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9. ABSTRACT

A project to determine the extent to which agricultural technology developed under high levels of management in tropical regions (Hawaii, for example) can be transformed to developing countries whose crop yields are low. This effort is based on the knowledge that with proper technology yields can often be doubled or tripled without soil deterioration. This project does not assume that technology transfer can be made in a single step. Rather, it plans to apply modern technology to soils similar to those in Hawaii or Puerto Rico. Selection will include some countries in Africa, Southern and Eastern Asia and Latin America. Probable crops: corn, upland rice or sorghum, yams or cassava. Objective: to develop applications of technology suitable to local soils and to establish crop yield bench marks which local governments can use in demonstrations and other socio-economic means for introducing improved methods to the local population.

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CROP PRODUCTION AND LAND CAPABILITIES OF A NETWORK OF TROPICAL SOIL FAMILIES-- A DESCRIPTION OF THE UH/UPR/AID BENCHMARK SOILS RESEARCH PROJECTS

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INTRODUCTION

From most authoritative sources in recent years it has been firmly stated that major emphasis must be given to increasing productivity per unit of land if the world food needs are to be met. Through research and extension, the temperate regions of the world have achieved high productivity in agriculture. The Green Revolutions in wheat and rice in Mexico, India, Pakistan, and the rice bowls of Asia give clear indication that such advances are also possible in the tropics. What is most needed is a clear indication of the regions in tropical countries where it is possible to concentrate immediate food production efforts. Throughout tropical Asia, Africa and Latin America, crop yields on the upland soils that will be the focus of this experiment are very low. Existing national knowledge, therefore, is no guide to the true potential of these soils. Thus, if it can be shown that profitable crop yields can result--yields two or three times greater than are presently thought possible--without consequent soil deterioration, a modern agricultural system can be developed without the necessity of 50 years of experimentation and extension.

The high yields resulting from extensive soil management in Hawaii on

tropical soils are based upon current practice in relation to sugar, coffee, sorghum, fruits, vegetables and tuber crop production, and upon 70 years of continuous agricultural research by the H.A.E.S. and the research stations of the sugarcane and pineapple industries. We need to find ways to transfer these results to other tropical regions. The purposes of these projects are to correlate food crop yields on a network of benchmark tropical soils, and to determine scientifically the transferability of agroproduction technology among tropical countries, and particularly from Hawaii and Puerto Rico to tropical developing countries.

The projects are central to the need for improved information on the management of tropical soils and water, a major current interest of the Agency for International Development. For the most part, temperate countries have made great progress in developing their soil resources. But the majority of the world's underprivileged people live in the tropics, and the soils of the tropics have so far proved difficult for most people to manage.

The magnitude of the problems of managing tropical soils was documented by the UN Conference on the Application of Science and Technology for the Benefit of the Less-Developed Areas(Vol. 3, Chap. 2, Geneva, 1963). More recently Aubert and Tavernier in Soils of the Humid Tropics (1972), a review undertaken by the National Research Council for AID, concluded: "In equatorial regions...basic agricultural experimental work is lacking for adequately predicting soils behavior."

Only when countries in the tropics have gained an appreciation of the potential of their soils under different levels of management will it be possible for them to plan both (a) to insure basic food and protein supplies and (b) to promote the production of exportable crops. But at present, in most tropical countries, research efforts related to basic food and protein

supplies are aimed at a low level of soil management with consequent high food prices and occasional food shortages. Under these conditions, lacking the information and perspective necessary, it is not possible to create the progressive rural structure and the modern agriculture that Mosher (1969) proposed in Creating a Rural Progressive Structure (Agricultural Development Council, N.Y.).

The benchmark soils that are to be the bases of the research network will belong to related soil families as defined by the new U.S. Soil Taxonomy. This Taxonomy, essentially completed in 1971, has as its major purpose the establishment of relationships among soils and between soils and their natural and cultural environments. Through proper use of the classification, predictions can be made about soil behavior from the relations of soils for which we lack experience, to soils on which we have conducted research or have experience.

This system of soil taxonomy has been developed over the last 22 years by the Soil Conservation Service of the USDA with active cooperation of the Land-Grant Colleges and soil scientists in foreign countries. It is by far the most comprehensive, precise and most nearly logical system of soil classification yet developed.

The fifth level of subdivision in the system is the soil family. Dr. Charles E. Kellogg, while Deputy Administrator for Soil Survey of the Soil Conservation Service, described the significance of soil families (Kellogg, 1964). He pointed out that many characteristics that can be related to plant growth and to engineering were related to the soil family subdivisions, and, in consequence, the soil family provides the link between soil classification and land capability groupings. Soils in the same family should have essentially the same management practices. Therefore, it is

essential to classify soils in different lands into their common families in order to make reasonably direct transfers of agricultural know-how, or, conversely, when soils have been classified into their common families, it should be possible to use the maximum production results of one soil as production targets for all soils in the same family.

Existing knowledge about the use of the soil family for technology transfer has been established in the continental United States and in Hawaii through cooperative work of the Soil Conservation Service of the USDA and the State Agricultural Experiment Station. De Ment, et al. (1971), critically examined the family classification system to see how well it has worked within the continental United States. In the abstract of their report they state, "In general, crop suitability correlates well within classes at the family level. Yields for short-season crops can be reliably predicted, particularly if soil slope and erosion phases are used. Yield predictions are less reliable for long-season crops that are subjected to moisture stress during parts of the growing-season." The authors suggest that some classes of soil moisture stress during the growing season should be used in family criteria.

Experience has shown that agricultural technology developed for temperate zone soils is not directly transferable to the tropics. But evidence has not yet been obtained to determine the extent to which agricultural technology developed under high levels of management in tropical regions can be transferred. Recent progress in soil classification related to questions of transfer of technology and research in Hawaii give considerable hope that this can be done.

For example, for short season crops, yields and cost of production of head cabbage and lettuce on the Kula and Waimea soil series, two soils in

the medial isothermic family of Typic Eustrandepts on different islands of the Hawaiian chain are very similar. For longer season crops, yields of sugarcane, pineapple, papaya, and pasture production on soils in the same family are listed as being equal by the SCS in their forthcoming reports on the soils of the State of Hawaii.

The success of the soil taxonomy system at the family level in many U.S. soils and within the limited testing that has been possible in tropical and subtropical Hawaii suggests that it can be used to transfer agricultural technology between soils in many tropical regions. Thus, the present high-level of agricultural technology developed in Hawaii for crops such as sugar (0.53 tons sugar per acre per month), pineapple (3T/A/Mo), papaya (2.5T/A/Mo), sorghum dry grain (1.0T/A/Mo), maize dry grain (1.1T/A/Mo) and beef production (83 lb/A/Mo) can be translated to the less-developed countries.

In making this assertion it is fully realized that the translation can only be made initially in terms of production targets. Many problems, social and economic as well as technical, will need to be solved before production targets become production realities. But this correspondence of soils will show what soils should be developed first, what comparative advantages exist, and what direction the countries should take in their development plans. It may also determine on what soils in Hawaii and Puerto Rico future research should be concentrated to provide the greatest benefit for the less-developed countries.

Although soil families have not yet been fully classified in tropical Asia, Africa or America, soil survey and characterization has progressed far enough in the countries indicated as possible participants that the selection of benchmark soils in soil families common with Hawaii and Puerto Rico should not be too difficult. One example of transference of Hawaii

soil management practices based on soil classification criteria, is response of sugarcane to soluble silicates in Humic Ferruginous Latosols in Mauritius following the earlier response to silicates on these soils in Hawaii (Plunkett, 1972).

The most likely countries in which the right soils will be found are Ethiopia, Zaire, Tanzania or Kenya in Africa; Sri Lanka, Indonesia, India (Kerala or Mysore), the Philippines (Mindanao) or Vietnam (the Central Highlands) in Asia; and Colombia, Peru, Venezuela or Brazil in Latin America.

Two crops will be grown at each station in the network in a series of linked-parallel experiments. The most probable crops will be a cereal, either corn, upland rice or sorghum, and a root crop, either cassava or yam. Yields and other output criteria will be correlated among the stations and in relation to land potentials and capabilities in the countries of the network.

The projects will establish by their findings the factors that must be taken into account in order to make the soil family level work in the tropics as it does in the temperate zone, as the classification level to be used in the transfer of agricultural knowledge from place to place.

In later phases of the projects and in concert with related AID research contracts and with national and international research institutions, the research network of benchmark soils will be extended to other areas in the above countries and to other countries in the tropical regions of the world. Because the crops used in the experiments will be of local importance --but probably of improved genetic stock--government agencies will be able to use the experiments for demonstration purposes in local development and to prepare for the creation of local village organizational structures to maintain long-term benefits from the work carried out.

SPECIFIC OBJECTIVES

1. University of Hawaii Project
   a. To correlate crop yields to land potential and capability on a network of upland tropical soils.
   b. To establish by experimentation and demonstration the transferability of agricultural technology between Hawaii and other tropical regions and among those regions.
2. University of Puerto Rico
   a. To correlate crop yield to soil parameters on a network of red upland soils of the tropics.
   b. To establish by experimentation the transferability of agricultural technology among tropical countries.
   c. To demonstrate the agricultural potential of tropical red upland soils in LDCs of Latin America.

DESIGN OF EXPERIMENTS

1. Selection of Soils

A comparative study of soil and climatic maps at scales around 1:5,000,000 will be used to delineate probable areas of interest. The resources of the Universities' holdings on tropical soils, the AID (211-d) Consortium on Tropical Soils, the World Soil Geography Unit of the USDA, and the FAO/UNESCO Soil Map of the World will be used to provide the information needed.

Detailed soil investigations will need to be conducted in the field to obtain the information necessary to classify soils and to determine if the soil areas meet the criteria that will be used to determine their suitability

for linked-parallel experiments on crop production.

Hawaii and Puerto Rico have one family of Tropeptic Eutrorthox and one family of Orthoxic Tropohumults in common. When these families occur in other regions they will be used. Otherwise other closely related soils will be used which have families in two or more of the locations of the network. In general, it is expected that the work will be concentrated in families of Andepts and Oxisols which are well represented and used for intensive agriculture in Hawaii.

2. Crop and Soil Management Experiments

The experimental designs to be used will be in part determined by the results of this workshop.

The objectives of the experiments will be:

a. To determine the potential productivity of soils under high management input.

b. To develop optimum management systems for multiple cropping.

c. To determine optimum plant population for various crops under local soil and climatic conditions.

The potential productivity of soils at each location will be determined with an N x P x K experiment to allow correlation with soil parameters and evaluation of transferability of agricultural technology. The aim is to attain maximum or near-maximum production with appropriate levels of these nutrients under optimum management conditions, i.e., adequate irrigation, calcium (pH), plant protection (weed, disease and insect control), and plant population.

3. Land Capabilities

The soils data, soil characteristics, yield data and related climatological data will be processed by methods of multivariate analysis to produce the desired land potential, capabilities and transferability information. Local yield data and land capability information where it exists will probably be included in the data base to increase the chances of making yield predictions at various levels of the soil classification to cover a larger group of soils than will be represented by the benchmark soil network.

Where similar soil indexes of production capabilities are determined by analysis, the information will be directly translated through the soil linkage as a first approximation to production targets for these soils where they occur in other tropical and subtropical lands.

CONTRIBUTIONS TO INSTITUTION BUILDING

The projects are proposing a creative approach to the development of modern agriculture in tropical countries. They will need to work closely with national research institutions to change in part their orientation and targets and retrain some of their staff, depending upon where the stations are established. The projects propose to work through the strengths of national institutions. Included in the proposals are funds enough to provide fellowships for staff members of these institutions to undertake training courses and graduate degree courses at the two Universities.

The seminars, workshops and meetings that will be part of these projects will also contribute to training institutional counterparts and national field staff of the project.

The projects will give participating countries a basis for understanding

and exploring the potential of their soils for crop production. They should lead to increased soil-based research in national institutions as they seek similar information for soil families not included in the project studies.

The two Universities will be strengthened by the project. Their staffs will gain a greater insight into the problems of tropical countries and will gain in knowledge and understanding through their contacts with other research scientists. Their store of research information will be increased by the experiments conducted.

The authors of The Soil Taxonomy of the USDA recognize its probable inadequacies in the classification of tropical soils. Referring to the Oxisols, soils central to the objectives of this project, the Taxonomy states, "The classification of Oxisols...seems to produce satisfactory groupings of the...soils in Hawaii and Puerto Rico. It needs to be tested more widely... and is far from completion." Soil scientists in tropical countries have recognized the value of the Taxonomy by using it to the extent that their limited analytical data will allow. The U.S. Soil Conservation Service and the use of the Soil Taxonomy in tropical countries should benefit substantially from the findings of this project.

DISSEMINATION AND APPLICATION OF THE RESULTS

It is expected that the projects will demonstrate that the transition from traditional to modern intensive agriculture can be made efficiently and with a minimum of error by means of technology transfer from the developed to the less developed regions of the tropics. It should also show that management systems implemented in one soil in one region can be transferred to the same soil in any other region.

This transferability of existing agricultural knowledge will be demonstrated on an international network of benchmark soils families. Preliminary results will also demonstrate transferability of knowledge for several in-country sites related to the international network.

The land capability schemes developed for the countries of the network should be able to indicate suitabilities of different regions for development under high, medium, or low levels of input and the probabilities for the success of information transfer from the network. This information will be available for incorporation into the 5-year development plans of the cooperating nations, and the project personnel will work to involve national planners in the project from its early stages, and include them in the training seminars and workshops.

Corn, sorghum or upland rice and cassava or yam will be cultivated continuously for three years. Two years of data will be obtained on other crops. Yields from the experimental plots are likely to be two to six times greater than those obtained by farmers cultivating similar soils and using traditional agricultural practices.

Bird and rodent damage in addition to disease, insect and weed infestation, will seriously limit yields in the control plot. The projects will therefore have strong visual impact and will also supply scientific data related to locally important crops.

Strict management control of the projects will be required in order to obtain highly profitable yields in upland areas. It is hoped that AID Missions and local and national institutions will assist in organizing farmer field days and other local training sessions that will be associated with the project. Governmental willingness to support farmers who have been psychologically prepared to make the change will be necessary in order to ensure basic

food supplies.

Fellowships will be offered to students from host countries with leadership potential. They will receive academic training at the Universities and field experience on the experimental site in their home country. Those students working on thesis research in their home countries can help local farmers incorporate the newer methods into their social and cultural framework.

Training seminars for the project staff will be held in years 1,2,4 and 5. These will provide training on soil families and classification, experimental design and crop management, and on interpretation of the project results by the staff. Project workshops will also be held to acquaint appropriate officials of cooperating countries and AID staff members with the purposes and benefits of the project, and the meaning of the results as they are obtained. These workshops will also be used to obtain important input into the project from individuals and to maintain their involvement to a high degree.

RELATION TO INDIGENOUS AND INTERNATIONAL INSTITUTIONS

When the stations of the network have been decided upon, arrangements will be made with indigenous institutions to assist and advise the projects. The willingness of such institutions to play such a role will be an important criteria in determining where stations will be.

The projects will draw directly on past and current research on crop and soil management by the Hawaii and Puerto Rico Agricultural Experiment Stations. It should be able to draw also on the expertise of the AID/University (211-d) Consortium on Tropical Soils, which includes Cornell University, North Carolina State University, Prairie View Agricultural and Mechanical University, and the

Universities of Hawaii and Puerto Rico.

For suitable crop varieties the project will cooperate with IRRI, ITTA, WARDA, CIMMYT, IFAT, and other research institutions that can provide the required information. For assistance in soil selection the project will cooperate with national soil survey institutions, the Soil Conservation Service of the USDA, ORSTOM, INEAC, and FAO.

Cooperative arrangements with other AID-sponsored projects working in similar regions or similar fields, is expected to be achieved through AID. We are hopeful that the AID-sponsored research by Cornell and North Carolina State that deals with soil fertility assessments and crop production in Latin America will help us with advice and information, and perhaps set up cooperative experiments on suitable benchmark soils in their regions of work.

The work in Africa will be closely coordinated with IITA which has on its staff several individuals who have worked in H.A.E.S. and obtained graduate training in the College of Tropical Agriculture of the University of Hawaii. The soil management program and orientation of IITA can be extended to other areas of Africa through such coordination.

Belgian scientists at INEAC and the Universities of Louvvain and Ghent, who have had considerable experience with soils of the type to be included in this project are also being consulted and included as cooperators when suitable arrangements can be made.

It is to be expected that the work in Asia will be coordinated with the new crop management extension program of the International Rice Research Institute. A proposal has recently been developed and has been approved in principle to conduct a major seminar on the relevance of modern soil and land classifications to the development of tropical soils with joint sponsorship by the Hawaii project and ICRISAT. The seminar would be held at ICRISAT in

December 1975.

