Dr. Kline's research regarding Arkansas lignite and its possible use as a soil amendment that could be useful to the rice industry in Arkansas:

What follows is a proposal that was drafted in 1994 for experimentation with Arkansas lignite to test certain agricultural products that can be produced from lignite. The soil amendments that can be produced from lignite have qualities that seem well suited for certain problems commonly encountered in Arkansas' rice industry. Funding for the project was not obtained at that time, and Dr. Kline went into other lines of research. This draft proposal is included here on this web site because if there are interested parties, a research program of this nature could still be implemented.

PROPOSAL FOR EXPERIMENTATION WITH ARKANSAS LIGNITE TO IDENTIFY ORGANIC SOIL SUPPLEMENTS SUITABLE TO REGIONAL AGRICULTURAL NEEDS

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SUMMARY

Numerous laboratory studies have shown that humic matter has significant impact on the development of plant organisms. Optimum plant growth is obtained with combined effects of humic substances and "mineral" nutrients. The approach of combined humic and mineral nutrition in agriculture has received increasing attention in some foreign countries and to some degree in the U.S. However, understanding regarding the agronomic worth of this approach has been clouded by bad perceptions created by misrepresentation of the concept by certain sales promoters and questions of economic feasibility left by a lack of field testing.

Some cropping systems and soil fertility programs practiced in the south-central US tend to gradually deplete soils of their natural organic constituents. One striking example is in the case of rice production, where precision leveling for irrigation often strips off topsoil and exposes problematic subsoils. Yields on such cut soils may drop to a of former levels, regardless of efforts with macro- or micronutrient supplements. Yields may be restored by application of poultry wastes, but at costs that are prohibitory if transport distance is significant.

Evolving new technologies for deriving humic substances from lignite may provide products that can, either alone or possibly in combination with poultry wastes, improve and sustain productivity of organically impoverished soils. Environmental factors also add to the attractiveness of the humic products, which have been shown to increase efficiency of soil-release and plant-uptake of N and P and thus may lead to lowered risk of groundwater pollution from inorganic fertilizers, which release nutrients faster than plants can utilize them. Lignite-derived humic substances have also had success in reducing problems created by soil alkalinity, a major problem in Arkansas, a leading rice producer.

Arkansas is well suited as a potential center of manufacturing of humic agricultural products. Several billion tons of lignite occur in near-surface deposits in parts of the state that are proximal to the main farming sector of the state and of the surrounding region. Arkansas and vicinity lead the world in rice production, a potential large consumer of this kind of product. The most important factor to stimulate demand in this region would be to validate through unbiased, rigorous field testing the agricultural and economic viability of humic acids in major crops. If the lignite-based agricultural products were proven advantageous, this region could benefit from (1) mining of lignite as a feedstock, (2) manufacture and sale of the lignite-based agricultural products, and (3) improved crop yields and expanded agricultural land use in areas of problem soils. (4) If synergistic effects are obtained by combination of poultry litter with the lignite product, greater use of this industrial waste may also be stimulated.

A research program is proposed to test the agronomic efficiency of lignite-derived humic substances in rice production in Arkansas through field trials. The approach is to test humic materials that are manufactured using technology potentially suitable for utilizing Arkansas lignite. Experimental design will test a range of application rates and combinations with mineral fertilizers and poultry litter. Experiments will target normal soils, problematic cut soils, and alkaline soils. Nutrient uptake and yield increases will be monitored. Experiments will also be implemented to monitor environmental impact. Combined results will be used to determine the extent of agronomic utility and optimum application rates. If promising results are obtained, a second year's field testing would be conducted, but with materials manufactured using Arkansas lignite as feedstock to determine if similar results can be obtained. A third year of testing will document reliability. Evaluation of benefits indicated by the field trials will be combined with production cost estimates to determine the agronomic value of the humic product. Personnel involved with the field trials are specialists with experience in rice experimentation and well positioned to propagate results to the agricultural community.

PROBLEM IDENTIFICATION

Agricultural Need

General

The history of the study of plant nutrition has been discussed by Chen and Aviad (1990). For generations man has recognized that crop production in black soils (rich in organic matter) is generally much better than in other soils. Similarly, use of manures and other kinds of composted organic material for boosting soil fertility has long been a common agricultural practice. However, in the 19th century as the role of certain elements (referred to as "mineral nutrients") in plant growth began to be understood, the "humus theory" of plant nutrition began to draw less attention. By the early 20th century it was proven that soil fertility could be maintained for extended periods of time by addition of inorganic mineral fertilizers. On the other hand, during the same period other experiments demonstrated that plants grown in mineral nutrient solutions with added humic substances fared better than the same plants grown in the nutrient solutions alone. In spite of this, over time use of inorganic "mineral" fertilizers, such as the well known NPK (nitrogen, phosphorus, potassium) fertilizers, have become the pillar of agronomic nutrition throughout most of the developed world.

In spite of the greater attention given to mineral fertilizers, research into the function of organic compounds, both those naturally occurring and those derived from such sources as composted vegetable and animal matter, peat, and various types of coal has continued. The humic substances derived from the decay of living organisms are an extremely complex and heterogeneous array of organic compounds containing a manifold diversity of chemically active functional groups (Hayes and others, 1989; MacCarthy and others, 1990). Over the years, numerous laboratory studies have demonstrated conclusively that both directly and indirectly humic substances have significant impact on the development of plant organisms (Chen and Aviad, 1990).

Humic substances in the soil improve "soil structure", affecting in a positive manner the behavior of water and air in the soil. Humus also markedly increases the cation exchange capacity (CEC) of soils, which affects the ability of the soil to hold and deliver macronutrients (NPK) and micronutrients (important elements, such as Fe and Zn, that occur in small quantities in the soil and aid in plant development) to plants. Humus also tends to lessen the negative effect of certain detrimental trace elements in the soil, increase a soil's pH buffering capacity, and provide a substrate for beneficial microorganisms.

