A bean, corn and manioc polyculture cropping system. I. The effect of interspecific competition on crop yield*

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COMPENDIO

Frijoles (Phaseolus vulgaris), *maíz* (Zea mays) *y yuca* (Manihot esculenta) *se plantaron separadamente en tres sistemas de monocultivo, y juntos en tres sistemas de policultivo, en Turrialba, Costa Rica. En un sistema de policultivo hay competencia interespecífica entre dos o más cultivos por un recurso limitante.*

Los policultivos consistieron de: 1) policultivo sucesivo en el que frijoles, maíz y yuca se plantaron todos a la vez y se cosecharon después de 9, 18 y 36 semanas respectivamente; 2) un policultivo al revés en el que yuca se planto sola y después fue intercalada con maíz después de 18 semanas y con frijoles después de 27 semanas, y todos los cultivos cosechados después de 36 semanas; y 3) un policultivo intensivo en el cual se intercalaron durante un período de 36 semanas cuatro cultivos de frijol, dos de maíz, y uno de yuca.

Se aplicaron cuatro tratamientos, que consistían del producto factorial de dos tratamientos de fertilizantes (sin fertilizante, y una aplicación inicial de 222, 160, y 40 kg/ha de N, P, y K respectivamente) y de dos tratamientos de deshierbos (sin deshierbo, y con deshierbos cada seis semanas), a los tres monocultivos y tres policultivos y a un sistema de cultivo de vegetación natural que consistía de las hierbas invasoras.

El efecto del fertilizante y deshierbos sobre el rendimiento de frijoles, maíz y yuca no fue el mismo en los sistemas de monocultivo y policultivo. La competencia interespecífica en el policultivo sucesivo dio resultado a una interacción dinámica entre el rendimiento de frijol y maíz. Cuando se aplicó fertilizante al policultivo, el rendimiento de maíz aumentó y el rendimiento del frijol disminuyó. — El autor.

Introduction

AGROECOSYSTEMS indigenous to the humid tropics have been characterized by Harris (2) as diverse assemblages of crops in polycultural patterns of structural and functional interdependence as opposed to temperate agroecosystems which are relatively simple and tend toward monoculture. Holdridge (3) has suggested that a mixed culture, simulating the natural vegetation as far as possible, combined with the shifting cultivation system or in a sense copying the natural process of succession following the opening of the canopy, might be a potentially successful farming system in the tropics.

Sequential and spatial arrangements of crop plant populations (cropping systems) which fit these criteria have been suggested by many investigators and have been given many different names. To avoid semantic difficulties, the following definitions will be used in the restrictive sense listed below.

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Monoculture: A cropping system in which crop plant species are not planted within sufficient spatial proximity to result in interspecific competition for a limiting or potentially limiting resource.

Polyculture: A cropping system in which two or more crop plant species are planted within sufficient spatial proximity to result in interspecific competition for a limiting or potentially limiting resource.

Interplanting: The physical act of planting a crop in a polyculture.

Intercropping: The physical sequence of events from planting to harvesting which results in a polyculture.

By definition, any crop planted in a polyculture will be affected by competition with the other crop species. In most cases, the yield from a particular crop species will be less in a polyculture than in a monoculture if the crop is planted at an optimum, or higher than optimum, population density.

Interspecific competition makes it difficult to predict the yield of a crop in a polyculture. Any variation in a factor which influences the resources available for plant growth will result in a selective advantage of one crop species over another. Two factors which influence available resources are fertilizer and weed competition. In the experiment which follows, the effects of these factors on yield of individual crops planted in monoculture and polyculture cropping systems are evaluated.

Methods

The field experiments were conducted at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), operated by the Instituto Interamericano de Ciencias Agrícolas (IICA), of the Organization of American States (OAS) in Turrialba, Costa Rica.

Turrialba is approximately 600 m above sea level, and has a mean annual precipitation of 2,700 mm, a mean annual temperature of 22C, and a mean annual solar radiation input of 138 kcal cm^{-2} (ten-year climatological records, 1960-1969). According to the Holdridge classification system, Turrialba is in the Premontane Tropical Wet Forest Zone (4).

Aguirre (1) classified the soil in the field plot area as in the Rocky Phase of the Instituto soil series, and in the Inceptisol order and Tropepts suborder of the Seventh Approximation classification system.