The work in Latin America will be coordinated with CIAT, CIMMYT and ICCA through the University of Puerto Rico.

FUTURE PLANS

Data for additional crops will be obtained at the stations of the research network. New stations on additional soil families will be established in the countries of the network to extend the usefulness of the results and test the validity of the land capability schemes more adequately.

First priority for extension of the projects to new locations will be given to regions with high agricultural potential in which a breakdown of the traditional agricultural system appears imminent. The transfer of technology will be linked to a strong farmer training program. The host country in turn must give assurance that a permanent support program which gives farmers access to fertilizer, chemicals and seeds will be established. Transfer of agrotechnology is only a necessary first step in agricultural development.

Second priority should be given to sparsely populated regions with high potential for development. Between the humid and arid regions there is a large segment of the tropics in which continuous cropping is restricted by low rainfall during three to six months of the year. Introduction of agrotechnology to these areas will give government planners the information which is needed to plan for water resource development and proper use of the soil resources.

Thirdly, the transferability of technology should be tested in regions of medium to low potential, where shifting agriculture will continue to be

practiced for many more generations. Introduction of agrotechnology to these areas will serve as a means to prepare the people for exposure to the outside world.

The projects, therefore, should have both visual impact in and technical value to the participating countries.

The experience and knowledge gained from this project will:

1. remain in the host country to create a progressive rural structure, and
2. be extended to other tropical regions with immediate and future growth potential.

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LITERATURE REVIEW

Temperate legume studies began more than 70 years ago, but the knowledge of tropical legumes is a more recent one. Tropical countries depend heavily upon legumes as the less expensive and most feasible source of protein for their livestock and will continue doing so in the future.

Importance of Tropical Legumes

Legumes in association with grasses may increase forage production, nutritive value of pastures, soil nitrogen and animal output per unit area.

Yates, Russell and Fergus (1971) comparing the effects of *Medicago sativa*, *Glycine wightii* and *Macroptilium atropurpureum* on *Sorghum almum* reported that the tropical legumes yielded more than alfalfa and were also associated with greater yields in a subtropical environment.

One of the disadvantages of most tropical grasses is the rapid decrease in nutritive value and intake through aging. This shortcoming may be prevented by using legumes in the mixtures. Milford (1960) found that tropical legumes had higher digestible crude protein

percentage than grasses and also that the nitrogen balance for the legumes is mainly positive whereas that for the grasses is mainly negative. Milford and Minson (1966) suggest that two of the most recommended legumes for mixtures with tropical grasses are Glycine wightii and Macroptilium atropurpureum cv Siratro. The reason for this is because the 250-day old legume regrowths have a higher crude protein (CP) percentage than the 60-day old grasses regrowths. The same authors (1967) added that voluntary intake is increased when legumes are incorporated into the pastures.

In fall and winter in South-eastern Queensland the CP content of grasses drops usually below 7%, so intake is reduced as a consequence of the low level of protein in the grasses. Milford (1967) indicates that Desmodium uncinatum might be used to prevent the fall in intake because this specie has a higher retention of leaves when compared with some other tropical legumes like Phaseolus lathyroides and Vigna vexillata. Jones (1969) compared the in vitro digestibility of Siratro and Desmodium intortum at 4, 8, and 16 weeks of age and concluded that Desmodium intortum had significantly lower organic matter digestibility (IVOMD) than Siratro independent of age. Both legumes showed a very slight fall in digestibility over time, particularly that of the stem, where normally occurs the greatest drop in

grasses. Also, digestibility of Siratro at 4 weeks regrowth was comparable to that of alfalfa at the same age.

Henzell (1966) recorded increases of N in the soil under a Desmodium uncinatum cover at 2 to 6 inches in depth. The low C: N ratio was consistent with the composition of the legume leaves which are suggested to be the active agent in the increase of the soil N content. The estimated accumulation of N under Desmodium uncinatum was 112 pounds per acre. Kretschmer (1966) in Florida, estimates that Siratro can contribute to the soil from about 50-125 pounds N/acre per year.

Establishment

This term has not yet been clearly defined. All the interpretations are quite arbitrary. Harriot (1958) makes some distinctions between "seedling establishment", "young establishment" and "final establishment". The former being considered the period of time from sowing to 4-8 weeks, "young establishment" from seedling stage up to the end of the seedling year and the latter up to the end of the first harvest year.

Normally the term "establishment" is believed to mean the period of time that passes from germination to early vegetative growths, as implicity given by

Northwood and MaCarney (1969) and Motoona et al (1967).

Some factors known to affect establishment are seed, soil, seed-bed, time of sowing and sowing technique.

Seed

Two characteristics of the seed seem to be closely related to legume establishment: seed size and dormancy due to impermeability of seed coats or hardseededness. Williams (1956) pointed out that the emergence force exerted by emerging seedlings of Crimson clover (*Trifolium incarnatum*), Subterranean clover (*Trifolium subterraneum*) and alfalfa (*Medicago sativa*) is highly and directly correlated with seed weight and also germination is quicker for the heavier seeds. Black (1959) indicates that large seeded species are able to emerge from greater depths than small seeded ones and postulates that there is more hardseededness in small seeds than in the large seeds within a single specie except in alfalfa where large size of the seed was associated with an abnormal condition. He concluded that the importance of the seed size lies in the direct relationship between seed size and the cotyledon area, so that the larger the seed the greater the photosynthetic area formed. Whiteman (1968) added that in tropical legumes the early positive correlation between the weight of plant tops and mean seed weight, at seedling

stage is no longer maintained and changes with time. Quinlivan (1971) stated that dormancy due to hardseededness is of great importance in countries with semiarid environments because pastures are based mainly on annual legumes. He suggested that the low relative humidity is the principal cause of hardseededness and also that impermeability of the seed coat is a varietal character which can be manipulated in breeding programs.

Time of Sowing. Temperature

Temperature requirements for tropical legumes are higher than for temperates but a little lower than for some tropical grasses. Whiteman (1968) studied the effect of temperature on the vegetative growth of *Glycine wightii* cv Tinaroo, *Desmodium uncinatum*, *D. intortum*, *D. sandwicense*, *Phaseolus lathyroides* and *Macroptilium atropurpureum* and concluded that growth of all species was severely impaired at the lowest temperature ranges compared, 15/10° C and 18/13° C, day/night. No one species stood out as being better adapted to low temperature; all species had a marked response in growth to increasing temperature between 18/13° C and 27/22° C; the combined data indicate that the optimum temperature for growth lies about 30/25 ± 3° C. The same author decided that above 33/28° C growth rates declined particularly in Desmodium species. Suttie (1968) confirmed the findings by Whiteman and suggested that the upper

limit of altitude for Desmodium is 5000 feet, in the tropics, which roughly corresponds to a mean temperature of 20° C. Jones (1969) investigating the effect of frosting in the first winter after sowing on morality of some tropical grasses and legumes determined that the percentage of survival of Siratro is 83%, Desmodium uncinatum is 56%, D. intortum is 36% and Lotononis angolensis is 46%.

Bryan, Sharpe and Haydock (1971) observed that in the winter even though Lotononis bainesii remained green, growth was not resumed until mean weekly temperature was 9° C. Bryan (1972) in two separate experiments with Lotononis bainesii under simulated winter conditions suggested that all parts of the plant continued growth in the frost room at -1° C at a steady rate up to 28 days of repeated frostings but when the plants were cut back to 2 cm above the soil before frosting regrowth was very slow. He concluded that root and nodules were unaffected in either experiment and the reduction of growth was due to partial defoliation rather than low temperature. Bryan, Sharpe and Haydock (1971) reported that among meterological factors, the most important for Lotononis bainesii are radiation and day length.

Sowing Technique

Calma, Valera and Santos (1959) planted Desmodium intortum

at several densities and observed that the closer the spacing the higher the yield and also that spacing had little effect on the chemical composition of plant tops. Middleton (1970) studied the effect of 3 sowing rates of Siratro and Desmodium intortum in Setaria at 2 sowing rates in a complete factorial. He decided that in every case the number of seedlings of Desmodium intortum was greater than for Siratro but the latter was more competitive; emergence of Siratro and Desmodium intortum seedlings were rapid with no additional increase in plant population after the 14th day; seedling densities increased in proportion to sowing rate and no seedling mortality was reported because of the low sowing densities utilized.

Response to Fertilizers

Calcium. Ca: Mn Relationship

Tropical legumes are more efficient than temperate legumes in extracting calcium from the soil, which indicates that this characteristic is due to better ability in Ca uptake rather than lower requirements. Andrew and Norris (1961) agreed with the preceding statement and added that liming increases the yield of temperate legumes greatly but has little effect on the growth of many tropical legumes. Kretschmer (1966) reported that Siratro, in Florida, responded to 1 ton lime/acre.

Truong, Wilson and Andrew (1971), investigating the effects of Ca, P and Mo levels in the substrate on Mn toxicity in four tropical legumes, observed that high lime application reduced Mn concentration in the root of only two species and lowered Mn content in the shoot of all four. He concluded that Mn distribution rather than absorption was affected at varying levels of calcium and also that the increase in yield observed sometimes after liming is not due to less P fixed but to less Mn toxicity. Henzell (1967) indicates that tropical legumes are sensitive to Mn toxicity and Glycine javanica, Phaseolus lathyroides and Siratro are more sensitive than white clover.

Phosphorus. P: Al Relationship

Genetic differences between legumes have been discovered with regards to phosphorus uptake. Henzell (1967) reported that Stylosanthes humilis and Lotononis bainesii are very efficient at extracting soil phosphate. Andrew and Norris (1969) investigated the role of P on the growth and chemical composition of 9 tropical legumes and alfalfa in both pot and field experiments on two different soils. The mean critical percentage of P at preflowering stage, was 0.24% for Siratro, 0.17% for Lotononis bainesii and 0.22% for Desmodium intortum, determined according to the method described by May, whereas the mean value for alfalfa was 0.24%.

Truong, Wilson and Andrew (1971) reported that application of P reduced the absorption of Mn and thus acted in a different fashion than lime. The same authors suggested that the responses obtained from lime application may be due to the effect of P in precipitating soluble Al in both the soil and the plant. McLeod and Jackson (1965) determined that a concentration of ionic Al of 0.5 ppm restricts the growth of temperate legume seedlings while 1.5-2.0 ppm will prohibit root growth almost completely. Henzell (1967) indicates that tolerance of Glycine javanica to ionic Al is similar to that of white clover.

Potassium

Andrew and Robins (1969) studied the effect of this element on the growth and chemical composition of 8 tropical and 4 temperate legumes sampled at preflowering stage. The critical percentages determined accord- to the May method were 0.72% for Desmodium intortum, 0.9% for Lotononis bainesii, 0.75% for Siratro and 1.2% for alfalfa.

Effect of Plant Competition

Very few papers in the literature have been devoted to a study of the effects of plant competition

on sown species. The lack of knowledge is most acute when talking about pastures. Black (1960) studied interspecific competition on the establishment of mixtures of red clover and alfalfa by planting pure stands of each from 50 to 12500 plants/m^2 and mixtures of all the combinations of 50, 250, 1250 and 6250 plants/m^2 in boxes maintained on the open after sowing. He concluded that interspecific competition had been operative and resulted in a small increase in clover yield and a considerable decrease in alfalfa yield. Donald (1951) observed that density, stage of growth and nutrient supply affected intraspecific competition among annual pastures and decided that in population of relatively low density no competition existed at any stage of growth. Calma, Valera and Santos (1959) reported no seedling mortality in Desmodium intortum at low sowing densities. Middleton (1970) confirmed the observation of the preceding authors and added that competition and subsequent high seedling mortality can occur quickly after emerging where high seedling densities exist.

Response Surfaces in Agricultural Experiments

There is a trend in modern agricultural research to use response surface designs to study a larger number of variables at a time. Still some limitations exist especially with respect to interpretation of the data that restrict in some way the use of these designs.

The study of simple first and second order response surfaces from factorial experiments has been known since the 1920's after the introduction by Fisher and Yates of factorial designs. Box and Wilson (1951) introduced new types of designs to fit a quadratic model which they designated as "composite designs". Box (1954) after several years of experimentation in the chemical field, described some modifications in the designs and produced the central composite and non-central composite designs. Box and Hunter (1957) having known that one of the limitations of response surface designs was the unequal variance through the experimental region, developed the concept of rotatability to reduce this shortcoming. Cochran and Cox (1957) give some plans for central composite second order response designs for four to six variables using complete factorial, fractional factorial and incomplete blocks as the basic design. Box et al (1954) gives detailed analyses for response surface designs with examples.

Most of the use of response surfaces designs has been on the industrial and chemical fields where the experimental error is quite small, the experiments can be performed sequentially and may be repeated under almost identical conditions. For these reasons, most of the papers cited by Hill and Hunter (1966) in their extensive literature survey belong to those fields.

Controversy concerning the convenience and the use of these designs exist in the literature. When 3 or more factors at several levels are to be studied, the number of treatment combinations for a complete factorial or even a fractional factorial is so large that many times it becomes physically impractical to conduct the experiment, as suggested by Anderson and Dillon (1969). Williams and Baker (1968) indicated that the coefficient of variation in agricultural experiments in Eastern Australia ranges from 5-50% being the highest for tropical pasture-legume mixtures. They also concluded that since "noise" is greater towards the corners than in the center, because of the replications of the central point, most central composite designs are unsuitable for studying fertilizer response.

Colwell and Stackhouse (1970) indicate that the problems commonly encountered when studying simultaneously 3 or more element requirements, can be attributed to the combined effect of experimental error and inappropriate choice of fertilizer treatment levels. Some rules are given to reduce those problems.

Evaluation of Establishment

There are several methods used to study botanical composition. Among them, actual counts of the number of plants, calculation of the density and percentage of total population are the most used. Normally,

sampling in the field is done either by means of quadrats or transects.

Brown (1954) reviewed the methods to perform botanical analysis and estimate productivity in natural vegetation and some of them are useful for studies of planted grassland. Considerations about sampling theory are given. Tothill and Peterson (1962) stated that counting methods are most conveniently applied to studies of early developmental stages of seedlings and permanent quadrats are useful in obtaining records of changes in the flora over time. Thilenius (1966) describes a new sampling device which actually has two quadrats in one frame and can be easily assembled in the field.

Description of Species used

Desmodium intortum cv Greenleaf (Mill.) Urb.

This cultivar was derived from a mixture of 3 introductions from El Salvador and Guatemala in Central America. Hutton (1968) indicates that this specie is hardier and more vigorous than D. uncinatum but it is slower to become established. Harding (1972) estimated that Desmodium intortum usually grows well in the first season but rapidly deteriorates due to leaf fungal diseases and legume little leaf virus. Rotar (1965), Hutton and Coote (1966) postulated that low palatability of Desmodium intortum is associated with high content

of tannins. Motooka et al (1967) reported that seedlings of this specie are quite sensitive to dehydration and intense sunlight in Hawaii.

Lotononis bainesii cv Miles Baker

A complete description of this cultivar is given by Bryan (1961). It was introduced to Australia from Africa. It is a slender procumbent, stoloniferous, herbaceous perennial, irregularly branched and quite glabrous. Leaves are digitately trifoliate and are born in groups of 3 to 5 at the nodes. It is known that Lotononis bainesii is the most frost resistant of the tropical legumes as suggested by Bryan, Sharpe and Haydock (1971). For some time it did not become well appreciated in Australia as a pasture legume until Norris (1958) isolated the specific Rhizobium. Hutton (1968) points out that Miles lotononis is highly compatible with pangolagrass on the Wallum in Australia.

Macroptilium atropurpureum cv Siratro

Siratro was developed at the Cunnigham Laboratory to replace Phaseolus lathyroides. Hutton (1962) describes the way he crossed the two Mexican strains that gave origin to the first 3 selections of Siratro. It is a perennial short-day plant with trailing stems of medium thickness. It has a cleistogamous habit so that

it has a high degree of homozygosity. At least 25% of the seeds in a freshly harvested sample are dormant; scarification and soaking in a 1% aqueous solution of thiourea for 16 hours can be used to overcome dormancy. Whyle et al (1953) indicates that Rhizobium specificity is very low. Sonoda, Kretschmer and Brolman (1971) reported the incidence of the disease Web-blight (Rhizoctonia Solani Kuhn) which causes strong defoliation in Florida and observed that cutting seems to retard the disease. Hudgens (Hudgens, R. E. 1973. The compatibility, persistence, and nutritive value of grass-legume associations in the wet-dry tropics of Coastal Ecuador. M.S. Thesis. University of Florida, Gainesville) decided that the fungal disease caused by Cylindrocladim spp, in Equador, caused severe damage to Siratro and the disease was associated with high rainfall and high humidity. However, regrowths appeared to be unaffected. Sands et al (1970) reported that in the preliminary selection of pasture plants for semi-arid areas of Kenya, Siratro, Dolichos argentius and Stylosanthes guyanensis showed some promise in mixtures with Cenchrus Ciliaris, Chloris gayana and Panicum maximum.