Beside these indirect effects, humic substances have been shown to play a direct role in aiding the actual transfer of macro- and micromineral nutrients into plants ("uptake"). In addition, humic substances themselves when taken into the plants (either through the root system or through the application of "foliar" sprays, that is, on growing leaves) can have beneficial effects on cell membranes, and in the synthesis of proteins and nucleic acids. In effect, the assorted organic compounds that occur in humic substances behave in certain ways like enzymes in the metabolism of plants.

These various mechanisms are apparently responsible for the positive effects that humic substances have been proven to have on plant growth by laboratory experiments (Chen and Aviad, 1990). The effects that have been demonstrated most conclusively include (1) improved rates of germination of seeds and development of seedlings, (2) enhanced root initiation and growth, and, (3) in correlation with root development, stimulation of shoot growth, especially among young plants. Tables 1 and 2, below, are presented to show the kinds of results found in numerous research papers. It should be stressed, however, that although humic substances can to a limited extent produce some of these kinds of effects when used alone, research verifies that humic substances work best in conjunction with mineral nutrients, and in fact combined applications of mineral nutrition and humic substances produce synergistic beneficial effects.Although numerous laboratory studies demonstrate the utility of organic matter in plant development, comparatively few rigorous field studies have been conducted to document the benefits of humic substances to crop yield (Brownell and others, 1987; Chen and Aviad, 1990).

With the predominant use of inorganic mineral fertilizers and comparative neglect of organic supplements over several decades, problems are beginning to be recognized. Repeated tillage and some other agricultural practices gradually deplete the soil of its natural organic component. Crop nutrition is maintained by addition of mineral fertilizers, but in some cases greater and greater amounts of such fertilizers become needed to maintain productivity. This condition not only increases production costs but also increases the potential for environmental problems connected with the use of the mineral additives. Macronutrients, especially N and P, are taken up by plants at a much slower rate than they are released from traditional chemical fertilizers, effecting a marked agronomic inefficiency and resulting in nitrate and phosphate pollution of ground water in areas of intensive agricultural activity (U.S. Department of Agriculture, 1989; Schepers and others, 1991). There is also among agronomists a growing awareness of the importance of sustainability. Not only is there the need of a sustainable supply of plant nutrition product, but in addition to giving immediate benefit to crops of a particular growing season there is also the need of a product that steadily improves the soil over time. These factors are causing a renewed attention among plant scientists to the subject of organics in plant nutrition.

Table 1. Effect of soil organic matter on seedling growth (Table 7-1 of Chen and Aviad, 1990, taken from Sladky, 1959).

			Fresh weight		Dry weight	
Treatment	**Stem length cm**	**Root lengthcm**	**Stem g**	**Roots g**	**Stem g**	**Roots g**
Control	20.9	13.1	6.4	1.6	0.52	0.05
Alcohol extract (10 mg/L)	32.4	17.0	8.9	3.3	0.62	0.09
Humic Acid (50 mg/L)	51.5	20.2	14.9	3.2	1.07	0.23
Fulvic Acid (50 mg/L)	56.8	14.0	17.5	5.4	1.60	0.24

Table 2. Indices of stimulating effects of humic acids (HAs) on green pepper growth (*given in terms of % of control*).
[Table 1 of Patti and others, 1988, taken from Petrovic and others, 1982]

Substance	Stem Length	Root Length	Stem Weight	Root Weight
Control	100	100	100	100
Has (dried at 105 1C)	152	119	142	143
Has (air oxidized, 180 1C, 6h)	134	115	133	172
Has from HNO_3 oxidized lignite	161	109	153	177

(Plants were grown in nutrient solution. Humic Acid (HA) was added to the medium in a concentration of 2 X 10^{-2} mg/ml.)

In Arkansas

Agriculture is one of Arkansas's most important industries, and its major crops are rice, cotton, soy beans, and wheat. Among these, perhaps rice and cotton suffer the most from depletion of soil organic matter. Tillage and harvesting practices return very little plant material to the soil in cotton fields, and ground leveling for irrigation in rice fields frequently strips off the organic-matter-bearing portion of the soil.

A number of factors in the germination and growth process in rice production make the various benefits attributable to humic substances especially important in that industry. Nitrogen is an important macronutrient in rice metabolism. Macronutrient fertilizers mixed with humic substances may release nutrients slower than traditional fertilizers (discussed below). A slow-release nitrogen fertilizer could be very effective because such a product may reduce or eliminate the need of some mid-season application of N fertilizer. Nitrogen is also critical for cotton, and the more balanced availability of N apparently possible with in the presence of humic acids might reduce problems that commonly occur with over- and under-fertilization.

Although acreage with normal soils in Arkansas' rice producing areas may benefit from humic acid products because of improved N-release efficiency, it is in areas of cut soils from precision leveling that the greatest potential for benefit arises. In many areas, the ground-leveling practice may strip off that part of the soil that contains natural organic matter, exposing problematic subsoils, and rendering many such soils essentially useless. Yields on such cut soils may drop to a of former levels, regardless of efforts with macro- or micronutrient supplements. Studies underway (discussed below) demonstrate that incorporation of organic matter can return soils to former usefulness in such situations.

Deficiency of the micronutrient Zn is also a common problem in rice. If the growing rice plants have not absorbed sufficient Zn by the time of flooding, they will need a supplement of Zn-EDTA by airborne foliar spray immediately. The flood may even need to be drained and soils dried to remediate the problem. Post-flooding N-fertilizer may then need to be reapplied. Since the presence of humic substances in soil solutions appears to enhance Zn-availability (Chen and Stevenson, 1986), rice plants grown in the presence of appropriate humic substances should have a better chance of accumulating adequate Zn prior to flooding. In many counties in Arkansas Zn uptake in rice is especially problematic because well water used for flooding rice fields has detrimentally high $CaCO_3$, causing high pH. The soils in these areas are generally silt loams with poor pH buffering capabilities. Under these conditions Zn is tied up as carbonate and insoluble oxides and becomes unavailable to rice plants creating chlorosis problems (Wells and others, 1973; Wells, 1980). High doses of Zn additives are recommended to solve the problem, but with generally unsatisfactory results (C.E. Wilson, Rice Specialist, SEREC, Monticello, AR, personal communication). Rectification of such problems might be possible with agricultural humic acids, based on information from Dr. Johan Dekker (Manager: Coal Conversion, CSIR, South Africa, personal communication, 1993) who said that his company's humic acid product has been evaluated in laboratory and field tests and shown to be successful in "chemical improvement of high pH soils... [improving] availability of trace elements in high pH (> 8) soils". These are not, however, published results.

