sheet.
2. Factor 2 soils are found also in Region III developed on the westward extension of the shallow limy materials found in Regions I and II. The profiles here also tend to be shallow, medium-textured, and contain fragments of limy rocks. A reference site may be found at coordinates 152-768, sheet 5874 I, Dajabon sheet.
3. Factor 8 soils occupy a large area in Region III, on the piedmont alluvial plain. These soils bear a similarity to the floodplain soils of Regions I and II but have heavy surface textures and are not subject to active flooding. Subsoils are sandy and open but water often accumulates on the surface. Colors grade from dark grey surface to a black subsurface. A reference site is located at coordinates 164-725, Sheet I, Dajabon.
4. Factor 5 soils are found in Region III in a floodplain area adjacent to the Massacre River and west of factor 8 soils. Though generally similar to the floodplain soils found in Regions I and II, these soils are heavier-textured and suffer from very poor drainage. They are deep silty clays of a dark gray brown color that grades into dark yellow brown with depth. Banded yellow brown mottles are distinct. The soils

are highly sticky and plastic when wet. The pH is neutral to slightly alkaline. Periodic flooding and a high fluctuating water table have influenced the development of these soils. A reference site is located at coordinates 125-715, sheet 5874 I, Dajabon sheet.

5. Factor 6 soils are shallow, stony, coarse-textured upland soils developed on igneous crystalline rocks. They are excessively drained and have low plasticity and stickiness. These soils are acid, ranging in pH between 6.0 and 7.0. The colors of the surface soils are dark grayish brown while the subsoils are yellowish brown. A reference site is located at coordinates 225-535, sheet 5874 II, Loma de Cabrera sheet.

There are two small areas of factor 7 soils located in the region. No samples fell within these areas. There is also a small area of factor 4 soils in Region III. The soils here resemble their counterpart soils in Region II, except that the red color is more subdued, the pH is a little higher, and the subsoil is whiter in color.

The geographic distributions of the soils in factor units are shown on Plates 3a, b, and c. The composition of the factor soil units as described by the nineteen soil variables used in the analysis is given in Table 1.

LAND SURFACE

A second variable that affects the potential agricultural productivity of different parts of the Linea Noroeste region is land surface. As mentioned in the previous sections on soils, configuration of land surface also is an important soil-forming agent. In addition, it influences the microclimatic regime.

As expected, the land surface of the Linea Noroeste is varied and reflects the geomorphic conditions prevailing in the area. The genesis of land surface

Table 1. Composition of Factor Soil Units, 19 Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Region and Factor Soil Unit	Texture of Surface Soil	Texture of Subsoil	Depth to Subsoil centimeters	Depth to Hardrock centimeters	Hardpan present	Color of Surface Soil			Color of Sub	
Entrada de Mao Lowland										
Factor Unit 1	silty clay loam	silty clay	22	> 183	absent	dark grayish brown			pale olive	
Factor Unit 2	sandy loam	loam	8	20	absent	grayish brown			olive gray	
Factor Unit 3	sandy loam	loamy sand	52	> 183	absent	dark brown			dark yellowi brown	
Santiago Rodriguez Inner Lowland										
Factor Unit 1	silty clay	clay	60	> 183	absent	dark yellowish brown			light olive	
Factor Unit 1a	sandy loam	clay loam	51	> 183	absent	dark brown			strong brown	
Factor Unit 2	silt loam	silt loam	8	35	absent	dark brown			olive	
Factor Unit 3	loamy sand	loamy sand	12	> 183	absent	olive brown			dark gray b	
Factor Unit 4	silt loam	sandy clay loam	30	> 183	absent	dark reddish brown			yellowish b	

Table 1 (cont.)

Composition of Factor Soil Units, 19 Variables (cont.)

(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
11	pH of surface soil	pH of subsoil	Effervescence of surface soil	Effervescence of subsoil	Wet consistency of surface soil	Wet consistency of subsoil	Drainage	Stoniness
	8.0	8.0	strong	violent	sticky, plastic	very sticky very plastic	imperfect	none
	7.4	7.6	strong	strong	slightly sticky slightly plastic	slightly sticky slightly plastic	excessive	frequent gra scattered in profile
	7.0	7.2	none	none	sticky slightly plastic	slightly sticky	well	frequent gra scattered in profile
DWT	7.0	7.8	strong	violent	very sticky very plastic	very sticky very plastic	imperfect	none
	7.0	7.2	none	slight	sticky slightly plastic	sticky slightly plastic	imperfect	occasional g scattered in
	7.2	7.6	none	none	slightly sticky slightly plastic	slightly sticky slightly plastic	somewhat excessive	frequent pebb cobbles scat profile
	7.2	6.8	none	none	slightly sticky	slightly sticky	poor	occasional g scattered in
	7.0	7.0	none	none	sticky slightly plastic	sticky plastic	excessive	frequent cobb profile

Table 1 (cont.)

Composition of Factor Soil Units, 19 Variables (cont.)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Factor and Soil Unit	Texture of Surface Soil	Texture of Subsoil	Depth to Subsoil centimeters	Depth to Hardrock centimeters	Hardpan present	Color of Surface Soil		Color of Subsoil			
Elgo Rodriguez Inner Lowland											
Factor Unit 6	sandy loam	sandy loam	41	79	absent	dark brown		strong brown			
Factor Unit 7	sandy clay loam	sandy clay loam	34	> 183	absent	dark reddish brown		yellowish brown			
Massacre River Basin											
Factor Unit 1	silty clay loam	clay	61	> 183	absent	brown		dark gray			
Factor Unit 1a	silt loam	clay	47	> 183	absent	very dark grayish brown		yellowish brown			
Factor Unit 2	silt loam	silty clay loam	39	59	absent	dark brown		yellowish brown			
Factor Unit 3	silty clay	loamy sand	25	> 183	absent	very dark gray		black			
Factor Unit 4	silt loam	clay loam	64	> 183	absent	dark brown		very pale brown			
Factor Unit 5	clay	silty clay	25	> 183	absent	very dark grayish brown		dark grayish brown			
Factor Unit 6	loamy sand	loamy sand	18	60	absent	very dark grayish brown		yellowish brown			

Table 1 (completed)

Composition of Factor Soil Units, 19 Variables (completed)

(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
pH of surface soil	pH of subsoil	Effervescence of surface soil	Effervescence of subsoil	Wet consistency of surface soil	Wet consistency of subsoil	Drainage	Stoniness
6.6	7.6	none	none	slightly sticky slightly plastic	sticky slightly plastic	well	occasional gravel cobbles in profile
6.8	7.6	none	none	sticky plastic	sticky slightly plastic	well	occasional gravel cobbles in profile
7.3	8.2	strong	violent	sticky plastic	very sticky very plastic	imperfect	none
7.0	8.0	none	slight	sticky slightly plastic	very sticky very plastic	imperfect	occasional gravel in profile
7.8	7.8	strong	violent	slightly sticky slightly plastic	very sticky plastic	imperfect	none
7.0	7.2	none	none	very sticky plastic	slightly sticky	poor	none
6.4	7.8	none	none	slightly sticky slightly plastic	sticky plastic	imperfect	frequent pebbles cobbles in profile
7.0	7.2	none	none	very sticky very plastic	very sticky very plastic	poor	none
6.0	6.4	none	none	slightly sticky	slightly sticky	somewhat excessive	frequent pebble cobbles in profile

features expresses the interaction of several forces. These are (1) initial relief or differences in elevation that are the result of internal earth pressures. Such differences permit the operation of gravity to move downslope loose material from one location to another, water being the chief agent of transportation. Elevation ranges from 290 meters to sea level, giving a relief in the order of 290 meters.

