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A bean, corn and manioc polyculture cropping system. II. A comparison between the yield and economic return from monoculture and polyculture cropping systems*

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COMPENDIO

Un experimento en el que se plantaron frijoles, maíz y yuca en sistemas de monocultivo y policultivo se describió previamente en la primera parte de este informe (Turrialba 25(3):294-301. 1975). Los resultados del experimento fueron usados para comparar el rendimiento y el beneficio económico de tres monocultivos, en los que cada cultivo se plantó separadamente, con los de tres policultivos, en los que los tres cultivos estuvieron intercalados.

El rendimiento y beneficio económico de los policultivos fue significativamente más alto que los de los monocultivos. El beneficio económico neto del policultivo en sucesión, que había sido diseñado como un análogo a una compartimentalización de biomasa de hojas, tallos y raíces, durante la sucesión natural, fue más alto que el de los otros dos policultivos.

El policultivo en sucesion fue evaluado comparándolo con un sistema hipotético de cosecha en rotación de monocultivos usando los mismos tres cultivos. El rendimiento y beneficio económico neto fueron 37 y 54 por ciento más altos, respectivamente, en el policultivo de sucesión que en el sistema de cosecha en rotación de monocultivo. El autor.

Introduction

POLYCULTURE cropping systems are characterized by interspecific competition between two or more crop species, as opposed to monoculture cropping systems in which there is no interspecific competition between crop species (10). The potential of polyculture cropping systems has been known for many years. Successful polycultures which combine two or more species of perennials such as cacao and coconut (11, 12, 15, 18), two or more species of annuals such as corn and beans (1, 13, 16, 20), and two or more species of annuals and perennials such as rubber and corn (5, 14) have been reported.

The principal goal of most experiments with polyculture cropping systems has been an increase in yield (7, 8) or economic return (3, 4, 17, 19). Anderson and Williams (3) suggested that there is also less risk of a complete crop failure in a polyculture cropping system.

The effect of interspecific competition on the yield of beans, corn, and manioc in polyculture cropping systems was evaluated in Part I of this report (10). Data from that experiment can also be used to compare total cropping system yields and economic returns from monoculture and polyculture cropping systems. The different polyculture cropping systems can also be compared and evaluated.

The succession polyculture cropping system was designed in an attempt to mimic functional and structural characteristics of natural succession. Ewel (9) measured changes in leaf, stem, and root biomass compartments during natural succession after a forest area was cleared in eastern Panama, and noted that energy was channeled first into leaves, then stems, and finally

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roots as the ecosystem matured. This trend in biomass compartmentalization was an important guideline in the design of the succession polyculture cropping system, and suggested the use of leaf, stem, and root crops.

Mehods

Two fertilizer and two weeding treatments were applied to seven cropping systems, which included three monoculture cropping systems in which beans, corn, and manioc were planted separately, three polyculture cropping systems in which all three crops were intercropped in three different sequential arrangements, and a "cropping system" which consisted of naturally invading weeds. The crop species, experimental design, fertilizer and weeding treatments, planting, harvesting, and analysis procedure have been described previously in Part I (10).

Results

The total cropping yield and estimated economic return from the monoculture and polyculture cropping systems is reported below in metric tons hectare (MT/ha) and dollars hectare ($/ha), respectively. In all references to statistical significance a .05 level is assumed.

The yield of individual crops in the different cropping systems has been reported previously in Part I (10).

Biomass dynamics within cropping systems

The effects of the fertilizer and weeding treatments on the crop and weed biomass in the seven cropping systems are shown in Figures 1 to 7. Results of particular interest are outlined below.

When the natural vegetation cropping system (Fig. 1) received the fertilizer and weeding treatment, there was a significant increase in weed biomass at the first weeding, but this response decreased with time, and there was an oscillating effect on the weed biomass. When the natural vegetation cropping system was not weeded, there was no significant effect due to fertilizer at the end of the 36-week experimental period.