A greater year-to-year consistency in production rates of rice may be possible with humic-amended soils. In general, disturbed soils may respond to a "shotgun" application of chemical fertilizers, but results are often inconsistent. Recent research indicates that especially in years with cool, wet springs rice crops commonly do not respond adequately to the application of traditional mineral fertilizers (David Miller, Dept. of Agronomy, Univ.of Arkansas, personal communication, 1993). Perhaps with the inclusion of humic substances, which have been shown to stimulate both the number and lengths of roots in young, growing plants, more uptake of nutrients may be brought about in cool weather, in spite of the slowed metabolism.

Humic Agricultural Products

In this section will be discussed those humic agricultural products pertinent to the present research topic. More attention will be given to potential products from lignite, the primary focus of this project.

Poultry Litter

Poultry litter has received attention lately as a possible source of humic substances for the Arkansas agricultural industry, especially for rice. This is because poultry litter not only has beneficial humic properties, but also it is in abundant supply through the large poultry industry of the region. Use of the waste products of the chicken industry for soil amendments in agriculture is a mutual benefit to both industries

Scientific research on the use of this material is being conducted by David Miller and others at the University of Arkansas and by scientists at the TVA National Fertilizer and Environmental Research Department. Positive responses have been documented for rice. The encouraging responses are primarily seen in rice grown on highly disturbed soils and include substantial yield increases, as well as greater consistency of crop yield (as mentioned above regarding problems with cool spring weather). However, the best results are obtained at rates of application, of about a ton/acre. These rates become uneconomical when transportation costs are factored in. Efforts are being made to understand more clearly the specific soil problems that are ameliorated by chicken litter, so as to define the circumstances in which this product will produce the most benefit.

A product from composted poultry wastes is now being marketed in Arkansas by OrganiGro, Inc. Pelletized compost sells for $150-180/ton and is commonly applied at rates of 200-300 lbs/acre. Revenues in 1992 were about $1 million and were expected to increase in 1993. The chicken litter is composted in Maysville (NW Arkansas), pelletized in eastern Oklahoma, and shipped to eastern Arkansas farms. Testimonials of rice, cotton, and soy bean farmers have indicated very positive responses (Arkansas Democrat Gazette, 1/10/93, p. G1 and G9).

Lignite and Derivative Humic Substances

If humic substance additives are to become a major factor in world agriculture, a long term abundant supply of the raw materials to produce them will be required. This is one factor that brought attention to the possibility of producing organic agricultural supplements from coal, because world coal reserves are immense. Arkansas has at least 9 billion tons of lignite reserves accessible within 150 ft of the surface (Prior and others, 1985). Lignite is a low-rank coal (essentially synonymous with "brown coal"), and low-rank coals have been recognized as being more suitable than other types of coal for production of organic agricultural products.

Research progress through the 1950s and 60s produced high expectations regarding the potential for developing, among other things, nitrogenous humic fertilizers (for example, Schwartz and others, 1965). These showed promise of the ability to release nitrogen slowly (and therefore with greater agronomic efficiency than chemical fertilizers) and at the same time rebuild humic contents of soils, contributing the other benefits associated with organic matter. However subsequent research demonstrated that in spite of substantial N contents, the N was for the most part unavailable to plants and these products were actually agriculturally inert (Berkowitz and others, 1970).

Another frustration to the development of coal-based agricultural products came from the industrial sector. Based on the promising implications of early research, some companies began production of various humic extracts from low rank coals. Products were in many cases pushed by "hustlers" with "hard sell" marketing strategies and with claims of miraculous qualities. However, apparently for the most part, these products did not deliver the claimed results. These developments led to a general mistrust of humic substance soil amendments among the scientific and agricultural community (for example, see Stevenson, 1979), and most research emphasis in the U.S. steered away to other things.

In spite of these developments, some researchers persisted with inquiry into coal as a source of organic soil treatments. Activity was primarily in foreign countries through the 70s and 80s, but some continued in the U.S. as well. Some of the more promising research advancements that indicate that agronomically useful and economically viable products from this vast resource are possible are discussed here.

1. Humic extracts from leonardite

Naturally oxidized lignite has been referred to as "leonardite". The most extensive deposits of lignite in this form are in North Dakota. This form of lignite is probably the richest in readily available humic substances and has been the most widely used raw material for extraction of humic acid by alkali solutions. One such product is Enersol, produced from leonardite by American Colloid of Chicago, Illinois. Humic products from leonardite are widely marketed, especially in foreign countries. For example, in Italy a range of humic acid formulations are available on the market, and the majority are derived from North Dakota leonardite (Patti and others, 1988). Although rigorous field trials have not been published to document either their worth or lack thereof, the acceptance of leonardite-derived products in such places by the farming community must indicate some merit to these products.

Besides the more traditional alkali extraction process, continued experimentation has led to development of other promising processes. One such process recently patented by the company Actagro of Fresno, California solubilizes the "humin" fraction of leonardite and mixes it with liquid phosphate fertilizer (John Marihart, V.P. of Actagro, personal communication). This solution is applied as an early-season soil treatment, but can also be applied as a foliar spray. The efficiency of the phosphate is greatly enhanced by this product, and it is especially useful as a "starter" because it can be applied at 2 the rate of traditional phosphate fertilizers and is safe for direct application to planted seeds. Excellent germination and early growth results are obtained. A foliar micronutrient supplement is also produced using the same humic extract.

