ABSTRACT

JOHNSON, BRUCE KARL. Soil characterization and reconnaissance survey of the Ranomafana National Park area, southeastern Madagascar. (Under the direction of Stanley Walter Buol).

The Madagascar rainforests display some of the richest biodiversity found anywhere on earth. This unique biodiversity is imperiled by deforestation resulting mainly from the accumulated impacts of small-scale slash-and-burn agriculture (*tavy*), practiced by subsistence farmers. The Ranomafana National Park (RNP), created to conserve an especially species-rich rainforest region, essentially depends upon developing sustainable agriculture and forestry alternatives to *tavy*. The main objectives of this study were to document soil systems of the region, provide detailed soil characterization data, and to provide soil interpretations for sustainable agriculture and forestry development.

The regional geology consists mainly of high-grade felsic metamorphic rocks (gneiss, migmatite) and granites. Saprolite on higher, stable landscape positions commonly reached 10-20+ meters thick, while saprolite on lower geomorphic surfaces was generally shallow to rock due to stream downcutting and geologic erosion. Alluvium was generally shallow (<2-3 meters) to gleyed saprolite in lower-order stream valleys, but deeper in major river valleys.

Long-term climate data indicated a udic soil moisture regime throughout the region. Soil temperature measurements indicated an isothermic soil temperature regime, and were highly correlated with elevation (r^2 = 0.97) and estimates of mean annual air temperature. The soil temperature data suggested that mean annual air temperature equals mean annual soil temperature, with no correction factor required.

Upland soils over thick saprolite profiles were generally classified as Oxic Dystrudepts. Some soils contained horizons that met all criteria for an oxic horizon, except that Soil Taxonomy considers sand-sized kaolinite pseudomorphs as weatherable minerals. Upland soils found in lower landscape positions, or places with thin saprolite profiles, tended to have higher cation exchange capacities and relatively high biotite and/or feldspar contents, and classified mainly as Typic Dystrudepts. Argillic horizons were rarely observed and were weakly expressed, and no mappable areas of soils with argillic horizons were found. Umbric epipedons occurred as small patches on the upland landscape, but represented only inclusions within potential soil map units.

Alluvial soils classified into various subgroups of Humaquepts, Dystrudepts, Fluvaquents, Udifluvents, and Udipsamments. Ochric, umbric, and histic epipedons were all described for these lowland soils.

Total elemental analyses of representative rock and saprolite samples revealed extremely low levels of bases and phosphorus. Soil characterization data generally indicated pH values of 4-5, high to very high aluminum saturation levels, extremely low exchangeable base levels, and extremely low Olsen phosphorus values, regardless of landscape position. One area contained a geologic anomaly with extremely high phosphorus contents, but was limited in extent. With minor exceptions, the RNP area soils reflected not only very low available nutrients, but also very low total nutrient reserves.

The combined geologic, total elemental, and soil characterization data revealed that soil nutrient levels in the RNP area are insufficient for sustained crop production without nutrient inputs. Those inputs must be obtained either from the rainforest

biomass through burning, through nutrient harvesting of live biomass for compost, or through chemical fertilizers. Rainforest burning is incompatible with the RNP conservation objectives. Nutrient harvesting can concentrate nutrients in agricultural fields, but at the expense of other portions of the ecosystem. Inputs in the form of chemical fertilizers therefore represent the only long-term solution for sustainable agriculture if present population densities are maintained. To suggest that “alternative” agronomic practices (e.g., SRI, or system of rice intensification) can overcome these fundamental biological and chemical constraints only provides a false hope that will be ultimately proven unsustainable in the long-term. That will eventually spell calamity for both the Malagasy rainforest and the Malagasy farmers.

SOIL CHARACTERIZATION AND RECONNAISSANCE SURVEY OF THE RANOMAFANA NATIONAL PARK AREA, SOUTHEASTERN MADAGASCAR

by

BRUCE KARL JOHNSON

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APPROVED BY:

_____	_____
Dr. Eugene J. Kamprath	**Dr. H. Joseph Kleiss**
_____	_____
Dr. Robert C. Kellison	**Dr. Stanley W. Buol** (Chair of Advisory Committee)

DEDICATION

This work is dedicated to the farmers of the Ranomafana National Park region, who lead lives of simplicity and dignity while seeking to provide sustenance for their families. Hopefully this soils research will contribute in some small way to developing effective and dependable systems for local food production, while preserving the remaining forest of their ancestors.

BIOGRAPHY

Writing your own biography is a curious thing (perhaps it feels to much like a presage to an obituary), but here it goes.

I was born in the Promised Land, Buffalo NY, on March 13, 1961, to Norman and Ruth Johnson. As the middle child with three sisters and two brothers, my childhood was blessedly unremarkable but never dull. By the time I was five, I had received stitches in my head a half-dozen times for various injuries, which according to my parents explains a lot. The recurring themes of my childhood were a love for the outdoors and an endless curiosity that eventually evolved into a love of science. These themes were later overshadowed by enthusiasm for girls, beer and the Buffalo Bills (not necessarily in that order), but that is another story.

