Conceptual Model for Sustainable Cropping Systems in the Southeast: Cotton System

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SUMMARY. Many small to mid-size family farms face an economic and ecological crisis due to the changing face of agricultural production. Increasing production costs and lower revenues are causing many producers to leave the farm. Rural communities face economic hardships due to declining farm numbers and continued loss of the brightest youths who often seek employment in urban areas. Small to mid-size family farms and rural communities can be sustainable if economic and environmental risks are recognized and solutions developed that reach all members of the farm and rural communities. Our project focuses on the involvement of farmers, scientists, and other stakeholders to enhance understanding of sustainable principles at the farm level and extend awareness of the central components to sustainability of rural communities. Conservation tillage with cover crops is being used to modify pest pressures, reduce chemical inputs, improve soil productivity and reduce environmental risks to producers, the community and the environment in cotton (*Gossypium hirsutum* L.) production systems. Preliminary results indicate that reductions in use of pesticides can be achieved due to enhanced presence of beneficial insects. Cotton offers the best opportunity to enhance the understanding and use of sustainable practices in ecologically-based farming systems because of its predominance in southern farm enterprises. Farmer participation and understanding is being facilitated through the participation of the farmer based Georgia Conservation Tillage Alliance. To achieve greater outreach and broaden community participation within the region we are involving at-risk rural youth through the Communities in Schools of Georgia program. Outreach includes the use of traditional and newer internet based technologies through the development of databases and expert systems that allow, farmers, ranchers, and community members an opportunity to evaluate economic and environmental effects of alternative production practices at local and regional scales. Through interactions with existing federal, state, and private organizations we are encouraging expansion of these sustainable approaches regionally.

KEYWORDS. Nutrient management, pest management, economic models, environmental index, insects, cover crops, rural sustainability

INTRODUCTION

Sustainability as a Concept in Agricultural Systems

Since World War II, modern agricultural practices and farm policy have affected a shift in US agriculture from localized diverse production systems that included draft animals, legumes, and animal manures to systems that depend on machines, fossil fuels, chemical fertilizers, and pesticides (Hildebrand and Russell, 1996). This shift in technologies has created a landscape of centralized homogeneous cropping systems that rely less and less on interdependent components. Although highly productive, decreasing diversity of production within a local area has contributed to destabilization of many rural economies (Olson and Francis, 1995). Many farming enterprises in the US face increasing costs of production while commodity prices continue to decline due to global market forces. This economic imbalance contributes to loss of producers and erosion of the stability of agriculturally based rural communities.

Because of this economic imbalance, producers are more and more in need of environment specific technologies aimed at improving productivity and economic sustainability. Until recently, the general consensus was that sustainable production practices do not lead to improved net economic return, especially at small to mid size scales. Sustainable production practices that focus on reduced input costs are perceived to cost more in labor and management and may not be credited for the increased production per unit of land area that can be achieved with intensive small systems. The question remains whether sufficient net income can be generated on enough acreage to support a family farm unit through the use of intensive systems. The necessity of producer focus on short-term economic viability, along with commodity based government policies continue to limit acceptance of practices that could improve long-term environmental and economic sustainability. In addition, greater support from research, extension, financial institutions, risk management professionals, governmental bodies, and local leaders is needed to effect change (Lewis and Jay, 2001).

Need for Community Support of Sustainable Principles and Practices

Land stewardship has long been recognized for sustaining productivity. Certain inherent principles of natural ecosystems when applied to farms and communities enable them to maintain balance and minimize negative effects of adverse disturbances. These strengths are: *interdependence*–components rely on each other for energy and cycling of materials; *self-sufficiency*–minimal import of resources; *self-regulation*–feedback loops maintain balance within certain bounds; *self-renewal*–perpetuation through effective reproduction, defense, and other strategies; *efficiency*–minimal waste, i.e., recycling; and diversity/versatility C insures ability to cope with cycles of fluctuating conditions. Sustainability of small and limited resource family based farm operations depends on applying these core principles to develop systems where solutions to problems are "built-in" and renewable (i.e., crop rotation, cover crops, intercropping, and integrated animal-crop systems) (Lewis et al., 1997b).

Over the past 50 years, spectacular short-term solutions for problems such as soil nutrition, weeds, insects, and plant diseases have been achieved through scientific research. On the near-term, dosages and costs of these therapeutic solutions were nominal. Thus, the practice of monoculture and high-input agriculture surged as yields per acre quadrupled (Odum, 1989). With availability of these tools, emphasis on inherent, self-renewing regulators such as biodiversity, natural enemies of pests, and recycling of nutrients generally fell by the wayside and sometimes resulted in secondary negative effects, i.e., water pollution, wildlife injury, and soil erosion.