(2) The resistivity to weathering and erosion of the rock materials exposed at the surface under the prevailing climate. It is clear from the earlier discussion on "Surface Morphology and Geology" and the tree diagrams that a variety of materials at contrasting elevations exist in the Linea Noroeste. These materials range from complex igneous and metamorphic crystalline rocks to variously cemented limestones, siltstones, sandstones, conglomerates, and unconsolidated alluvial sediments. Each weathers in a unique manner and is associated with a peculiar set of land surface features. (3) The influences on land surface of both relief and lithology are partially dependent upon climate. The weathering reactions of rocks respond differently to precipitation and temperature. High relief provides the slopes and steep gradients for streams and rivulets to acquire sufficient energy to carry weathered material in suspension. But rainfall is equally essential to furnish water to disaggregate consolidated material, and to act as a transporting agent. Total rainfall and storm intensity are the important climatic elements in the Linea Noroeste region. (4) In a landscape occupied by man as long as the Linea Noroeste region with the peculiar system of slash and burn shifting agriculture (Tumba), it is likely that man-induced or accelerated erosion has had an important impact on land surface. A geomorphic system initially in equilibrium among its

elements of rocks, climate, and slopes has been seriously disturbed by the removal of a protective natural vegetative cover, and the mechanical influences of farming. The net effect of these changes has been to shift the equilibrium in the direction of greater erosion, which manifests itself in the removal of top soil, deep gullying, and increased flooding and deposition in the lowlands.

Field Methods and Data Analysis

These forces and agents interact to produce peculiar landscapes and surface configurations of slope, local relief, and channel forms in a complex environment of land surface evolution. It is the object of the study design to uncover and generalize the patterns. The surface of the land can be disaggregated empirically into two sets of variables, macro and micro. The macro-elements describe the broad terrain features or physiographic units. The micro-elements describe the more localized surface features with which the farmer has to contend directly as he tills the land. At each 100 square-meter sample site, data on elevation, relief, slope, ruggedness, and soil erosion were taken and recorded on field sheets. The scored variables at each site were compared to those at every other site to set up uniform types whose geographic location could be shown on maps. The data were processed by a factor analysis machine program on an electronic computer, and the output grouped as factor land surface units. The land surface units that are mapped and described are factor categories, not surface features. But each factor unit is composed of a different proportion of the land surface variables measured directly in the field. These variables "load up" differently on each factor and define its composition in terms of the original field measurements. The land surface composition of a particular

site is explained best by one factor. When all 595 sites are thus examined, they cluster or group into factor categories. The site with the "closest fit" to a factor is used as the reference site and the variables contributing to each factor, together with their geographic distribution, reveals the patterns of land surface variation in the Linea Noroeste.

All of the factors taken together describe the compositional variation for all the land surface samples. It was found, however, that three factors were adequate to describe the system.

Factor Land Surface Units of Region I, Entrada de Mao Lowland

1. Factor 1 land surface units are areas of low relief, low ruggedness, and low slopes. Ruggedness scores are less than 5, which means that gullies when present, are less than one-third meter deep, and that there are less than five gullies per 100 meter length of traverse. Associated with these features are slopes less than three per cent, and a relief less than two meters.
2. Factor 2 land surface units are areas of low relief, moderate ruggedness, and slope. Ruggedness scores generally are five and nine. This may be interpreted to mean that one to five gullies usually are present, and that they are likely to be one to five meters deep and steep-sided. Ignoring height differences of the gully itself, the relief of the sample site is generally less than two meters. Slopes in unit 2 rarely easily exceed ten per cent.
3. Factor 3 land surface units are characterized by high ruggedness, high relief, and high slopes. These surfaces tend to be located at higher elevations. Ruggedness scores range between five and fifteen. This means that gully counts usually are five to ten per 100 meter traverse, and gully

depth is from five to ten meters. Relief within the sampling site usually ranges from three to twenty meters. The slope of the land surface in factor 3 ranges from ten to sixty per cent.

Most of the Entrada de Mao Lowland lies within factor units 1 and 2. The reader is cautioned to interpret these groupings broadly for within the area mapped for each unit there are other types.

Factor Land Surface Units of Region II, Santiago Rodriguez Inner Lowland

The descriptions used for the Entrada de Mao Lowland may be applied to the Santiago Rodriguez Inner Lowland. In this region, however, no land surface area belonging to factor unit 3 has been delineated. Hence, taken as a whole, the inner lowland has subdued land surface features. It is a region of modest slope, relief, and ruggedness. Again, the reader is cautioned to take a broad view.

Factor Land Surface Units of Region III, Lower Massacre River Basin

All three land surface factor units are found in this region, and the description given in the discussion of the Entrada de Mao Lowland is applicable here. The distribution of the factor land surface units within the Lower Massacre River Basin is interesting. The area of high slope, relief, and ruggedness, factor unit 3, occupies almost all of the southern sector which lies within the Central Cordillera. The northern half almost entirely falls within factor unit 1, low relief, slope, and ruggedness, and is associated with the Piedmont Plains and the Massacre River floodplain.

Within any major unit, particularly units 2 and 3, there is likely to be found representatives of all other types occupying small areas. The geographic distribution of the factor land surface unit areas are shown on Plates 4a, b, c.

CLIMATE

The third major group of variables that affects the potential agricultural productivity of the Linea Noroeste region is climate. As used in this report, climate has two aspects: macroclimate, the general long-term weather patterns prevailing in the area; and microclimate, the localized climate variations within the area that occur close to the ground. Although obviously dependent on macro influence and forces, it is the microclimate effects that impinge directly on the plant.

The macroclimatic regimen of the Linea Noroeste study area is controlled by: (1) the complexity of terrain in the northwestern sector of the Dominican Republic; (2) the tropical conditions of the island's low latitudinal location; and (3) the variability of the northeast trade winds which influence both the air mass movement and the storm track of tropical hurricanes. Moisture associated with the maritime tropical gulf air masses and the maritime tropical Atlantic air masses, is generally brought in by the trade winds. When these moist air masses encounter the hill and mountain slopes, orographic rain results. Dry weather prevails where the air is adiabatically heated by descent on the lee sides of mountains. During mid-September and October, periodic weather disturbances occur. These are either easterly waves of slowly moving troughs of low pressure originating within the belt of tropical easterlies, or equatorial waves of weak low pressure inclusions forming in the center of the equatorial trough which develop into eddies in the tropical easterlies.

The Linea Noroeste region has a wide variation in annual rainfall, ranging from 507 mm. at Villa Vasquez up to 1,279 mm. at Loma de Cabrera. The areas that are situated on the northern side of the valley receive much less rainfall, because of their location in a rain shadow of the east-west trending mountains

lying to the north. The areas situated on the southern side of the valley receive considerably more rainfall due to orographic lifting. These differences in the amount of rainfall are shown in Figure 4. The annual distribution of precipitation is bi-modal, with the two wettest periods occurring during the months of May-to-June and September-to-early November. The winter months from December until March are the driest in the study area.

The annual range in temperature in the study area is small. Average July temperature is 27.5° C., while the average January temperature is 22.2° C. These constant high values throughout the year do not restrict the length of growing season; however, the high temperature values do have a direct bearing upon water loss by evapotranspiration.

The annual march of temperature within the study area is fairly constant. The largest annual range in temperature is 5.6° C. which occurs at Villa Vasquez. The constant high temperatures, in conjunction with the annual rainfall distribution, permit three distinct growing periods: the first from January through April; the second from May through August; and the third from September through December. While the intensity of solar radiation does not impose a direct limiting restraint upon crop response, its effects upon the rate of evapotranspiration and availability of soil moisture are significant at the microclimatic level. Hence, attention was directed to soil moisture as the key microclimatic parameter.

Methods and Data Analysis

In order to determine the variations in available soil moisture in the region and to utilize this information to set up climate areas, the total annual precipitation measured in millimeters first was averaged over the

number of years of observation for ten uniformly distributed meteorological stations, occurring both within the study area and along the periphery.* Isohyet lines were drawn about these stations to conform with those for all of the Dominican Republic, which were published by the Servicio Meteorológico Nacional. The precipitation values for each sampling site were read directly from the synthetic isohyet map. Next, the available soil moisture for plants was calculated theoretically in the following manner. A program for the IBM 7094 digital computer, was used to calculate the monthly water budget for any station in the northern hemisphere using a modified Thornthwaite method^{403 cont'd}. The computations are similar to those described by Thornthwaite and Mather (Laboratory of Climatology, Centreton, New Jersey, U.S.A., 1957). Mean monthly temperature and precipitation values, station latitudes, elevation, and water-holding capacity of the soil were used as input data.