MATERIALS AND METHODS

Very little is known about the effect of fertilizers at the early establishment stage on tropical legumes. There is also lack of knowledge about the reliability of using more than one legume simultaneously in a pasture, as it is normally accepted in temperate regions.

Factors Studied

A. 1. Legume species: 3 total species

2. Legume-species treatments: 7

B. Fertilization: P and K at 0,100,200,300 and 400 Kg/ha, trace minerals (TM) at 0, 10,20,30 and 40 Kg/ha

Factors Levels

A. 1. Legume species:

Desmodium intortum (Mill.) Urb.	Greenleaf desmodium
Lotononis bainesii Baker	Miles lotononis
Macroptilium atropurpureum	Siratro

2. Legume-species treatments: (complete factorial)

A. 2. Legume-species treatments:
(complete factorial)

	Coded Values		
	desmodium	lotononis	Siratro
Desmodium alone (D)	1	0	0
Lotononis alone (L)	0	1	0
Siratro alone (S)	0	0	1
Desmodium + lotononis (DL)	1	1	0
Desmodium + Siratro	1	0	1
Lotononis + Siratro (LS)	0	1	1
Desmodium + lotononis + Siratro (DLS)	1	1	1

B. Fertilizer treatments
(Central composite design)

Treatment no.	Kg/ha P (X_1)	Kg/ha K (X_2)	Kg/ha TM (X_3)	Coded values P (X_1)	Coded values K (X_2)	Coded values TM (X_3)
1	100	100	10	-1	-1	-1
2	300	100	10	1	-1	-1
3	100	300	10	-1	1	-1
4	100	100	30	-1	-1	1
5	300	300	10	1	1	-1
6	300	100	30	1	-1	1
7	100	300	30	-1	1	1
8	300	300	30	1	1	1
9	0	200	20	-2	0	0
10	400	200	20	2	0	0
11	200	0	20	0	-2	0
12	200	400	20	0	2	0
13	200	200	0	0	0	-2
14	200	200	40	0	0	2
15	200	200	20	0	0	0
16	200	200	20	0	0	0
17	200	200	20	0	0	0
18	200	200	20	0	0	0
19	200	200	20	0	0	0
20	200	200	20	0	0	0

Experimental Procedure

Site

A 2000 m^2 experimental site at the Beef Research Unit owned by the University of Florida was selected on July 1973 on the basis of uniform topography, accesibility and proximity to the forage area being developed for a grazing trial. The selected area had been planted in corn as previous crop and at the time of selection was a partially invaded by Digitarias and Cynodons. Visual differences in weed population, moisture and soil color indicated the possibility of differences in fertility between two major sections of the selected area.

Soil samples were taken and the results for each soil confirmed the assumption made:

			lbs/acre			
		pH	CaO	MgO	P_2O_5	K_2O
Soil A	Sample 1	6.2	1521	113	24	83
Soil A	Sample 2	6.2	1903	124	30	56
Soil B	Sample 1	6.1	921	68	6	28
Soil B	Sample 2	5.9	741	85	4	35

Soil A was consistently higher in calcium, magnesium, phosphorus and potassium than soil B.

Land Preparation

At the end of July 1973, the sod on the experimental site was disked. One month later, after emergence of many weeds the area was again disked prior to seeding time to control some grasses already present. On September 1 the plots were marked and the area was ready to be planted.

Planting and Fertilization

These operations were accomplished by using a two-wheel spreader which could be pulled by tractor or by hand. In this case it was pulled by hand because of the small plots. Two days were spent cleaning and calibrating the Gandy spreader (Trade Mark) using cracked corn as dummy load to give volume to seeds and fertilizers The "Gandy" was calibrated to sow various proportions of the corn-legumes mixtures depending upon the seed size of each species. The same procedure was used to calibrate the machine for the fertilizers application.

The spreader which had been calibrated already was checked in the field immediately prior to seeding. Extra amounts of the corn-legume mixtures were prepared and placed into the machine in order to have a small leftover of seeds in the machine to prevent the underseeding of the last plots.

After seeding, the fertilizer was applied. Care

was taken to put excess fertilizer-corn mixtures into the machine to achieve the most uniform dressing possible.

After the fertilizers were applied, the area was hand raked lightly to cover the seed and fertilizer with soil. One week was spent planting and applying the fertilizer to the experiment.

Sowing densities utilized: Desmodium was seeded at 6 Kg/ha; lotononis, 2 Kg/ha and Siratro, 10 Kg/ha. The densities used are about double those recommended for planting commercial pure stands of each legume.

Sources of nutrients used: Triple superphosphate (42% P_2O_5) was used as a source of phosphorus; for potassium, potassium chloride (60% K_2O), and for trace minerals, Frit 503 (Ferro micronutrient) commercial product.*

*Frit 503. Composition: N, 0; P, 0; K, 0; B, 3.0; Cu, 3.0; Fe, 18.0; Mn, 7.5; Mo, 0.2 and Zn, 7%.

Observations

Establishment of the legumes was evaluated as seedling counts on September 30, October 15 and November 10. Counts were made with a $1m^2$ counting frame made of wood and divided into four quarters by wires stretched across the frame. The seedlings in two quarters were counted each time to get an estimate of the sampling error because the experimental error is generated from the central points of the central composite design.

The frame was thrown at random on each plot at the first count only. The two quarters with the most uniform visual population of seedlings were chosen thereafter to remain the same in order to be able to evaluate the changes in legume population over time. Two stakes were placed at two predetermined corners of the frame to know exactly the position of the chosen quarters at each count.

At the time of the counts, legume seedlings were conspicuous so, no problem was encountered in differentiating the legumes. The seedlings of each were counted separately and recorded separately.

The area per plot was $2 \times 3 = 6\ m^2$ with an utilizable area of $1m^2$. A border of 0.5 m was discarded from the countings.

Statistical Analysis

Effect of Fertilizers.

Original data from the seedling counts 0.25 m^{-2} of all plots were keypunched on IBM computer cards. The two observations per plot were pooled and converted to seedlings m^{-2}. This generated variable was analyzed using the Regression Procedure of Statistical Analysis System (SAS) designed by Barr and Goodnight (1972). One analysis was performed for each soil on the basis of individual species within legume combinations and counts.

The first print out from the computer was the 72 regression equations with the standard statistics indicated in the SAS manual. The estimations of the pure error from the response surface design are not included into the standard print out so, the values of the experimental error generated from the 6 central points (5 df) were calculated directly from the computer output on a desk calculator for each regression equation, according to the method described by Cochran and Cox (1957). The lack of fit sum of squares (5 df) were calculated by difference, subtracting the error sum of squares from the residual sum of squares, which are given by the computer. In this way, it was possible to calculate the F ratio lack of fit/pure error for

each prediction equation, with n_1 = 5 df and n_2 = 5 df.

Calculation of Optimum Combinations of P, K and Trace Minerals

Partial derivatives from each prediction equation in function of X_1 (phosphorus), X_2 (potassium) and X_3 (trace minerals) were taken and equalized to zero. This produced a set of 3 equations with 3 unknowns which is equivalent to a 3 x 3 matrix. The matrices were solved by using again the Regression Procedure of SAS with the no intercept option (NOINT). The values thus obtained were the optimum amounts of P, K and trace minerals in Kg/ha.

Contour Plotting

To better visualize the response surfaces of seedlings m^{-2} as functions of P, K and trace minerals (TM), it was decided to plot the contours for certain fertilizer combinations. Since contours can be plotted in just two dimensions, there was a need to fix the least significant variable for each soil at a level close to the optimum calculated in order to have reduced equations in two variables instead of the original three independent variables.

For soil A the least significant effect was obtained with phosphorus and for soil B, it was obtained with

trace minerals (TM). The calculated optimum of P and TM for soil A and B respectively were close to the zero level so, P was fixed at 200 Kg/ha on soil A and TM was fixed at 20 Kg/ha on soil B.

The coefficients of each reduced equation were keypunched and processed using the Contour Plotting Procedure of SAS.

Changes in Population Over Time and Comparison of Species

Overall means for each specie association at each count were analyzed as a factorial experiment. Values of the sum of squares of single degrees of freedom for the comparisons of the two and three-species mixtures against the check (desmodium, lotononis or Siratro alone) were computed. The analysis of variance were performed manually using the method described by Cochran and Cox (1957).

RESULTS AND DISCUSSION

Three legumes, Desmodium intortum, Macroptilium atropurpureum and Lotononis bainesii were each seeded alone and in all possible combinations with the other legumes making a total of seven species treatments. Fertilizer treatments including five levels each of P, K and trace minerals in a central composite design were imposed upon each of the species treatments on two different soils. The parameter measured in the field was number of seedlings m^{-2} and the observed results are presented in tables 1 to 14 in the appendix. The equations for the response to fertilizers generated from the central composite design were computed according to Box (1954). The analyses of variance, regression coefficients and significance probabilities for Student "t" test are given in tables 15D to 20SDL in the appendix.

The regression coefficients are used in the equations which describe the response surfaces for number of seedlings m^{-2}. For example, if we consider desmodium in the combination D of the soil A, the equation for number of seedlings m^{-2} in the first count, as a function of phosphorus, potassium and trace minerals applied, is

$$Y = 6.15909 - 0.28420X_1 + 0.73580X_2 - 0.31705X_3 + 0.00077X_1^2 - 0.0016X_2^2 - 0.02364X_3^2 - 0.00072X_1X_2 + 0.00975X_1X_3 + 0.00325X_2X_3$$

where X_1, X_2 and X_3 are phosphorus, potassium and trace minerals applied to the soil at the time of planting.

Results will be discussed for each soil separately on the basis of:

1. Effect of fertilizer on number of seedlings m^{-2} for individual species
2. Changes in population of individual species over time when planted alone and in combination with some other species
3. Comparison of species

Effect of P, K and trace minerals on number of seedlings m^{-2} of individual species

Soil A

In general, for this soil, there was no unique response but rather some trends. Potassium gave consistently the best results probably due to high leaching loses of this element which might occur from heavy rainfall on these sandy soils. The potassium added might have been quickly incorporated into the pool of the soil and thus, some response was observed. The response to the addition of trace minerals was somewhat lower than for

potassium; this indicates the good adaptation of the tropical legumes studied to a wide range of nutrient content in the soil. Phosphorus did not show a sustained good response probably due to the fact that the pH of this particular soil was not low enough to fix P and also some residual P may be present in the soil from previous crops.

Desmodium intortum cv Greenleaf desmodium

For desmodium, when planted alone, fertilization with potassium increased the number of seedlings m^{-2} as summarized in table 15D. But when planted in combination with lotononis no response was obtained (see table 15 DL In combination with Siratro, desmodium showed a response to K at the 0.01 level on the last two counts which seems to indicate that some potassium was still available two months after planting (table 15 DS). Trace minerals produced an increase in number of seedlings m^{-2} in the first count, but the effect was progressively reduced thereafter due to high seedling mortality as will be discussed later.

In the desmodium-lotononis-Siratro combination, the only response to phosphorus shown by desmodium was obtained in the first count, as indicated in table 15 DLS Potassium gave some response but decreased over time which is in agreement with the preceding observation.

As expected, because of the significance of the main effects, the interaction KxTM was more important than PxK or PxTM.

Lotononis bainesii cv Miles lotononis

For lotononis, when planted as a single component, non-significant effects of P, K and trace minerals were found but K produced a better response than P or TM, as show in table 16 L. This is probably due to the slow establishment of lotononis even though persistance was acceptable. When planted in combination with desmodium, lotononis again gave non-significant main effects, probably because desmodium had so many seedlings that the establishment of lotononis was impaired. Quantitative data are summarized in table 16 LD. In the lotononis-Siratro mixture, K increased the number of seedlings m^{-2} of lotononis at the 9% level as can be seen in Table 16 LS. As a part of the lotononis-desmodium-Siratro mixture, positive results were obtained for lotononis as a response to potassium in the first two counts but not at the third. The explanation for this is that at the third count the large number of desmodium seedlings and the shading effect from the vigorous development of Siratro plants did not allow additional lotononis seedlings to develop. Also, warm and moist weather did not allow lotononis to compete favorably with the associated legumes. Data are found in table 16 LDS.

Macroptilium atropurpureum cv Siratro

Siratro, when planted alone or in combination with desmodium, lotononis or both did not present significant differences between treatments as shown in tables 17 S, 17 SD, 17 SL, and 17 SDL. This specie seems to be very well adapted to the soil and climate at the experimental site. During the establishment period at the time of the experiment, the response of Siratro to fertility treatments was minimal.

Soil B

The chemical characteristics of soil B were somewhat different than those of soil A. The pH was lower, levels of P, Ca and K were also lower. The response to P addition was greater than in soil A. Perhaps there is some phosphorus fixation in this soil. Some response was obtained from K addition but on a reduced scale. Even lower was the response to trace minerals.

Desmodium intortum cv Greenleaf desmodium

Desmodium, when planted alone showed significant responses to P, K and trace minerals in the first two counts but not at the same level of significance; data are presented in table 18D. At the time of the third count some seedlings might have been coming up but the high rate of mortality masked the effect, if any, of the fertilizer treatments. When planted as a component of

the desmodium-lotononis mixture (table 18 DL) no main treatment effect was detected, because the seedling mortality affected more than seed germination the number of seedlings. Generally, the losses were of the order of 50% of initial population.

Desmodium, when planted in combination with Siratro had low seedling counts from the beginning (table 18 DS). Several treatments had zero number of seedlings throughout the experiment, probably because the seedlings were dying as rapidly as they emerged. At the time of the counts no live seedlings were found. More detailed information is present in table 5 (appendix).

Lotononis bainesii cv Miles lotononis

This specie, when planted alone showed a negative response to P, K and trace minerals in the third count. At that time the reduction in seedling population was obtained probably due to lack of vigor of this specie according to the data in table 19L.

In the lotononis-desmodium mixture, lotononis had a very low number of seedlings from the first count. In the second count a significant reduction due to P was found, as indicated in table 19 LD. The explanation for this is that even though the population of desmodium was reduced a great deal, the desmodium seedlings emerged faster than lotononis seedlings which did not allow a good lotononis establishment. Weather conditions also were not favorable for lotononis. Table 19LS shows

quantitative data for lotononis when planted together with Siratro. The analysis of variance of this table indicates that the F derived by testing the lack of fit against the error is much greater than 1 which means that a second degree equation does not adequately fit this particular data but there appears to be no biological reason by which a higher degree polynomial should give a better fit.

If we consider lotononis as a member of the lotononis-desmodium-Siratro mixture, no significant response was detected but K gave better results than P and TM.

Macroptilium atropurpureum cv Siratro

Siratro establishment, as in soil A, did not respond to additions of P, K and trace minerals. Tables 20S, 20 SD, 20 SL, and 20SDL present data to support this conclusion. When Siratro was planted in combination with lotononis an increase due to P was obtained in the first and second count. This might be due to the fact that lotononis, under favorable conditions, cannot compete with Siratro. In the third count no response was found probably because there were some adult Siratro plants that inhibited the germination of Siratro seeds.

Plotting the contours

The response surface for seedlings m^{-2} is best visualized with the aid of contours which are lines formed by points of same number of seedlings m^{-2}. A

complete presentation of all the 72 response surfaces does not appear appropriate but a few examples are given for the effect of K and trace minerals on selected species on soil A and for the effect of P and K on selected species on soil B.

For soil A, the contours were constructed by substituting the value of X_1 = o level (200Kg/ha P) the fitted equations in order to obtain reduced equations in terms of X_2 (potassium) and X_3 (trace minerals). Potassium and trace minerals were chosen because they largely represent the most important main effects and interactions. The middle level of phosphorus was selected because this level is close to the values of calculated optimum P levels for maximum number of seedlings m^{-2}.

For soil B, the contours were constructed by substituting the value of X_2 = 0 level (20 Kg/ha trace minerals) in the prediction equations in order to obtain reduced equations in terms of X_1 (phosphorus) and X_2 (potassium). Phosphorus and potassium gave the most significant effects, so trace minerals (TM) was fixed at a level close to the values of optimum TM.

Another reason to choose the zero level of the fertilizers is that greater accuracy is expected at the replicated center points of the design.