In 1983, I received a B.S. in Geology from Allegheny College. This led to an assignment mapping natural resources in Grenada for the Peace Corps (1985-1987), which was not “the toughest job you’ll ever love,” but closer to an ideal job in paradise. My subsequent desire to link earth sciences, mapping, and people’s basic needs led me to pursue soil science graduate studies. After Peace Corps, I enrolled at Michigan State University and received a Master’s in Soil Science (Pedology) in 1990. My Master’s thesis was titled, Nitrate Leaching Potential as Affected by the Spatial Variability of Bt Horizon Morphology, completed under the direction of Dr. Jim Crum.

My Ph.D. program at NCSU began as a desire to learn more about tropical soils, since my career goal at the time was to pursue international consulting work in Africa and Asia. NCSU not only provided some of the world’s top faculty in tropical soils, it also offered the uncommon opportunity to perform soils research in Madagascar. The Madagascar research greatly influenced my professional growth as a

pedologist, challenged many ideas that I had regarding international development and conservation, and affected me deeply as a member of the human family. Each person's life has several "turning points;" Madagascar was one such turning point for me.

A divorce and a hiatus in my Ph.D. program conspired to land me back in Buffalo, where in 1997 a miracle and an epiphany occurred. My parents bumped into my old high-school sweetheart, the former Deborah Ann Beck, who was visiting from south Florida and whom I hadn't had any contact for 18 years. Some might say that the meeting was more than random chance, since it occurred at Debbie's childhood church in summer, and my parents were attending a summer sermon there for the first time ever. They say you just "know" when it's right. By the time three days were up, the old romance had fully rekindled, and we knew. We now have a beautiful family with Jenessa (age 17, from Debbie's prior marriage), Angelica (age 2), and Evan (age 2 months), living in Naples, Florida. Whatever I have done to deserve such good fortune, I don't know. Perhaps God is trying to compensate me for all of those knocks on the head when I was little.

I'm currently employed by WilsonMiller, Inc. as an environmental consultant, performing hydric soil determinations, wetland delineations, vegetation mapping, water quality investigations, and a variety of scientific tasks. In other words, I'm playing outdoors and doing science.

ACKNOWLEDGEMENTS

Let me state the obvious at the beginning of this section: it is impossible to thank everyone who contributed to this work. Therefore, I offer my sincere thanks to everyone who provided support, ideas, time, and energy for the completion of this task. If I neglect to acknowledge anyone here who deserves specific mention, please forgive an erratic memory, a hectic lifestyle, and final deadlines for the omission. At the risk of being long-winded, I feel that explicit thanks are due to many people.

First, I thank my intrepid advisor, Dr. Stan Buol, for being a true scholar, mentor, and friend throughout my Ph.D. program. I learned more about pedology and Soil Taxonomy through afternoon chats (steeped in pipe smoke) than I could ever learn through formal instruction. The rare opportunity to map soils alone in relatively uncharted terrain was a gift that few modern pedology students receive. I thank the other members of my committee, Dr. Gene Kamprath, Dr. Bob Kellison, and Dr. Joe Kleiss for their reviews, critiques and enhancements of the research, and their flexibility in staying the course until the dissertation was complete. To Dr. Ray Daniels, who was originally on the committee but moved out of state, I thank you for your love of geomorphology and your boyish enthusiasm for field work and "arm-waving." Dr. Rob Mikkelsen receives my gratitude for coordinating this Ph.D. program via long distance.

I thank the US Agency for International Development (USAID) for financial support. The RNPP soils research was funded by USAID Grant 623-0106-G-SS-0030-00 to Duke University and the Soil Science Department at North Carolina State University.

During my time in Madagascar, my work was aided by Dr. Patricia Wright, Mr. Mark Fenn, and Mr. Benjamin Andriamihaja, all associated with the RNPP. I am

indebted collectively to the superb RNPP research guides who guided me throughout the study area, identified vegetation, translated language when necessary, coordinated the digging of soil pits, and generally facilitated the fieldwork. My sincere thanks to Dr. Dennis del Castillo, RNPP agronomist, friend, and my field supervisor, who provided logistical and moral support during my stay in Ranomafana. Most importantly, thanks to the many villagers of the RNP region who unselfishly shared their knowledge of soils, agriculture, forestry, and life with me.

Special thanks go to my former wife, Susan Canty, for everything done to support this work while in Madagascar and Raleigh; it was no easy task living overseas and I'm grateful for the effort. To my dearest friends Joe and Dai Peters, my neighbors in Ranomafana and lifelong kindred spirits, deepest thanks for constantly reminding me that life is at once achingly beautiful and ridiculously absurd. I'm also grateful to Dan "Moonbeam" Turk, a remarkably eclectic and talented scholar, for his vast forestry knowledge and comic relief. While in Raleigh and points beyond, I'm became indebted to my old Peace Corps friend Craig Payne for his kind loan, and subsequent donation, of a laptop computer to the dissertation effort.