The Thornthwaite method defines a relationship between actual evapotranspiration and potential evapotranspiration. Evapotranspiration is the combined vaporization of water from the soil, from free water surfaces on the soil, or from the plant through special cells after being absorbed by the roots. The potential evapotranspiration is the amount of water that would be vaporized if water is non-limiting; that is, sufficient water always is available to satisfy the bio-climatic capacity to vaporize water. The actual evapotranspiration is the amount of water that actually is vaporized under field conditions. Whenever the actual is less than the potential, a moisture deficiency exists that curtails plant growth. The retardative effect of the deficiency depends on its severity and the length of time the condition

* The stations used were Dajabon, Loma de Cabrera, Moncion, Monte Cristi, Pepillo Salcedo, Santiago, Santiago Rodriguez, San Jose de Las Matas, Valverde, and Villa Vasquez.

prevails. All the moisture that is evapotranspired comes from precipitation, but the portion that passes through the plant reaches it via the soil. Soils vary in their available moisture storage capacities, largely because of differences in depth and texture. During periods of low rainfall, the stored available soil moisture is drawn upon to close the gap between potential and actual evapotranspiration. For a time this prevents the appearance of a moisture deficit. As the stored soil moisture declines, it becomes increasingly unavailable to the plant, and the difference between the actual and potential evapotranspiration widens. Ultimately, the moisture content of the soil may reach the wilting point and the plant dies. It is the objective of the Thornthwaite method to trace the ratio between actual and potential evapotranspiration on an annual, seasonal, or monthly basis. Figure 4 shows these relationships graphically for selected stations by climographs.

The soil moisture held in storage within the root zone was calculated for various combinations of different textural and depth classes of soils, and for various depths of the plant roots for the ten meteorological stations of the study area. The theoretical values for available soil moisture held in storage were then converted to per cent of maximum available moisture for plants during each of the three growing periods. This gave a relative measure of the available water in the plant root zone compared with the maximum holding capacity of the soil.

Thiessen polygons were constructed around the meteorological stations to outline the extent of the area controlled by each station. By superimposing the polygon grid over a map showing the location of the sampling sites, with known soil texture and depth classes, it was possible to determine the theoretical soil moisture value for any sampling point in the study area.

At each sample site, data were available on the following macro- and microclimate variables: (1) total annual precipitation; (2) average soil moisture for the year; and (3) soil moisture in per cent of maximum available moisture during each of the three growing periods. A factor analysis machine program processed these five variables for the 595 sample sites in order to discover the underlying factor-geographic patterns. The results of the analysis show that five factors are adequate to describe the variations in climate as measured by the five variables at each sample site. Since given sample sites fitted more closely to one factor than to any other, climatic boundaries were drawn to subdivide the Linea Noroeste region. The areas that have been delineated are factor climatic units each composed of the climate variables which have "loaded up" on the factor and describe its composition. The factor climatic units are given below for the whole study area.

Factor Climatic Units of the Linea Noroeste Region

1. Factor Unit 1: Dry throughout the Year

This unit is located along the northern part of the Entrada de Mao Lowland. The annual rainfall is sporadic and ranges from 800 to 920 millimeters. The constant high temperatures cause the potential-evapotranspiration to exceed precipitation during all months of the year. The soil moisture in storage in the plant root zone is close to the wilting point level. On the average, the water deficit ranges from 95 to 100 per cent of the water-holding capacity of the soil.

2. Factor Unit 1a: Dry Eleven Months of the Year

This unit occurs in the northern part of the Lower Massacre River Basin, centered on Pepillo Salcedo. The total annual precipitation ranges from

1050 to 1150 millimeters. The rainfall is well below the potential-evapotranspiration level for eleven months of the year. This is an area of high water deficit where the soil moisture ranges from the wilting point to approximately 10 per cent of water-holding capacity of the soil.

3. Factor Unit 2: Two Moist Periods

This unit covers most of the Santiago Rodriguez Inner Lowland and extends into the Entrada de Mao Lowland. The total annual precipitation ranges as high as 1000 to 1120 millimeters; however, it is highly seasonal. Two distinct moist periods occur when the precipitation exceeds potential evapotranspiration. The second growing season which occurs from May until August is the wettest season. The soil moisture in storage in the plant root zone during this period is on the average at 60 per cent of its maximum available level. During the third and first growing seasons, which occur from September until April, the soil moisture is about 18 per cent of the maximum soil-holding capacity.

4. Factor Unit 3: One or Two Intermittent Moist Periods

This unit occurs in the western part of Santiago Rodriguez Inner Lowland and extends across the central part of the Lower Massacre River Basin. In the area centered on Dajabon, the total annual precipitation ranges from 1250 to 1400 millimeters. Most of the precipitation falls in two periods, from mid-May through June and also during October and November. The availability of soil moisture increases from north to south. During the wettest growing season, the soil moisture in storage is from 45 to 50 per cent of field capacity. It declines to 8 to 12 per cent during the dry periods.

5. Factor Unit 4: Wet throughout the Year

This unit is located in the southern part of the Lower Massacre River Basin. The total annual precipitation varies from 1700 to 2100 milliliters of rain per year. Much of this rainfall is orographic due to the higher elevation. A moisture deficit does not occur during all three growing seasons. The available soil moisture drops to 78 per cent in areas having fine sandy soils during the first growing seasons and increases to field capacity during the second and third growing seasons.

The factor descriptions should be interpreted conservatively; that is, the statements of moisture content should read as "on the average." For even where severe moisture deficits are shown, plant life exists and farming is carried on during the wet season, though it is hazardous and of low productivity. The geographic distribution of the factor climate unit areas are shown on Plates 5a, b, c.

V

MULTIVARIATE AREAS OF UNIFORM AGRICULTURAL POTENTIAL

In the previous chapter, three types of separate areas have been developed independently through the use of factor analysis. Eight factor units were discovered and mapped for the soils of the Linea Noroeste region, three for land surface, and five for climate. However, in nature, soil, land surface, and climate associate in space as components of the natural environment affecting the potential agricultural activity. Moreover, the use of land for agriculture does not involve the variables separately or even sequentially, but jointly and concurrently. The farmer, as he cultivates the land, is confronted holistically by all of them acting and interacting simultaneously.

From the utilitarian view point the question is, how many agriculturally significant environmental states, composed of combinations of the three variables, can be identified in the Linea Noroeste region? In other words, how can the landscape of the region be classified into units of agricultural potential, by type, and geographic location? Given the three variables, soil, land surface, and climate, and the factors for each, it is possible to have a theoretical maximum of 120 landscape types in the Linea Noroeste region.*

Not all of these, however, will be found in the field because nature is

* This is computed from the rule for multiplying probabilities. Given eight soil factors, three land surface factors, and five climatic factors, the probability of any three in combinations, or the simultaneous happening of three events, is $1/8 \times 1/3 \times 1/5 = 1/120$; that is, the total possible number of combinations is 120.

not a simple mathematical system, or because the region does not exhaust all the possibilities. For example, it would be very unusual to find poorly drained soils subject to flooding on a steep and rugged land surface. Thus, the classification task is simpler than appears at first glance.

Method of Formation

A map of the simultaneous geographic occurrence of the three variables in the Linea Noroeste region was prepared by overlaying the separate factor maps for soil, land surface, and climate on each other and tracing the boundaries of unique combinations on a base map. The result is a multivariate factor map of landscape types. Each delineated area represents the peculiar joint occurrence of soil, land surface, and climate according to the factor groupings of each. The separate factors, it will be recalled, are composed of the different variable loadings that have been used to describe them. These tie the system of analysis to field reality.

The multivariate factor landscape type map was simplified and transformed into a map of areas of uniform agricultural potential by rating each factor unit for each variable according to its constraining effect on farming. Because of the semi-reconnaissance level of the study, and the limited agronomic information available to the investigators, the map is somewhat generalized. The factor rankings are subjective. Hence, the map is intended to serve as a guide to the location of areas of varying agricultural potential in the Linea Noroeste region, especially to those that merit more intensive study.