The contours of predicted number of seedlings m^{-2} for desmodium when planted alone, soil A, first count are presented in figure 1. The contours describe a true

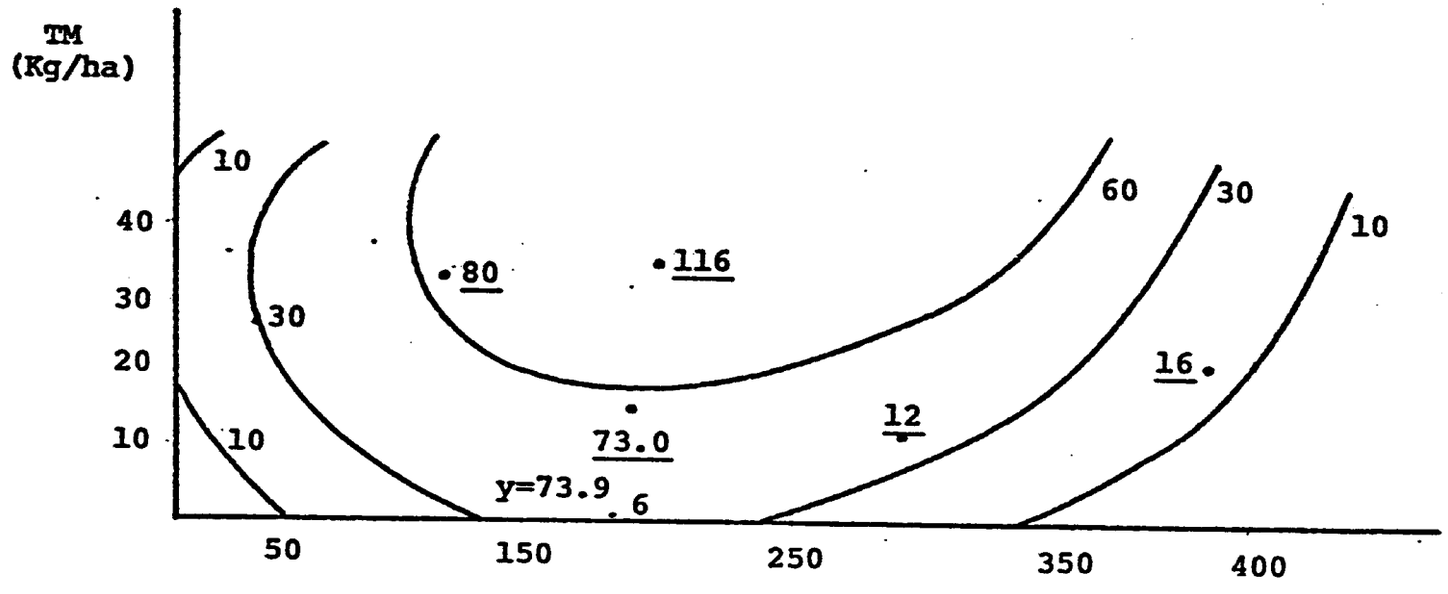


Figure 1.
Contours of seedlings m^{-2} of desmodium when seeded alone on soil A at the first count, as affected by additions of potassium and trace minerals (TM) and the middle level of phosphorus.

maximum; an observed value of 116 seedlings m^{-2} is at the center of the contours. The lines of the contours are not fully closed because they represent only the experimental region. The mean of the observed values at the 6 central points of the design is not in complete agreement with the contours because of the high variability in number of seedlings m^{-2} between the central points (see table 1).

Contours of the response of lotononis, as a component of the lotononis-desmodium mixture on soil A, first count are plotted in figure 2. The observed values at the center of the design are correctly localized inside the contours. The shapes of the contours appear to suggest the existence of some complementary effect between potassium and trace minerals.

Figure 3 represents the contours of the response of Siratro in a mixture of Siratro and desmodium. The contour lines increase in one direction. Response is greater when high levels of potassium are combined with high levels of trace minerals. Substitution is not as efficient as it was in figure 2 above.

In soil B, contours of the response to P and K at zero level of trace minerals (20 Kg TM/ha) for desmodium alone, third count are presented in figure 4. Complementary effects between P and K rather than substitution is the pattern.

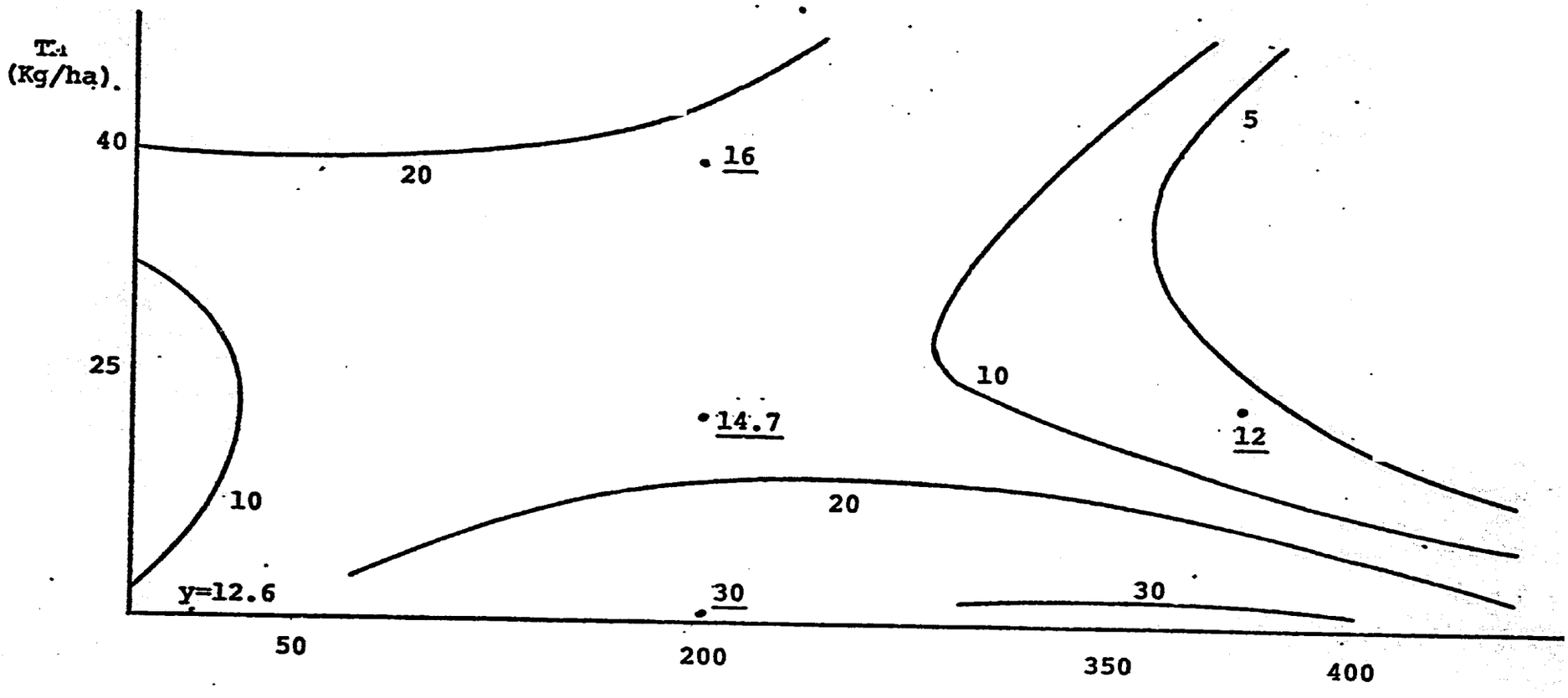


Figure 2.

Contours of seedlings m^{-2} of lotononis when grown in combination with desmodium on soil A at the first count, as affected by additions of potassium and trace minerals (TM) and the middle level of phosphorus

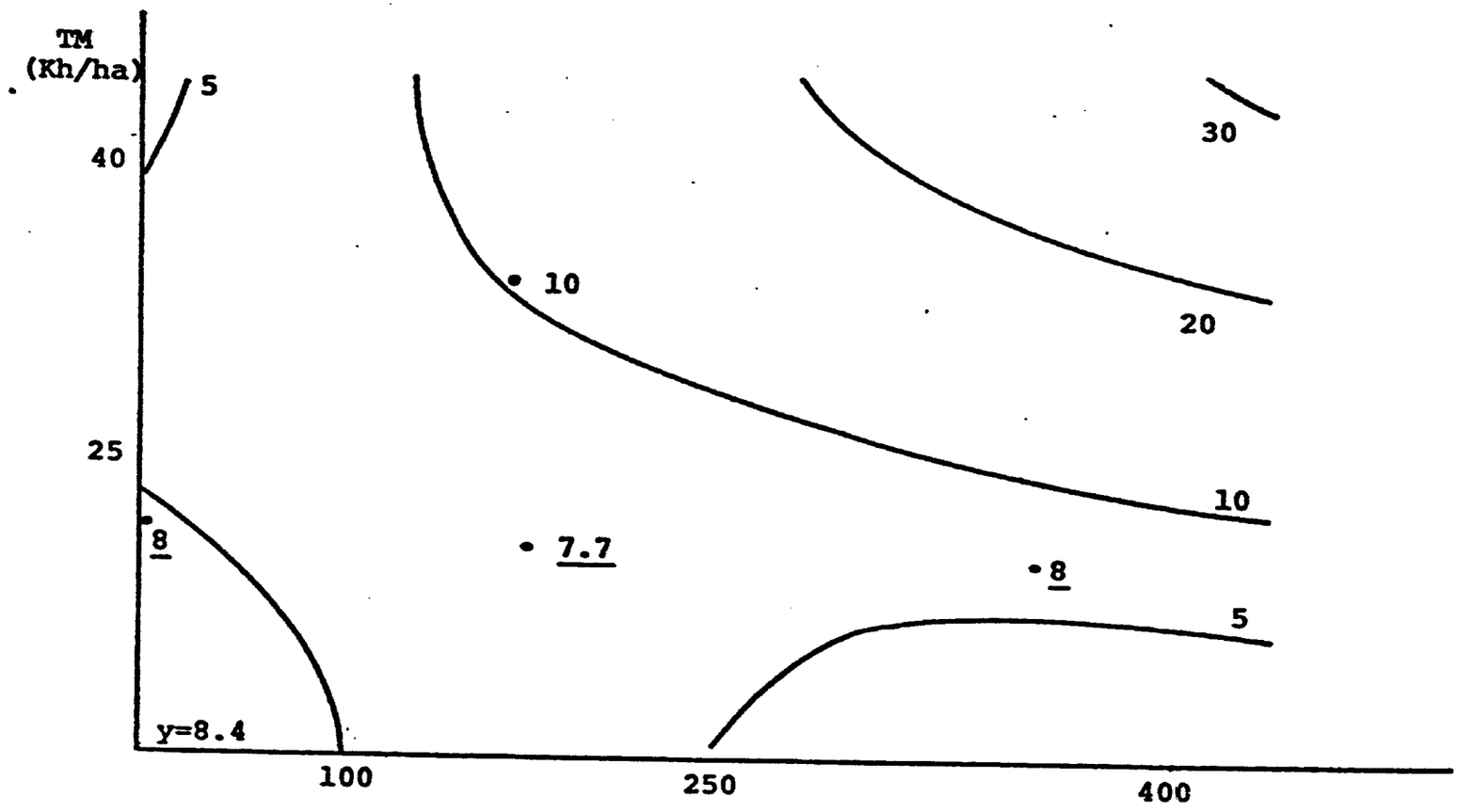


Figure 3.

Contours of seedlings m^{-2} of Siratro when grown in combination with desmodium on soil A at the first count, as affected by additions of potassium and trace minerals (TM) and the middle level of phosphorus

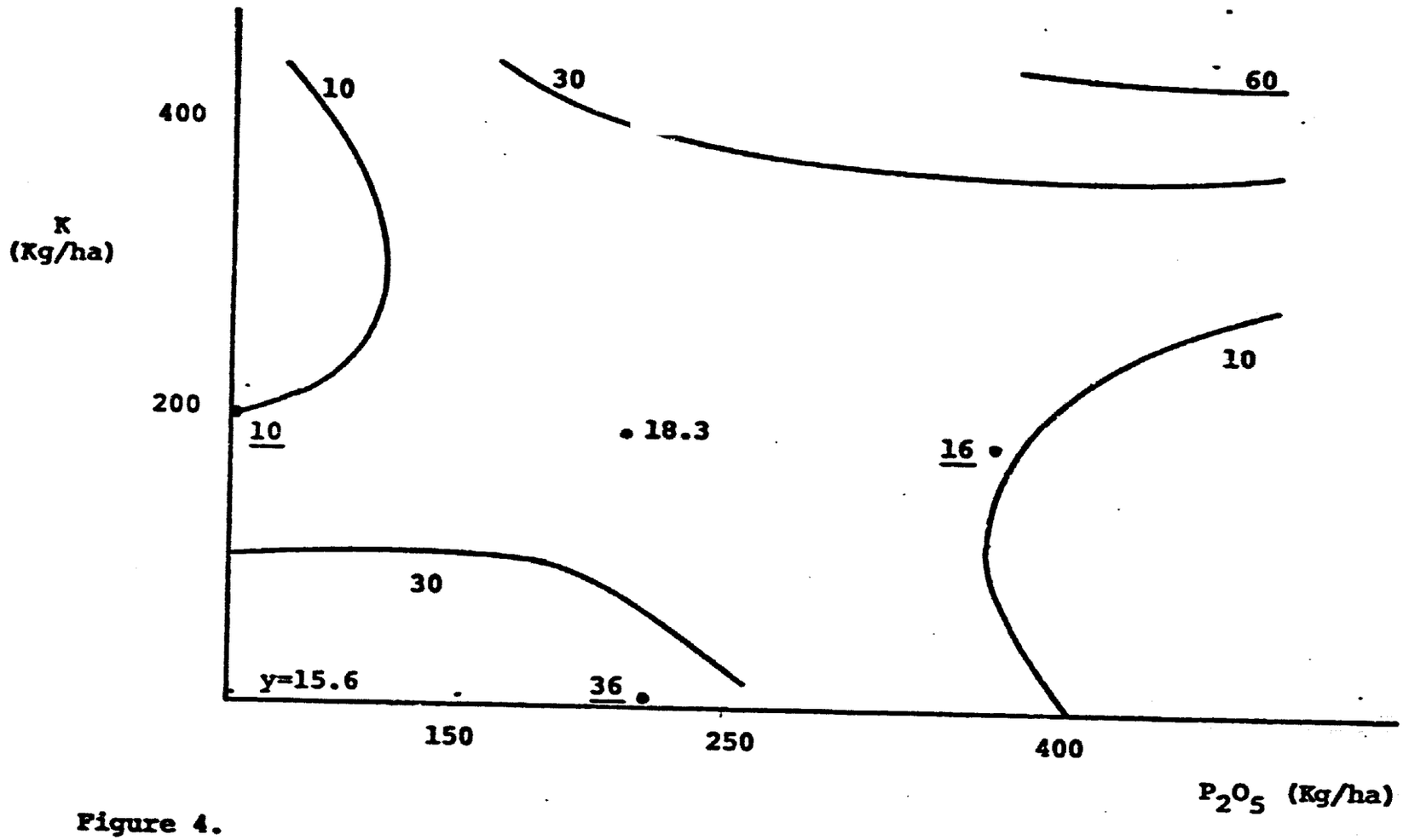


Figure 4.

Contours of seedlings m^{-2} of desmodium when seeded alone on soil B at the third count, as affected by additions of phosphorus and potassium and the middle level of trace minerals

In the same soil (B), a somewhat different response was obtained for lotononis, when planted in combination with Siratro, second count. The center of the contours describes an intermediate plateau region with reduction in number of seedlings m^{-2} towards one direction and increase in the other. Several larger and small amounts of P and K should be used in the future to further evaluate the results obtained in this experiment that either very low or very high amounts of phosphorus and potassium gives better results than intermediate levels (Figure 5).

Since the contours are plotted in two variables keeping the third one fixed, in many cases, the theoretical optimum combination of the three variables computed as explained in the materials and methods section, may or may not agree with what the inspection of the contours suggests. Tables 21 to 26 in the appendix show the calculated optimum combinations of phosphorus, potassium and trace minerals (TM) for desmodium, lotononis and Siratro in the various associations at each count, for each soil. To give some idea of how close the optimum calculated combinations approach the center of the design, the general frequency distributions are presented in figures 6 and 7. In soil B, it seems appropriate to use higher levels of fertilizer, so the center of the design can be moved up to the coded level one instead of zero.