The promising claims of "Actagro" are not just the fancies of aggressive sales personnel. Results of rigorous field trials by impartial soil scientists have been published in the scientific literature (Brownell and others, 1987; Irion and others, 1988). Replicated field trials over several years demonstrated that treatment with Actagro products improved yields over conventionally treated fields by 11-26% in various trials with tomatoes and from 8-23% in trials with cotton, most trials having yield improvements near 10%. Nonreplicated trials with a number of varieties of grapes improved yields by 25% on the average. The cotton response was attributed to improved uptake and utilization of nutrients leading to improved rooting system, earlier fruiting, and better boll retention.

2. Humic extracts from common lignite and other coals

Leonardite is naturally oxidized lignite, and natural oxidation has enhanced the humic acid content above the content in unoxidized lignite. Common lignite, in turn, has higher humic acid contents than bituminous coal. However, processes have been developed to synthetically oxidize lignite and other coals to produce biochemically active humic substances. A new process of "dry oxidative depolymerization of coal" developed by Eniricerche in Italy (Rausa and others, 1992) can convert almost any coal into a high yield of humic acids, but lignite yields a product with the highest abundance of chemically active functional groups. The process has been tested up to the stage of a pilot plant, with which reproducible results have been attained. Yield increases of 5-25% have been obtained in greenhouse tests of the oxyhumic acids on tomatoes, wheat, and maize. Laboratory experiments with this product have shown that with low application rates water penetration is improved greatly in problem soils. In other experiments, sugar beets, sorghum, and green peas treated with Fe-enriched oxyhumates showed 2- to 3-fold increases in uptake of Fe relative to commercial Fe-EDTA. Rausa and others (1992) believe that the product is also effective in delivering other micronutrients. The oxyhumates were also shown to act as a complexing agent for herbicides, reducing their solubility and decreasing their potential for pollution of ground waters.

Another relatively new process (out of South Africa) is the "oxygen/air-driven wet oxidative conversion of reactive coals" whereby humic products are obtained in high yields (85% m/m), with fulvic acids as a by-product (Dekker and others, 1990). The South African process is said to be relatively inexpensive and suitable for large scale production, and a variety of coals can be utilized, including lignite (Dekker, personal communication, 1993). A demonstration process development unit with a continuous daily coal through-put of 1.5 tons has been built. Published lab experiments have demonstrated that the "oxicoal sodium humate" produced by this process has a stimulatory effect on primary root growth on seedlings of onion, lettuce, and cantaloupe (Van de Venter and others, 1991). Further lab and field tests have shown physical improvement of compacting soils, increased micro-organism growth in soil, and improved shoot growth and crop yields (Dekker, personal communication, 1993). As discussed above, this product has also been tested in rectifying micronutrient deficiency in high-pH soils, an important problem in Arkansas rice production.

An older, yet still potentially valuable process for deriving useful humic substances involves nitric acid oxidation and ammoniation of coal (again, low-rank coal is especially suitable for this process). As discussed above, earlier attempts to develop this idea were eventually (Berkowitz and others, 1970). However, later reports indicate that through further work, nitrohumic products were subsequently obtained without the limitations of the earlier formulations (Coca and others, 1984). Various papers have been published discussing refinement of process parameters (Coca and others, 1984; Baris and Dincer, 1983; Patti and others, 1992), but it is the publication of pot and field trials of products using nitrohumic "coal acids" on several crop types (Mazumdar, 1982; Mazumdar and others, 1988) that lend the greatest credence to their potential value.

Workers at the Central Fuel Research Institute of India did extensive experimentation with nitric acid oxidation and ammoniation of coal, including construction of a pilot plant and pot and field trials with various formulations (Mazumdar, 1982). The end products in their process were designated "ammonium polycarboxylate" (AMP) and "composite ammonium polycarboxylate" (CAMP). AMP and CAMP were thought to have all the basic benefits commonly attributed to soil organic matter, such as improvement of soil aggregation, water handling properties, CEC, and microbial activity; and some of these benefits were confirmed by laboratory experiments. In addition, these products were shown to behave as slow-release nitrogen fertilizes. The rate of nitrogen release from AMP and CAMP is closer to the rate of uptake of growing plants than is the rate for common chemical fertilizes such as urea, resulting in greater agronomic efficiency. Also the coal acids were found to have residual effects in the following year after application. Table 3 shows results from some field trials comparing AMP and CAMP to urea.

Later it was found that better results could be obtained through a mixture of 10-20% CAMP with traditional chemical fertilizer (Table 4). It was also found that a substance, nitrohumic acid (NHA), that is an intermediate step in the process to make AMP/CAMP could substitute for CAMP with nearly the same results. Since it is an intermediate step, it obviously would be cheaper to produce. Then, as urea supergranules were recognized to perform in a superior manner to broadcast urea, it was also found that pelletized urea/coal-acids combination fertilizer also outperformed the broadcast combination fertilizer, and outperformed urea supergranules as well (Tables 5 and 6).

Table 3. Agronomic utility of the coal-derived fertilizers AMP/CAMP in the cultivation of several crops. Field experiments at CFRI in India (from Table 2 of Mazumdar, 1982).

Crop	Year	N-fertilizer	Input of N kg/ha	% Yield increase over urea
Paddy	1972	Urea	50	--
		Ammon. sulf.	50	36
		AMP	50	40
Onion	1963	Urea	75	--
		AMP	75	18.6
Maine (stalk)	1975	Urea	100	--
		CAMP	100	10.5
Paddy	1979	Urea	60	--
		CAMP	60	23.9

Carrot	1979	Urea	75	--
		CAMP	75	27.0
Garlic	1979	Urea	75	--
		CAMP	75	22.9

Table 4. Nitrogen utilization efficiency of combination fertilizers containing coal acids, in cultivation of paddy and wheat in rotation (CFRI, India, 1981-1982). (From Table 6 of Mazumdar, 1982).