Ranking of Areas

The ratings of each factor unit for soil, land surface, and climate, together with a description of the factor are given in Table 2. Three ranks are used for each factor; to go much beyond that number would have extended the writers' present knowledge in an unwarranted manner. As indicated above, the agricultural ranking of the factor units for the variables further simplified the raw data and transformed them into a form that was more useful to planners. Thus, for example, eight soil factor units are collapsed into three rank classes; five climate factor units are collapsed into three rank classes; and three land surface factors are retained as three rank classes.

In this manner the multivariate factor landscape type areas were converted into areas of uniform agricultural potential. Plates 6a, b, c shows their geographic distribution. Each delimited area is marked with a three-digit symbol giving the rank of that area for the agricultural potential of its soil, land surface, and climate. The symbol order is Soil - Land Surface - Climate. Since the agricultural productivity of an area depends upon the simultaneous use of all three variables, any one may be limiting. The potential of an area is determined by its poorest-quality variable. In order to identify the variable property that is responsible for a particular rank score, it is necessary to work back from the variable to the factor unit and the factor description or "loading." The decision is left to the economic planner whether or not to mitigate the constraining attribute.

In general, it can be said that an area with a rank score of "3" for any variable is an area of low agricultural potential, unless the appropriate investment is made to remove the limiting aspect of nature. Once a decision has

Table. 2

FACTOR RANKS

SOIL

Factor Unit

Factor Description

Factor Rank Score
(1 = most favorable)

1

deep, fine-textured, plastic alkaline soils

1

1a

deep, fine-textured, plastic moderately alkaline soils

1

2

shallow, stony, fine-textured soils less than 183 centimeters deep

3

3

medium- to coarse-textured, deep alluvial floodplain soils subject to flooding

3a

4

neutral-medium to coarse-textured, excessively drained upland soils

2

5

deep, heavy-textured alluvial floodplain soils subject to flooding

3a

6

slightly acid, coarse-textured, shallow upland soils

3

7

neutral, medium-textured, shallow upland soils with heavy subsoils

2

8

*medium to heavy textured soils, neutral soils*LAND SURFACE

(a = alluvial soil requiring drainage and flood protection)

1

level land surfaces of low relief, low ruggedness, and low slope

1

2

undulating land surfaces of low relief and moderate ruggedness and slope

2

3

hilly land surfaces of high relief, high ruggedness, and high slope

3

CLIMATE

1

climate dry throughout the year

3

1a

climate dry eleven months of the year

3

2

wet-dry climate with two definite moist periods

2

3

wet-dry climate with one or two intermittent moist periods

2

4

wet climate moist throughout the year

1

been made to do this, the agricultural potential may be altered drastically. When the investment has been accomplished, and the necessary installations maintained adequately, productivity may be increased. A clear example of this pertains to the unprotected alluvial floodplain areas which have a favorable land surface but unfavorable climate and soils in their natural states. The soils of these sites have been accorded a score of "3", with a subscript "a" to indicate their high agricultural potential if diked, drained, and irrigated. Such areas are among the most productive presently farmed in the Linea Noroeste region.

There are virtually no natural limitations on agricultural use encountered in the study area that human ingenuity and engineering skill cannot mitigate. It is the payoffs from the investments that differ. Net returns will depend on conditions prevailing at a particular place at a particular time. All the difficulties of land surface, soil, and climate responsible for the downgrading of areas in the region already have been overcome, either in the area itself or elsewhere in the world. Of nature's resistances to agriculture in the Linea Noroeste, the ones that appear to give the greatest returns to ameliorating investments are aridity and flooding. Irrigation and flood control are the complementary techniques. Difficulties of soil (physical, chemical, depth) and difficulties of land surface (slope, ruggedness, relief, erosion) appear to offer uneconomic investments.

The geographic location and areal extent of the different landscape units are shown on Plates 6a, b, c, Multivariate Land Units. Soils ranked "1", first digit, are regarded as the best soils in their natural state. They are deep and fine-textured. However, one reservation the writers have that could not be checked, because of the unavailability of laboratory

facilities to make chemical analyses, is the possibility that some of the soils may be saline or alkali soils, because of the many pH determinations around 8.0. The content of soluble salts or the degree of alkalinity may be high enough to interfere with the growth of crop plants. Neither can we comment on the fertility status of these or any other soils. Also, these and many other upland soils show evidence of serious soil erosion, even though they have been farmed intermittently through the years, and presently are covered by a dense vegetative cover.

Even if the doubts about the rank "1" soils were waived and their association with favorable land surface features assumed, serious limitations of climate would restrict their use. They are found associated with a climate that is dry virtually throughout the year, rank "3". The major environmental constraint to higher productivity is the moisture deficit.

Large areas of soils ranked "3a" are also shown on Plates 6a, b, c associated with a level land surface, rank "1", and dry or wet-dry climates, ranks "2" and "2". These are sites with deep recent alluvial soils with poor drainage that are subject to stream flooding. Flood protection, drainage, and irrigation, developed concurrently make these areas highly productive by overcoming soil and climatic limitations.

The remaining areas have qualities that are seriously deficient in one or more of the environmental variables. Many of the soils are shallow and stony, rank "3"; much of the land surface is hilly, rank "3"; and the climate is frequently wet-dry or dry, ranks "2" and "3". Where one variable is favorable, the others usually are severely restrictive, so that the potential productivity of the area is low. For example, deep neutral upland soils, rank "2", are found with wet-dry to wet climates, ranks "2" and "1", but they

are associated typically with a hilly land surface, rank "3". The erosion hazard is high and potential productivity is low. Terraces, bench terracing, contour farming, mineral fertilizer, and pasture management are practices employed elsewhere that may make it possible to farm these areas more efficiently. But they are not widespread, or may be uneconomic, in the Linea Noroeste region.

Areas of wet climate, moist throughout the year, rank "1", are associated with hilly land surfaces, rank "3", and shallow upland soils, ranks "2" and "3". It seems best to utilize these areas for the production of water, wood products, and tree crops. While maintaining the land in forest, stream flow would be regularized, flooding curbed, dam and canal siltation reduced, and aquifers recharged.

The areas of agricultural potential that have been delimited on Plates 6a, b, c include subareas of contrasting features. Alluvial soils and level surfaces are scattered throughout all regions. The uplands, generally characterized as hilly, contain undulating and level surfaces. Shallow soil units encompass deep soils and vice versa. In total, these anomalies add significantly to the overall potential agricultural productivity of the Linea Noroeste region. This study can do no more than suggest their presence and call attention to their importance.

The geographic information on the ranked multivariate environmental factor land units are statistically summarized in Table 3 for each region separately and for the entire study area. The comparison of the land units applies only to the Linea Noroeste region. Seventeen different ranked land units are identified in the table and the approximate area of each is given. Table 4 is a general composite summary for the entire study area.

Table 3 RANKED MULTIVARIATE ENVIRONMENTAL FACTOR LAND UNITS

REGION I

Symbol	Description	Constraint	Area, sq. km.
1-1-2	deep silty alkaline soils on level land surfaces with wet-dry climate	moisture deficit and possible soil alkalinity	15
1-2-2	deep silty alkaline soils on undulating land surfaces with wet-dry climate	moisture deficit and possible soil alkalinity	28
1-2-3	deep silty alkaline soils on undulating land surfaces with dry climate	high moisture deficit and possible soil alkalinity	13
1-3-2	deep silty alkaline soils on hilly land surfaces with wet-dry climate	moisture deficit, slope, and possible soil alkalinity	8
1-3-3	deep silty alkaline soils on hilly land surfaces with dry climate	high moisture deficit, slope, and possible soil alkalinity	17
3-1-2	shallow soils on level land surfaces with wet-dry climate	moisture deficit, soil depth	2
3-2-2	shallow soils on undulating land surfaces with wet-dry climate	moisture deficit, soil depth	18
3-2-3	shallow soils on undulating land surfaces with dry climate	high moisture deficit, soil depth	0.5
3-3-2	shallow soils on hilly land surfaces with wet-dry climate	moisture deficit, slope, soil depth	10
3-3-3	shallow soils on hilly land with dry climate	high moisture deficit, slope, soil depth	2
3a-1-2	alluvial soils on level land surface with wet-dry climate	moisture deficit, flooding	1
3a-1-3	alluvial soils on level land surface with dry climate	high moisture deficit, flooding	8
			125.5