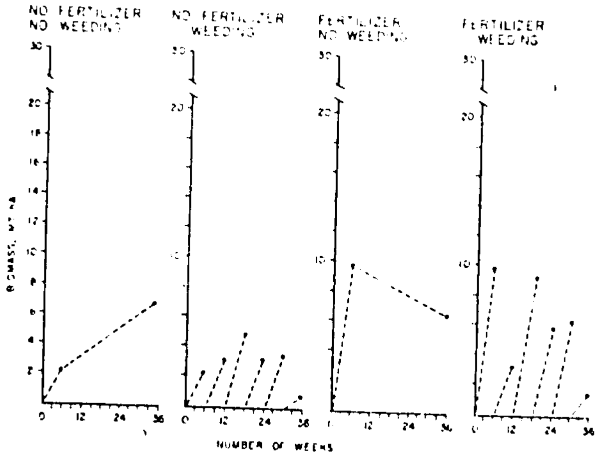

Fig. 1.—*Dry matter production of weeds (dotted line) in the natural vegetation cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

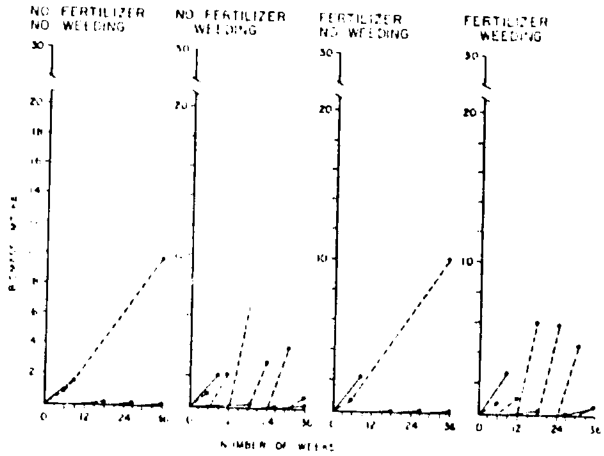

Fig. 2.—*Dry matter production of weeds (dotted line) and beans (solid line) in the bean monoculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatments, were assumed to be equal at six weeks.*

When the bean monoculture (Fig. 2) received the weeding treatment, the first and fourth crops were able to compete successfully with the weeds. The weed biomass was reduced due to competition from the first bean crop. The weeding treatment did not significantly affect the second and third bean crops, suggesting that the crop failures were not due to interspecific competition from weeds. In the bean monoculture which received the no-weeding treatment, the natural vegetation was able to successfully exclude the fourth bean crop.

When the corn monoculture (Fig. 3) received the weeding or fertilizer treatment, the corn was able to

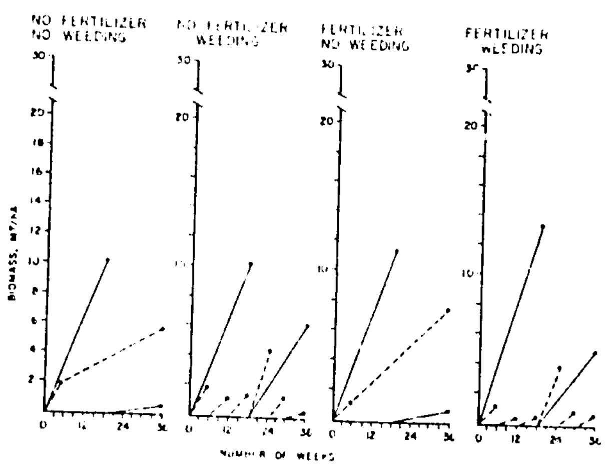

Fig. 3.—*Dry matter production of weeds (dotted line) and corn (solid line) in the corn monoculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

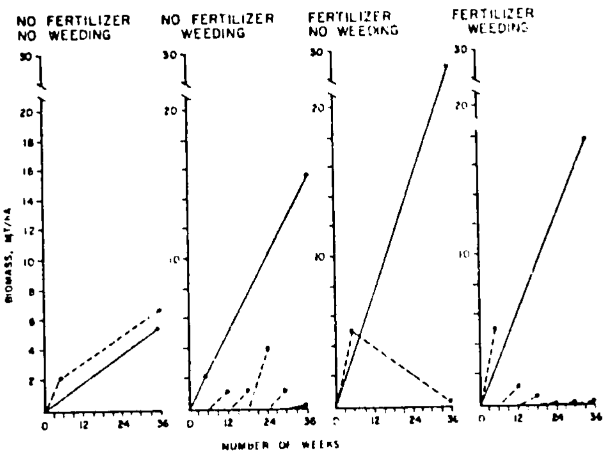

Fig. 4.—*Dry matter production of weeds (dotted line) and manioc (solid line) in the manioc monoculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