Predicted maximum number of seedlings m^{-2} can be

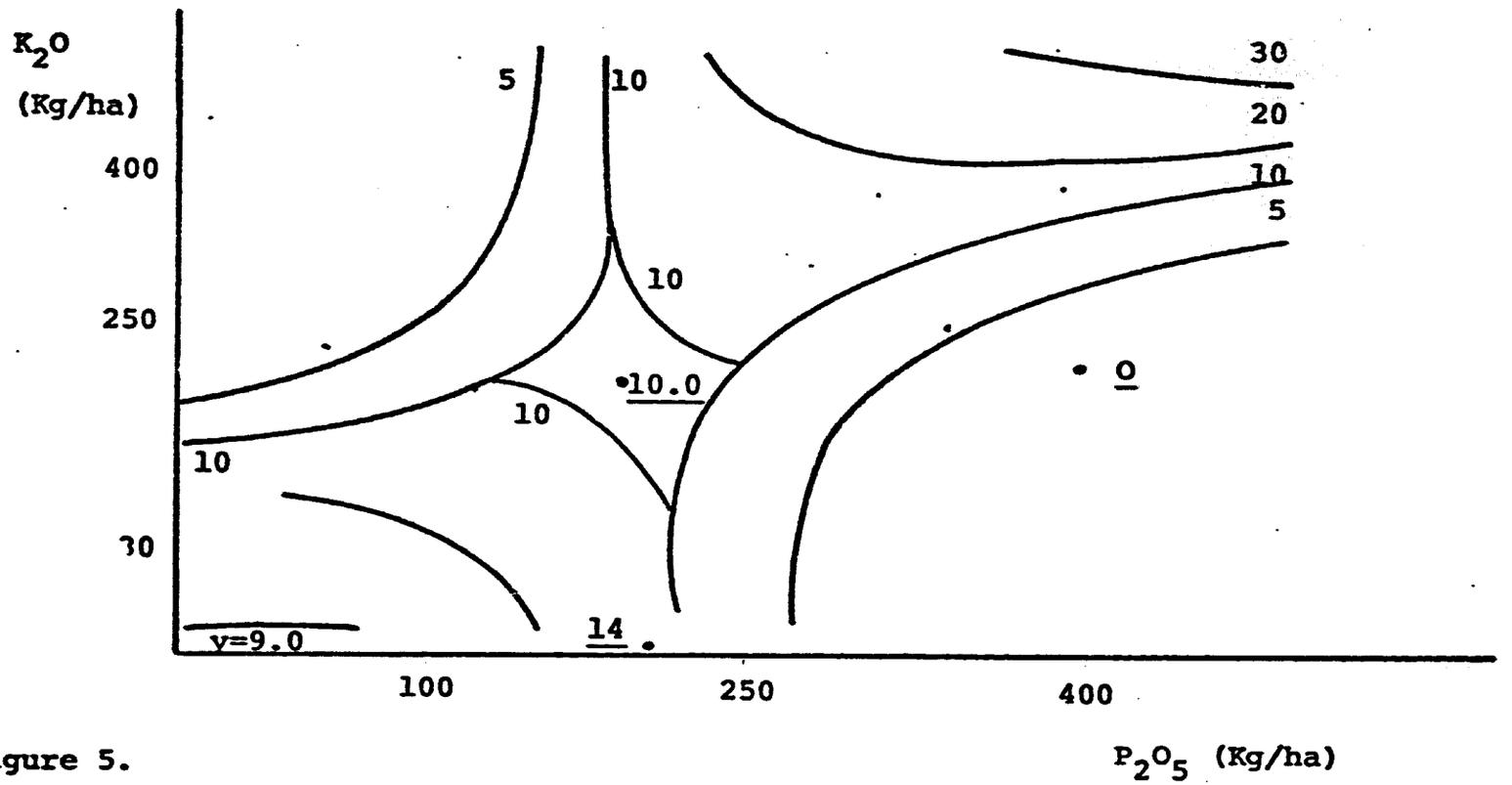


Figure 5.

Contours of seedlings m^{-2} of lotononis when seeded alone on soil B at the second count, as affected by additions of phosphorus and potassium and the middle level of trace minerals

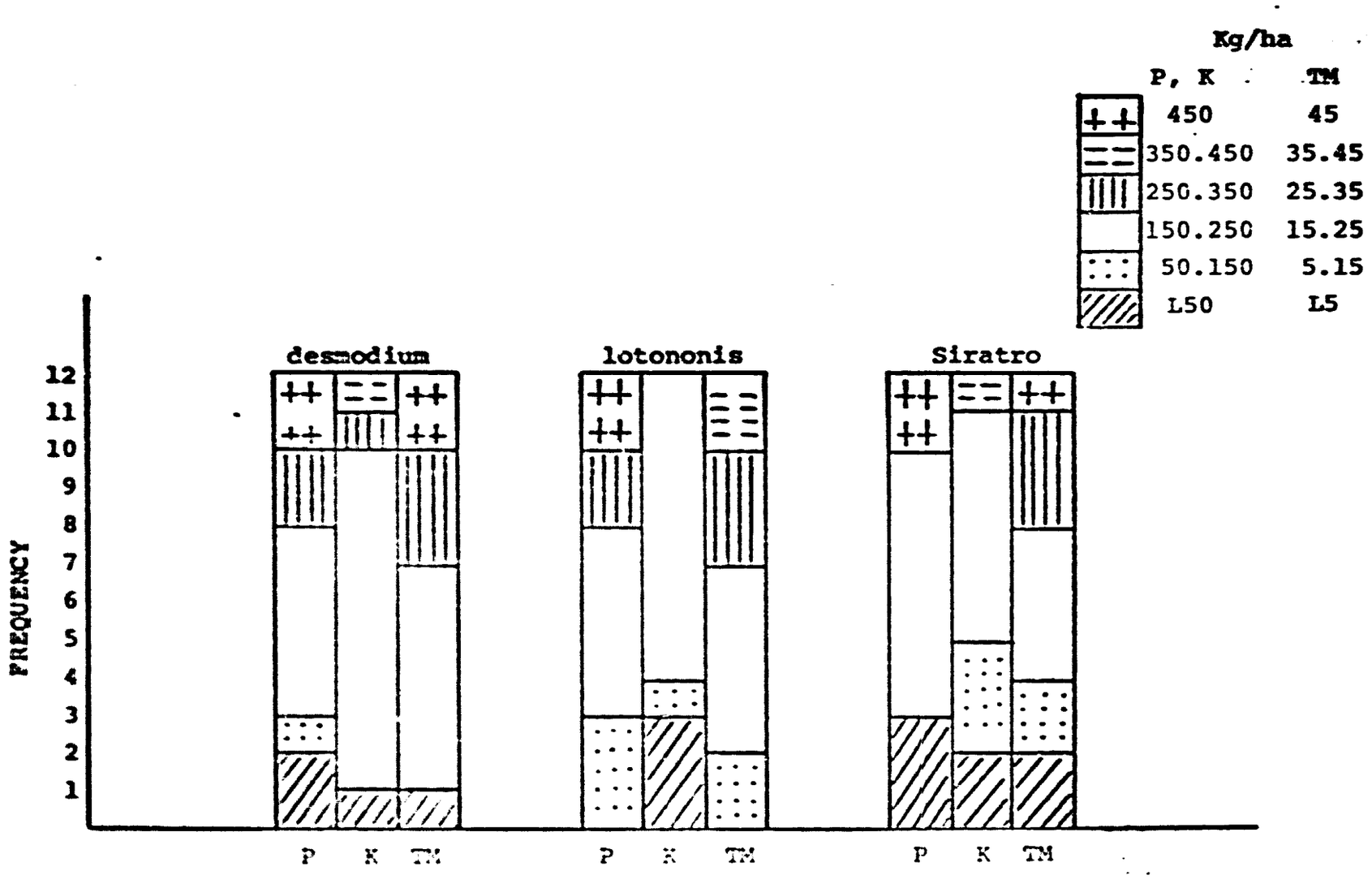
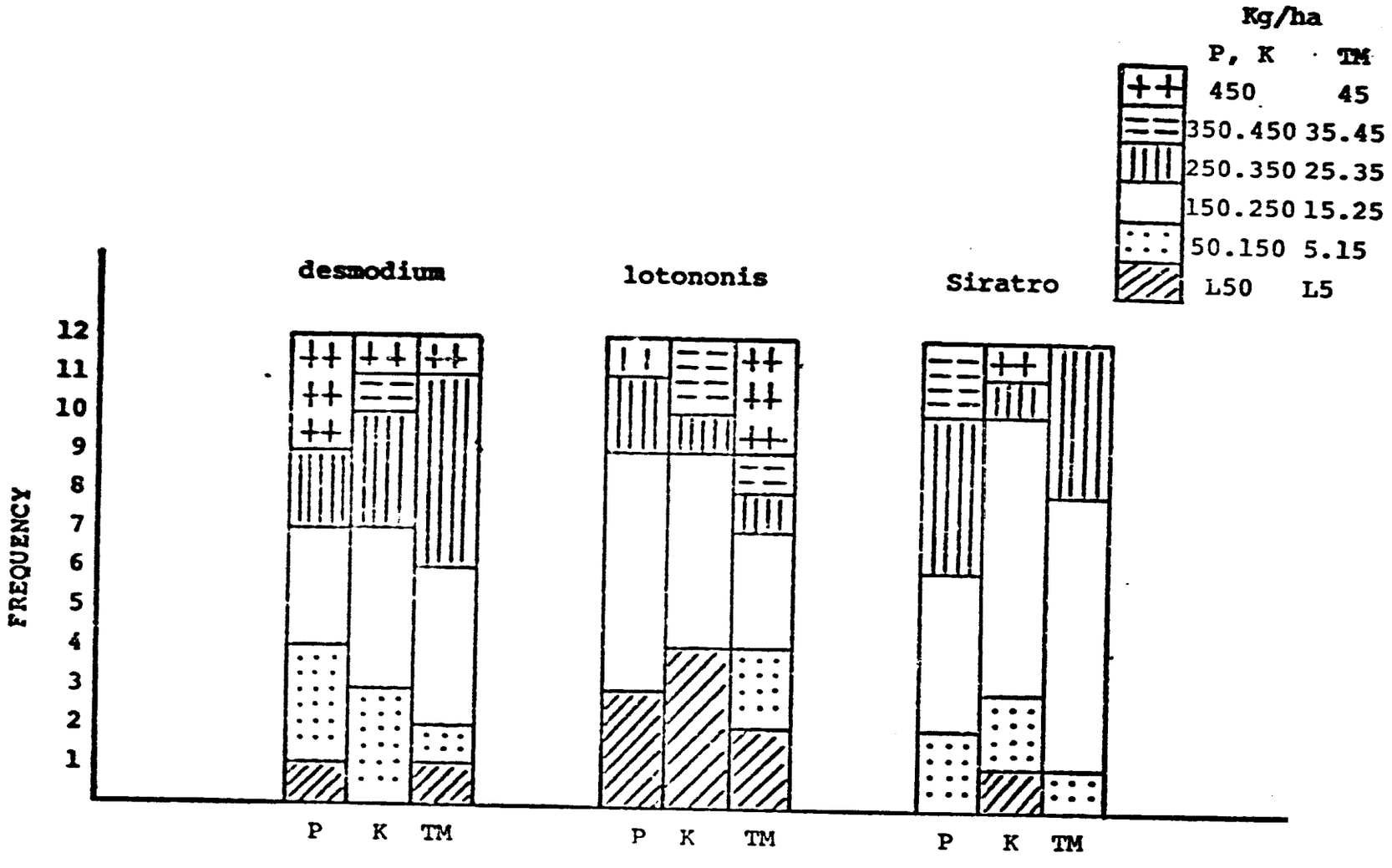


Figure 6. Frequency distribution of calculated optimum combinations of P, K and trace minerals (TM) for desmodium, lotononis and Siratro on soil A



PARAMETERS

Figure 7.

Frequency distribution of calculated optimum combinations of P, K and trace minerals (TM) for desmodium, lotononis and Siratro on soil B

calculated by substituting the optimum values of P, K and trace minerals in the respective prediction equation for each species or combination of species count number and soil. Some values were calculated for the species to which contour plotting was made. These predicted maximum number of seedlings m^{-2} are represented as point Y in the contours.

Changes in population of individual species over time

The mean and the analysis of variance of the number of seedlings m^{-2} of desmodium, lotononis and Siratro observed throughout the experiment are presented in tables 27 to 32. Desmodium consistently decreased its population. High rates of seedling mortality accounted for losses of about 50% of the initial population. Losses were greatest between the first and second counts. The causes are out of the scope of this study but deserve further experimentation. Similar results were obtained by Motooka et al (1967) in Hawaii and intense sunlight and dehydration were reported as the causes of the high seedling mortality of desmodium under burned trees.

Lotononis showed a different trend and population remained the same or even increased over time. Germination was lower than for desmodium and Siratro even though a larger number of seeds per unit area was used.

Siratro behaved quite similar to lotononis but in some cases a small reduction in population was detected,

probably due to shading effect from older Siratro plants.

Changes for individual species when planted as a component of a two-legume mixture were detected for desmodium, lotononis and Siratro. There was a reduction in population of desmodium when planted with lotononis and the inverse was true. There was a reduction in seedlings m^{-2} of Siratro when planted either with desmodium or lotononis but Siratro did not produce significant reduction of desmodium or lotononis seedlings m^{-2}. This result confirms partially Bryan's observations (1961) where lotononis could not persist in mixture with climbing legumes but did not elaborate on the effect of lotononis over its companion legumes, at the seedling stage.

Results obtained from the three-species mixture indicate that desmodium was not affected on soil A but increased its population significantly on soil B. Lotononis was unaffected on soil A but its seedlings m^{-2} were reduced on soil B as a consequence of the increase in desmodium number of seedlings just reported. Siratro population was significantly reduced on both soils.

SUMMARY AND CONCLUSIONS

The effect of phosphorus, potassium and trace minerals on the establishment of desmodium, lotononis and Siratro on two soils at the Beef Research Unit, near Gainesville, Florida, was studied. Legumes were planted alone and in all possible combinations. Five levels of each fertilizer were compressed into a central composite design with twenty treatments, superimposed upon each of the seven legume treatments. Seeds and fertilizers were applied in September 1973. Seedling counts were made on September 30, October 14 and November 10 by using permanant quadrats in order to estimate also the changes in seedlings m^{-2} throughout the experiment.

Differential responses in seedling population for the two soils were found. On one soil there was consistently positive response to K and trace minerals whereas in the other soil response to P and K was detected. Responses were associated with soil fertility prior to the experiment. Optimum calculated values of P, K and trace minerals for seedling establishment were mainly in the region close to the central points of the design.

High seedling mortality of desmodium accounting

for loses of about 50% of initial population was observed. Lotononis did show a slower establishment but population tended to remain the same or even increase with time. Siratro population had a slight non-significant decrease over the three month period.

Desmodium and lotononis appeared to be very competitive and thus each of them exerted a significant negative effect over the other and over Siratro. Siratro, in this experiment, presented good characteristics for association with the other two legumes because it did not have an adverse effect over desmodium or lotononis.

In general, the weather conditions favored desmodium and Siratro over lotononis. Had heavy frosts occurred perhaps lotononis would have been superior.

Investigation of the causes of the high seedling mortality of desmodium needs further study. The use of a completely replicated response surface design may produce a better estimate of the experimental error than that derived from only the central points of the design. The high variability of the land and the adverse weather conditions during the establishment period contributed to the high experimental error.

APPENDIX

Table 1. Observed number of seedlings m^{-2} of desmodium when planted alone on soil A.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	56	32	28	38.7
2	38	36	24	32.7
3	46	22	28	32.0
4	16	10	16	14.0
5	42	26	36	34.7
6	80	40	34	51.3
7	62	34	26	40.7
8	54	28	20	34.0
9	90	44	28	54.0
10	130	78	42	83.3
11	14	6	12	10.7
12	16	10	14	13.3
13	24	14	12	16.7
14	116	100	80	98.7
15	102	94	54	83.3
16	54	32	26	37.3
17	34	24	22	26.7
18	60	42	42	48.0
19	98	56	34	62.7
20	90	68	52	70.0
$\bar{X}$	61.1	39.8	32.5	44.5

Table 2. Observed number of seedlings m^{-2} of lotononis when planted alone on soil A.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	14	6	24	14.7
2	12	16	22	16.7
3	10	12	12	11.3
4	10	14	24	16.0
5	4	6	6	5.3
6	18	26	16	20.0
7	16	32	20	22.7
8	8	8	4	6.7
9	12	16	14	14.0
10	16	28	22	22.0
11	4	8	8	6.7
12	24	20	18	20.7
13	8	8	24	13.3
14	16	14	22	17.3
15	12	4	18	11.3
16	44	30	20	31.3
17	16	10	16	14.0
18	8	6	4	6.0
19	22	20	28	23.3
20	4	8	12	8.0
$\bar{X}$	13.9	14.6	16.7	15.1

Table 3. Observed number of seedlings m^{-2} of Siratro when planted alone on soil A.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	26	18	30	24.7
2	36	22	12	23.3
3	56	26	24	35.3
4	18	16	14	16.0
5	38	20	30	29.3
6	24	18	16	19.3
7	36	16	16	22.7
8	22	12	16	16.7
9	22	12	14	16.0
10	10	12	10	10.7
11	34	20	12	22.0
12	8	6	8	7.3
13	20	14	16	16.7
14	36	20	16	24.0
15	42	22	28	30.7
16	28	22	20	23.3
17	14	14	14	14.0
18	28	20	22	23.3
19	24	14	22	20.0
20	30	26	22	26.0
$\bar{X}$	27.6	17.5	18.1	21.1

Table 4. Observed number of seedlings m^{-2} of desmodium and lotononis when planted in association on soil A.