The field plots were located in an area which had been used for fertilizer and variety experiments with beans until 1972. The area had been fallow one year. In May 1973, one month before the beginning of the experiment, the natural vegetation was cleared from the site.

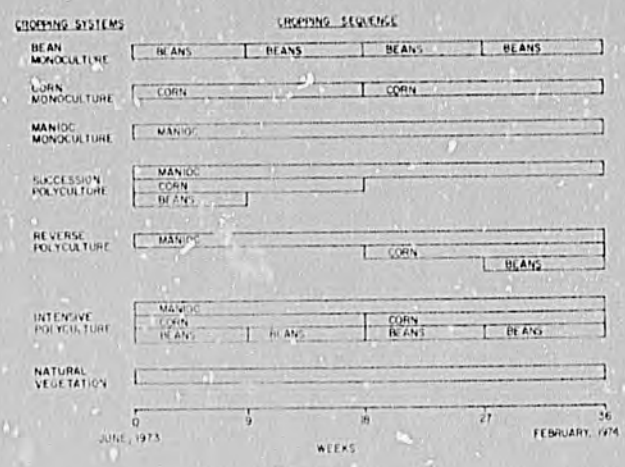

Fig. 1.—*The sequence of crops which composed the seven cropping systems in the experimental design.*

Crop species

Crop species used in the experiment were beans (*Phaseolus vulgaris* L.), corn (*Zea mays* L.), and manioc (*Manihot esculenta* Crantz).

The bean variety used, 'R-27', is a red bean with an erect growth habit. It matures at Turrialba in 60 to 70 days. The corn variety used, 'T-66', is a white hybrid. It matures at Turrialba in 130 to 140 days. The manioc variety used, 'Brasil', is a local variety. It matures at Turrialba in 8 to 9 months, but can be harvested earlier with a reduction in yield. All the varieties used are grown locally and commonly sold in the Turrialba market.

Experimental design

The experiment was designed to evaluate 28 crop production systems. Production systems consisted of four treatments applied to seven cropping systems. Cropping systems were designed by considering ecological descriptions of ecosystems in the humid tropics, and reports and observations of successful polycultures. The cropping systems consisted of beans, corn, and manioc planted in monocultures (respectively) and in three polycultures, and a natural vegetation system (Fig. 1).

In the monoculture cropping systems, four crops of beans were planted in sequence, two crops of corn were planted in sequence, and manioc was planted once. In the polyculture cropping systems, beans, corn, and manioc were interplanted.

Three polyculture cropping systems were designed. In the succession and reverse polycultures the individual crops were planted and harvested once. In the succession polyculture cropping system, the three crops were interplanted at the beginning of the experimental period and harvested as each crop matured. In the reverse polyculture, the three crops were interplanted at different time intervals but harvested at the same time at the end of the experimental period. In the

intensive polyculture, four bean crops, two corn crops, and one manioc crop were interplanted.

The natural vegetation which invaded the plots in which no crops were planted was considered as a seventh cropping system.

The four treatments applied to the seven cropping systems were the factorial product of two fertilizer treatments and two weeding treatments. The four treatments were:

(1) no fertilizer, no weeding

(2) no fertilizer, weeding (all weeds removed every six weeks)

(3) fertilizer (222, 169, and 40 kg/ha N, P, and K respectively), no weeding

(4) fertilizer, weeding.

The 28 production systems were replicated three times in a completely random design. Each field plot was 5 by 5 m in size. Data were collected from a 3 by 3 m subplot in the center of each plot. A 1 m buffer zone was left between plots. The 84 field plots formed a rectangle, 6 by 14 plots, which measured 36 by 83 m.

Beans, corn, and manioc were planted in seed or cutting populations equivalent to a planting rate of 400,000, 70,000, and 10,000 plants per hectare, respectively. The higher than optimum population rates were used to insure high intraspecific and interspecific competition. The spatial planting design for each crop species (Fig. 2) was the same regardless of cropping system or treatment in order to insure that any observed difference in yield of an individual crop between cropping systems would be due entirely to the different levels of interspecific competition. Beans were planted in a lattice design with 0.50 m between rows and 0.10 m between seeds. Corn was planted in a lattice design with 1 m between rows and 0.25 between seeds. Manioc was planted with 1 m between rows and 1 m between cuttings.