Table 3 RANKED MULTIVARIATE ENVIRONMENTAL FACTOR LAND UNITS

REGION II

Symbol	Description	Constraint	Area, sq. km.
1-1-2	deep loamy soils on level land surfaces with wet-dry climate	moisture deficit	78
1-2-2	deep loamy soils on undulating land surfaces with wet-dry climate	moisture deficit	169
2-2-2	medium textured shallow to deep soils on undulating land surfaces with wet-dry climate	moisture deficit	20
3-1-2	shallow loamy soils on level land surfaces with wet-dry climate	moisture deficit, soil depth	12
3a-1-2	deep sandy alluvial soils on level land surfaces with wet-dry climate	moisture deficit, flooding	36
Total			315

Table 3 RANKED MULTIVARIATE ENVIRONMENTAL FACTOR LAND UNITS

REGION III

Symbol	Description	Constraint	Area, sq. km.
1-1-3	deep silty alkaline soils on level land surfaces with dry climate	high moisture deficit and possible soil alkalinity	15
1-2-2	deep silty alkaline soils on undulating land surfaces with wet-dry climate	moisture deficit and possible soil alkalinity	20
2-1-2	medium textured shallow to deep soils on level land surfaces with wet-dry climate	moisture deficit, soil drainage	34
2-2-2	medium textured shallow to deep soils on undulating land surfaces with wet-dry climate	moisture deficit	2
3-1-3	shallow soils on level land surfaces with dry climate	high moisture deficit, soil depth	9
3-2-2	shallow soils on undulating land surfaces with wet-dry climate	moisture deficit, soil depth	8
3-2-3	shallow soils on undulating land surfaces with dry climate	high moisture deficit, soil depth	14
3-3-1	shallow soils on hilly land surfaces with wet climate	slope, soil depth	41
3-3-2	shallow soils on hilly land surfaces with wet-dry climate	moisture deficit, steep slope, soil depth	12
3a-1-2	deep heavy alluvial soils on level land surfaces with wet-dry climate	moisture deficit, flooding	12
3a-1-3	deep heavy alluvial soils on level land surfaces with dry climate	high moisture deficit, flooding	2
Total			169

Table 4 GENERAL SUMMARY OF LAND QUALITY

Description	Area, sq. km.
1. Good soils, good land surface, poor moisture	93
2. Good soils, good land surface, very dry	15
3. Good soils, medium land surface, poor moisture	217
4. Good soils, medium land surface, very dry	13
5. Good soils, poor land surface, poor moisture	8
6. Good soils, poor land surface, very dry	17
7. Fair soils, good land surface, poor moisture	34
8. Fair soils, medium land surface, poor moisture	22
9. Very poor soils, good land surface, poor moisture	14
10. Very poor soils, good land surface, very dry	9
11. Very poor soils, good land surface, poor moisture	26
12. Very poor soils, good land surface, very dry	14
13. Poor soils, poor land surface, good moisture	41
14. Very poor soils, poor land surface, poor moisture	22
15. Very poor soils, poor land surface, very dry	2
16. Very good alluvial soils (if flood protected), good land surface, poor moisture	52
17. Very good alluvial soils (if flood protected), good land surface, very dry	10
18. Peripheral areas not suited for cultivation	200
19. Poor and very poor soils	119
20. Alluvial soils requiring flood protection	62
21. Steeply sloping land surfaces	65
22. Dry and very dry areas	507

VI

CONCLUSIONS AND RECOMMENDATIONS

The classification of land according to its potential agricultural productivity is, part science and part art. The science consists of an examination and evaluation of the natural environmental parameters that affect the behavior of ecosystems. The art consists in making intuitive judgments about the separate and joint influences of the parameters on the biologic productivity of altered or new agricultural systems. There are as many potential, use-capability, or recommended classes for a specific area as there are possible crops and methods for producing crops. Productivity estimates based on actual production that have been recorded for an area, or inferences from similar areas, do not give the full range of potential for the area under study, because they neglect new methods and systems. Indeed, to rule out innovation is, in one sense, to defeat the object of studying the agricultural potential of an area.

In assessing the agricultural potential of the separate areas of the Lines Noroeste region, the writers have been guided by the ecological principle that each subarea is a site reflecting the integration of all landscape features. Land is a complex of many characteristics, more or less interdependently related. When man and his schemes are introduced into the system, the interdependency may be altered and disturbed, sometimes critically, but in no way is it bypassed.

The three features significant in the growth of plants that have been stressed in this study are soil, land surface, and climate. The soil affects

the supply of nutrients and moisture to plants, and provides support for roots. The land surface affects cultural operations, erodibility, and drainage through slope, relief, configuration, and stoniness. The climate supplies the plant with light and heat energy, rainfall, carbon dioxide, nitrogen, and affects the moisture balance. .

Despite the soundness of this approach, the report does not make a final assessment of the agricultural potential of the Linea Noroeste region. Instead, it directs attention to the natural parameters that must be considered in such an effort. Nor is it possible to evaluate them definitively. The reason for this is that social, economic, and technologic conditions that have influenced the use of the land in the past, and are likely to affect its use in the foreseeable future, have not been considered explicitly. The present and potential productivity of land would need to be evaluated for various crops under various methods of management and under various economic conditions. Without knowledge of yield response, cost-price relationships, developmental investment costs, and farm organization, it is not possible to designate the potential of areas.

Profits from changes in farming systems are determined by, (1) yield increases from various crops, (2) prices received from such crops, (3) the cost of applying the new methods, and (4) all other costs associated with the new system of production. Reliable data often are not available on changes in input costs and output prices. Nor are the cost-price relationships known that will prevail in the future. Because of this lack of knowledge, the evaluation of the potential of different areas must be based on the best judgment of the observer, considering the suitability of the soil for various crops, the productivity response of the site to new crops

and methods, and the presence or absence of such limitations as poor drainage, high slope, and shallow profile. However, even if such information is not available, it is still possible to make "educated" statements about the ranking of various areas, and say that under most conditions and for most crops some areas are more likely to yield a profit from a particular innovation (as irrigation) than others. This has been done.

Another economic consideration that has been ignored is geographic location in relation to markets, transport routes, and general accessibility. These factors are extremely important in the evaluation of the potential. It seemed desirable, however, to exclude them in order to avoid confusing inherent site factors with external influences affecting the degree to which the site can be developed economically.

The basic assumption of the educated judgment followed in reasoning that some areas are likely to yield greater returns than others from given inputs is that the best is likely to remain so. That is, the better site probably will yield a greater net return from a given investment than a poorer site, even though both are likely to be profitable. A poor soil may be made fair or even good with irrigation, but net gains probably will be greater from making better soils even more productive with irrigation. There are, of course, exceptions to this assumption that depend on the nature of the constraint, and the planner needs to be alerted. The response of poorly drained alluvial soils to flood protection is an illustration. Another factor that may be significant to the evaluation is the recognition of joint economies and extended benefits from certain investments.

This report has uncovered and presented a substantial amount of information on the physical geography of the Linea Noroeste region that is

essential to the assessment of its agricultural potential. Because of the semi-reconnaissance informational level, the report is not intended as a project planning or feasibility study. Nonetheless, the writers conclude with the following specific recommendations.

1. That the deep, fine-textured silt soils of the undulating lowlands (factor 1 and 1a soils) be examined more closely. There are large areas of favorable land surface idle in this area presently covered with a dense thorn thicket vegetation. Photo VI-1 shows an overview of the area and Photo VI-2 gives an interior view showing the forbidding vegetation. On the other hand, Photo VI-3 shows an open clearing recently farmed, and Photo VI-4 shows a commercial sisal crop adjacent to a thorn thicket forest in the background. The illustrations show that the simple appearance of the land may be misleading. In some places the soil has suffered from erosion while elsewhere it may contain an indurated lens of siltstone, as shown by Photos VI-5 and VI-6. The soils also tend to be highly alkaline, and this feature should be investigated. The availability of water for irrigation should be explored.