Fertilizer Treat No.	desmodium Count number I	II	III	$\bar{X}$	lotononis Count number I	II	III	$\bar{X}$
1	30	30	24	28.0	20	0	0	6.7
2	70	48	32	50.0	10	14	10	11.3
3	70	36	28	44.7	18	12	6	12.0
4	54	32	16	34.0	20	14	12	15.3
5	48	44	28	40.0	20	10	14	14.7
6	20	8	10	12.7	4	2	2	2.7
7	44	18	24	28.7	8	4	10	7.3
8	30	32	32	31.3	8	8	8	8.0
9	24	8	14	15.3	8	12	14	11.3
10	70	50	40	53.3	28	20	20	22.7
11	74	62	50	62.0	8	6	12	8.7
12	46	12	10	22.7	8	4	4	5.3
13	84	62	54	66.7	30	12	14	18.7
14	46	30	20	32.0	16	8	12	12.0
15	42	40	34	38.7	12	18	16	15.3
16	76	44	38	52.7	28	8	26	20.7
17	78	62	40	60.0	22	16	32	23.3
18	108	52	36	65.3	8	18	14	13.3
19	28	14	16	19.3	8	12	12	10.7
20	22	12	20	18.0	10	2	12	8.0
$\bar{X}$	53.2	34.8	28.3	38.8	14.7	10.0	12.5	12.4

Table 5. Observed number of seedlings of desmodium and Siratro when planted in association on soil A.

Fertilizer Treat No.	desmodium Count number I	II	III	$\bar{X}$	Siratro Count number I	II	III	$\bar{X}$
1	128	90	46	88.0	12	20	24	18.7
2	52	30	20	34.0	14	10	12	12.0
3	44	16	20	26.7	12	12	10	11.3
4	28	22	20	23.3	10	12	10	10.7
5	50	42	44	45.3	8	4	4	5.3
6	76	34	26	45.3	12	14	12	12.7
7	100	66	34	66.7	14	14	18	15.3
8	104	54	36	64.7	12	14	10	12.0
9	32	34	34	33.3	16	4	8	9.3
10	40	28	16	28.0	12	12	8	10.7
11	100	76	78	84.7	8	16	10	11.3
12	44	40	24	36.0	8	2	6	5.3
13	64	32	24	40.0	4	0	4	2.7
14	28	22	10	20.0	10	8	6	8.0
15	72	32	16	40.0	8	14	8	10.0
16	44	46	32	40.7	6	4	4	4.7
17	20	12	10	14.0	4	6	4	4.7
18	40	34	20	31.3	10	10	8	9.3
19	100	44	26	56.7	12	12	12	12.0
20	68	36	30	44.7	6	16	4	8.7
$\bar{X}$	61.9	39.5	28.3	43.2	10.2	9.1	10.4	9.9

Table 6. Observed number of seedlings m^{-2} of lotononis and Siratro when planted in association on soil A.

Fertilizer Treat No.	latononis Count number I	II	III	$\bar{X}$	Siratro Count number I	II	III	$\bar{X}$
1	14	12	8	11.3	8	24	18	16.7
2	14	14	18	15.3	20	12	8	13.3
3	16	16	22	18.0	12	10	6	9.3
4	8	8	6	7.3	14	6	4	8.0
5	26	14	20	20.0	16	14	10	13.3
6	12	4	8	8.0	12	6	4	7.3
7	4	8	4	5.3	14	6	12	10.7
8	2	0	4	2.0	10	6	4	6.7
9	16	4	16	12.0	20	8	12	13.3
10	22	8	14	14.7	8	2	6	5.3
11	18	4	16	12.7	14	8	8	10.0
12	6	4	4	4.7	16	16	14	15.3
13	12	4	16	10.7	8	6	4	6.0
14	40	58	20	39.3	16	8	14	12.7
15	38	10	10	19.3	16	10	10	12.0
16	16	12	22	16.7	12	12	8	10.7
17	58	32	26	38.7	20	14	12	15.3
18	38	28	12	26.0	18	18	10	15.3
19	12	22	18	17.3	14	12	12	12.7
20	18	6	20	14.7	10	6	6	7.3
$\bar{X}$	19.5	13.6	14.2	15.8	14.7	9.9	9.0	11.2

Table 7. Observed number of seedlings m^{-2} of desmodium, lotononis and Siratro when planted in association on soil A.

Fertilizer Treat No.	desmodium Count number I	II	III	$\bar{X}$	lotononis Count number I	II	III	$\bar{X}$	Siratro Count number I	II	III	$\bar{X}$
1	10	10	4	8.0	4	4	4	4.0	4	2	6	4.0
2	70	38	40	49.3	12	8	22	14.0	8	0	6	4.7
3	78	68	56	67.3	36	16	12	21.3	50	10	12	24.0
4	36	42	26	34.7	10	12	16	12.7	4	6	8	6.0
5	68	30	28	42.0	14	8	16	13.33	10	8	10	9.3
6	82	16	12	36.7	12	6	12	10.0	12	14	10	12.0
7	60	32	12	34.7	16	8	4	9.3	8	4	12	8.0
8	18	12	14	14.7	16	8	10	11.3	4	6	4	4.7
9	54	28	26	36.0	18	10	18	15.3	6	10	14	10.0
10	20	30	28	26.0	10	6	8	8.0	6	6	6	6.0
11	30	20	12	20.7	12	2	10	8.0	18	10	10	12.7
12	58	32	28	39.3	6	0	10	5.3	10	10	12	10.7
13	30	10	12	17.3	4	2	4	3.3	4	4	4	4.0
14	26	12	14	17.3	4	2	10	5.3	4	8	8	6.7
15	70	28	26	41.3	8	14	16	12.7	8	10	8	8.7
16	98	82	84	88.0	18	14	34	22.0	10	12	22	14.7
17	30	26	20	25.3	12	2	6	6.7	10	8	10	9.3
18	58	14	22	31.3	26	12	14	17.3	10	4	6	6.7
19	56	36	22	38.0	24	8	16	16.0	12	6	10	9.3
20	20	16	46	27.3	8	6	8	7.3	4	0	2	2.0
$\bar{X}$	48.6	29.1	26.6	34.8	13.5	7.4	12.5	11.1	10.1	6.9	9.5	8.8

Table 8. Observed number of seedlings m^{-2} of desmodium when planted alone on soil B.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	130	96	40	88.7
2	32	16	18	22.0
3	44	28	20	30.7
4	64	58	30	50.7
5	58	58	30	48.7
6	40	32	32	34.7
7	16	16	12	14.7
8	8	8	6	7.3
9	34	18	10	20.7
10	22	22	16	20.0
11	34	40	36	36.7
12	38	42	28	36.0
13	96	58	40	64.7
14	38	40	40	39.3
15	46	10	18	24.7
16	52	32	32	38.7
17	40	16	16	24.0
18	28	18	24	23.3
19	22	10	12	14.7
20	20	12	8	13.3
$\bar{X}$	43.1	31.5	22.9	32.5

Table 9. Observed number of seedlings m^{-2} of lotononis when planted alone on soil B.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	12	16	20	12.7
2	4	4	0	2.7
3	0	2	2	1.3
4	4	2	8	4.7
5	6	16	10	10.7
6	12	8	4	8.0
7	8	6	4	6.0
8	6	16	20	14.0
9	2	4	2	2.7
10	0	0	2	0.7
11	12	14	10	12.0
12	8	12	4	8.0
13	12	36	26	24.7
14	4	4	4	4.0
15	0	24	6	10.0
16	4	6	2	4.0
17	4	2	4	3.3
18	8	4	4	5.3
19	26	16	14	18.7
20	4	8	4	5.3
$\bar{X}$	6.8	10.1	7.5	8.1

Table 10. Observed number of seedlings m^{-2} of Siratro when planted alone on soil B.

Fertilizer Treat No.	Count number I	II	III	$\bar{X}$
1	14	26	20	20.0
2	16	18	16	16.7
3	20	14	14	16.0
4	20	22	20	20.7
5	8	14	8	10.0
6	20	14	22	18.7
7	14	14	16	14.7
8	14	18	20	17.3
9	12	10	10	10.7
10	18	14	14	15.3
11	18	26	18	20.7
12	12	16	8	12.0
13	16	10	18	14.7
14	20	14	10	14.7
15	10	22	16	16.0
16	16	24	16	18.7
17	28	28	18	24.7
18	22	32	24	26.0
19	12	14	16	14.0
20	20	18	16	18.0
$\bar{X}$	16.5	18.4	16.0	17.0

Table 11. Observed number of seedlings m^{-2} of desmodium and lotononis when planted in association on soil B.

Fertilizer Treat No.	desmodium Count number I	II	III	$\bar{X}$	lotononis Count number I	II	III	$\bar{X}$
1	84	48	48	60.0	6	6	2	4.7
2	28	14	12	18.0	4	2	4	3.3
3	46	26	16	29.3	0	6	8	4.7
4	80	50	38	56.0	0	4	2	2.0
5	92	54	36	60.7	0	6	18	8.0
6	20	16	4	13.3	0	2	0	0.7
7	92	32	18	47.3	4	10	12	8.7
8	56	30	28	38.0	4	6	2	4.0
9	96	48	38	60.7	8	22	24	18.0
10	32	18	8	19.3	2	2	6	3.3
11	32	24	18	24.7	0	0	0	0.0
12	72	70	68	70.0	4	6	14	8.0
13	40	38	28	35.3	0	0	0	0.0
14	18	20	20	19.3	0	2	4	2.0
15	106	84	70	86.7	0	0	6	2.0
16	26	20	16	20.7	0	6	12	6.0
17	24	10	12	15.3	8	4	8	6.7
18	4	4	2	3.3	0	6	4	3.3
19	66	44	30	46.7	0	2	6	2.7
20	14	10	6	10.0	0	0	2	0.7
$\bar{X}$	51.4	33.0	25.8	36.7	2.0	4.6	6.7	4.4

Table 12. Observed number of seedlings m^{-2} of desmodium and Siratro when planted in association on soil B.

	desmodium				Siratro			
	Count number				Count number			
Fertilizer Treat No.	I	II	III	$\bar{X}$	I	II	III	$\bar{X}$
1	0	0	0	0.0	20	12	22	18.0
2	2	0	0	0.7	14	14	12	13.3
3	14	0	0	4.7	6	12	12	10.0
4	12	0	0	4.0	8	14	10	10.7
5	6	6	4	5.3	16	10	6	10.7
6	0	0	0	0.0	16	12	12	13.3
7	0	2	0	0.7	14	12	14	13.3
8	0	0	0	0.0	14	16	14	14.7
9	14	0	0	4.7	8	26	16	16.7
10	0	0	0	0.0	16	16	14	15.3
11	0	0	0	0.0	20	18	24	20.7
12	0	0	0	0.0	20	8	16	14.7
13	10	2	2	4.7	20	20	16	18.7
14	0	0	0	0.0	18	18	20	18.7
15	0	2	0	0.7	22	12	14	16.0
16	14	20	8	14.0	8	8	12	9.3
17	0	2	0	0.7	26	26	28	26.7
18	0	8	0	2.7	18	20	20	19.3
19	16	0	0	5.3	12	12	16	13.3
20	0	0	0	0.0	20	24	20	21.3
$\bar{X}$	4.4	2.1	0.7	2.4	15.8	15.5	15.9	15.7

Table 13. Observed number of seedlings m^{-2} of lotononis and Siratro when planted in association on soil B.

Fertilizer Treat No.	lotononis Count number I	II	III	$\bar{X}$	Siratro Count number I	II	III	$\bar{X}$
1	0	20	22	14.0	22	18	16	18.7
2	8	2	12	7.3	34	32	24	26.7
3	14	22	18	18.0	28	16	14	19.3
4	4	8	8	6.7	32	28	20	26.7
5	8	10	8	8.7	28	22	26	25.3
6	6	8	8	7.3	30	28	28	28.7
7	0	4	6	3.3	12	8	6	8.7
8	20	6	8	11.3	0	16	18	11.3
9	10	20	32	20.7	24	2	18	14.7
10	0	0	2	0.7	18	16	20	18.0
11	0	4	2	2.0	16	12	12	13.3
12	0	4	4	2.7	26	28	18	24.0
13	0	0	0	0.0	46	34	36	38.7
14	0	2	4	2.0	40	32	32	34.7
15	0	0	8	2.7	28	24	22	24.7
16	2	12	14	9.3	36	34	36	35.3
17	14	18	10	14.0	32	24	16	24.0
18	2	4	4	3.3	40	26	32	32.7
19	6	10	8	8.0	34	22	20	25.3
20	0	2	4	2.0	48	38	30	38.7
$\bar{X}$	4.7	7.8	9.1	7.2	28.7	23.0	22.2	24.6

Table 14. Observed number of seedlings of desmodium, lotononis and Siratro when planted in association on soil B.

Fertilizer Treat No.	desmodium Count number I	II	III	$\bar{X}$	lotononis Count number I	II	III	$\bar{X}^0$	Siratro Count number I	II	III	$\bar{X}$
1	90	74	62	75.3	0	16	12	9.3	16	16	18	16.7
2	50	22	20	30.7	0	0	0	0.0	26	22	20	22.7
3	144	64	36	81.3	12	16	16	14.7	38	26	30	31.3
4	32	20	22	24.7	0	0	0	0.0	24	22	16	20.7
5	52	66	40	52.7	0	16	12	9.3	10	12	16	12.7
6	38	18	12	22.7	0	8	2	3.3	12	18	14	14.7
7	60	28	18	35.3	6	6	10	7.3	8	2	10	6.7
8	32	26	18	25.3	0	6	2	2.7	2	12	16	10.0
9	66	48	34	49.3	0	10	10	6.7	12	12	14	12.7
10	34	26	12	24.0	0	0	0	0.0	22	22	20	21.3
11	56	14	10	26.7	0	0	0	0.0	18	8	14	13.3
12	48	20	8	25.3	2	10	10	7.3	10	26	20	18.7
13	64	46	26	45.3	2	4	4	3.3	14	22	14	16.7
14	56	28	18	34.0	2	0	4	2.0	16	26	20	20.7
15	90	48	20	52.7	6	10	12	9.3	14	22	16	17.3
16	44	46	26	38.7	0	8	12	6.7	12	12	10	11.3
17	50	26	20	32.0	0	4	8	4.0	14	16	16	15.3
18	124	82	44	83.3	0	16	18	11.3	16	26	24	22.0
19	24	22	16	20.7	0	0	2	0.7	10	22	20	17.3
20	66	42	34	47.3	6	6	8	6.7	10	6	10	8.7
$\bar{X}$	61.0	38.3	24.8	41.4	1.8	6.8	7.1	5.2	15.7	17.7	16.8	16.7

Table 150. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted alone on soil A. (See table 1).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	2.12	1.19	1.56
Lack of fit	5	1.03	1.00	2.37
Error	5			
CV%		45.5	64.8	40.9

Regression coefficients and P

	b	P	b	P	b	P
Intercept	6.15909	0.94	-27.40909	0.72	-10.72727	0.83
P	-0.28420	0.54	0.08796	0.79	-0.02114	0.92
K	0.73580	0.07	0.51546	0.15	0.36386	0.13
TM	-0.31705	0.93	0.00454	0.99	0.48864	0.83
P^2	0.00077	0.20	0.00614	0.90	0.00008	0.81
K^2	-0.00161	0.02	-0.00126	0.03	-0.00072	0.06
TM^2	-0.02364	0.68	-0.00386	0.94	0.01091	0.75
PxK	-0.00072	0.52	-0.00045	0.64	-0.00015	0.81
PxTM	0.00975	0.65	0.002	0.82	0.001	0.87
KxTM	0.00325	0.75	0.004	0.67	-0.002	0.75

Table 15 DL. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted in combination with lotononis on soil A. (See table 4).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.29	0.75	1.35
Lack of fit	5	0.48	0.75	2.41
Error	5			
CV%		54.5	54.5	46.5