The experimental period began in May 1973, and ended in February 1974. A chronological summary of events, including land clearing, soil sampling, fertilizer applications, weedings, planting, and harvesting, is outlined in Table 1 and discussed below in greater detail.

Table 1.—Chronological summary of events.

Week	Date	Event
—3	May, 1973	Land cleared, first soil sample taken
—2		Field plots measured
—1		Triple super phosphate and 8-32-6 fertilizer applied
0	June	First bean, corn, and manioc planting
2	July	Nitrogen fertilizer applied
4		Second soil samples
6		First weeding
9	August	First bean harvest, second bean planting
12		Second weeding
16	September	First corn folded
17		First corn harvest
18	October	Third weeding, second bean harvest third bean planting, second corn planting
24	November	Fourth weeding
27	December	Third bean harvest, fourth bean planting
30		Fifth weeding
34	January, 1974	Second corn folding
35		Second corn harvest
36	February	Sixth weeding, fourth bean harvest, manioc harvest, third soil samples

Soil sampling

Soil samples were taken two weeks before the first fertilizer application, two weeks after the last fertilizer application, and at the end of the 36 week experimental period.

All soil samples were analyzed for levels of P and K by the Soil Laboratory of the Ministry of Agriculture (Costa Rica) in Guadalupe, Costa Rica. Soil N was not measured.

Fertilizer application

Fertilizer was first applied one week before the initial planting, by broadcasting 2 kg of 8-32-6 fertilizer and 0.7 kg of triple super phosphate (0-46-0) on each field plot which had been assigned the fertilizer treatment. The fertilizer was subsequently disked into the soil. The initial fertilizer was equivalent to 64, 169, and 40 kg/ha of N, P, and K respectively. A second application of nitrogen fertilizer was applied as ammonium nitrate (33-0-0) two weeks after the initial planting. An equivalent of 158 kg/ha of N was applied to each plot which had been assigned the fertilizer treatment, by broadcasting 1.2 kg of ammonium nitrate per plot.

Weeding

Weeding was done by hand. An effort was made to remove the entire weed plants including the roots. The weeds from each subplot which had been assigned the weeding treatment were removed and weighed. This procedure was repeated every six weeks. At the end

of the experimental period all 84 field plots, regardless of weeding treatment, were weeded as described above.

Planting

Crops were planted in 72 of the 84 field plots. The 12 plots in which no crops were planted constituted the natural vegetation production system.

Beans and corn were planted with a dibble stick. One bean seed or three corn seeds were dropped into each hole. Manioc cuttings were planted at an angle of approximately 30° from horizontal with 2 cm of the cutting protruding above the soil surface.

Harvesting

Beans were harvested by removing the entire bean plants from each subplot and were taken to the laboratory to be weighed. One week before the corn was harvested, the corn stems were folded over just below the mature ear and were left in a folded position until harvested. The entire corn plants were harvested from each subplot and were taken to the laboratory to be weighed. Manioc was harvested by removing the nine plants from each subplot. One manioc plant, which was subjectively judged to be representative of the nine plants, was taken to the laboratory to be weighed. The tubers were separated from the remaining eight manioc plants weighed separately on a tripod balance in the field.

Measurements and analyses

Bean, corn, and manioc yield were calculated in metric tons per hectare (MT/ha) through a procedure of oven-drying samples of a known quantity of wet-weight edible biomass, and weighing and calculating dry-weight edible biomass (yield).

Yields in MT/ha were extrapolated from the subplot measurements by multiplying the yield from each subplot by a ratio of the area in one ha (10,000 m²) to the area of the subplot. The area of the 3 by 3 m subplot was assumed to be 9 m² when beans and manioc were harvested, and 12.4 m² when corn was harvested. The area of the corn subplot was larger than the bean and manioc subplots due to the spatial design used to plant the corn (see Fig. 2).

All meteorological data were collected by a meteorological station operated by CATIE, which was located approximately 2 km from the field plots. Precipitation, solar radiation, relative humidity, and pan evaporation were measured at the station on a daily basis during the experimental period.

The data were subjected to analysis of variance with a split plot in time statistical model. When there was no interaction between treatments, means were compared with a Duncan Multiple Range test. When there was interaction between treatments, means of each treatment were compared separately.