		Paddy		Wheat (residual effect)			
Treatment	N input Kg/ha	Dry yield paddy+straw q/ha	N-uptake over control kg/ha	Dry yield wheat+straw q/ha	N-uptake over control kg/ha	Total N-uptake kg/ha	N-utilization efficiency %
Control	--	31.5	--	8.3	--	--	--
Urea	75	45.3	19.6	9.6	0.3	19.9	26.5
Urea + 20% CAMP	75	61.6	27.9	12.0	3.0	30.9	41.2
Ammon. Sulfate	75	60.9	33.4	10.6	1.7	35.1	46.8
Ammon. Sulfate + 10% CAMP	75	73.3	44.1	12.2	3.4	47.5	63.3

Table 5. Pot experiments for agronomic efficiency of urea-NHA combination fertilizer applied in loose mixture versus briquettes in the cultivation of paddy and wheat. (From Tables 3 & 4 of Mazumdar and others, 1988).

		Average yield (g/pot)		Yield increase over urea (%)	
Treatment	**Crop**	**Paddy/Wheat**	**Straw**	**Paddy/Wheat**	**Straw**
Control (no added N)	Paddy	11.0	15.0	--	--
Urea, 60 kg N/ha	"	16.5	23.0	--	--
Urea, 60 kg N/ha + 20% NHA	"	20.8	44.7	26.1	94.3
Urea briquette, 60 kg N/ha	"	21.9	43.8	32.7	90.4
Urea/NHA briquette (60 kg N/ha + 20% NHA)	"	32.0	50.6	93.9	120.0
Urea, 60 kg N/ha (control)	Wheat	7.2	4.6	--	--
Urea, 60 kg N/ha + 20% NHA	"	8.4	5.5	16.7	19.6
Urea briquette, 60 kg N/ha	"	9.7	6.1	34.7	32.6
Urea/NHA briquette (60 kg N/ha + 20% NHA)	"	9.6	6.8	33.3	47.8

Basal dressing: K_2O--50 kg/ha; P_2O_5--60 kg/ha. Weight of briquettes used: 0.63-0.75 g. Briquettes placed. 1 in deep; other fertilizer was broadcast. Paddy experiment: 7/22/86 - 10/30/86. Wheat experiment: 12/12/86 - 3/16/87.

Table 6. Field trial of urea-NHA combination fertilizer applied in loose mixture versus briquettes in the cultivation of paddy, kharif, 1987. (From Table 5 of Mazumdar and others, 1988).

	Average yield (q/ha)		Yield increase over urea (%)	
Treatment	**Paddy**	**Straw**	**Paddy**	**Straw**
Urea, 60 kg N/ha (control)	16.6	22.5	--	--
Urea, 60 kg N/ha + 20% NHA	21.7	27.5	30.7	22.2
Urea briquette, 60 kg N/ha	32.5	63.5	95.2	182.2
Urea/NHA briquette (60 kg N/ha + 20% NHA)	36.6	67.5	120.5	200.0

Basal dressing: K_2O--50 kg/ha; P_2O_5--60 kg/ha. Weight of briquettes used: 0.63-0.75 g. Briquettes placed. 1 in deep; other fertilizer was broadcast. Area of each plot: 4 m 5; 72 plants /plot. Experiment date: 8/17/87 - 12/7/87.

Mazumdar (1982) did some cost/benefit estimations that showed economic possibilities for this process. However, in consideration of this concept some others have doubted the economic potential except in the case of some specialty applications or high-selling-price crops (Patti and others, 1992; Coca and others; 1984). But one indication that suggests that wider application of nitrohumic products may be viable is the experience in Japan. For over 20 years, nitrohumic acids have been produced through nitric acid oxidation of low-rank coals and formulated for sale on the Japanese market as nitrogen and phosphate fertilizers (Heng, 1991; Rausa and others, 1992). Around 70,000 tons of nitrohumic acid products are produced yearly from imports of Australian and Russian low-rank coals. If the product can survive for 20 years on the market in a rather small country, when the raw material (lignite) must be imported from overseas, there must be substantial economic benefit relative to its cost for those who evidently continue to buy it.

The longer discussion of the humic products from this Indian process is not meant to imply that it is necessarily the most promising process for use with Arkansas lignite. It is included because more extensive agricultural field testing has been published for this product than for others. Johan Dekker of CSIR in South Africa tells me by written communication that the humic product obtained by their process gets similar and even better results than the products discussed in the Mazumdar (et al.) papers considered above. But not much of the data from testing of the South African product is published.

Perhaps the most innovative new process for enhancing and extracting the humic acid fraction of lignite has been developed by Arctech, Inc. of Chantilly, Virginia. Their humic acid product, Actosol, is derived from microbial digestion of lignite (Daman Walia, President of Arctech, personal communication, 1993). This product has been on the market for only a few years, principally in the mid-Atlantic states and in foreign countries. Its application has been in the turfgrass industry and in some vegetable crops and flowers. Arctech shows, in a promotional video tape, how vegetables grown in organic-matter-poor Saudi Arabian soils had yield increases of up to 30% when soils were treated with Actosol in greenhouse tests. Actosol has also been successfully used to promote rapid beach grass growth in order to stabilize sand dunes, an environment with very low organic content to the "soils". It is significant that not only are those "soils" very sandy, but also the environment very salty. It may be that the organic matter in some way aids in overcoming the stress from the salty chemistry.

Actosol, Enersol (mentioned above), and another commercial humate were studied by Lobartini and others (1992) and compared with humic acid from natural soil. The lignite-derived humates performed at least as well as the natural soil humic acid in enhancing shoot and root growth in corn plants. The humic acids from lignite showed properties similar to humic acid in Mollisols, the fertile soils of the U.S. corn belt. This is an important paper, because some (for example Stevenson, 1979) have questioned whether humic acids derived from coals are similar to natural soil humic acid. An almost identical percentage of increase in shoot dry weight for young corn plants was obtained (over control, which had nutrient solution only, without humic additive) with the Enersol and Actosol products. The actual total weight of biomass from Actosol was more, but that was apparently due to the Actosol experiment having been run in the summer and the Enersol in the winter.

