USDA-Forest Service	1. Number FS-SRS-4154	2. Station Southern Research Station
RESEARCH WORK UNIT DESCRIPTION Ref: FSM 4070	3. Unit Location Research Triangle Park, NC and Athens, GA	

4. Research Work Unit Title
Biological Foundations of Southern Forest Productivity and Sustainability

5. Project Leader (Name and address)
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6. Area of Research Applicability	7. Estimated Duration
Southern Regions with National Applicability	5 years

8. Mission

To quantify above-ground and below-ground processes governing forest productivity and sustainability.

9. Justification and Problem Selection

The foundation of sustainability is the concept that it is possible to manage natural resources to satisfy basic human needs in the present without compromising the ability of future generations to meet their basic needs. Sustainable forest management depends upon developing a system of technologies that integrates ecological principles in the production of desired forest benefits. Maintaining current levels, and achieving and maintaining enhanced levels, of forest productivity are central to meeting the goal of sustainable forest management. Our success in achieving sustainable forest management depends upon our ability to measure, evaluate, predict, and manage the impact of human and natural actions on the forest ecosystem. Productivity is the integrated outcome of the complex of soil, plants, animals, pathogens, climate and human activity at a given location. The productivity of any forest system depends upon the combined function and efficiency of the canopy, root systems, and soil processes. Reaching the goal of sustainability requires a range of activities including preservation and restoration, developing ways to use resources more efficiently, and environmentally sound intensive production on limited acres. We must determine the measures needed to sustain varied levels of productivity and use this information to develop sustainable management systems that deliver the quantity and quality of forest benefits desired by society. Our ability to manage forested systems to sustain current and enhanced

10. Approach to Problem Solution (Start at conclusion of item 9.)

Signature	Title	Date
Recommended: /s/ Nancy G. Herbert	Assistant Director for Research	11/12/97
/s/ Paul Dunn	Assistant to Staff Director	01/12/98

/s/ William T. Sommers	Staff Director, VMPR	01/12/98
Approved /s/ Peter J. Roussopoulos	Station Director	01/21/98
Concurred /s/ Barbara C. Weber	Deputy Chief for Research	02/10/98

levels of productivity depends on our understanding the driving processes and linkages between soils, plants, and the environment. Every experiment testing suites of silvicultural treatments cannot be carried out on a variety of sites. Models must be used to integrate experimental results across sites and scales to support science-based decision-making, and must be developed to form a framework for understanding and predicting changes in forest productivity.

Management activities frequently alter soil properties, resulting in both positive and negative effects on plant growth. For example, new edaphic conditions have resulted from past forest management practices, intervening agricultural activities, and other anthropogenic activities and disturbances on many sites. These conditions have resulted in cases whereby forest tree species that have historically occupied such sites are no longer adapted to current ecological conditions brought about by such activities. Novel root disease problems and declines in productivity characterize many of these situations. A key to properly managing forests to maintain or enhance productivity is in understanding how soil properties and processes influence plant growth and vigor. Much of the previous work on forest soils was empirical by design, focusing on the response of vegetation to experimental treatments such as fertilization or site preparation. While these studies did indicate tree growth for given treatment classes, the underlying relationships between plant growth and the actual impact of these treatments on soil processes such as decomposition, mineralization, and water supplying capability, were often not quantified, limiting our ability to understand and predict system response.

The composition and dynamics of the soil carbon pool may provide information key to understanding and managing both long-term and short-term productivity of a site, but our understanding of soil carbon pool function and dynamics and its relationship to plant growth is extremely limited. There is evidence to indicate that fine root turnover is a significant factor in soil carbon pool maintenance and nutrient availability, but we have little understanding of what above-ground or below-ground conditions and mechanisms trigger fine root mortality.

Plant productivity depends upon the root systems and associated microorganisms involved in water and nutrient processing and uptake, and includes those pathogenic organisms that interfere with processing and uptake. Information on root biology and form in forest systems is fragmented and scattered, and our understanding of rhizosphere function and dynamics is rudimentary. Management activities and seasonal temperature and moisture fluctuations influence carbon allocation to root systems and may affect root function by altering root and mycorrhizal development, influencing nutrient uptake, and changing populations of associated organisms. Results from field experiments on nutrient, water, and light availability show shifts in carbon allocation between root systems and above-ground plant components; however, we have little or no understanding of the threshold conditions that trigger shifts in carbon allocation patterns, or the biochemical and physiological mechanisms controlling them. Less is known about the relationship between the physiology and biochemistry of tree root growth and development and the dynamics of saprophytic, symbiotic, and pathogenic microbial relationships in the rhizosphere.