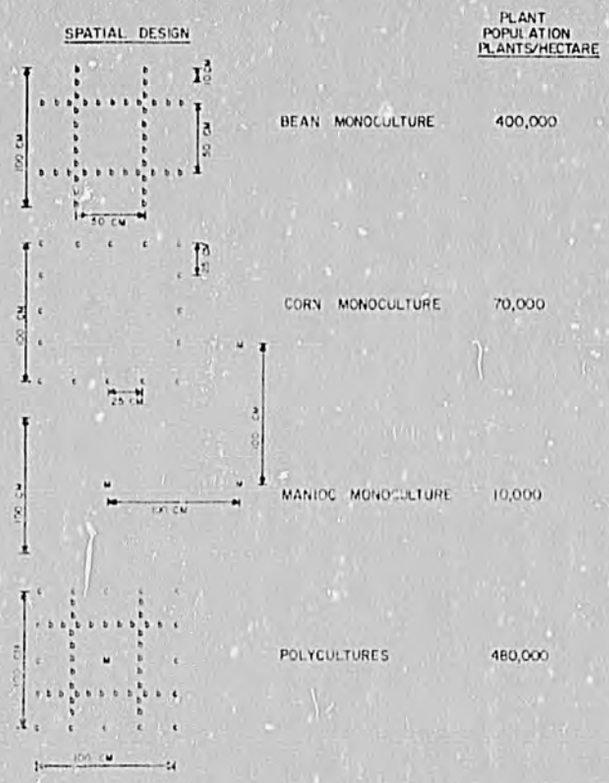

Fig. 2.—*The spatial design and planting densities of each crop. The symbols "b", "c", and "m" represent one bean and corn seed and one manioc cutting, respectively.*

Results

Crop yields are presented in tables as the mean of three replications with a confidence interval of one standard error. A conservative estimate of a 95 per cent confidence interval for comparing two means can be made by multiplying the standard error by three (approximate *t*-value). In all references to statistical significance in the discussion which follows, a 0.05 level is assumed.

Bean yield

Bean yields from the bean monoculture and three polyculture cropping systems are compared in Table 2.

The difference between the yield from the first crop in the bean monoculture and the yield from the bean crop in the succession polyculture can be assumed to be due to the effect of interspecific competition from the corn and manioc crops in the polyculture. The polyculture bean yield was not significantly different from the monoculture bean yield when both cropping systems received the no-fertilizer treatment (Fig. 3). When both cropping systems received the fertilizer treatment, the polyculture bean yield was significantly lower than

Table 2.—Bean yields (MT/ha) from four cropping systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Monoculture				
First Crop	0.476 (±0.011)*	0.493 (±0.042)	0.482 (±0.067)	0.650 (±0.110)
Second Crop	0.002 (±.0.002)	0.001 (±0.001)	0.001 (±0.001)	0.001 (±0.001)
Third Crop	0.001 (±0.001)	0.001 (±0.001)	0.001 (±0.001)	0.001 (±0.001)
Fourth Crop	0.040 (±0.022)	0.230 (±0.016)	0.026 (±0.022)	0.267 (±0.061)
Succession Polyculture	0.429 (±0.041)	0.407 (±0.185)	0.227 (±0.054)	0.291 (±0.063)
Reverse Polyculture	0.166 (±0.055)	0.196 (±0.047)	0.107 (±0.024)	0.191 (±0.049)
Intensive Polyculture				
First Crop	0.492 (±0.020)	0.449 (±0.062)	0.280 (±0.082)	0.271 (±0.017)
Second Crop	0.001 (±0.001)	0 (±0)	0 (±0)	0 (±0)
Third Crop	0.001 (±0.001)	0 (±0)	0 (±0)	0 (±0)
Fourth Crop	0.008 (±0.004)	0.091 (±0.048)	0.026 (±0.008)	0.366 (±0.015)

* Confidence interval is one standard error (S.D. $\bar{X}$).