Combination of Poultry Litter and Lignite

Derivatives. An idea well worth considering is the notion that perhaps a more effective organic soil treatment might be possible through some combination of poultry litter and derivatives of lignite discussed above. Philosophically the concept can be compared to human nutrition. The manifold biochemical processes of human metabolism require an extensive suite of organic molecules that act independently or in various combinations as enzymes, or organic catalysts. For maintaining the needed profusion of enzymatic materials, a broad-based diet is recommended. In the same way, humic substances are heterogeneous, and different suites of chemical functional groups occur in humic substances derived from different starting materials. In the native habitat of plants in undisturbed soils, naturally occurring humic substances accumulate from breakdown of materials derived from an assortment of both animal and vegetable sources. It may be that the enzymatic functions of humic substances in plant metabolism (Chen and Aviad, 1990) are best accomplished through a liberal "diet" of diverse humic substances issuing from varied sources.

Evidence that this concept might have practical application in agriculture comes from research in Germany. Rheinbraun, a large German coal corporation, in seeking to ameliorate soils in reclaimed mined land, found that a combination of dried sewage sludge and milled brown coal as a soil amendment improved vegetation growth better than either of these constituents used alone (Petzold and Kortmann, 1976). The utility of this product led to marketing it in pelletized form as "Perlhumus" to the agricultural community of Germany at large. This product is still manufactured and distributed by a company, WESKO, at a pace of about 3500 tons/year (Wolfrum, of Rheinbraun, personal communication, 1993).

Petzold and Kortmann (1976) mentioned that in place of sewage sludge other "easily decomposing" organic materials could be used. By inference, I concluded that in Arkansas a combination of the readily available chicken wastes with lignite might be a convenient alternative to sewage sludge + brown coal. Recently I have been informed that an Australian company is beginning to produce a soil amendment from chicken litter + brown coal (Brian Young, EERC, personal communication, 1993). Rheinbraun (and now WESKO) used low rank coal in simply a ground form, and perhaps that is the approach of the Australian company. However, it may be that chicken litter combined with humic acids derived from lignite, as from the various technologies discussed above, could make an even better soil amendment than a formulation using untreated lignite. I have been informed by Dr. K.H. Tan (Dept. of Agronomy, Univ. of Georgia, personal communication, Dec. 1993) that he is reviewing a report on application of lignite-derived humic acid (Enersol) in rice growing in the Philippines and that the experimentation included some combinations with poultry litter. He considered the information proprietary and therefore could not supply details, but he said that the results of the field tests looked impressive. Representatives at American Colloid, the supplier of the Enersol used in the experimentation, have been very cooperative and have forwarded my request for information on to the scientist conducting the experiments, but as yet I have no specifics on the results.

RESEARCH GOALS AND GENERAL APPROACH

It seems evident from the above discussion that there exists a distinct possibility for increased economic development in Arkansas (and surrounding region) because of several factors that come together at this time and place. Arkansas has extensive reserves of essentially untapped lignite resources in the south-central and eastern parts of the state. New technologies have been and are being developed that can utilize lignite to produce humic agricultural products that are being increasingly recognized as effective in many applications. Arkansas, and the surrounding region, is a major center of U.S. agriculture, and therefore a potential major consumer for the agricultural products. If the lignite-based agricultural products can be proven to have significant, economical applicability to crops in this region, the economy could benefit from (1) mining of lignite as a raw material, (2) manufacture and sale of the lignite-based agricultural products, and (3) improved crop yields and expanded agricultural land use in areas of problem soils. (4) If synergistic effects are obtained by combination of poultry litter with the lignite product, greater use of this industrial waste may also be stimulated.

The research plan to provide an impetus to stimulate development of Arkansas-based manufacturing of such products pivots upon the need of field testing of the humic acid products with crops that are potential large consumers of the products, in order to demonstrate their agricultural and economic worth. We should stress that in the scientific literature there is no lack of lab tests demonstrating that humic substances are beneficial to plants, but what is lacking is field testing (Chen and Aviad, 1990). Humic substances are beneficial in general, but which formulations are suitable for major crops in this area? Just how suitable are they? How much benefit and how much cost should growers actually expect? A few scientifically rigorous field tests are published, but most of what we know about the likelihood of economic viability of this line of products comes from extrapolation from lab data, from apparent increasing market success of these products in certain areas of the world, from recognizing that some foreign governments and some companies are investing money into research to develop technology for these products, and from promotions from producers of the lignite products themselves. If humic agricultural products from lignite can indeed significantly improve agriculture in this region, still use of these materials will never take hold at anything other than a very slow pace if there is not the backing of the scientific community (for example, through county extension agents who give recommendations to farmers). Field testing would be the major factor that would convince the experts that advise the growers. Thus field testing could provide the stimulus needed to create the demand for this kind of product in this region.

The basic research plan is summarized here; details are provided below. In agricultural experimentation it is important to demonstrate consistency by field testing through more than one growing season, preferably three. In the first year, a humic acid product or products fabricated by a process (or processes) amenable to using Arkansas lignite as a feedstock would be field tested in rice growing. The product(s) tested in this first year would be the product as it is presently being manufactured, and application rates in the tests would be guided by the manufacturer (but still a range of rates tested in order to establish optimum for this crop, climate, soil, etc.). A preliminary evaluation of economic viability of the product(s) would be made based on the agronomic behavior of the product(s) and on the retail cost of the product (s). If first year results are promising, a second year of field testing would be conducted, but this time with the same products manufactured using Arkansas lignite as feedstock. A required volume of Arkansas lignite would be extracted and sent to be processed in existing facilities in order to determine the yield and quality of end product that can be obtained. Lignite process response, agricultural field testing, and mining/reclamation cost estimates would be combined to obtain a better evaluation of the economic viability of the product as it would be if manufactured in Arkansas. A third round of field testing would be used to prove dependability and to refine understanding of growth mechanisms, so that advisors to the agricultural community can correctly prescribe the use of the product. Results of the field testing would be published by presentations at professional meetings and in scientific literature where appropriate; but, more important to aiding commercial development, they would also be published in fact sheets and popular journals read by agriculture extension agents and growers in the region. If the humic product proves beneficial to agriculture through rigorous scientific field testing, its use would be promoted by unbiased specialists by way of recommendation, rather than by sales promotion alone.