2. That all alluvial sites should be studied and mapped more thoroughly and considered for flood protection, drainage, and irrigation. Specifically, the unused portion of the floodplain of the Lower Massacre River, and the smaller dispersed alluvial sites in the undulating lowlands merit further detailed study.

3. That the upland hilly areas be mapped in greater detail in order to identify, locate, and evaluate the level areas of favorable soil included within them. Photo VI-7 shows a likely site.



Photo VI-1, Overview



Photo VI-2, Dense, thorn thicket cover.



Photo VI-3, Recently abandoned field.



Photo VI-4, Sisal crop; note thorn thicket in rear midground.

Photos VI-1, 2, 3, 4

Views of the undulating lowlands, showing contrasting uses and misleading landscape impressions of agricultural potential.

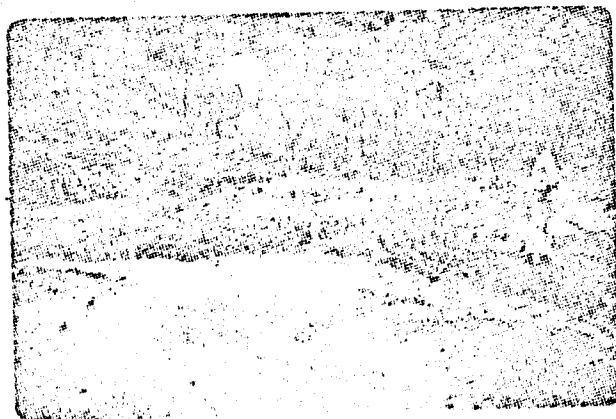


Photo VI-5, Erosion and compaction of silty soil.



Photo VI-6, Indurated lens of siltstone.

Photos VI-5, 6

Two soil limitations on the silts of
the undulating lowlands.



Photo VI-7, Level area within complex crystalline hills.



Photo VI-8, Farming on steep cuesta slope and summit (background).

4. That upland areas of steep slopes be identified with a view to taking them out of crop production. Consideration should be given to a reforestation program and the care of the watersheds for the production of water under conditions that would reduce flood hazard and siltation. The farming of slopes of 60 per cent and higher, as shown in the background of Photo VI-8, requires large labor inputs and yield meager returns, while causing diseconomies at lower elevations. This labor is available at a low opportunity cost, and an effort should be made to shift it to the more productive agricultural areas as they are opened; or the people may be transferred out of agriculture. However, the programming of these changes should be accomplished so as to minimize social and economic dislocation.

5. That the soil samples collected by our field party be analyzed to obtain more complete information that may be useful in the evaluation of the study area.

While the report has uncovered much information on the natural environmental factors affecting potential agricultural productivity within the Linea Noroeste region, it does not claim to provide a definitive answer to the question, what is the agricultural potential of the region? Indeed, it possibly raises more questions than it answers. This should come as no surprise because it is a first effort to systematically present the physical geography of a long-settled under-utilized area. The report does make a logical start toward the research required to answer the question implied in the title.

APPENDIX I. REVIEW OF PREVIOUS RESEARCH AND GEOLOGIC LITERATURE

Numerous scientists have focused their attention on the Cibao Valley region and have studied the rich molluscan localities of Miocene age on the Yaque del Norte River and its tributaries, the Mao, Gurabo, Amina, and Cana (Chapeton). The igneous and metamorphic rocks of the central mountain range, bearing varying amounts of iron, copper, nickel, and gold, have been mined since the pre-Columbian period. However, no large-scale surface geological or morphological maps of the area have been published. The most detailed studies found in a search of the literature deal with the Miocene formations.

T.S. Heneken (1853) published a brief geologic description of a portion of our study regions and listed fossil faunas within the Cibao. The reports of Gabb (1871, 1872, 1873, 1881) are comprehensive descriptive works on the geology of the country, but are mainly of historical interest. Maury's studies (1917, 1918, 1919) provide the very basis for defining formations within the Miocene found within our Region I, and the eastern portion of Region II. The publication of Vaughan et al. (1921) contains a wealth of information on Tertiary rocks. Few metasedimentary and plutonic igneous rocks are described and type localities cited between Santiago Rodriguez, Dajabon, and Restauracion. The Bermudez study (1949) is the most recent, comprehensive paleontological reference on the Miocene and covers portions of Regions I and II. Weyl's article (1948) presents an accurate, small-scale regional description of the metamorphic and igneous rocks of the country. Unfortunately, his maps are so small-scale that the reader's interpretation is sometimes liable to question.

Recent work by the Caribbean Research Project of Princeton University adds a wealth of detailed information to the hitherto little known geology of the Cordillera Central. While outside the limits of our three regions, the reports of Bowin (1960) and Palmer (1963) have enabled us to identify and extend westward, metasedimentary and igneous plutonic rock units bordering the Santiago Rodriguez/Dajabon region, and southern portion of Region III lying between Juan Calvo, Loma de Cabrera, and Capotillo.

At present, a semi-reconnaissance geological field program is being carried out by a group of Japanese scientists, notably from Moncion to Dajabon, which is along and south of the Region II southern boundary. In addition, the OAS-CEPAL group has recently compiled a reconnaissance soil association map at a scale of 1:250,000 of the Dominican Republic, which includes the area covered by this report.

A bibliography of the geologic literature is included in this appendix.

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APPENDIX II. CARTOGRAPHIC FIELD AND LABORATORY METHODS

A period of six months was spent during the summer and fall of 1965 in obtaining air photo and map coverage, annotating the photographs, and reviewing the existing literature. In addition, a period of five months was spent in the Cibao Valley during the winter of 1965 and spring of 1966 in preliminary field reconnaissance.

Most of the field geologic and morphologic mapping for this project was done on aerial photographs taken by the U. S. Army Air Force in 1948, and printed at a scale of approximately 1:40,000. Transfer of geologic features from the air photographs to the respective Army Map Service Series E733 and E034, 1:50,000 topographic and photomaps was accomplished in the following stages.

First, in areas of slight to moderate relief, an overlay was prepared for radial line compilation by plotting ground control points, center points, and six pass points for each photo. Field data were rectified and transferred at a 1:1 ratio. Rectified data were then reduced to a scale of 1:50,000 and plotted on the Army Map Service maps which served as our base, using a Saltzmann P-1414A Vertical Reflecting Projector with restitutional easel at Columbia University, New York, N. Y.

Second, in areas of moderate to high relief, limited mostly to the complex crystalline upland in Region III, almost every geologic feature that was plotted accurately was located by a pass point. An adjustable Vertical Sketchmaster, K & E Model, was used for radial line plotting and reducing the 1:40,000 field data scale to the 1:50,000 base map.

Third, a comprehensive laboratory analysis was then undertaken of the entire project area in an attempt to fit together all elements of stratigraphy, structure,

and topography. Geomorphological units, termed herein natural subregions, were then mapped.

Fourth, during the field season, October 1966 to April 1967, field check was performed on all poorly defined or questionable features. A general supplemental reconnaissance was undertaken filling in details as required.

Fifth, separate overlays each showing: (1) surface morphology, or natural subregions, and (2) surficial geology were rechecked and drafted.

In addition, two hundred and fifty rock samples were collected in the field. Laboratory studies were carried out at the Department of Geology, Columbia University, and were based upon one hundred and forty-seven hand specimens. Microscopic and X-ray analysis techniques were used on several specimens. The remaining one hundred and three samples, mostly of sedimentary composition, were classified in the field.

Field descriptions of coarse, medium, and fine-grained fragmental sediments and rocks were classified according to Dunbar and Rodgers (1957). Unconsolidated surficial materials were grouped according to the system outlined in the United States Department of Agriculture Soil Survey Manual (1951). Color codes of surface lithologic units are after the Munsell Soil Color Charts published by the Munsell Color Company (1954).

APPENDIX III. SAMPLING PROCEDURE

The purpose of the sampling procedure was to insure that a sufficient number of samples was collected in an unbiased manner in order to permit the drawing of reliable inferences about the whole region from them. The sample specimens consisted of bits of space which were examined for their soil, climate, and land surface properties.