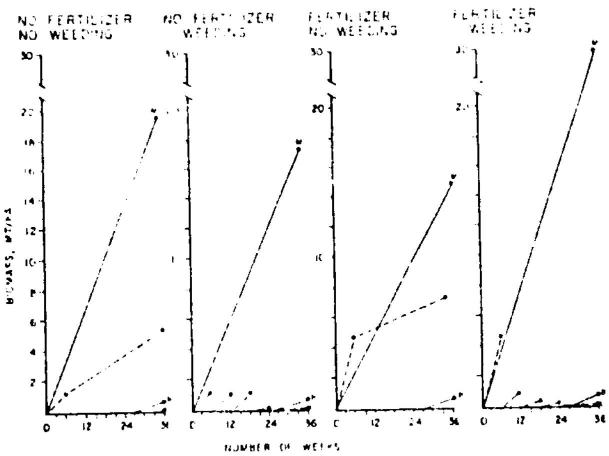

Fig. 5. *Dry matter production of weeds (dotted line), beans, corn, manioc (solid lines labelled b, c, and m, respectively) in the succession polyculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

successfully compete with the weeds. However, the weed biomass was reduced less by the first crop in the corn monoculture than by the first crop in the bean monoculture. When the no-weeding treatment was applied, the weeds were able to successfully exclude the second corn crop.

When the manioc monoculture (Fig. 4) received the weeding or fertilizer treatment, the manioc was able to compete successfully and exclude almost all weeds. The weed biomass after the first weeding was reduced less by the manioc monoculture than by the first crop in the bean or corn monoculture.

In the succession polyculture (Fig. 5), the effects of the beans, corn, and manioc on weed biomass noted in the three monoculture cropping systems were combined. There was very low weed invasion during the first 18 week period. After the corn crop in the succession polyculture was harvested, the manioc in the succession polyculture was not able to compete with the weeds as successfully as the manioc in the manioc monoculture.

In the reverse polyculture (Fig. 6), the effects of the beans, corn, and manioc on the weed biomass were similar to that noted for the manioc monoculture cropping system. The corn crop planted at the 18th week was a complete failure due to interspecific competition from the manioc. However, the bean crop planted at the 27th week was able to successfully compete with the manioc.

In the intensive polyculture (Fig. 7), the effects of the beans, corn, and manioc on the weed biomass were similar to that noted for the manioc monoculture cropping system. As in the bean monoculture, the second

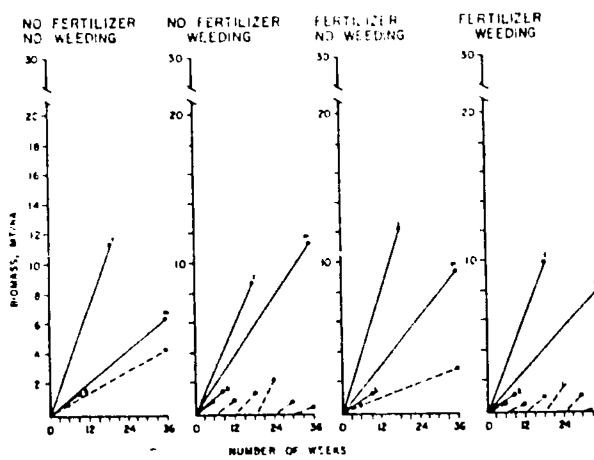

Fig. 6.—*Dry matter production of weeds (dotted line), beans, corn, and manioc (solid lines, labelled b, c, and m, respectively) in the reverse polyculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

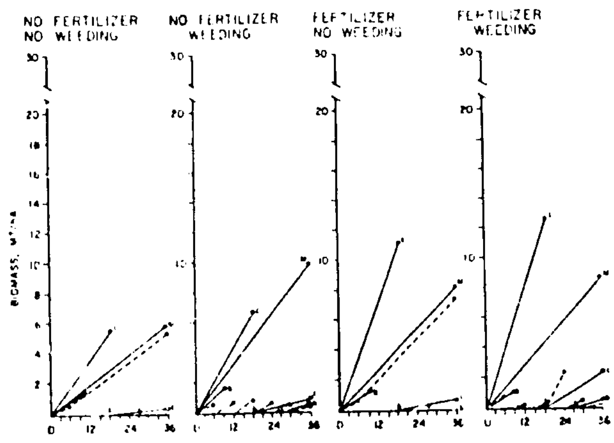

Fig. 7.—*Dry matter production of weeds (dotted line), beans, corn, and manioc (solid lines, labelled b, c, and m, respectively) in the intensive polyculture cropping system under four fertilizer and weeding treatments. The weed biomass under the no-weeding and weeding treatments, receiving the same fertilizer treatment, were assumed to be equal at six weeks.*