Current production practices depend on large inputs to maintain yields, thus placing US producers at risk for economic disaster which is often overcome only through emergency farm payments. To effectively change the current system will take multiple levels of interaction among producers, scientists, educators, economists, politicians and other stakeholders. One way to incorporate holistic sustainable management principles applicable to problems in rural communities and agriculture is through interdisciplinary, on-farm research and demonstrations, partnered with a broad, community-based educational outreach program. A successful approach will require collaborative interactions among existing federal, state, and private organizations so that their individual strengths can be drawn upon to insure expansion to other regions.

On Farm Research to Promote Sustainable Practices

Farmers are justifiably reluctant to adopt new technologies before seeing convincing tests and demonstrations under farming conditions similar to their own (Rzewnicki, 1991). This reluctance often results from limited producer involvement in technology development. Separation of research priority setting from actual agricultural production often results in development of inappropriate technologies that require significant end-user modification. Producers become the ultimate integrators of site-specific management systems based on their knowledge of current technologies, available resources, and environmental conditions. The current system of technology transfer increases the economic risks associated with adoption of new practices and limits early adoption to the most innovative and usually larger producers. This often inhibits adoption by limited resource or small farm producers.

Contributions of scientists become more important and more difficult as the need for integrating regional and site-specific factors increases. However, the site-specific applicability of data from on-farm research helps facilitate technology transfer to other regional farmers. Participatory research encourages synergism among scientists and farmers working together to design, implement, and evaluate research (Wuest et al., 1999). Including farmers ensures identification of high priority problems and potential solutions, aids in design and implementation, and improves interpretation of results and recommendations (Hildebrand and Russell, 1996). Farmer participation provides greater insight into how new technologies will be applied and provides a more robust evaluation due to the broader, more variable, and unpredictable range of environmental conditions (Rzewnicki, 1991; Wuest et al., 1999). Farmers also become "scientists" in learning to critically analyze their farms and self-initiate on-farm research activities. On-farm research/demonstrations and shared learning experiences help to facilitate major paradigm shifts both with producers and in research.

Historic Perspective on Cotton (Gossypium hirsutum L.)

Cotton played a significant role in the economic welfare of the south from the time of colonial settlement in the late 1700s until the boll weevil (*Anthonomous grandis grandis*, Boheman) caused significant declines in yields and increases in production costs during the early 1900s (Haney, Lewis, and Phatak, 1996). The long history of row crop production, predominantly cotton, and intensive tillage practices were responsible for extensive soil erosion and loss of soil productivity in the region. Trimble (1974) estimated that 15 to 30 cm of soil were lost on sloping soils of the region from 1865 to 1920. Much of the soil loss is attributed to lack of crop rotation that resulted in 50 to 75 years of continuous cotton. Arrival of the boll weevil could be heralded as an important stimulus for diversification and change at the farm, community, and regional scales in the south (Haney, Lewis, and Phatak, 1996).

A new era of cotton dominance in the south has emerged due to the success of the Boll Weevil Eradication program. Production increased from 3.7 million hectares in 1989 to 4.7 million hectares in 1998 (CTIC, 1998). This increase has not occurred without risks. Intensive tillage practices like fall plowing followed by winter fallow and spring discing are practiced on over 85% of the cotton grown in the south (CTIC, 1998). Most of this cotton is grown on land that is not rotated to other crops. These practices leave soils vulnerable to the intensive rain and wind that continue to cause erosion and loss of soil productivity. In addition to environmental problems, recent increases in per unit cost of inputs and drops in prices have contributed to reduced farm profitability for cotton farmers. Cotton prices declined from \$2.53 kg^{-1} in 1995 to less than \$1.10 in 2001 (Shurley, 2001) while farm expenditures from 1993 to 1998 increased 14% (USDA/NASS, 1999).

The expanded production of cotton, success of the Boll Weevil eradication program, and continued availability of economic support to producers from Loan Deficiency Payments (US government support of cotton prices) makes cotton an ideal crop on which to base a project for promoting sustainable practices such as the use of cover crops, conservation tillage, and integrated pest management (IPM). Producers are more familiar with IPM principles due to the success obtained in the Boll Weevil program and should be willing to try new and innovative approaches for reducing pesticide and other chemical inputs.