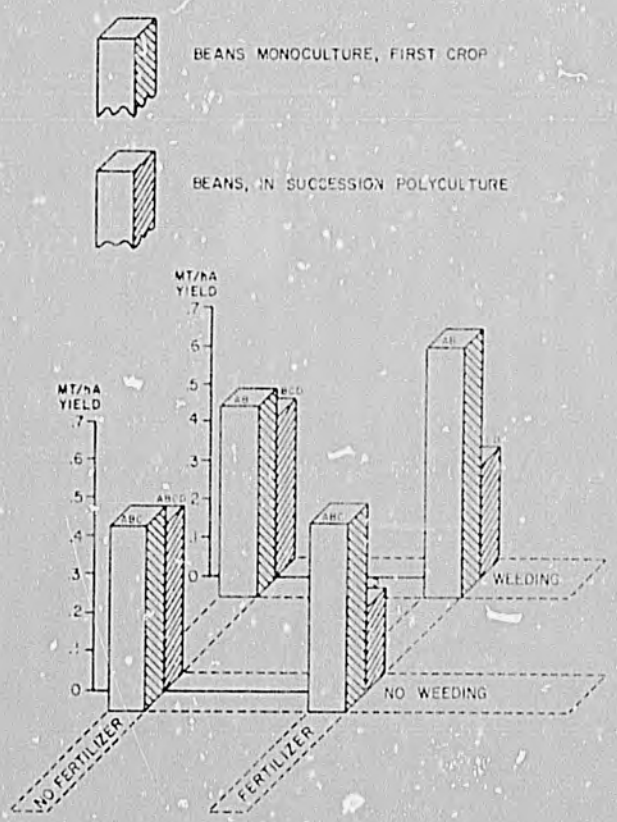

Fig. 3.—*A comparison between bean yields (MT/ha) from the first crop in the bean monoculture and the bean crop in the succession polyculture, under four fertilizer and weeding treatments. Columns with the same letter (a, b, c, ...) are not significantly different.*

the monoculture bean yield. The weeding treatments had no significant effect on the first crop in the bean monoculture or on the bean crop in the succession polyculture.

Bean yields from the succession polyculture and from the first crop of the intensive polyculture were not significantly different.

The bean yields from the second and third bean crops from the bean monoculture and intensive polyculture were complete crop failures due to a fungus infestation.

The yields from the fourth bean crops in both the monoculture and intensive polyculture were, in general, much lower than the yields from the first crops. In both cropping systems, the yields from the fourth crops were significantly higher under the weeding treatment than under the no-weeding treatment. Bean yield from the reverse polyculture was higher than the yield from the intensive polyculture or the bean monoculture when the no-weeding treatment was applied, but was lower than the yield from the monoculture when the weeding treatment was applied.

The bean crop in the succession polyculture was not planted at the same time as the bean crop in the reverse polyculture, but a comparison was of interest because in both cropping systems one bean crop was interplanted with one corn crop and one manioc crop. The bean yield from the reverse polyculture was approximately 50 per cent lower than the bean yield from the succession polyculture under all treatments.

Corn yield

Corn yields from the corn monoculture and three polycultures are compared in Table 3.

Table 3.—Corn yields (MT/ha) from four cropping systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Monoculture				
First Crop	3.270 (±0.220)	3.550 (±0.120)	5.100 (±0.780)	3.460 ±(0.600)
Second Crop	0.020 (±0.020)	0.680 (±0.280)	0.060 (±0.030)	0.460 (±0.170)
Succession Polyculture	2.230 (±0.410)	2.580 (±0.240)	4.040 (±0.190)	3.510 (±0.190)
Reverse Polyculture	0 (±0)	0 (±0)	0 (±0)	0 (±0)
Intensive Polyculture				
First Crop	1.890 (±0.320)	2.440 (±0.340)	2.930 (±0.490)	4.170 (±0.550)
Second Crop	0 (±0)	0 (±0)	0 (±0)	0 (±0)

* Confidence interval is one standard error (S.D. X).

The differences between the corn yield from the first crop in the corn monoculture and the corn yield from the succession polyculture can be assumed to be due to the effect of interspecific competition from the bean and manioc crops in the polyculture. When the no-fertilizer treatment was applied to both cropping systems, the monoculture corn yield was significantly higher than the polyculture corn yield (Fig. 4). However, when the fertilizer treatment was applied to both cropping systems, there was no significant difference between the corn yields. The weeding treatments had no significant effect on the first crop in the corn monoculture or on the corn crop in the succession polyculture.

Corn yields from the succession polyculture and from the first corn crop in the intensive polyculture were not significantly different.