The basic design of the field experimentation is described below. However, determining how many and which humic acid products to test will be influenced by which products are probably amenable to using Arkansas lignite as feedstock and by the funding source for this project.

Of the processes developed for making humic agricultural materials, only some are likely to be viable with Arkansas lignite. Straight alkali extraction of humic acids seems to be best suited for naturally oxidized lignite, leonardite, because of leonardite's much higher natural humic acid content. The process used to make the product "Actagro", discussed above, also works best with leonardite according to John Marihart, V.P. of the company that makes it. The nitric acid oxidation processes, both the one discussed in the Mazumdar articles above and the similar process used in Japan, work well with common lignites. The "dry" air/oxidation process developed in Italy and the "wet" air/oxygen oxidation process in South Africa also are well disposed to the use of common lignites as a feedstock. Kurt Knudson, a Principal Research Scientist (in coal process chemistry) at the Energy and Environmental Research Center at the University of North Dakota, says (personal communication, 1993) that of these three chemical approaches (the Indian, Italian, and South African), the Indian process would be significantly more expensive than the other two. The microbial digestion process used by Arctech to make Actosol is also suitable for using lignite (Daman Walia, personal communication), and Arctech has successfully tested Texas lignite in their process (Texas lignite occurs in the same geologic formations as does Arkansas lignite). Therefore, of the technologies I am aware of, the most likely ones to be successful with Arkansas lignite are the "Arctech" process, the "Italian" process, and the "South African" process. All these are patented, and I have no way to say which would be the "cheapest" to produce, nor is there sufficient data available to indicate which would be the most suitable agriculturally or work best with Arkansas lignite.

I am assuming in this preliminary proposal that there are several possible funding sources from potentially interested parties. These would include federal and state funding programs that have a goal of promoting agricultural development and/or industrial development. Also growers associations that want to promote developments advantageous to their crop industry might support this research. Other "players" might be companies that now produce humic acid products from other deposits that would be interested in expanding to this region if the demand for the product were to be generated. Alternatively other companies, perhaps already in the agricultural chemicals business, but not "humic" products, might want to expand into this arena, given a viable market for the products. Or a company with holdings of lignite properties that could be developed if this research is fruitful might want to support the research. Then again, it is possible that some combination of these interested parties might jointly support the research.

Perhaps an ideal case scientifically would be a program in which two or three of the most promising technologies for humic acid products from lignite were tested in order to ascertain the one with the best cost/benefit capabilities. If there is a difference in the agronomic potential of the products from the different processes, that difference would be quantitatively established. Also if Arkansas lignite responded differently to the different processes, information regarding product yield per unit of input lignite could be compared. The combined effects of the responses of the lignite to the various processes and the agronomic efficiencies of the end products would establish which process is most economically effective for the situation in this region. This information being made available to potential manufacturers would give decision makers the best intelligence to guide them in establishing production here. To accomplish this research plan, however, would multiply the cost by the number of processes/products to be tested. This would probably be the course of choice if the research were to be supported by neutral parties and if sufficient funds were available.

If the proposed research were to be supported largely by a company that has an established process, then the application of the experimentation would be solely with one targeted humic product. If it were to be supported by a potential manufacturer not holding a patented process, and limited funds were available, still one process would likely be targeted. This would be done with an understanding that the company could eventually lease the process from the patent holder or form some kind of partnership or other business arrangement. Some other arrangements of partnerships or other agreements might be possible between potential manufacturers, process patent holders, land owners, mining companies, and potential distributors of the products, and the disposition of such agreements would effect which product or products would be targeted in this research proposal.

We have chosen rice growing for agricultural experimentation with the humic acid products. Rice is the largest agricultural industry in Arkansas and the surrounding region, and this region leads the world in rice production. Not only does the size of this industry make it a large potential user of the product, but the problems in rice production discussed above seem suited to this kind of product based on available information. The research that has been done already into the amelioration of the problems in rice production also provides a good basis of comparison with the results to be obtained with the lignite-based products.

What is described next is the basic research procedure based on the testing of one lignite-derived humic product. The same basic procedure would be carried out in multiple if more than one product is evaluated.

RESEARCH METHODS

Rice field testing: Experimental design

Two basic experiments will be initiated to evaluate the influence of applications of a humic acid product derived from lignite on rice growth, nutrient uptake, fertilizer requirements, and grain yields. The experimentation will be described for liquid humic product, such as Actosol. Modification for granular product, such as the one from CSIR of South Africa, would only be minor. The experiments will be conducted on typical rice soils in southeast Arkansas at the University of Arkansas Southeast Branch Experiment Station (SEBES) near Rohwer, Ark., on a clay and a silt loam soil, and on a soil that has a history of reduced productivity due to precision-grading. The effects of combinations with poultry litter will also be evaluated. Rice will be seeded into 9-row plots on 6-inch spacing and 15 feet long. If liquid humic acid product is used, it and herbicides will be applied with a backpack CO_2 sprayer.