A SUSTAINABLE COTTON PRODUCTION SYSTEM FOR THE COASTAL PLAIN

The foundation components of the system are the use of conservation tillage and cover crops to manage insect habitat so as to enhance the presence of beneficial insects, and also improve nutrient and water availability. Previous work with cotton growers in south Georgia has shown that cotton grown in strip-killed crimson clover (*Trifolium incarnatum* L.) using reduced tillage improves soil health, cuts tillage and insecticide costs, and reduces fertilizer inputs by 56 to 67 kg ha^{-1} (Haney, Lewis, and Phatak, 1996; Lewis, Haney, and Phatak, 1996). One producer reported a savings of \$300 ha^{-1} on inputs and yields of 7.4 bales ha^{-1} of cotton compared to 3 bales ha^{-1} in his conventional system (Reed et al., 1997). Increases were observed in beneficial insect numbers and duration of presence in the fields. For many producers switching to a system that relies on reduced off-farm inputs will require planning, management, and time to implement (Stark et al., 1999). However, interactions among system components must be better understood to increase applicability to a wider area (Lewis et al., 1997c). We are working with producer members of the Georgia Conservation Tillage Alliance (GCTA) to evaluate these practices on small to mid-size farms in areas of rural Georgia in an effort to expand adoption of sustainable practices.

Role of Reduced Tillage and Cover Crops

Conservation tillage reduces the number of operations required to prepare a field for a crop thus reducing field traffic, labor and fuel costs, machinery needs and time (Liu and Duffy, 1996). In addition, reduced tillage practices can increase soil productivity due to influences on surface soil organic matter and water infiltration/availability (Bruce et al., 1995). Accumulation of organic matter with reduced tillage is attributed to a reduction in the rate of organic matter decomposition.

Cover crops are grown primarily to protect the soil from erosive forces and usually are not harvested. Use of green manure crops to increase biomass inputs back to soil has long been known to be a sound agronomic practice (Reeves, 1994). When used with conservation tillage, cover crops provide many of the benefits attributable to green manure crops. Besides protecting soil against erosion, they improve soil structure, enhance soil fertility, suppress pests, enhance soil quality, conserve soil moisture, protect water quality, and help safeguard personal health (Reeves, 1994). In addition to the physical effects, cover crops reduce runoff and erosion through effects on soil structure. Microorganisms decomposing crop residues produce compounds that increase aggregate stability which is only sustained through continuous inputs of new organic matter (Kladivko, 1994). Cover crops thus serve as a source for organic matter input.

Using cover crops with conservation tillage can restore soil productivity of degraded soils through increases (or reduced losses) in soil organic matter (Bruce et al., 1995; Franzluebbers, Langdale, and Schomberg, 1999). Soil organic matter supports the abundant diversity of organisms important in decomposition and nutrient cycling, serves as a source of plant nutrients through release of organic N, S, and P, and supplies inorganic nutrients through its cationic exchange capacity and chelation reactions (Schomberg, Ford, and Hargrove, 1994). Reduced tillage practices can result in organic matter increases of up to 2.3 Mg ha^{-1} yr^{-1} (Reicosky et al., 1995) depending on the rate at which biomass is added minus the rate at which erosion and biological oxidation are removing organic matter. Effectiveness of cover crops to increase biomass input will depend on how well the cover crop is adapted to the area and management variables like planting date, fertility, and killing date (Reeves, 1994).

Availability of N to a subsequent crop is directly influenced by cover crop residue effects on N mineralization and immobilization and/or through N fixation by legume cover crops. The N value of legumes can range from 30 to 180 kg N ha^{-1} depending on growing conditions and type of legume (Frye et al., 1988; Hargrove, 1986; Stute and Posner, 1995). Availability of N to a crop during the growing season can be 20 to 40% greater following a legume than following rye (*Secale cereale* L.) (Schomberg, 1998). Scavenging of N remaining in the soil profile by gramineous cover crops reduces loss of leached N up to 60% compared to no cover crop (Meisinger et al., 1991). Legume and grass cover crop mixtures can improve nutrient conservation through complementarity of residue chemical composition that affects decomposition and N mineralization rates thus leading to greater synchrony of nutrient availability to the following crop. Grasses conserve soil N (uptake) and impede release of N due to slower decomposition while legumes increase available N through N fixation and rapid decomposition supplying N early in the growing season (Rannells and Wagger, 1996). A complex mixture of crimson clover, hairy vetch (*Vicia villosa* Roth), rye and barley (*Hordeum vulgare* L.) provided significant inputs of N (220 to 360 kg N ha^{-1}) in a low input system for tomato (*Lycopersicon esculentum* Mill.) production and suppressed weeds as well as a herbicide system in Ohio (Creamer et al., 1996). Greater diversity in a mixture can provide greater resilience to climatic and biological adversity because of growth compensation by individual components of the mixture.