At the NCSU Soil Science Department, my thanks to Roberta Miller-Haraway for assistance with numerous laboratory procedures and for a droll sense of southern charm. Thanks also to Betty Ayers and Steve Monteith for assistance with soil mineralogy procedures, and to Bertha Crabtree for running soil carbon and nitrogen analyses. John Schmidt provided very useful phosphorus fractionation data for selected RNP soils, as did Mike Beck.

The Interlibrary Loan department at Florida Gulf Coast University (FGCU) provided world-class access to dozens of hard-to-find journals and books, and special

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Since this dissertation was written while working full time, thanks go to my employer, WilsonMiller, Inc. and many of its staff. Above all, I'm grateful for the flexibility provided by my supervisor, Tim Durham, because without that flexibility I could not have simultaneously completed this research and fed the family. Walt Johnson generously provided every computing resource I could need, along with friendship and constant encouragement. My thanks go to Chris "Mr. Wizard" McGarry for his exceptional GIS talents and DEM manipulation, and to Judy Blakemore and Jennifer Chase for scanning and graphics production. To the entire staff of the WilsonMiller Ecological and Water Resources Department, thanks for the daily support and for your patience with my insomniac disposition.

To my parents, Norm and Ruth Johnson, thanks for being there every step of the way, and for sacrificing greatly when we needed you most. To my in-laws, Ed and Emmie Beck, your constant encouragement and support for our family are also deeply appreciated. Heartfelt thanks go to my “wacky” brother Jeff Johnson and sister-in-law Pam for numerous acts of kindness, and moral support, that had a direct effect on finishing my dissertation. And to my sister Bonnie, who chose a Ph.D. in motherhood instead of a Ph.D. in psychology, thank you for your cheerleading. You chose the right degree.

I humbly thank my wife and children for bearing the brunt of this extended effort. To my dear children, you each contributed something essential and wonderful that helped me to achieve this goal. Jenessa, I’m grateful for all of your hard work in helping Mom while I was away from home at night, and appreciate the many teenage things that you do well; it made a huge difference. I’m also thankful for your love, dedication, and growth in living through the highs and lows of bonding with a stepdad through your teen (“Alien”) years. Angelica (“Boo-ba-loo!”), you made me laugh hard and live in the moment due to your inimitable toddler way, at a time when doing either was often difficult. Your infant and toddler milestones helped me to keep things in perspective, and your love energized me. Evan, you reminded me that miracles do occur even when unlooked for, and your gentle infant demeanor grounded me as this work came to a close. At eight weeks old, you’re already connecting with your eyes, bonding, and smiling so much that it melts my heart.

Finally, to my wife, there simply are not sufficient words to express my thanks. Debbie, you unselfishly sacrificed on a *daily* basis to reach this goal, and this work is truly half yours. Being a wife, raising a teenager, bearing two more children, teaching

first grade, and maintaining a household is almost more fun than anyone can take even under normal circumstances, let alone when your husband disappears back to the office on most nights. Every single day I thank heaven for your presence in my life, admire your wonderful combination of qualities, and remain awestruck at the good fortune that brought us together (again!) and created this family. If these acknowledgements were to acknowledge only one thing, it would be that without your love and support, this dissertation and this Ph.D. degree would never have been completed. For that I will always be grateful, and hope that I have the opportunity to support you as well in whatever future pursuits you choose.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF ACRONYMS AND ABBREVIATIONS

AFTT	Apatite fission-track thermochronology
CEC	Cation exchange capacity
CEC7	Cation exchange capacity (by NH_4OAc, pH 7.0)
DEM	Digital elevation model
DTA	Differential thermal analysis
ECEC	Effective cation exchange capacity
FAO	Food and Agriculture Organization (of the United Nations)
FCC	Fertility Capability Classification system
ICDP	Integrated conservation and development project
IRD	Institut de Recherche pour le Développement
ITCZ	Inter-tropical convergence zone
Ma	“Mega anna,” or millions of years ago
MAAT	Mean annual air temperature
MAST	Mean annual soil temperature
NCSU	North Carolina State University
NGO	Non-governmental organization
NRCS	Natural Resources Conservation Service (USDA)
NSSC	National Soil Survey Center (USDA-NRCS)
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer
PET	Potential evapotranspiration
PZC	Point of zero charge
RNP	Ranomafana National Park
RNPP	Ranomafana National Park Project
SMR	Soil moisture regime
STR	Soil temperature regime
TGA	Thermal gravimetric analysis
UNESCO	United Nations Education and Scientific Cooperation Organization
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
XRD	X-ray diffraction