The total study area is 820 square kilometers but for sampling purposes this was reduced to 606 square kilometers after air photo and topographic map inspection had revealed peripheral areas obviously of no utility for agriculture. The remaining area was subdivided into three main regions and 18 subregions as described in Part II of the text, "Surface Morphology and Geology." The sampling method employed may be described as a stratified random areal sample with variable proportions. The region was stratified into the aforementioned regions and subregions in order to take advantage of previous knowledge. Stratified sampling gives more reliable estimates of universe parameters from the same number of observations than simple random methods, especially when the controls of stratification are related to the items that are to be observed. This is true of the present study.

The following procedure was followed:

- 1) A one-quarter-square-kilometer grid was imposed on a 1:50,000 topographic base map of each region to yield 2440 sampling cells.
- 2) A number of sampling cells was allocated to each region and subregion in proportion to its area. The area of each region is given by the following table:

Region and Subregion	Square kilometer
I. Entrada de Mao Lowland	
1. Recent floodplains	9
2. Stream terraces	12
3. Cuesta summit	3
4. Cuesta slopes	52
5. Undulating lowland	49
Subtotal	125
II. Santiago Rodriguez Inner Lowland	
1. Recent floodplains	8
2. Stream terraces	23
3. Piedmont plains	170
4. Piedmont upland	19
5. Horizontal structural plains	84
6. Belted metamorphics	4
7. Complex crystalline hills	7
Subtotal	315
III. Lower Massacre River Basin	
1. Recent floodplains	8
2. Younger piedmont plains	39
3. Older piedmont plains	23
4. Horizontal structural plains	26
5. Complex crystalline hills	74
6. Belted metamorphics	< 1
Subtotal	170
GRAND TOTAL	610

3) A given sampling cell is defined by an X and Y axis and the specific cells were selected by randomly generated coordinates.

- 4) The number of sampling cells to be selected was dictated by available resources of time, personnel, finances, and map scale. One-fourth of the cell population was chosen as the sample size, or 606 sample cells.
- 5) Each randomly selected sample cell was visited in the field subject to the rule that a cell crossed by a major regional boundary was rejected to eliminate border effects.
- 6) Within each sample cells one randomly selected point sample was taken. The point sample was located by means of a one-quarter kilometer square transparent grid that was divided into twenty-five point sampling sites, each 100 square meters. The point sampling sites were numbered 1 through 25 and one was selected from a table of random numbers each time the grid was superimposed on the one-quarter-square-kilometer sampling cell. A 100-square-meter sample site was used because it was the smallest area that could be located in the field on a map scale of 1:50,000.
- 7) Each sample site selected was described in terms of the soil, climate, and land surface variables, the data being recorded on a field sheet. The field investigator was given the option of deciding the precise location within the 100-square-meter sample site at which the soil was to be sampled. He was also given the option of selecting a new site if in his opinion it was inaccessible or unrepresentative of the cell. A new site was then randomly chosen. Less than ten per cent of the sites were rejected.

In this manner 606 samples were taken whose location is shown by Figure 5. Eleven samples were rejected and the actual analyses were performed on 595 samples. The sampling procedure provides sufficient punctiform data to furnish a maximum of information within the design of the project. It permits the generation of maps and land resource units at known levels of reliability. Reliability may be described as follows: If, for example, in a sample of size 600 the mean value of a property, as depth to "C" horizon, is 44 centimeters and the standard deviation is 25 centimeters, the standard error of the estimate is one centimeter and the 95 per cent confidence limits lie between 42 and 46 centimeters. That is, we do not know the true value of the population mean, but we can say that it is between the limits 42 and 46 centimeters, although there is a 2.5 per cent chance that it is less than 42 centimeters and a 2.5 per cent chance that it is greater than 46 centimeters. Thus, it is correct to say that absolute knowledge which would come from a complete study of the entire population has been traded for probabilistic knowledge with a known range of possible error. The pragmatic question is, is the absolute information worth the additional cost in time and money to acquire it?

62 a

FIG. 5, DISTRIBUTION OF SA

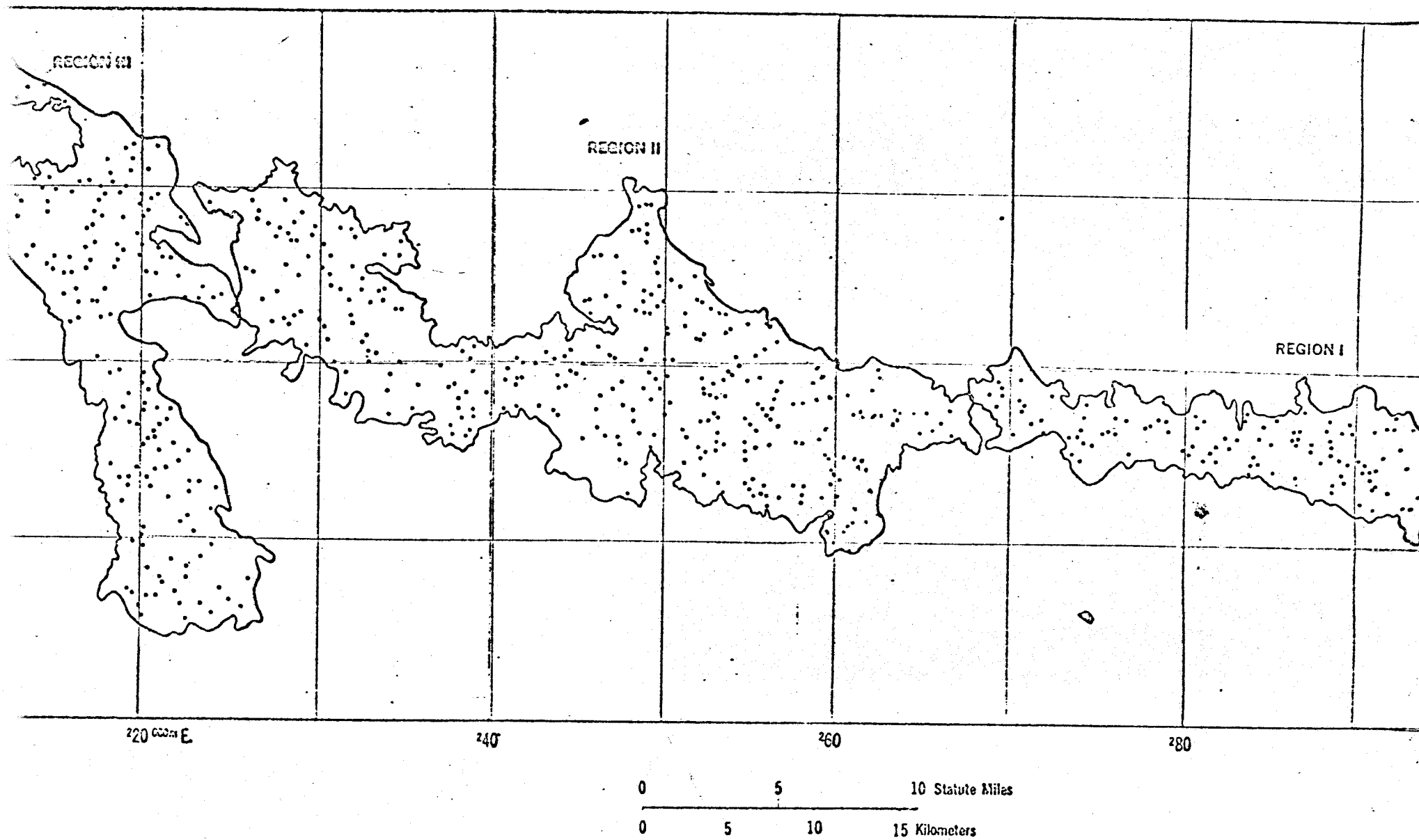
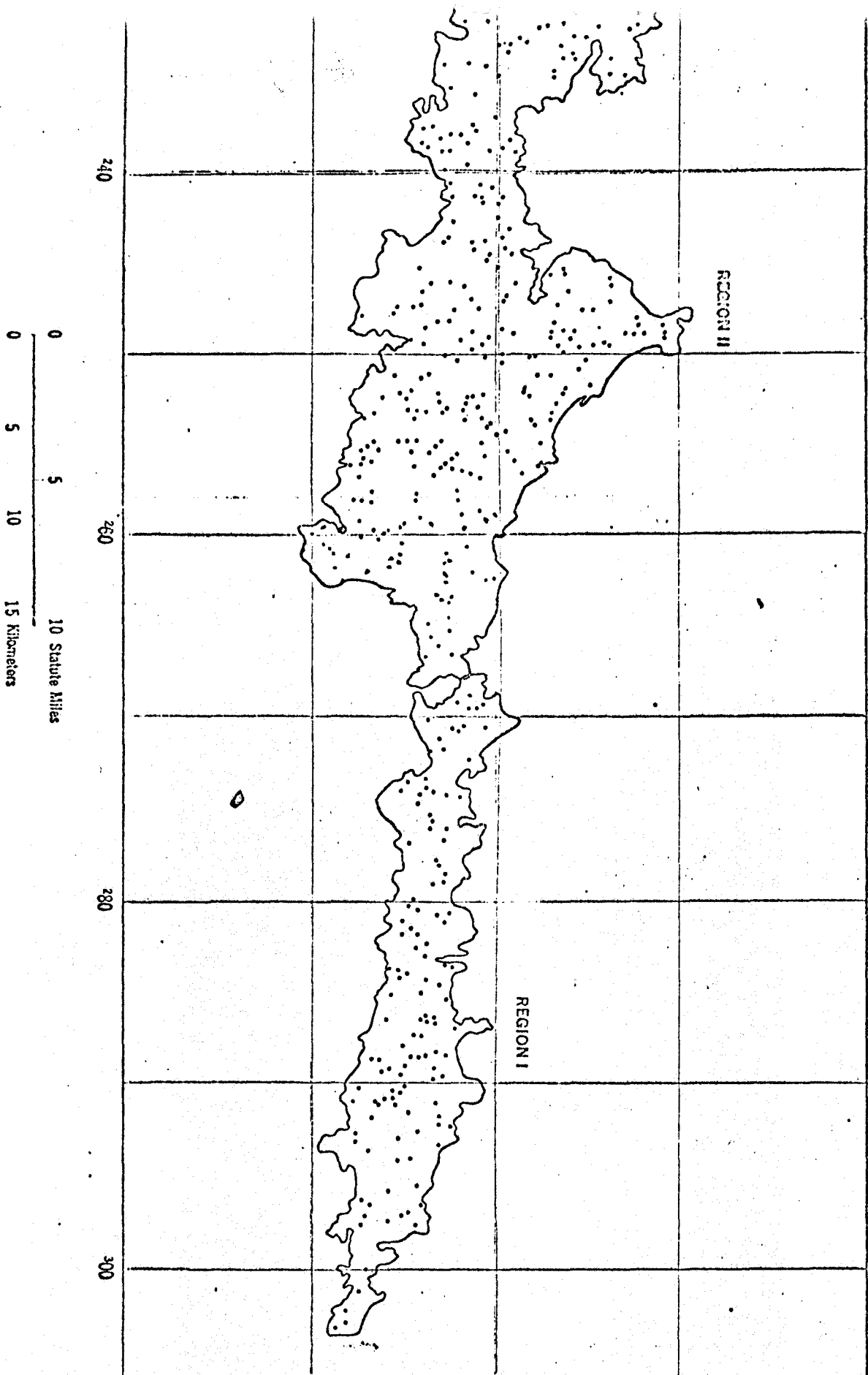