Habitat Management

Habitat management as a pest management tool is an ecologically-based strategy aimed at designing agroecosystems to support populations of natural enemies of pest species (Altieri and Whitcomb, 1979; Altieri, Martin, and Lewis, 1983). The well-known S-shaped curve of growth through time illustrates the sequential progression of natural ecosystems with growth beginning slowly, rapidly increasing, and leveling off thereafter (e.g., Flint and Van den Bosch, 1981). Conventional monoculture agroecosystems typically operate in the linear portion of this curve where large oscillations in species occur until the latter part of the growing season when increasing interactions tend to stabilize the oscillations. Conventional monoculture agroecosystems seldom reach the plateau of the S-curve as chemical inputs often remove or debilitate many species and annual removal of biomass forces growth to start over each year. Habitat management through conservation tillage and cover crops as well as other types of field landscaping (e.g., field borders, hedgerows, adjacent crops) help promote more year-round natural enemy-pest-species interactions by providing alternate prey or hosts, reproductive sites, and shelter from adverse conditions for natural enemies of pests. These landscape effects on natural-enemy-pest interactions suggest a potentially high utility as a pest management tool (Landis, Wratten, and Gurr, 2000) but more information on species-specific interactions of targeted pests and natural enemies are needed to facilitate the design of appropriate landscapes.

Studies of cotton arthropod pests and their natural enemies in conservation tillage and cover crop systems in the south-southeast have been conflicting. Generally ground-dwelling beneficial species are higher in conservation tillage cotton with and without cover crops compared to conventional tillage (Blumberg and Crossley, 1982; Sullivan and Smith, 1993; Haney et al., 1995; Lewis, Haney, and Phatak, 1996), while cutworm (*Noctuidae* sp.) pest populations are higher in reduced tillage and legume cover crop systems than in conventional tillage systems where crop residues are incorporated into the soil (Guthrie et al., 1993; Leonard et al., 1993; Sullivan and Smith, 1993; Turnock, Timlick, and Palaniswamy, 1993). However, no consistent patterns in significant pest populations and plant-dwelling beneficial species or in cotton yields have been reported (Leser, 1995; Ruberson, Phatak, and Lewis, 1997; Stapel et al., 1998). In some studies, increases in aphid (*Aphis* sp.) populations and decreases in heliothine eggs and plant-dwelling beneficial species were correlated with higher numbers of predacious fire ants (*Solenopsis invicta*) in conservation tillage cover crop systems (Leser, 1995; Ruberson et al., 1995;

Stapel et al., 1998). Differences among cover crop species, years, field histories and locations, and surrounding landscape contribute to the conflicting results of these studies. Longer-term studies may provide a better understanding of how various cover crops, reduced tillage, and other landscape factors affect arthropod pests and beneficial species, and how these translate into plant protection over time.

Habitat management also offers the potential to activate inherent mechanisms for suppressing plant-parasitic nematode populations (i.e., promoting the presence of nematophagous organisms like nematode-parasitic fungi and predaceous nematodes) (Stirling, 1991). Plant-parasitic nematodes feed on plant roots and are major pests of many crops including cotton. In Georgia, cotton yield losses from nematodes were $25 million and the cost of control was $11 million in 1998 (Williams-Woodward, 1999). The southern root-knot nematode [*Meloidogyne incognita* (Kofoid and White) Chitwood] and the reniform nematode (*Rotylenchulus reniformis*) are the most widespread and damaging plant-parasitic nematodes in cotton production. These nematodes reproduce on a wide range of plant species, including most winter cover crops. Moreover, no agronomically acceptable cotton varieties exist with resistance to southern root-knot nematode or reniform nematode and growers have few choices for non host crops to rotate with cotton. Alternative nematode management options are needed but the effects of most cropping practices on natural enemies of nematodes are unknown. Conventional tillage may displace natural enemies from the area of greatest nematode activity and expose them to upper layers of soil where their survival is diminished by desiccation and ultraviolet irradiation. Rotation with non-host plants, such as Bahia grass (*Paspalum notatum* Flügge), reduces nematode populations as well as populations of its natural enemies. Several well-documented cases indicate nematode-suppressive soils can develop in response to continuous planting of a host crop (Stirling, 1991). Year-round plant growth has the potential to increase populations of plant-parasitic nematodes because of the extended presence of nematode susceptible crops (cotton and cover crops); however, this may also lead to a buildup of host-specific natural enemies that consistently suppress nematode populations below damaging levels.