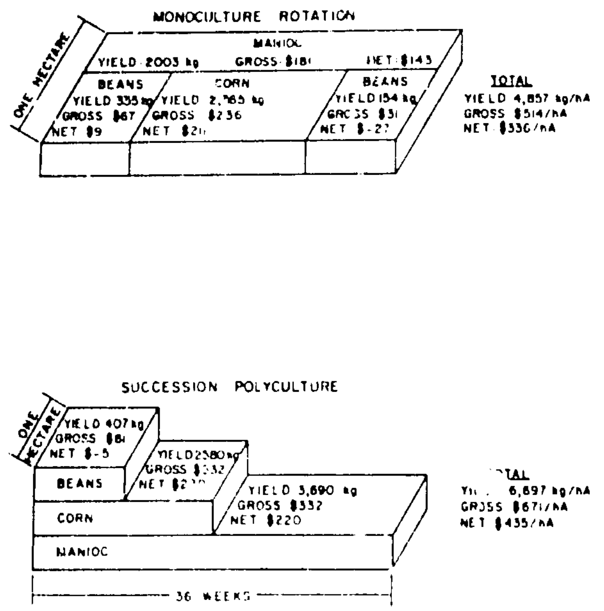

Fig. 8.—*A comparison between a hypothetical monoculture rotation cropping system and the succession polyculture cropping system.*

and third bean crops were complete crop failures due to a fungus infestation. When the intensive polyculture received the no-weeding treatment, the fourth bean crop and second corn crop were not able to successfully compete with the manioc and weeds.

Cropping system yield and economic return

The total yield from each cropping system is listed in Table 1. In general, the highest yields were obtained with the application of the fertilizer and weeding treatments. If only one of the treatments was applied, there was no significant decrease in yield from any cropping system. However, if neither treatment was applied, the yields from the bean and manioc monocultures were significantly reduced.

Under all treatments, higher yields were obtained from the polyculture cropping systems than from the monoculture cropping systems. The highest yield was obtained from the intensive polyculture cropping system which received the weeding and fertilizer treatment.

Gross and net economic return from each cropping system was calculated using the prices listed in Table 2. The prices are those which were obtained when the crops were sold in the market at Turrialba, Costa Rica. An estimate of the number of man-days required to plant and harvest each crop was made using data collected by Daines (6) in Colombia, South America. The cost of weeding was assumed to be the same for all cropping systems. The estimate used is the mean time required to weed the 42 field plots at the first weeding period. Field plot measurements of weeding costs in $/kg of weeds harvested from each cropping system were not reliable enough to be extrapolated for comparison of cropping systems.

The gross economic return (total market value of yield) from each cropping system is listed in Table 3. The economic response to the treatments is similar to that noted for the total yield from each cropping system. When the same fertilizer and weeding treatment was applied, the total yield and gross economic return from any of the polycultures was higher than from any of the monocultures.

An estimate of the net economic return(gross economic return minus total expediture) from each cropping system is listed in Table 4. An estimated negative net economic return was obtained from the bean monoculture under all treatments, from the manioc monoculture