The corn yields from the second corn crops in the corn monoculture and the intensive polyculture were significanlty lower than the first corn crops. The second corn crop in the intensive polyculture was a complete failure due to the high interspecific competition from the manioc crop. The yield from the second crop in the corn monoculture was significantly higher under the weeding treatment than under the no weeding treatment.

Manioc yield

The manioc yields from the manioc monoculture and three polyculture cropping systems are compared in Table 4. The manioc yield is given in dry weight to facilitate comparisons between cropping systems, even though manioc tubers are sold commercially on a wet weight basis. A close approximation of the wet-weight yield can be calculated by multiplying the dry-weight by a factor of three.

The difference between the manioc yields from the manioc monoculture and from the succession polyculture can be assumed to be due to interspecific competition from the bean and corn crop in the polyculture (Fig. 5). The effect of the interspecific competition

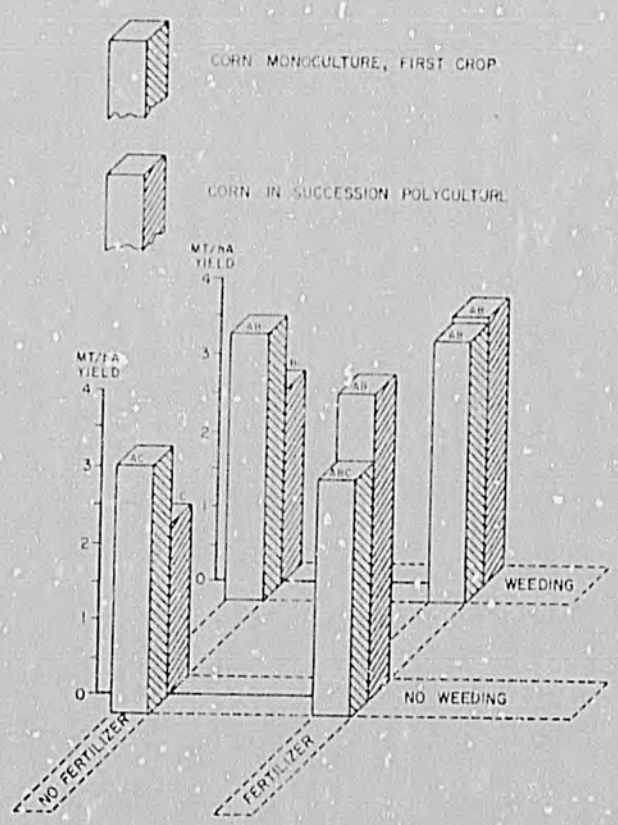

Fig. 4.—*A comparison between corn yields (MT/ha) from the first crop in the corn monoculture and the corn crop in the succession polyculture, under four fertilizer and weeding treatments. Columns with the same letter (a, b, c, ...) are not significantly different.*

Table 4.—Dry Weight manioc yields (MT/ha) from four cropping systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Monoculture	1.370 (±1.020)*	6.070 (±0.330)	4.770 (±1.460)	4.990 (±1.180)
Succession Polyculture	1.900 (±0.400)	3.690 (±0.220)	2.510 (±0.880)	3.570 (±1.350)
Reverse Polyculture	7.050 (±1.710)	5.910 (±1.140)	4.710 (±0.700)	6.260 (±1.810)
Intensive Polyculture	2.590 (±0.490)	3.730 (±0.570)	3.190 (±0.920)	3.980 (±1.110)

* Confidence interval is one standard error (S.D. $\bar{X}$).