Environmental Impact

Pesticide losses in run-off are reduced with conservation tillage and cover crops because less water leaves the field. Conservation tillage promotes a change in soil physical properties while cover crops help slow the rate of water moving at the surface thus increasing infiltration. This reduced run-off has caused concern that there is greater potential for groundwater contamination from pesticides or nitrate (Fawcett, Christensen, and Tierney, 1994). Preferential flow through macropores, which may be more prevalent with no-till, can allow water and dissolved solids or suspended sediments to by-pass upper layers of soil. Although preferential flow through macropores can allow rapid transport of water and certain pesticides a few feet deep in the soil, it is not clear that this process can deliver pesticides to deeper depth (Fawcett, Christensen, and Tierney, 1994). Pesticides that move deeper into the soil have been found to diffuse into the soil matrix and are no longer subject to preferential flow (Gish et al., 1991; Gish, Helling, and Mojasevic, 1991).

Concern has also been raised that adoption of conservation tillage practices increases use of herbicides and insecticides with greater potential for contamination of the environment. While adoption of conservation tillage can change weed and insect problems and the types of herbicides used, total usage of pesticides has not changed when farmers convert to conservation tillage (Hanthorn and Duffy, 1983; Fawcett, 1987; Bull et al., 1993; Day et al., 1999). Day et al. (1999) evaluated pesticide use by producers in the major corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.) production areas of the US for 1990, 1993, and 1995. Combining the conclusions of their study with previous studies (Hanthorn and Duffy, 1983; Bull et al., 1993) indicated that as tillage moves from conventional systems to conservation tillage to no-till, herbicide use per hectare tends to increase. This increase in the no-till system was mostly related to the need for a burn-down herbicide. For ridge-till and mulch-till systems rates were not much different from those used in conventional systems. Statistical analysis of insecticide application rates showed that conventional tillage used more insecticide than no-till and about the same as mulch-till and ridge-till (Day et al., 1999). Measured changes in quantities of pesticides over time did not reflect quality changes that occurred (i.e., newer and more potent pesticides entering the market often require lower application rates). Future effects on the environment depend on the inherent toxicity of the active ingredients and characteristics that affect persistence as well as management strategies developed to reduce acquisition of resistance by target pests.

Economics (Farm and Rural Communities)

System benefits and costs of alternative management strategies are being evaluated at the farm level to determine optimum combinations of cover crops, crop rotation, and pest management that sustain revenues. Consideration must not only be given to the potential for increasing returns and reducing volatility due to changes in productivity but also to the environmental benefits of reduced fertilizer and pesticide inputs. Likelihood of producers adopting sustainable management strategies will depend on their expected future change in yields and associated economic volatility. Possible tradeoffs between short-term returns versus long-term sustainability can only be addressed to a limited degree with data that are now available.

We are developing a set of indices to evaluate how changes in system components affect long-term viability. These indices will be used in a general procedure for determining a "sustainability" score for different practices. They will also provide a useful measure of the contribution of farms to sustainability of communities and geographic areas, and an objective, numeric basis for conservation or environmental protection planning and payment programs. One index focuses on pesticide effects on density and diversity of pest and beneficial species over time and how these interact to affect production. An environmental impact index incorporates exposure and toxicity ratings for (a) terrestrial species in the field: non-target/biodiversity impacts on agroecosystems and (b) potential for agrochemical transport to aquatic ecosystems and impacts on indicator species. An index of soil quality is being used to determine an economic value of system effects on soil productivity. And a wildlife index describes the relative economic and environmental benefits of alternative crop management scenarios to producers and rural communities.

ON-FARM RESEARCH DEVELOPING A SUSTAINABLE COTTON PRODUCTION SYSTEM

Focusing on cotton as the base system, because of its prevalence throughout the south, we are working to achieve a more sustainable production system that will reduce pesticide, fertilizer, and fuel inputs through adoption of conservation tillage (minimizing tillage intensity and frequency) and cover crops to add diversity, fix N, and provide habitat to beneficial insects. In addition, the system encourages diversification to include other cash crops and livestock and extend the basic principles of sustainability to other crop production systems in the region. Work on six farms in two areas of the state began in the fall of 2000.