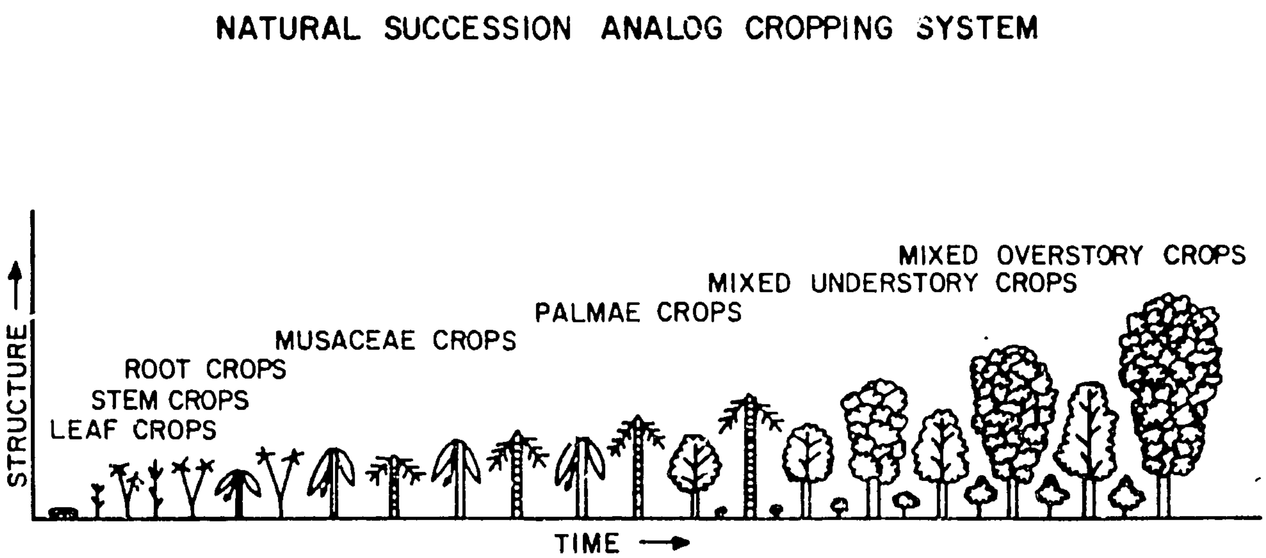

Fig. 9.—*A hypothetical natural succession analog cropping system shown diagrammatically.*

Table 1.—Total yield (Mt/ha) from six croppings systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Bean Monoculture	0.518 (± 0.011)*	0.725 (± 0.057)	0.547 (± 0.057)	1.020 (± 0.170)
Corn Monoculture	3.290 (± 0.230)	4.220 (± 0.370)	5.160 (± 0.770)	3.920 (± 0.760)
Manioc Monoculture	1.370 (± 1.020)	6.070 (± 0.320)	4.770 (± 1.160)	4.990 (± 1.180)
Succession Polyculture	4.560 (± 0.810)	6.680 (± 0.419)	6.780 (± 0.820)	7.370 (± 1.230)
Reverse Polyculture	7.210 (± 1.760)	6.110 (± 1.100)	4.510 (± 0.730)	6.450 (± 1.850)
Intensive Polyculture	4.980 (± 0.800)	6.730 (± 0.400)	6.440 (± 1.200)	8.600 (± 0.820)

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

Table 2.—Prices used to calculate gross and net economic return.

		Expenditure by crop		
Crop	Price	Seed	Plant and Harvest	Total
Beans	$.20/kg	80 kg $16	47 man-day/ha $ 70	$ 86
Corn	$.10/kg	21 kg $ 2	24 man-day/ha $ 36	$ 38
Manioc	$.09/kg	Cuttings $ 0	75 man-day/ha $112	$112

	Expenditure by treatment ($/ha)	
Weeding	20 man day/ha	$ 30
Fertilizer		$168

Expenditure by cropping system ($/ha)

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Monocultures				
Beans	544	521	512	692
Corn	76	256	244	424
Manioc	112	292	280	460
Polycultures				
Succession	236	416	404	584
Reverse	236	416	404	584
Intensive	532	712	700	880

Table 3.—Gross economic return ($ ha) from six cropping systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Bean Monoculture	101 (± 3)*	145 (± 11)	109 (± 12)	202 (± 34)
Corn Monoculture	330 (± 22)	422 (± 37)	316 (± 77)	392 (± 76)
Manioc Monoculture	123 (± 92)	546 (± 29)	430 (± 130)	419 (± 106)
Succession Polyculture	479 (± 76)	661 (± 25)	666 (± 80)	730 (± 132)
Reverse Polyculture	667 (± 94)	571 (± 93)	418 (± 53)	601 (± 171)
Intensive Polyculture	522 (± 70)	692 (± 41)	644 (± 106)	856 (± 84)

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

which received the weeding and fertilizer treatment, and from the intensive polyculture under all treatments. When the no-weeding and no-fertilizer treatment was applied, the highest net economic returns were obtained from the corn monoculture, the succession polyculture, and the reverse polyculture. When the weeding and fertilizer treatment was applied, the highest net economic return was obtained from the succession polyculture cropping system.