Changes in the physiological processes of above-ground tree components, such as increases in photosynthesis rates in response to elevated CO_2 and increased resource availability, or decreases in photosynthesis rates related to nutrient and water imbalances, pest attacks, or shading affect carbon allocation and accretion patterns. As with root growth, we have limited understanding of the threshold conditions that trigger the related shifts in carbon allocation. The interaction of resource availability and plant condition with photosynthesis, respiration, photoprotection, tissue carbohydrate and nutrient content, metabolite pathways, and metabolite content and partitioning is poorly understood. This information is needed to understand the metabolic limits and drivers of plant growth and form, and to link resource availability to standard measures of forest productivity and dynamics.

The proportion of Quercus species on high quality bottomlands, coves, and other highly productive mesic sites continues to decline throughout the southern region despite intensive research during the past 50 years. This reduction of Quercus species seriously affects major wood using industries and is having a serious impact on the more than 200 species of birds and other wildlife species that depend on mast production for their survival. Based upon current trends and management practices, it appears unlikely that some species like northern red oak and white oak can be maintained as viable components on highly productive sites in southern forests. No currently recommended regeneration system has been shown to be effective in increasing the percentage of these oaks on high quality sites because of more rapid early growth of competitor species. A system must be developed to accelerate production of advanced oak regeneration as 1-0 nursery stock and to evaluate a seedling's competitive potential if many oak species are to remain an important component of future stands.

Productivity is an integrated outcome of a complex of conditions, organisms and processes. Sustainable production systems must be based on the synthesis of our knowledge of governing processes with our understanding of the actual impact of management actions on governing processes and conditions. We must be able to predict forest functional dynamics, and model the interaction of soil processes, plant physiology, forest management and the environment. We must understand and quantify the primary above-ground and below-ground biological and physical processes, their governing factors, and their integral control of forest productivity and sustainability (Problem 1).

Users include other researchers in silviculture, physiology, biochemistry, soils, pathology, and modeling. Additional users will be the owners, managers, and administrators of industrial, nonindustrial private, and public lands, and the Southern Global Change Program and related environmental research programs.

Beneficiaries include private nonindustrial, industrial, and public forest landowners and managers, as well as the general public.

Potential benefits of this research will be to sustain current and enhanced levels of forest productivity, resulting in a sustainable supply of forest benefits.

Likelihood of success: Research in this problem is long term, and much of the process level and linkage research is still in the discovery phase. In 5 years we expect to have established a framework for linking above-ground and below-ground growth of trees, and to have working models of loblolly pine response to fertilization, loblolly pine shoot elongation patterns, and short-term soil carbon dynamics.

10. Approach to Problem Solution

Problem 1: Understand and quantify the primary above-ground and below-ground biological and physical processes, their governing factors, and their integral control of forest productivity and sustainability.

The problem is stated as one of understanding the interactions and linkages between the soil, plant, pathogens, and environment and their controlling factors. It implies an integrated approach. The intellectual resources of the RWU allow an integrated, interdisciplinary approach to the problem. The RWU is divided into three teams: the Above-ground Team (AT), the Below-ground Team (BT), and the Soils Team (ST). The approach, while integrated across teams, will be focused in four major areas: above-ground processes, below-ground processes, soils processes, and modeling and integration. Each team is responsible for developing the primary hypotheses in their area related to sustaining and enhancing forest productivity. There are no absolute boundaries between teams and team leaders will bring the teams together to determine the most effective means of integrating hypotheses across the teams, developing interdisciplinary studies as appropriate, and developing models of the systems that allow us to integrate, test, and improve our understanding and prediction of productivity and related processes. While individual studies may be specific to soil or plant factors and responses, each study will be conceived and executed as an integral part of the whole.

All of the work of the teams is integrated. Each team pursues a set of variables appropriate to the team's focus -- above-ground, below-ground, or soils. The teams' research is conducted on shared experimental sites with common design and the variables are measured on spatial and temporal scales allowing integration of the results. Work will capitalize on, and complement, research on the existing major field studies maintained by the RWU (Long Term Soil Productivity study on the Croatan National Forest; Southeast Tree Research and Education Site (SETRES) in Scotland County, NC; large scale burning study in longleaf pine at the Savannah River Site, Aiken, SC; and selected major hardwood outplanting studies across the South). Research will concentrate on managed stands of loblolly pine, longleaf pine, and selected commercially important hardwood species. In addition to silvicultural treatment classes, management activities will be characterized on a continuum of light, soil moisture and nutrient availability; physical characteristics; and biologically active soil organic matter pool content.