Our research plots focus on the use of conservation tillage to enhance soil quality factors such as increasing soil surface cover and organic matter content at the soil surface. Both factors are important for improving water infiltration and water-use efficiency. We are comparing cover crop mixtures (clovers plus rye) for biomass production and insect habitat. Cotton is planted into killed strips of cover crops. The remaining live strips serve to prolong the presence of insect habitat. The combined results of tillage and cover crop management should help to reduce inputs of fertilizer and pesticides and also help with water management thus reducing costs of cotton production.

Combining traditional field days, newer internet-based education, and extension-led outreach, producers, educators, and civic and community leaders will be exposed to holistic ecologically-based tools to foster sustainability at the farm and community levels. The support of a strong farmer-based conservation tillage alliance, i.e., GCTA, has been instrumental in helping to develop the project and provide contacts from its 200 plus members and four regional subchapters. Through its monthly newsletter and internet page, GCTA provides an effective conduit for disseminating information from the project. On-farm field day demonstrations in cooperation with GCTA and workshops on sustainability at GCTA's annual meetings provide effective means for transfer of information. Involvement of broader community components such as financial institutions, risk management professionals, governmental bodies, and community leaders is being targeted to help develop a sense of the need for sustainable practices at the community level (Lewis and Jay, 2001).

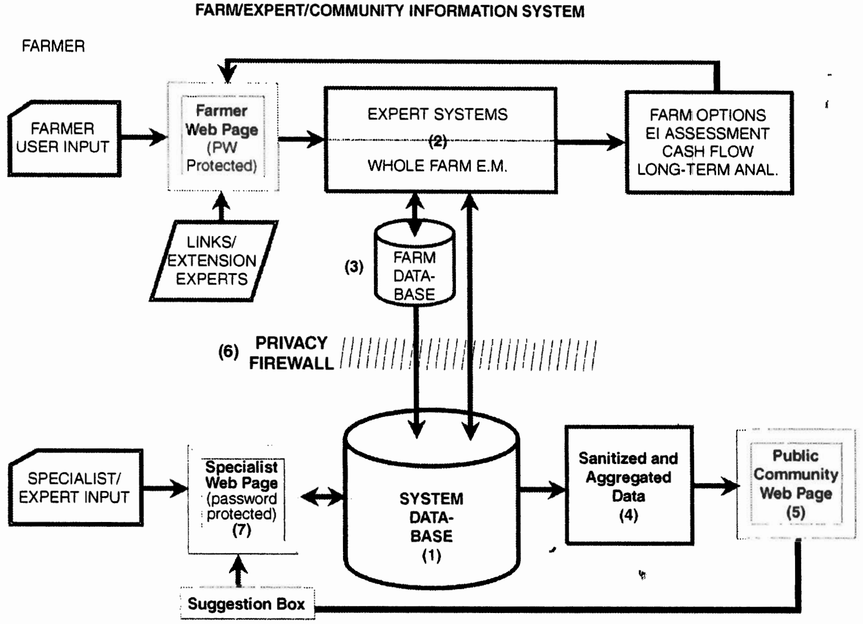
Internet-Based Technology Transfer

An internet-based system in which whole-farm economic analysis is combined with agronomic and horticultural knowledge and environmental impact analysis is being developed to extend the project's activities to a much broader audience (Figure 1). Numerous frameworks or approaches to whole farm planning are possible and are being explored by various groups in the US and in other countries (Freyenberger, Janke, and Norman, 1997). Janke and Freyenberger (1997) considered applicability of these approaches to range from user friendly to not likely to be used at all. They identified the Ontario Environmental Farm Plan as thorough but complex; the Farm-A-Syst checklist approach as providing a snapshot at a certain point in time but does not promote ongoing monitoring; PLANETOR, a computer based system, allowed more what if evaluations; and the Minnesota Land Stewardship Project incorporated several monitoring tools that encourage interaction among farm families and researchers.

The system under development in this project is based on interactive (farmer as well as scientist initiated) technology transfer and knowledge transfer. Methods to assess economic and environmental benefits of management practices are used to provide researchers and individuals a way to compare sustainable alternatives based on research results, whole-farm economic analysis (Lamb, Davidson, and Butts, 1992), and environmental indexing (a relative ranking of the environmental impacts of an agricultural management practice, see below).

Multiple interfaces will allow farmers, extension-research specialists, and the general public access to database information. Participating producers will manage records of their own farm through a password protected internet access. This producer data is aggregated to maintain privacy for research, analysis, policy, and community purposes. Expert system functionality will be used to provide knowledge exchange for alternate crops and production practices using input from farmers and specialists which will also provide direct link-

FIGURE 1. Internet Based System for Information Transfer and Agroecosystem Analysis.