Discussion

The monoculture cropping systems compared in the experiments were designed under the restriction of the experimental design, and probably cannot be considered as practical cropping systems. For example, it would seldom be practical to plant four sequential bean crops. However, the data collected from the experiment can be used to compare the succession polyculture cropping

Table 4.—Estimated net economic return ($ ha) from six cropping systems under four fertilizer and weeding treatments.

	No Weeding No Fertilizer	Weeding No Fertilizer	No Weeding Fertilizer	Weeding Fertilizer
Bean Monoculture	—210 (± 3)*	—379 (± 11)	—405 (± 12)	—490 (± 34)
Corn Monoculture	251 (± 22)	166 (± 37)	72 (± 77)	— 52 (± 76)
Manioc Monoculture	11 (± 92)	251 (± 29)	150 (± 130)	— 11 (± 106)
Succession Polyculture	213 (± 76)	245 (± 25)	262 (± 80)	146 (± 132)
Reverse Polyculture	431 (± 94)	155 (± 93)	41 (± 53)	17 (± 171)
Intensive Polyculture	— 10 (± 70)	— 20 (± 41)	56 (± 106)	— 24 (± 84)

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

system with a more realistic hypothetical bean, corn, and manioc rotation monoculture cropping system.

A comparison between the succession polyculture and a hypothetical rotation monoculture is shown in Fig. 8. Each cropping system utilizes one hectare of land and a 36-week cropping period. The yield and economic return obtained from the monoculture cropping systems which received the no-fertilizer and weeding treatment were used to calculate the yield and economic return for the rotation cropping system. The first and fourth bean monoculture crops, which were not affected by the fungus infestation which lowered the yield of the second and third crop, were used as estimates of the two bean crops in the rotation. The first corn crop and the manioc crop from the respective monoculture cropping systems were used as estimates of the corn and manioc crops in the rotation. The yield and economic return from the succession polyculture which received the no-fertilizer and weeding treatment in the experiments were used directly in the comparison.

The results of the hypothetical polyculture monoculture comparison outlined above indicate the potential of the succession polyculture cropping system. A farmer changing from the monoculture rotation system to the succession polyculture would obtain a 37 per cent increase in total yield over a 36 week period. Assuming the same prices used to calculate gross and net economic return in the experiment (Table 2), the polyculture would produce a 29 per cent increase in gross economic return and a 54 per cent increase in net economic return.

The results obtained in this comparison are consistent with the reports of other investigators. Parijs (16) interplanted beans, corn, and manioc and obtained higher yield from the polyculture than from any monoculture systems planted for comparison. Willey and Osiru (21) studied bean and corn mixtures (polycultures) under different population densities and obtained a 38 per cent higher yield from the highest yielding polyculture than could have been obtained by growing the crops separately. Lepiz (13) obtained significantly higher gross economic return from bean and corn polycultures than from monocultures of either crop.

The characteristics of the succession polyculture cropping system which contributed to the high yield and economic return obtained in this experiment are difficult to identify conclusively. One characteristic of probable importance was the ability of the cropping system to successfully compete with invading weeds (Fig. 5). Higher polyculture yield was probably also related to a modification of the architecture of the corn and manioc in the polyculture. When the corn and manioc yield from the succession polyculture and the respective monocultures (10) is compared with the total crop biomass harvested (Figs. 3 and 4), the percentage of edible corn and manioc increased from 22 and 28 in the monocultures to 35 and 42, respectively, in the succession polyculture. The polycultures were probably able to use the available resources of soil nutrients and solar energy more efficiently than the monocultures, but this could not be verified from the soil samples analyzed.

The succession polyculture cropping system evaluated in the experiment was partially designed by using biomass compartmentalization during natural succession as a guideline. The success of a cropping system which was only evaluated over a 36-week period is not, of course, conclusive evidence that a cropping system designed to mimic natural succession over a longer period would be successful. However, a cropping system such as the hypothetical natural succession analog cropping system, shown diagrammatically in Fig. 9, should be the subject of further investigations. In the succession analog cropping system proposed, *Musaceae* crops such as banana and plantain are interplanted after the stem crops are harvested. As root crops are harvested, they are replaced by *Palmae* crops, and the succession could be continued until the tree crops are ready for harvest. The trees are then harvested and the succession analog cropping system is repeated.

Summary

An experiment in which beans, corn, and manioc were planted in monoculture and polyculture cropping systems was described previously in Part I of this report (10). The results from the experiment were used to compare the yield and economic return from three monocultures, in which each crop was planted separately, and three polycultures, in which the crops were interplanted.