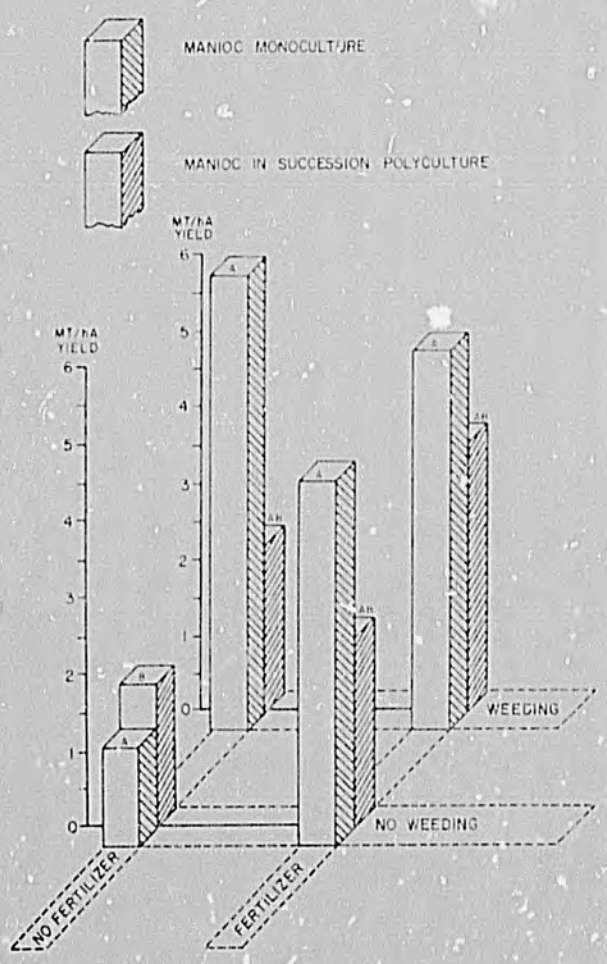

Fig. 5. A comparison between manioc yields (MT/ha) from the manioc monoculture and the manioc crop in the succession polyculture, under four fertilizer and weeding treatments. Columns with the same letter (a, b, c, . . .) are not significantly different.

was difficult to isolate due to the variance among replications. There was no significant difference between the monoculture manioc yields and the polyculture manioc yields under the same weeding and fertilizer treatments, except for a significantly higher yield from the monoculture which received the no-fertilizer and weeding treatment.

The manioc yields from the succession polyculture and intensive polyculture were not significantly different.

The manioc yield from the reverse polyculture was significantly higher than the yield from the monoculture, succession polyculture, and intensive polyculture when all cropping systems received the no-fertilizer and no-weeding treatment.

Discussion

The effect of the fertilizer and weeding treatments on the yield of beans, corn, and manioc can be evaluated by examining Figs. 3 to 5.

Weeding and the application of fertilizer resulted in the expected increase in yield from all crops when planted in monocultures, although in many cases the increase was not significant.

In the polyculture, fertilizer and weeding, which increased available resources for crop growth, resulted in an increase in corn and manioc yield but in a decrease in bean yield. The corn and manioc crops were able to compete successfully for the available resources, while the bean crop was less successful. This dynamic interaction between crops can result in less risk of a decline in total yield due to disease or physical stress on a crop species. When the yield of one crop decreases, the yield of another crop will increase. The interaction between crop species must be considered in the designs of polyculture cropping systems and in the calculation of fertilizer requirements. Interaction between components is a "systems" attribute and is evidence that

polycultures must be designed and evaluated as whole systems. The total yield and economic return from the monoculture and polyculture cropping systems will be compared in future reports on this experiment.

Summary

A polyculture is a cropping system in which crop plant populations of two or more species are planted within sufficient spatial proximity to result in interspecific competition for a limiting or potentially limiting resource. A monoculture is a cropping system with no interspecific competition.

Beans (*Phaseolus vulgaris* L.), corn (*Zea mays* L.), and manioc (*Manihot esculenta* Crantz) were planted separately in three monoculture cropping systems, and together in three polyculture cropping systems. The polycultures consisted of: 1) a succession polyculture in which beans, corn, and manioc were all planted at the same time and harvested after 9, 18, and 36 weeks respectively; 2) a reverse polyculture in which manioc was planted alone and then interplanted with corn after 18 weeks and beans after 27 weeks, and all crops harvested after 36 weeks; and 3) an intensive polyculture in which four bean crops, two corn crops, and one manioc crop were all interplanted during a 36 week period.

Four treatments consisting of the factorial product of two fertilizer treatments (no fertilizer, and an initial fertilizer application of 222, 169, and 40 kg/ha of N, P, and K respectively) and two weeding treatments (no weeding, and weeding every six weeks) were applied to the three monocultures and three polycultures and to a natural vegetation cropping system which consisted of the invading weeds.

The effect of the fertilizer and weeding treatments on the yield of beans, corn, and manioc was not the same in the monoculture and polyculture cropping systems. Interspecific competition in the succession polyculture resulted in a dynamic interaction between bean and corn yield. When fertilizer was applied to the polyculture, corn yield increased and bean yield decreased.

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