(1) System Database: Input data for whole-farm analysis, environmental impact index calculator, irrigation and any other expert systems used. Spatial information to calculate aggregate watershed information such as water use, chemicals and nutrients applied, added in future versions.

(2) Whole-Farm Economic Model/Expert Systems Management Assistant Model Suite: Accessed via the Farmer-Client Web Page using a password, farmer may either download suite for offline run or run online and construct private database of input data within system. Suite provides economic analysis, options, and answers to "what-if" questions, long-term economic viability of choices and cash flow analysis. Environmental index calculations for each field/management/crop combination.

(3) Client Farm Database: Private space provided in the system for clients to build a "permanent" database describing his/her farm operations and financial data.

(4) Sanitized and Aggregated Data: A "sanitizer filter" is used to remove the identity of individual farms (to protect individual farm operations and farmer privacy) and aggregate the data based on farm type, county, and region to provide data for community planners, environmental agencies, public planning, conservation payment system structuring, and public information web page.

(5) Public/Community Information Web Page: Internet based technology transfer providing a description of the project, how to participate, services provided, and data access. Using database information and expert systems, economic and environmental index calculations can be developed for alternative farm enterprises by anyone.

(6) Privacy Firewall: Separates client program suite and farmer database from public- and expert-access parts of system; sanitizes and disconnects private data for aggregation.

(7) Specialist/Farmer Input Page: Specialists (agronomists, ecologists, economists, entomologists, and others) create and maintain system databases through this interface. Public/farmers can provide information via a "suggestion box." Specific database areas are the responsibility of individual "authors," who have exclusive access to those fields.

ages between farmers and specialists. The system will allow evaluation of production alternatives for community planning and watershed environmental assessment as well as on-farm information for producers.

Environmental Impact: Quantifying Relative Risk Reduction

Because there is little knowledge relating off-site actual ecological impacts to specific practices on farms, research groups in the US and elsewhere are using the concept of relative risk as an initial approach to defining this aspect of the sustainability of practices (Bockstaller, Girardin, and van der Werf, 1997; Lewis et al., 1997a; Lukk, Tindall, and Potts, 1995; Newman 1995; van der Werf and Zimmer, 1998). Although this approach has mainly been used for comparing pesticides with each other and with alternative pest management practices, it can in principle be extended to agronomic practices such as use of herbicide resistant crops and application of animal waste in cropping systems. For pesticides, a weighted relative environmental impact "risk index" is calculated by combining indicator species, human toxicity and exposure data obtained in many cases from risk assessment data used for pesticide registration.

Initially the conceptual model uses a simplified version of the index developed by Kovach et al. (1992) which was developed to determine the relative environmental impact of pesticides in conventional, IPM, and organic systems of apple (*Pyrus malus* L.) production. Their index combines a relative risk calculation for "ecological," "consumer," and "farm worker" components using such indexes as dermal toxicity, fish toxicity, leaching and runoff potential, etc., for relative hazard, and using application rate as a surrogate for exposure.

Initially we will neglect the "farm worker" part of this index because it is less well characterized than consumer and ecological risk. However, as our experience with this process grows it will be added. The form of the resulting simplified Environmental Index Quotient (EIQ) is thus

$$EIQ = [(C \bullet ((S + P)^2) \bullet Sy) + L] + [(F \bullet R) + (D \bullet ((S + P)^2) \bullet 3 + (Z \bullet P \bullet 3) + (B \bullet P \bullet 5)]^2$$

Where the first and second terms in square brackets compute relative consumer risk and ecological risk, respectively. The components are: C = mammalian chronic toxicity, S = soil half-life, P = plant surface half-life, Sy = plant sorption potential, L = leaching potential, F = fish toxicity, R = runoff potential, D = bird toxicity, Z = bee toxicity, and B = beneficial arthropod toxicity. Each of these individual factors is in itself an index scaled in order to weigh properly in the calculation. For example, "toxicity to beneficial arthropods" can have values from 1 to 5 assigned to "low impact" through "high impact," respectively.