Above-ground Team Focus: Research on above-ground processes will quantify the impact of water and nutrient availability, soil supply characteristics, rhizospheric microorganisms, woody lateral roots, and whole-tree elevated CO_2 exposure on photosynthesis, respiration, tissue carbohydrate and nutrient content, carbohydrate metabolic pathways, metabolite content and partitioning, chlorophyll content, xanthophyll cycle, carotenoid content, antioxidant content, nutrient demand dynamics, and above-ground phenology and growth. Additional work will compare results of whole-tree CO_2 exposure with branch chamber results to develop reliable methods of scaling branch chamber exposure results to the tree and stand level. This work will build upon active research quantifying a number of the above factors.

Below-ground Team Focus: Research on below-ground processes will quantify seasonal growth and development patterns of root systems including rhizospheric microorganisms as affected by light, seasonal temperature and moisture dynamics, soil nutrient and carbon pool dynamics, the temporal and spatial regulation of carbohydrate metabolizing pathways, spatial photosynthate allocation within trees, and the interactions between microorganisms and plants. Additional research will quantify root carbohydrate metabolism, seasonal root respiration costs, fine root development and turnover rates, identification and quantification of symbiotic and pathogenic soil organisms and the growth and distribution of roots in relation to light, soil temperature and nutrient and water availability in pine and hardwood stands. The impacts of silvicultural practices such as prescribed fire and various harvesting regimes on root growth and development, mycorrhizal dynamics, and pathogenic fungal populations will be evaluated with several indicators such as carbohydrate metabolizing enzyme activity for the physiological status of roots and ergosterol as a surrogate for live fungal biomass. Relationships between the above- and below-ground components of pines and hardwoods will be investigated via the spatial and temporal patterns of carbohydrate metabolizing enzyme pathways, stem growth potential and first-order lateral root heritability, shifts of dry matter allocation within trees associated with nutrient imbalance, shading, and colonization by symbiotic microorganisms or infection by pathogenic microorganisms. Initially work will focus on <u>Heterobasidion</u> <u>annosum</u>, <u>Leptographium</u> species, and selected mycorrhizal associations and their relationship to conditions resulting from specific silvicultural treatments. The RWU has significant expertise in existing methodology for characterizing and quantifying soil microbial populations. The unit also has significant expertise in developing and refining methods for studying these organisms.

Soils Team Focus: Research will be conducted to determine the impact of physical and chemical changes in soil conditions on nitrogen and phosphorus mineralization rates, selected arthropod populations, microbial activity as a primary driver of mineralization and decomposition processes, and on soil organic matter pool composition and dynamics as a primary substrate for microbial activity. Initial arthropod work will focus on Collembola populations as a potential indicator of fungal activity associated with decomposition. Additional studies will be conducted to determine the potential usefulness of monitoring biologically active and recalcitrant soil carbon pool content and dynamics as an index of both long- and short-term productivity.

Modeling and Integration Focus: Modeling provides both a means of developing integrated hypotheses and a means of delivering a product. Models are useful in integrating experimental results across sites and scales to form a framework for understanding forest productivity and to support science-based decision-making. To be useful in a management context for predicting system response, models must synthesize our knowledge of governing processes with quantified impacts of silvicultural treatments such as spacing, thinning, vegetation control, fertilization, harvesting, and site preparation. Research in this area will focus on developing models linking above-ground, below-ground, and soil processes to predict tree and stand carbon allocation and accretion patterns. Any one model cannot meet all needs for management and research tools, so RWU scientists are currently working with several models in a number of collaborative efforts. Work is underway to parameterize BIOMASS and to update its associated soil supply module. Additional work is underway with cooperators in SRS-4111 to parameterize and test the combination of PTAEDA and MAESTRO models. Still other research is ongoing using the NCSU Loblolly Pine Stand Simulator. In addition, model components needed to synthesize and test our understanding of tree and stand growth are being developed as research tools. Work will build upon active RWU research in parameterizing a process level model for loblolly growth, developing a model linking shoot elongation patterns to water availability, and incorporating fertilization response into a stand level model for loblolly pine. The long-term goal is to develop models that will be useful in evaluating and modifying management strategies for both pine and hardwoods based on the impacts of silvicultural treatments on primary resources. Basic research on this topic will facilitate the generalization of forest growth models which are mechanistically driven allowing prediction of responses to combinations of treatments that are as yet untested. A significant amount of work in this focus area will be concentrated on developing ways to integrate the results of current studies, determine the gaps in our knowledge, and prioritizing those gaps to provide guidance to unit scientists in developing needed studies.

The RWU is responsible for research on the Croatan National Forest installation of the North American Long Term Soil Productivity (LTSP) study. A significant amount of the research carried out by the unit is on that site or in cooperation with other LTSP PI's across sites. For example, we are currently initiating research with other RWUs to quantify woody decomposition rates, termite activity, and soil carbon pool dynamics as a function of micro- and macroclimatic conditions on the LTSP study sites across the South.