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-9.02273	0.91	44.27273	0.55	49.61364	0.23
P	0.47239	0.24	0.18887	0.53	0.10057	0.58
K	0.15989	0.68	-0.11864	0.65	-0.08943	0.62
TM	1.02387	0.79	-0.76137	0.76	-1.59432	0.62
P^2	-0.00041	0.50	-0.00027	0.50	-0.00015	0.51
K^2	-0.00008	0.88	-0.00007	0.86	-0.00008	0.76
TM^2	0.00409	0.94	0.01591	0.68	0.00955	0.72
PxK	-0.00052	0.62	0.00035	0.62	0.00007	0.87
PxTM	-0.00825	0.56	-0.0045	0.52	0.00075	0.87
KxTM	-0.00225	0.82	0.001	0.88	0.00375	0.56

Table 15 DS. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^2 when planted in combination with Siratro on soil A. (See table 5).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	1.20	2.31	3.89
Lack of fit	5	1.37	1.69	4.29
Error	5			
CV%		49.9	42.7	50.0

Regression coefficients and P

	b	P	b	P	b	P
Intercept	257.29545	0.02	184.84091	0.04	111.52273	0.02
P	-0.25852	0.54	-0.2633	0.26	-0.19239	0.31
K	-0.86352	0.56	-0.7783	0.01	-0.52739	0.01
TM	-7.51023	0.09	-3.68295	0.12	-0.69886	0.71
P^2	-0.00036	0.58	-0.00001	0.97	0.00008	0.76
K^2	0.00059	0.64	0.00066	0.07	0.00073	0.02
TM^2	-0.01068	0.86	-0.01136	0.74	-0.01159	0.69
PxK	0.00047	0.68	0.00077	0.22	0.00057	0.27
PxTM	0.01525	0.19	0.00425	0.71	0.00125	0.80
KxTM	0.02325	0.06	0.01575	0.02	0.00325	0.53

Table 15 DLS. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings M^2 when planted in combination with latononis and Siratro on soil A. (See table 7).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.89	0.41	0.40
Lack of fit	5	0.42	0.38	0.35
Error	5			
CV%		48.6	71.4	77.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-145.56818	0.06	-69.59091	0.28	-73.54545	0.25
P	0.64216	0.06	0.23204	0.58	0.26727	0.66
K	0.78216	0.03	0.40204	0.17	0.45478	0.12
TM	5.87159	0.08	4.29546	0.14	3.79773	0.19
P^2	-0.00035	0.52	-0.00006	0.88	-0.00024	0.57
K^2	-0.00018	0.71	-0.00014	0.75	-0.00042	0.33
TM^2	-0.05772	0.25	-0.05114	0.24	-0.05932	0.18
PxK	-0.00197	0.04	-0.00075	0.33	-0.0006	0.57
PxTM	-0.00575	0.51	-0.0045	0.56	-0.0025	0.74
KxTM	-0.01325	0.14	-0.008	0.30	-0.0065	0.60

Table 16 L. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted alone on soil A. (See table 2).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.14	0.81	0.34
Lack of fit	5	0.26	0.42	1.28
Error	5			
CV%		81.9	57.8	51.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-7.54545	0.82	-22.00	0.60	16.81818	0.52
P	0.07728	0.62	0.09	0.56	0.04909	0.67
K	0.09228	0.55	0.1225	0.29	0.02409	0.83
TM	0.44773	0.77	0.825	0.52	-0.53409	0.65
P^2	-0.00019	0.62	0.00022	0.21	0.00003	0.87
K^2	-0.00019	0.62	0.00002	0.88	-0.0001	0.59
TM^2	-0.01682	0.52	-0.005	0.77	0.01523	0.60
PxK	-0.00025	0.55	-0.00065	0.05	-0.00015	0.64
PxTM	0.001	0.80	-0.002	0.52	-0.002	0.53
KxTM	0.001	0.80	0.0005	0.86	0.0015	0.64

Table 16 LD. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted in combination with desmodium on soil A. (See table 4).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.93	0.71	0.72
Lack of fit	5	0.81	0.87	0.72
Error	5			
CV%		54.1	61.6	62.1

Regression coefficients and P

	b	P	b	P	b	P
Intercept	23.59091	0.34	-13.77273	0.53	-24.250	0.31
P	-0.06454	0.55	0.03614	0.67	0.11125	0.30
K	0.04545	0.67	0.11364	0.19	0.12875	0.23
TM	-0.49545	0.65	1.03636	0.22	1.6875	0.12
P^2	0.00006	0.71	0.00007	0.61	-0.00001	0.54
K^2	-0.00019	0.26	-0.00021	0.12	-0.00032	0.06
TM^2	0.01864	0.27	-0.00841	0.51	-0.02	0.22
PxK	0.00035	0.24	-0.00000	1.00	0.00007	0.20
PxTM	-0.001	0.73	-0.0025	0.28	-0.00375	0.20
KxTM	-0.002	0.50	-0.0015	0.51	-0.00075	0.39

Table 16 LS. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted in combination with Siratro on soil A. (See table 6).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.38	1.34	1.05
Lack of fit	5	0.70	2.62	1.90
Error	5			
CV%		84.0	104.2	51.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-32.90909	0.51	-22.59091	0.60	-13.34091	0.55
P	0.17045	0.55	0.16705	0.61	0.09830	0.33
K	0.26045	0.25	0.20455	0.29	0.17580	0.09
TM	1.72954	0.56	-0.10455	0.95	0.60796	0.54
P^2	-0.00036	0.29	-0.00031	0.30	-0.00012	0.53
K^2	-0.00053	0.13	-0.00041	0.17	-0.00024	0.13
TM^2	-0.01886	0.58	0.02636	0.64	-0.00364	0.60
PxK	0.00005	0.93	-0.0001	0.84	-0.00017	0.52
PxTM	-0.001	0.86	-0.0015	0.77	-0.00075	0.77
KxTM	-0.0035	0.56	-0.001	0.84	-0.00275	0.31

Table 16 LD3. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted in combination with desmodium and Siratro on soil A. (See table 7).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.98	0.81	0.26
Lack of fit	5	1.23	0.95	0.49
Error	5			
CV%		61.7	64.7	68.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-18.59091	0.53	-12.25	0.59	-19.59091	0.54
P	0.02705	0.80	0.00875	0.89	0.08705	0.54
K	0.21455	0.07	0.12375	0.07	0.09705	0.59
TM	1.17046	0.31	0.8975	0.14	1.74545	0.15
P^2	-0.00001	0.95	0.00000	1.00	-0.00006	0.73
K^2	-0.00014	0.56	-0.00017	0.09	-0.00014	0.55
TM^2	-0.02614	0.14	-0.015	0.14	-0.02114	0.24
PxK	-0.0004	0.20	-0.00007	0.67	-0.00005	0.87
PxTM	0.002	0.52	-0.00025	0.88	-0.0025	0.57
KxTM	-0.003	0.33	-0.00175	0.33	-0.002	0.53

Table 17 S. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted alone on soil A. (See table 3).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.89	0.48	2.11
Lack of fit	5	3.55	0.22	2.89
Error	5			
CV%		49.6	30.8	34.7

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-2.59091	0.95	-1.90909	0.90	20.34091	0.29
P	0.17955	0.34	0.10295	0.17	-0.0258	0.76
K	0.19205	0.31	0.10795	0.15	0.0692	0.58
TM	-0.10455	0.95	0.37955	0.61	0.04205	0.96
P^2	-0.00021	0.54	-0.00016	0.16	-0.00019	0.16
K^2	-0.00009	0.76	-0.00014	0.22	-0.00024	0.08
TM^2	0.00886	0.75	-0.00387	0.73	-0.00886	0.50
PxK	-0.0006	0.24	-0.0002	0.32	0.00027	0.24
PxTM	0.00000	1.00	0.00000	1.00	0.00175	0.55
KxTM	-0.002	0.69	-0.0015	0.55	-0.00125	0.59

Table 17SD Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted in combination with desmodium on soil A. (See table 5).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	1.67	1.32	2.31
Lack of fit	5	0.88	1.69	3.92
Error	5			
CV%		28.9	52.6	56.3

Regression coefficients and P

	b	P	b	P	b	P
Intercept	17.70455	0.06	26.27273	0.12	38.27273	0.03
P	-0.05898	0.14	-0.04364	0.55	-0.06864	0.33
K	-0.01398	0.72	-0.06864	0.65	-0.10864	0.13
TM	-0.23977	0.54	-0.28636	0.69	-1.01136	0.16
P^2	0.00018	0.01	-0.00002	0.88	0.00008	0.57
K^2	0.00003	0.59	0.00001	0.93	0.00008	0.57
TM^2	0.00068	0.90	-0.01159	0.31	0.00091	0.93
PxK	-0.00012	0.24	0.00000	1.00	-0.00005	0.78
PxTM	0.00025	0.80	0.0025	0.22	0.0015	0.57
KxTM	0.00125	0.24	0.002	0.32	0.0035	0.08

Table 17SL. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted in combination with lotononis on soil A. (See table 6).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	0.92	1.22	1.80
Lack of fit	5	2.29	1.55	5.56
Error	5			
CV%		32.6	45.6	47.1

Regression coefficients and P

	b	P	b	P	b	P
Intercept	25.84091	0.09	13.70455	0.32	16.54545	0.21
P	-0.0133	0.83	0.02852	0.64	-0.00227	0.97
K	-0.0633	0.34	-0.03648	0.55	-0.04977	0.61
TM	0.01705	0.98	0.11023	0.85	-0.14773	0.79
P^2	-0.00001	0.88	-0.00017	0.09	-0.00003	0.71
K^2	0.00001	0.90	0.00001	0.94	0.00002	0.83
TM^2	-0.00636	0.53	-0.01182	0.22	-0.00318	0.71
PxK	0.00007	0.67	0.00012	0.54	0.00005	0.74
PxTM	-0.00075	0.67	0.00025	0.87	-0.0005	0.74
KxTM	0.00175	0.33	0.00075	0.65	0.002	0.21

Table 17 SDL. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted in combination with desmodium and lotononis on soil A. (See table 7).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total	19			
Regression	9	18.67	0.92	0.33
Lack of fit	5	16.23	0.30	0.09
Error	5			
CV%		80.1	50.5	53.6

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-16.59091	0.50	-2.88636	0.78	-10.54545	0.50
P	0.03455	0.75	-0.02943	0.54	0.04227	0.54
K	0.022205	0.06	0.05557	0.25	0.07477	0.29
TM	0.37045	0.73	0.53068	0.27	1.02273	0.15
P^2	-0.00004	0.82	0.00002	0.77	-0.00004	0.68
K^2	0.00016	0.34	0.00007	0.34	-0.00002	0.86
TM^2	-0.00864	0.61	-0.00295	0.68	-0.01432	0.19
PxK	-0.0007	0.03	-0.00007	0.56	-0.00015	0.57
PxTM	0.0005	0.11	0.00175	0.18	-0.0005	0.78
KxTM	-0.0065	0.04	-0.00325	0.02	-0.0015	0.57

Table 18D. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted alone on soil B. (See table 8).

		Count number I		Count number II		Count number III	
Analysis of Variance							
Source	df	F		F		F	
Total	19						
Regression	9	6.88		10.99		2.27	
Lack of fit	5	3.79		7.55		1.05	
Error	5						
CV%		47.6		54.0		38.1	
Regression coefficients and P							
		b	P	b	P	b	P
Intercept		216.81818	0.01	174.27273	0.01	60.52273	0.04
P		-0.49841	0.09	-0.47114	0.06	-0.02239	0.84
K		-0.39341	0.17	-0.54864	0.03	-0.17989	0.14
TM		-5.88409	0.05	-3.68636	0.12	-1.57386	0.19
P^2		-0.0001	0.81	0.00016	0.65	-0.00017	0.63
K^2		0.0001	0.80	0.00068	0.07	0.00031	0.10
TM^2		0.08773	0.06	0.08841	0.03	0.05091	0.02
PxK		0.0016	0.05	0.0016	0.02	0.00042	0.20
PxTM		0.0065	0.61	0.002	0.74	-0.00025	0.93
KxTM		-0.0025	0.74	-0.005	0.57	-0.00325	0.32

Table 180L. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted in combination with lotononis on soil B. (See table 11).

		Count number		
		I	II	III
Analysis of Variance				
Source	df	F	F	F
Total				
Regression		0.74	0.39	0.56
Lack of fit		0.27	0.12	0.24
Error				
CV%		59.9	69.2	76.8

Regression coefficients and P

	b	P	b	P	b	P
Intercept	132.11364	0.17	77.56818	0.27	98.13636	0.12
P	-0.54443	0.20	-0.26466	0.60	-0.28432	0.30
K	-0.45193	0.29	-0.29466	0.65	-0.41182	0.14
TM	1.83068	0.66	0.97841	0.75	-0.36818	0.88
P^2	0.00075	0.25	0.0001	0.82	-0.00002	0.96
K^2	0.00045	0.51	0.00045	0.65	0.00048	0.25
TM^2	-0.01295	0.83	0.00023	0.99	0.00045	0.99
PxK	0.00157	0.18	0.00117	0.17	0.00125	0.10
PxTM	-0.01075	0.65	-0.00375	0.66	-0.001	0.88
KxTM	0.00275	0.80	-0.00275	0.74	0.0015	0.83

Table 18DS. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted in combination with Siratro on soil B. (See table 12).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.57	0.18	0.18
Lack of fit	0.21	0.04	0.08
Error			
CV%	139.6	267.6	342.1

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-6.25	0.73	-14.90909	0.61	-3.77273	0.61
P	-0.03875	0.64	0.06795	0.62	0.01614	0.62
K	0.12375	0.15	0.06045	0.57	0.01614	0.62
TM	0.7125	0.60	0.70455	0.64	0.18636	0.57
P^2	0.00005	0.69	-0.00014	0.24	-0.00003	0.50
K^2	-0.00012	0.33	-0.00014	0.24	-0.00003	0.50
TM^2	0.00000	1.00	-0.00136	0.34	-0.00091	0.85
PxK	0.00002	0.91	0.00005	0.80	0.00005	0.57
PxTM	-0.00075	0.74	-0.001	0.63	-0.0005	0.57
KxTM	-0.00375	0.11	-0.0005	0.80	-0.0005	0.57

Table 18 DLS. Analysis of variance, regression coefficients (b) and probabilities (P) of desmodium seedlings m^{-2} when planted in combination with lotononis and Siratro on soil B. (See table 14).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.74	1.05	2.05
Lack of fit	0.43	0.53	1.42
Error			
CV%	49.8	48.8	46.8

Regression coefficients and P

	b	P	b	P	b	P
Intercept	74.15909	0.57	76.61364	0.19	82.77273	0.03
P	-0.05170	0.89	-0.25943	0.31	-0.26114	0.11
K	0.46330	0.27	0.20057	0.57	-0.001864	0.90
TM	-2.64205	0.53	-1.24432	0.62	-1.38636	0.62
P^2	-0.00036	0.57	-0.00013	0.73	-0.00002	0.94
K^2	-0.00031	0.62	-0.00063	0.12	-0.00037	0.14
TM^2	-0.01114	0.85	-0.01295	0.73	-0.00409	0.86
PxK	-0.00107	0.34	0.00067	0.33	0.0007	0.12
PxTM	0.01375	0.23	0.00575	0.59	0.0035	0.58
KxTM	-0.00425	0.70	-0.00225	0.74	0.001	0.81

Table 19 L. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted alone on soil B. (See table 9).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.16	1.09	3.72
Lack of fit	0.31	0.85	2.98
Error			
CV%	110.9	82.6	80.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	9.82719	0.77	70.89862	0.08	76.84562	0.02
P	0.05203	0.68	-0.09032	0.51	-0.19407	0.07
K	-0.05047	0.69	-0.21082	0.13	-0.23907	0.03
TM	0.09263	0.94	-2.37834	0.10	-2.26475	0.04
P^2	-0.00017	0.29	-0.0002	0.26	-0.00007	0.61
K^2	0.00006	0.71	0.00008	0.66	0.00006	0.64
TM^2	0.00076	0.96	0.02505	0.16	0.02598	0.05
PxK	0.00006	0.84	0.00063	0.08	0.00078	0.01
PxTM	0.00014	0.96	0.00228	0.51	0.00272	0.28
KxTM	0.00014	0.96	0.00228	0.51	0.00272	0.62

Table 19 LD. Analysis of variance, regression coefficients (b) and probabilities (P) of lotonomis seedlings m^{-2} when planted in combination with desmodium on soil B. (See table 11).