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Environmental Impact: Quantifying Relative Risk Reduction

Because there is little knowledge relating off-site actual ecological impacts to specific practices on farms, research groups in the US and elsewhere are using the concept of relative risk as an initial approach to defining this aspect of the sustainability of practices (Bockstaller, Girardin, and van der Werf, 1997; Lewis et al., 1997a; Lukk, Tindall, and Potts, 1995; Newman 1995; van der Werf and Zimmer, 1998). Although this approach has mainly been used for comparing pesticides with each other and with alternative pest management practices, it can in principle be extended to agronomic practices such as use of herbicide resistant crops and application of animal waste in cropping systems. For pesticides, a weighted relative environmental impact "risk index" is calculated by combining indicator species, human toxicity and exposure data obtained in many cases from risk assessment data used for pesticide registration.

Initially the conceptual model uses a simplified version of the index developed by Kovach et al. (1992) which was developed to determine the relative environmental impact of pesticides in conventional, IPM, and organic systems of apple (*Pyrus malus* L.) production. Their index combines a relative risk calculation for "ecological," "consumer," and "farm worker" components using such indexes as dermal toxicity, fish toxicity, leaching and runoff potential, etc., for relative hazard, and using application rate as a surrogate for exposure.

Initially we will neglect the "farm worker" part of this index because it is less well characterized than consumer and ecological risk. However, as our experience with this process grows it will be added. The form of the resulting simplified Environmental Index Quotient (EIQ) is thus

$$EIQ = [(C \bullet ((S + P)^2) \bullet Sy) + L] + [(F \bullet R) + (D \bullet ((S + P)^2) \bullet 3 + (Z \bullet P \bullet 3) + (B \bullet P \bullet 5)]^2$$

Where the first and second terms in square brackets compute relative consumer risk and ecological risk, respectively. The components are: C = mammalian chronic toxicity, S = soil half-life, P = plant surface half-life, Sy = plant sorption potential, L = leaching potential, F = fish toxicity, R = runoff potential, D = bird toxicity, Z = bee toxicity, and B = beneficial arthropod toxicity. Each of these individual factors is in itself an index scaled in order to weigh properly in the calculation. For example, "toxicity to beneficial arthropods" can have values from 1 to 5 assigned to "low impact" through "high impact," respectively.

the community are teen mothers and school drop-outs. Therefore, educational opportunities that demonstrate sustainable principles must be provided early on (e.g., Middle School) and continued through life. Understanding these principles can play an important role in development of stewardship responsibilities in the community.

A unique part of our approach to bringing sustainability principles to rural communities is through participation of the Communities in Schools of Georgia (CISG) program (www.cisnet.org). This program is designed to improve education by teaching kids how to help themselves. Taking a holistic view, the program seeks to combine the benefits of specialization and modern technology. Hands-on or applied learning techniques, which CISG has found to be effective for engaging youth who are most at risk of dropping-out of school, are used to present sustainability issues. Through hands-on service learning, youth identify an important social issue, plan an activity to address the issue, implement the plan and then reflect on the learning as the plan is implemented and concluded. Application of this method to engaging youth with sustainable farming practices allows rural youth to reconnect with their heritage while learning key components of safeguarding natural resources.

CONCLUSION

Economic and environmental sustainability of family based small-farms in the southern US depends on the development and promotion of integrated systems of crop and farm management. Most producers in the region are interested in protecting natural resources and being good land stewards, but are also economically motivated. Producers are increasingly interested in knowing the effects of management decisions on their immediate environment including soil health (Brock, 1999), water quality, and wildlife. A set of indices that allow an objective measure of the benefits and costs of alternative management strategies in sustainable agroecosystems will help evaluate economic returns of production as well as the environmental benefits of reduced run-off and inputs. These indices also provide a measure of a farm's contribution to sustainability of the community and geographic area; information needed for conservation or environmental protection planning and useful in determining payments to farms with high sustainability indices. Long-term benefits are potentially greater for researchers, producers, and society.

At this point our on field efforts have just begun and preliminary results from the 2001 season are encouraging. Producer involvement has presented real world problems that the researchers would not have faced on small plot scales such as planting problems, and cover crop management problems. Insect pressures have been reduced in some cases by the treatments with some of the producers surprised by the positive effects. Greater communication between researchers and producers is needed to clearly define the role of each group and expectations during the research process. As we continue through the project and put more of the concepts into practice we envision the expansion of the practices to surrounding farms and communities.

Support for sustainable agriculture requires expansion of the concepts within rural communities which can be accomplished by targeting youth (the future rural community leaders). Although youth evolvement has yet to be achieved, we are encouraged by the continued support and encouragement of the Communities in Schools of Georgia participants. By engaging rural youth to understand the complex interactions occurring within agroecosystems, we can help them understand and safeguard local resources as well as reconnect them with their rural heritage.

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