The yield and economic return from the polycultures was significantly higher than from the monocultures. The net economic return from the succession polyculture, which had been designed as an analog to leaf, stem, and root biomass compartmentalization during natural succession, was higher than from the two other polycultures.

The succession polyculture was evaluated by comparing it with a hypothetical monoculture rotation cropping system using the same three crops. The yield and net economic return were 37 and 54 percent higher, respectively, from the succession polyculture than from the monoculture rotation cropping system.

Literature cited

1. ALVIM, R., and ALVIM, P. de T. Efeito da densidade de plantio no approveitamento da energia luminosa pelo milho *(Zea mays)* e pelo feijão *(Phaseolus vulgaris)*, em culturas exclusivas e consorciadas. Turrialba 19 (3):389-395. 1969.

2. ANDERSON, E., and WILLIAMS, L. O. Maize and sorghum as a mixed crop in Honduras. Annals of the Missouri Botanical Garden 41(2):213-215. 1954.

3. ANDREWS, D. J. Intercropping with sorghum in Nigeria. Experimental Agriculture 8(2):139-150. 1972.

4. ANTHONY, K. R. M., and WILLIMOTT, S. G. Cotton interplanting experiments in the South-West Sudan. Empire Journal of Experimental Agriculture 25(97): 29-36. 1957.

5. BANGHAM, W. N. Hule y maíz; una excelente combinación para los trópicos americanos. *In* Conferencia Interamericana de Agricultura, 3A, Caracas, Venezuela. Serie Internacional Nº 7, 1946. 21 p.

6. DAINES, S. R. Summary results of employment income distribution and small farm analysis. Analytical Working Document Nº 2. Colombia Agriculture Sector Analysis. AID, Bogotá. 1972.

7. EVANS, A. C. Studies of intercropping I. Maize or sorghum with groundnuts. East African Agriculture and Forestry Journal 26(1):1-10. 1960.

8. ————, and SREEDHARAN. Studies of intercropping II. Castorbean with groundnuts or soya-bean. East African Agriculture and Forestry Journal 28(1): 7-8. 1962.

9. EWEL, J. J. Biomass changes in early tropical succession. Turrialba 21(1):110-112. 1971.

10. HART, R. D. A bean, corn, and manioc polyculture cropping system I. The effect of interspecific competition on crop yield. Turrialba 25(3):294-301. 1975.

11. JOSE, B. M. Intercropping cacao with coconut. Coffee and Cacao Journal 11(9-10):128-130. 1968.

12. LEACH, J. R. Underplanting coconut with cocoa in West Malaysia. Cocoa Growers Bulletin 16:21-26. 1971.

13. LEPIZ, I. R. Asociación de cultivos maiz-frijol. Agricultura Técnica en México 3(3):98-101. 1971.

14. MORALES, J. O., BANGHAM, W. N., and BARRUS, M. F. Cultivos intercalados en plantaciones de *Hevea*. Turrialba, Costa Rica. Instituto Interamericano de Ciencias Agrícolas. Boletín Técnico Nº 1. 1949. 26 p.

15. OWEN, J. B. Underplanting coconut stands with cocoa on Kuala Perak Estate with special reference to planting methods and manufacturing procedures. Planter 43(3):95-98. 1957.

16. PARIJS, A. van. Rotation des plantes vivrières dans la région de Nioka (Haut-Ituri). Bulletin Agricole du Congo Belge 48(6):1515-1544. 1957.

17. SEN, S., MUKHERJEE, D., and MAZYMDAR, H. K. A preliminary study on the possibilities of growing cotton in unirrigated areas of West Bengal. Indian Agricultural turist 5(1):52-59. 1961.

18. TRAEHOLT, P. The cocoa industry in Malaya, ways of introducing it, and its prospects. Planter 38(5):248-251. 1962.

19. VARMA, M. P., and KANKE, M. S. S. R. Selection of intercrops for cotton in India. Experimental Agriculture 5(3):223-230. 1969.

20. WILKEN, G. C. Drained-field agriculture; an intensive farming system in Tlaxcala, Mexico. Geographical Review 59(2):215-241. 1969.

21. WILLEY, R. W., and OSIRU, D. S. O. Studies on mixtures of maize and beans *(Phaseolus vulgaris)* with particular reference to plant populations. Journal of Agricultural Science 79(3):517-529. 1973.