The RWU is a full partner in the Below Ground Initiative (BGI) being developed. While there has been no specific program direction of research articulated for the BGI as yet, our current and planned research is very much in line with, and documented as part of, that program.

The RWU carries on coordinated research with SRS-4111 (Pineville, LA) linking work done on the ECOPHYS site (thinned stand conditions) to work carried out on SRS-4154's SETRES (Southeast Tree Research and Education Site; Scotland County, NC). SETRES is a designed experiment controlling water and nutrient availability. Collaborative work carried out by scientists in both RWUs is currently focused primarily on root dynamics and soil carbon pools.

The work of this RWU is long term by definition and end-products may not be available in all areas at the end of 5 years. It is not expected that the Work Unit problem will be solved within the next 5 years, however it is expected that significant progress will be made in the following areas:

Above-ground focus:

- Determining the effects of temperature, available soil water and nutrients on the dynamics of the rhizophere microbial population, nutrient flows, soil respiration and their linkages to top and root growth rhythms of trees.

- Determining the effects of nutrition on woody tissue and foliage construction costs in loblolly pine

- Quantifying effect of whole tree CO_2 exposure and branch chamber CO_2 exposure, on photosynthesis, respiration, and growth of loblolly pine.

- Clarify the use of some cartenoids as biological indicators for the long-term light environments of individual seedlings, saplings, and trees

Below-ground Focus:

- Determining the effect of temperature, water and nutrient availability on fine root and mycorrhizae turnover

- Determining the impact of fire on root pathogenic fungi dynamics in loblolly and longleaf pine stands

- Determining the impact of elevated CO_2 levels and water and nutrient availability on loblolly pine root phenology

- Quantifying the relationship of loblolly pine root phenology to uptake potential

- Evaluate the relationship between initial first-order lateral rood numbers and seedling size to long-term survival and growth of planted southern pines and hardwoods

- Identify populations of root infecting fungi, determine their structure, and begin quantifying interactions among root infecting fungi, insects, disturbance, and management regimes on root disease incidence in pine and its impact on productivity and sustainability

- Assess effects of chronic, sublethatl root infections by selected root disease fungi on conifer host energy capital and its relationship to predisposition to insect attack

Soils Focus:

- Determining the effects of biosolids application on soil organic matter content and quality and microbial activity in sweetgum plantations

- Quantifying loblolly pine root growth and distribution over time as impacted by organic matter removal, compaction, and weed control

- Assessing feasibility of using soil carbon pool content and dynamics as an indicator of long- and short-term productivity

- Quantifying the change in macro- and microporosity five years after organic matter removal, compaction, and weed control

Modeling and Integration Focus:

- Develop methods for scaling results of branch and whole tree CO_2 exposure to the stand level

- Develop stand level model for loblolly pine incorporating effects of fertilization

- Develop model of loblolly pine shoot elongation patterns based on water availability

- Develop model of short-term soil carbon dynamics based on temperature, moisture, availability, and substrate composition.

- Parameterize stand level model for loblolly ine incorporating CO_2 response, and ipact of different levels of water and nutrient availability.

- Qunatitatively and physiologically define shade tolerance for selected oak species based on parameters such as photosynthesis, xanthophyll cycle-mediated photoprotection, antioxidant levels, sucrolytic enzyme zctivitiy, and dry mass production and allocation

Staffing: This research will require an average of nine scientists per year at an average cost of $2.2 million per year. The scientific staff is expected to consist of nine permanent full time scientists, one of whom is the Project Leader. Specialties are given in Table 1. There are seven permanent and six temporary full-time technicians and two administrative support personnel. To fully address the process-level modeling, an additional scientist (ecophysiological modeling) is needed. While there is not currently staff or funding in the RWU to pursue all of the modeling needed, we recognize that this is a critical component of the work and are exploring a variety of options for accomplishing the work. The need can potentially be met through a post-doctoral appointment, or through a shared appointment with another RWU.

Table 1. Scientist staffing by specialty.

Specialty	Number
Research Forester	2
Research Plant Physiologist	2
Research Plant Pathologist	2
Research Soil Scientist	1
Research Chemist	1
Biological Scientist	1

Environmental Considerations: The laboratory, greenhouse, and small-scale in situ studies in this problem area are expected to have little or no potential for soil movement, water quality degradation, or impact on sensitive resource values and are therefore covered under FSH 1909.15, Chapter 30, "Categorical Exclusion from Documentation in an EIS or EA." The environmental concerns for new studies will be evaluated in the Study Plan and, if necessary, an

Environmental Assessment will be prepared. Existing large-scale field studies have already been evaluated by Environmental Assessments completed at the time of installation. Any new large-scale studies will be evaluated within individual study plans, or by Environmental Assessments prepared by the staff at the cooperating District, National Forest, or at the Savannah River Forest Station.