	Count number		
	I	II	III
Analysis of Variance			
	F	F	F
Total			
Regression	0.89	4.31	5.30
Lack of fit	0.25	1.14	2.71
Error			
CV%	129.1	68.9	70.0

Regression coefficients and P

	b	P	b	P	b	P
Intercept	16.97545	0.05	15.88636	0.11	-8.68182	0.55
P	-0.05602	0.12	-0.12307	0.01	-0.04341	0.50
K	-0.05352	0.14	-0.00557	0.89	0.05659	0.62
TM	-0.38523	0.28	0.11932	0.77	1.24091	0.07
P^2	0.00009	0.10	0.00023	0.005	0.00002	0.05
K^2	0.00002	0.73	0.00005	0.94	0.000002	0.98
TM^2	-0.00318	0.56	-0.00455	0.51	-0.01227	0.22
PxK	0.00002	0.79	0.00002	0.82	0.00000	1.00
PxTM	0.00025	0.79	-0.00025	0.82	-0.003	0.10
KxTM	0.00225	0.03	0.00075	0.52	0.001	0.57

Table 19 LS. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^2 when planted in combination with Siratro on soil B. (See table 13).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.48	0.96	5.87
Lack of fit	2.81	0.47	3.81
Error			
CV%	157.7	80.4	64.7

Regression coefficients and P

	b	P	b	P	b	P
Intercept	10.18182	0.65	28.18182	0.15	39.02273	0.04
P	-0.08659	0.61	-0.18159	0.05	-0.21239	0.02
K	0.03591	0.72	0.04341	0.61	0.01261	0.87
TM	-0.19091	0.74	-0.04091	0.96	-0.37386	0.64
P^2	0.00007	0.64	0.0001	0.54	0.00026	0.05
K^2	-0.00005	0.73	-0.00005	0.69	-0.00009	0.54
TM^2	-0.00523	0.73	-0.01273	0.33	0.01159	0.65
PxK	0.00005	0.85	0.0001	0.66	0.00002	0.90
PxTM	0.0025	0.63	0.004	0.10	0.00275	0.21
KxTM	-0.0005	0.85	-0.002	0.61	0.00075	0.73

Table 19 LDS. Analysis of variance, regression coefficients (b) and probabilities (P) of lotononis seedlings m^{-2} when planted in combination with desmodium and Siratro on soil B. (See table 14).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	1.24	1.31	1.50
Lack of fit	0.91	1.10	0.62
Error			
CV%	168.1	82.4	67.8

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-8.47727	0.64	15.00	0.62	-1.29545	0.93
P	0.03511	0.60	-0.0875	0.26	0.00102	0.98
K	0.08011	0.07	0.045	0.56	0.09602	0.15
TM	-0.07386	0.85	-0.125	0.86	0.31022	0.64
P^2	-0.00004	0.52	-0.00002	0.82	-0.00012	0.25
K^2	-0.00002	0.79	-0.00002	0.82	-0.00012	0.25
TM^2	0.00091	0.88	-0.01	0.60	-0.01432	0.16
PxK	0.00022	0.06	0.0001	0.63	-0.00002	0.88
PxTM	0.00075	0.50	0.003	0.16	0.00125	0.51
KxTM	-0.00075	0.50	-0.0015	0.53	-0.00075	0.67

Table 20 S. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted alone on soil B. (See table 10).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.35	1.25	2.05
Lack of fit	0.26	0.17	2.47
Error			
CV%	32.2	27.2	26.4

Regression coefficients and P

	b	P	b	P	b	P
Intercept	4.79545	0.76	22.63636	0.15	23.27273	0.09
P	0.04398	0.55	0.04568	0.51	0.00886	0.87
K	0.07648	0.30	-0.08682	0.21	-0.00863	0.87
TM	0.13977	0.84	0.70682	0.31	-0.31136	0.59
P^2	-0.00008	0.54	-0.00027	0.02	-0.00012	0.20
K^2	-0.00008	0.54	-0.00005	0.66	-0.00009	0.31
TM^2	-0.00068	0.95	-0.02705	0.02	-0.00659	0.54
PxK	-0.00017	0.62	0.00025	0.19	0.00000	1.00
PxTM	0.00125	0.53	0.0005	0.78	0.002	0.21
KxTM	-0.00125	0.53	0.0015	0.58	0.001	0.52

Table 20 SD. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted in combination with desmodium on soil B. (See table 12).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	0.48	0.27	0.72
Lack of fit	0.62	0.62	0.81
Error			
CV%	37.7	42.7	34.2

Regression coefficients and P

	b	P	b	P	b	P
Intercept	23.5	0.21	22.70455	0.27	35.61364	0.05
P	0.0575	0.52	-0.04398	0.63	-0.00943	0.89
K	-0.075	0.64	0.02352	0.79	-0.07443	0.32
TM	-0.55	0.50	-0.21477	0.80	-0.07443	0.32
P^2	-0.00017	0.17	0.00006	0.68	-0.00013	0.26
K^2	0.00002	0.83	-0.00014	0.30	-0.000005	0.97
TM^2	0.00000	1.00	0.00068	0.96	-0.00545	0.63
PxK	0.0001	0.65	0.00002	0.91	0.00002	0.89
PxTM	0.0005	0.81	0.00025	0.91	0.00225	0.27
KxTM	0.002	0.63	0.00075	0.75	0.00275	0.18

Table 20 SL. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^2 when planted in combination with lotononis on soil B. (See table 13).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	3.88	2.84	1.30
Lack of fit	.36	1.94	0.82
Error			
CV%	31.5	34.0	33.5

Regression coefficients and P

	b	P	b	P	b	P
Intercept	-33.93182	0.23	-15.90909	0.51	0.27273	0.99
P	0.29034	0.03	0.26045	0.03	0.09386	0.64
K	0.34034	0.02	0.12795	0.24	0.15886	0.13
TM	1.17841	0.66	0.27955	0.78	-0.13636	0.89
P^2	-0.00045	0.03	-0.00049	0.01	-0.00022	0.17
K^2	-0.00045	0.03	-0.00021	0.20	-0.00032	0.06
TM^2	-0.01023	0.59	0.01114	0.50	0.01591	0.31
PxK	-0.00027	0.59	-0.00000	1.00	0.0001	0.71
PxTM	-0.00325	0.33	-0.0015	0.60	0.00000	1.00
KxTM	-0.00625	0.08	-0.0025	0.61	-0.003	0.28

Table 20 SDL. Analysis of variance, regression coefficients (b) and probabilities (P) of Siratro seedlings m^{-2} when planted in combination with desmodium and lotononis on soil B. (See table 14).

	Count number		
	I	II	III
Analysis of Variance			
Source	F	F	F
Total			
Regression	5.59	3.98	0.36
Lack of fit	21.99	1.70	1.37
Error			
CV%	52.3	48.9	35.7

Regression coefficients and P

	b	P	b	P	b	P
Intercept	15.97727	0.53	14.43182	0.59	14.88636	0.58
P	-0.03011	0.78	-0.01534	0.89	-0.02057	0.79
K	0.06739	0.55	0.07966	0.50	0.05693	0.51
TM	-0.25114	0.81	-0.055341	0.64	-0.23068	0.77
P^2	0.00014	0.59	-0.00003	0.87	0.00003	0.80
K^2	0.00007	0.70	-0.00003	0.87	0.00003	0.80
TM^2	0.00909	0.60	0.01477	0.58	0.00295	0.80
PxK	-0.00027	0.63	-0.00002	0.93	-0.00012	0.57
PxTM	0.00125	0.68	0.00225	0.52	0.00175	0.57
KxTM	-0.00275	0.63	-0.00275	0.60	-0.00175	0.57

Table 21. Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of desmodium on soil A.

Pasture	Count No	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
D	I	102.45	236.18	30.66
	II	-541.36	440.01	88.24
	III	468.38	236.10	-22.22
DL	I	-24.30	220.53	30.26
	II	228.19	198.85	23.31
	III	329.83	331.65	31.32
DS	I	246.38	182.37	22.80
	II	166.45	221.56	22.62
	III	242.25	230.59	15.24
DLS	I	248.17	187.02	17.03
	II	314.68	167.68	15.03
	III	496.16	-310.38	129.81

Some calculated optimum combinations of P, K and TM fall outside the experimental region. This indicates that the true optimum over the experimental region is on the border of the experimental region.

Table 22. Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of lotononis on soil A.

Pasture	Count No	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
L	I	779.62	-320.10	26.97
	II	236.47	167.99	43.61
	III	65.43	174.60	13.23
LD	I	239.25	185.25	29.65
	II	149.34	191.64	22.33
	III	134.02	183.33	26.18
LS	I	213.13	173.31	24.11
	II	206.19	209.20	11.82
	III	276.57	42.41	39.04
LDS	I	253.84	166.06	22.57
	II	928.12	40.62	22.82
	III	228.15	123.10	24.90

Table 23. Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of Siratro on soil A.

Pasture	Count No.	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
S	I	191.16	164.57	24.46
	II	186.01	210.39	8.28
	III	28.61	181.37	-7.59
SD	I	189.93	128.02	23.66
	II	570.34	-52.41	81.99
	III	230.30	176.85	25.83
SL	I	481.04	382.36	-33.36
	II	182.18	234.02	14.02
	III	-148.18	120.80	26.39
SDL	I	212.66	168.16	19.73
	II	-606.31	-203.66	22.26
	III	196.47	74.01	28.41

Some calculated optimum combinations of P, K and TM fall outside the experimental regions. This indicates that the true optimum over the experimental region is on the border of the experimental region.

Table 24. Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of desmodium on soil B.

Pasture	Count No	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
D	I	258.77	232.37	27.26
	II	232.91	217.68	24.37
	III	239.07	253.53	24.14
DL	I	243.29	145.20	32.10
	II	148.32	240.16	22.07
	III	71.47	265.81	45.02
DS	I	615.62	66.87	32.65
	II	31.96	177.47	25.69
	III	136.72	136.72	27.30
DLS	I	461.44	528.74	-339.51
	II	466.30	366.66	22.95
	III	338.46	317.63	14.16

Table 25 Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of lotononis on soil B.

Pasture	Count No.	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
L	I	215.54	312.92	12.87
	II	181.05	154.09	32.22
	III	213.73	210.65	20.95
LD	I	250.63	193.90	17.87
	II	228.00	-74.29	0.73
	III	478.96	-1426.10	50.11
LS	I	213.00	374.84	14.75
	II	39.02	-727.37	61.67
	III	276.60	203.37	23.26
LDS	I	210.24	197.49	35.37
	II	-16.67	-903.33	59.00
	III	-53.20	419.76	-2.48

Some calculated optimum combinations of P, K and TM fall outside the experimental regions. This indicates that the true optimum over the experimental region is on the border of the experimental region.

Table 26 Calculated optimum combinations of P, K and trace minerals (TM) for the establishment of Siratro on soil B.

Pasture	Count No.	P (Kg/ha)	K (Kg/ha)	TM (Kg/ha)
S	I	129.93	227.03	13.49
	II	351.10	515.68	30.61
	III	292.74	114.74	29.50
SD	I	198.19	-22.05	28.14
	II	318.96	151.34	15.79
	III	207.70	203.28	25.85
SL	I	191.93	162.92	22.67
	II	232.49	169.70	22.16
	III	260.94	188.15	22.03
SDL	I	97.99	73.85	18.25
	II	374.08	312.84	19.36
	III	310.18	207.73	17.39

Some calculated optimum combinations of P, K and TM fall outside the experimental regions. This indicates that the true optimum over the experimental region is on the border of the experimental region.

Table 27 Means and analysis of variance of the observed number of seedlings m^{-2} of desmodium when planted alone (D), in association with lotononis (DL), in association with Siratro (DS) or in association with lotononis and Siratro (DLS) on soil A.

Legume Association	Count number I	II	III	$\bar{X}$
D	61.1	39.8	32.5	44.5
DL	53.2	34.8	28.3	38.8
DS	61.9	39.5	28.3	43.2
DLS	48.6	29.1	26.6	35.9
$\bar{X}$	56.2	36.6	28.9	40.6

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	7.35*
L	1	19.76*
S	1	1.97
LS	1	0.32
Counts	2	122.23**
Counts x Leg	6	
Residual	12	

Table 28. Means and analysis of variance of the observed number of seedlings m^{-2} of lotononis when planted alone (L), in association with desmodium (LD), in association with Siratro (LS) or in association with desmodium and Siratro (LDS) on soil A.

Legume Association	Count number I	II	III	$\bar{X}$
L	13.9	14.6	16.7	15.1
LD	14.7	10.0	12.5	12.4
LS	19.5	13.6	14.2	15.8
LDS	13.5	7.4	12.5	11.1
$\bar{X}$	15.4	11.4	14.0	13.6

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	3.46
D	1	9.62*
S	1	0.06
DS	1	0.70
Counts	2	3.96
Counts x Leg	6	
Residual	12	

Table 29. Means and analysis of variance of the observed number of seedlings m^{-2} of Siratro when planted alone (S), in association with desmodium (SD), in association with lotononis (SL) or in association with desmodium and Siratro (SDL) on soil A.

Legume Association	Count number I	II	III	$\bar{X}$
S	27.6	17.5	18.1	21.1
SD	9.9	10.2	9.1	9.7
SL	14.7	9.9	9.0	11.2
SDL	10.1	6.9	9.5	8.8
$\bar{X}$	15.6	11.1	11.4	12.7

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	14.43**
D	1	21.15**
L	1	13.06*
DL	1	9.06*
Counts	2	3.72
Counts x Leg	6	
Residual	12	

Table 30. Means and analysis of variance of the observed number of seedlings m^{-2} of desmodium when planted alone (D), in association with lotononis (DL), in association with Siratro (DS) or in association with lotononis and Siratro (DLS) on soil B.

	Count number			
Legume Association	I	II	III	$\bar{X}$
D	43.1	31.5	22.9	32.5
DL	51.4	33.0	25.8	36.7
DS	4.4	2.1	0.7	2.4
DLS	61.0	38.3	24.8	41.4
$\bar{X}$	40.0	26.2	18.5	28.2

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	19.40**
L	1	29.18**
S	1	10.14*
LS	1	18.86**
Counts	2	9.67*
Counts x Leg	6	
Residual	12	

Table 31. Means and analysis of variance of the observed number of seedlings m^{-2} of lotononis when planted alone (L), in association with desmodium (LD), in association with Siratro (LS) or in association with desmodium and Siratro (LDS) on soil B.

Legume Association	Count number I	II	III	$\bar{X}$
L	6.8	10.1	7.5	8.1
LD	2.0	4.6	6.7	4.4
LS	4.7	7.8	9.1	7.2
LDS	1.8	6.8	7.1	5.2
$\bar{X}$	3.8	7.3	7.6	6.2

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	5.47*
D	1	15.01**
S	1	0.01
DS	1	1.40
Counts	2	11.04*
Counts x Leg	6	
Residual	12	

Table 32. Means and analysis of variance of the observed number of seedlings m^{-2} of Siratro when planted alone (S), in association with desmodium (SD), in association with lotononis (SL) or in association with desmodium and lotononis (SDL) on soil B.

Legume Association	Count number I	II	III	$\bar{X}$
S	16.5	18.4	16.0	17.0
SD	15.8	15.5	15.9	15.7
SL	28.7	23.0	22.2	24.6
SDL	15.7	17.7	16.8	16.7
$\bar{X}$	19.2	18.6	17.7	

Analysis of Variance

Source	df	F
Total	23	
Legume assoc.	3	11.67**
D	1	14.38**
L	1	12.95*
DL	1	7.66*
Counts	2	0.49
Counts x Leg	6	
Residual	12	

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BIOGRAPHICAL SKETCH

Pablo E. Mendoza was born on June 12, 1944 in El Banco, Magdalena, Colombia, to Pablo and Elena Mendoza. From February 1963 to December 1967 he attended the Universidad Nacional in Bogota, Colombia and received the Ingeniero Agronomo degree. Two semesters was awarded free tuition from the Universidad Nacional for his dedication to study.

He joined the Instituto Colombiano Agropecuario (ICA) in January 1968 and worked in applied research and extension for two years at the eastern region of his home country. Then, was transferred to "Tibaitata", the Colombia's most important experiment station--located in Bogota--where besides his normal work he used to do some teaching at the Universidad Nacional and Universidad del Tolima. He has attended several international meetings as participant from Colombia. In September 1972 he was granted a scholarship to study toward the degree of Master of Science in Agriculture. Specialization was focused on Forages and Pastures. Animal Science and Statistics were selected as minors.

Pablo E. Mendoza is married to the former Kyrina Crespo and they have two children: Pablo Elias and Sara Elena.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Agriculture.

Gerald O. Mott, Chairman
Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Agriculture.

John E. Moore
Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentatio and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Agriculture.

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This thesis was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Master of Science in Agriculture.

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