The first experiment will compare the effects of the humic acid product, poultry litter, and phosphorous (P) on rice growth. The latter two have already been shown to have effect on rice growth in local problem soils. This experiment will determine which product used alone, or which combination of products, produces the optimum improvement of soil fertility, and the extent of benefit. Macronutrient fertilizers will also be applied with these supplements at rates commonly used in rice growth.The experiment will be arranged in a factorial randomized complete block design with four replications. Four rates of the humic acid product (0-10 gal/A), five rates of poultry litter (0-2000 lbs/A), and four rates of P (0-40 lbs P/A) will be utilized. This design will provide a statistical comparison of a complete range of combinations of these materials, as well as the materials used alone in varying proportion. The experiment will be conducted on two soils at SEBES that do not have a history of reduced production and on a producer's field that has been precision graded. The use of these different soil substrates will indicate not only if problem soils can be remediated, but also if these products can increase yield on normal soils.

The second experiment will evaluate the effects of the humic acid product on N fertilizer management of rice. Nitrogen is the most important macronutrient in rice growth, and research discussed above suggests that total N use might be reducible in the presence of humic substances. The experiment will be arranged in a split plot design with four replications. The main plot will be 14 rates of N fertilizer (0-180 lbs N/A) applied in three-way split applications. The sub-plot will be two rates of the humic acid product. The experiment will be conducted at SEBES on two different soils. The N fertilizer will be applied either as a liquid form or as granular urea. The liquid humic acid fertilizer material will be applied with a backpack CO_2 sprayer. This design will establish curves by which exact fertilizer requirements can be determined for rice without humic additive and with humic additive.

For both field experiments, plant samples will be collected from 1 m of row at mid-tillering, panicle differentiation, heading, and 21 days following heading to monitor seasonal nutrient uptake patterns with respect to the soil amendments. Nutrients to be measured include N, P, K, Ca, Mg, S, Fe, Cu, Zn, and Mn. Also, water pH and EC will be monitored with portable meters when the plant samples are collected. Grain yields will be measured at maturity. The study will be conducted for three years.

Greenhouse studies will also be established to measure the possibility of utilizing the lignite product as an acidification product for use on alkaline soils. This study is with reference to Zn deficiency problems discussed above. Soils that have been limed such that the pH exceeds 7.5 will be utilized in the study. Rice will be grown and harvested 14 days after flooding. The treatments will include applications of lignite-based humic product, poultry litter, Zn, and P in various combinations. The plants will be analyzed for total dry matter and total nutrient uptake including N, P, and Zn.

To evaluate environmental impact from use of the product, additional studies will be implemented to evaluate the nutrient load of rice irrigation water resulting from applications of the lignite material. Irrigation water run off can be an environmental problem in rice growing areas. Microplots (0.58 m^2) will be established utilizing galvanized steel collars that are driven into the soil 15 cm. Applications of the humic acid product at rates of 0-10 gal/A and poultry litter at rates of 0-2000 lbs/A will be made. Water samples will be collected following the first flush irrigation and then weekly after the permanent flood is established. Electrical conductivity (EC) and pH of the water will be monitored weekly. The water samples will be analyzed for NH_4-N, NO_3-N, PO_4-P, total N, total P, and metals (Ca, Mg, Na, K, Fe, Cu, Mn, Zn, Co, Pb).

Sampling of Arkansas lignite

In the second year of field testing we want to do the agricultural experiments with humic acid product obtained from Arkansas lignite. A number of localities occur where lignite is close to the surface, so obtaining sample with a back hoe should be possible (Ben Clardy, Arkansas Geological Commission, personal communication). Owners of lignite properties have shown willingness to cooperate in verbal communications.

Testing Arkansas lignite in humic acid derivation technology

For each product to be tested we will want to see how well Arkansas lignite responds to the process from which the product is manufactured. I have contacted Arctech, Inc. (makers of Actosol), CSIR (the organization with the patented process in South Africa), and Eniricerche (the company with the Italian patent) regarding their willingness to run Arkansas lignite through their system, if funds become available for using their product in this research. Arctech has shown willingness to cooperate, but I have not yet heard from the other two at the time of this writing.

To run a batch of Arkansas lignite through the Arctech process would require some preliminary laboratory testing to determine optimum process parameters. Running the lignite would then tie up their equipment and personnel for a period of time. There would also be additional lab tests to determine product yield and characterize the byproducts as to humic acid content, etc. The budget discussed below for this part of the overall research is based on an estimated total 200 man/hours, which includes laboratory and equipment use.

PROJECT PERSONNEL

Project Coordinator:

Dr. Stephen W. Kline, Research Scientist
Arkansas Mining and Mineral Resources Research Institute

Arkansas Tech University, Russellville, AR 72801

Dr. Kline is a Geologist and has authored or co-authored 21 research papers on subjects in geology, mining and mineral deposits, and environmental geology.

Dr. Kline conceived the idea of this project while researching alternative uses of lignite. His role, besides general administration of the project, is to obtain a sample of Arkansas lignite and ship it to the company or companies whose humic acid product and technology is/are being used, so that the lignite can be analyzed and processed for second and third year agricultural testing. He will communicate with the principal investigator regarding progress of the project and will conduct research in comparing results with other published results. He will also handle some of the dissemination of information from project results, including preparation of progress reports and final reports.

Principal Investigator:

Dr. Charles E. Wilson, Jr., Research Assistant Professor
University of Arkansas, Southeast Research and Extension Center
Monticello, AR 71656

Dr. Wilson is Extension Rice Specialist for the SEREC with a Ph.D. in Chemistry of Soil Fertility. His area of specialization is assessment and development of management strategies to increase rice production on problem soils through the investigation of the chemistry of irrigation water, fertilizer materials, and flooded soils. He has authored and co-authored six refereed papers in national journals and regional educational and service publications on subjects of rice nutrition.

Dr. Wilson's contribution to the project will include design and implementation of all agronomic experimentation with the lignite derivatives and poultry wastes. A research assistant will perform most of the analyses and student hourly workers will be employed to tend to growing plants and to prepare plant samples for analysis. Dr. Wilson will evaluate the results of these experiments to make assessment of the agronomic effectiveness of the products. Dissemination of information to the agricultural community will be primarily the responsibility of Dr. Wilson as well.

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