FIG. 5 DISTRIBUTION OF SAMPLING POINTS



APPENDIX IV. SOIL VARIABLES

In all, forty-one soil variables were examined in the field. As stated in the text, the properties of these variables were unaffected by bucket auger sampling. Unfortunately, satisfactory arrangements could not be made for selected laboratory physical and chemical analyses to supplement and expand the usefulness of the field samples. However, surface and subsoil material from 165 randomly selected sites was collected and bagged. Also, samples from 606 field sites were collected and bagged. They are now stored in Santiago. Some are also located in La Vega.

The following table lists the soil variables used in the study together with selected field methodological comments:

Variable	Scaling	Method
* 1. texture of A, A ₁ , or A ₂	sands, to clays	moist feel
2. texture of B or B ₂	ditto	ditto
* 3. texture of C	ditto	ditto
4. thickness of A	in centimeters	-
5. thickness of B, if present	ditto	-
* 6. depth to C	ditto	-
* 7. depth to consolidated	in centimeters; if beyond auger depth, set at 183 centimeters	-
8. lithologic layers	number	-
* 9. hardpan	present or absent	-

Variable	Scaling	Method
10. depth to hardpan, if present	in centimeters	-
11. strength of hardpan, if present	in three ranks	-
12. development of A or A ₂	in four ranks	-
13. development of B or B ₂	in four ranks	-
* 14. hue of A or A _p	in six scores	moist color.
* 15. value of A or A _p	Munsell numbers	ditto
* 16. chroma of A or A _p	ditto	ditto
17. hue of B or B ₂	in six scores ⁽¹⁾	ditto
18. value of B or B ₂	Munsell numbers	ditto
19. chroma of B or B ₂	ditto	ditto
* 20. hue of C	in six scores ⁽¹⁾	ditto
* 21. value of C	Munsell numbers	ditto
* 22. chroma of C	ditto	ditto
23. mottling, if present	scored sum	based on abundance, size, contrast
24. depth to mottles	in centimeters	-
25. clay skins in B or B ₂	four scores from 0 to 10	hand lens examination
* 26. pH A	direct reading	La Motte soil kit
27. pH B	ditto	ditto
* 28. pH C	ditto	ditto
* 29. effervescence A	four scores from 0 to 5	dilute hydrochloric acid
30. effervescence B or B ₂	ditto	ditto
* 31. effervescence C	ditto	ditto
* 32. wet consistency A	scored sum	based on stickiness and plasticity

Variable	Scaling	Method
33. wet consistency B or B ₂	ditto	ditto
* 34. wet consistency C	ditto	ditto
* 35. drainage	in seven ranks	based on surface and internal drainage
36. frequency of coarse fragments	four scores	based on per cent of surface area or soil volume
37. size of coarse fragments	ditto	based on modal size
38. distribution of coarse fragments	three scores	surficial or in profile
39. sum of 37, 38, 39	-	-
40. sources of coarse fragments	six scores	residual, transported, mixed
41. lithology of coarse fragments	four scores	-

(1) With a Munsell color chart and the ordination method of O. W. Bidwell and F. D. Hole, "An Experiment in the Numerical Classification of Some Kansas Soils," Proceedings, Soil Science Society of America, vol. 28, No. 2 (March-April), 1964, pp. 263-268.

Because of intercorrelations, persistent missing data, and data judged to be unreliable the number of variables used in the factor analytic program was reduced to nineteen. These are asterisked in the above table.

APPENDIX.V. LAND SURFACE VARIABLES

Five land surface variables were examined and scored in the field at each 100-square meter sample site. The variables were factored for the 595 samples taken in all the regions. The definition of each variable and the method of scoring are given in the table below:

<u>Variable Definition</u>	<u>Scoring</u>
1. elevation - height above sea level	read directly to nearest 20 meters from topographic maps
2. slope - inclination of surface of land away from perfect flatness	determined directly in per cent by a Brunton Pocket Transit.
3. relief - difference between height and lowest point	estimated to one meter
4. erosion - sheet and gully removal of soil	scaled 1 to 5 after estimate of soil loss deposition, or loss of less than 25% of topsoil - 1 25%-75% of topsoil removed - 2 > 75% of topsoil to < 50% subsoil - 3 > 50% subsoil and exposed C - 4
5. ruggedness - combination of gully depth and counts	sum of depth and number of gullies a. depth in meters > 1/3 meter = 1 1/3-2 meters = 4 2-5 meters = 7 > 5 meters = 10 b. count across 100-meter square site none = 0 1-5 = 4 5-10 = 7 > 10 = 10