POPULATION PRESSURE AND AGRICULTURAL INTENSITY*

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ABSTRACT. A positive relationship between population pressure and agricultural intensity is fundamental to Boserup's thesis of agricultural growth and to several of its modifications. Correlation analysis reveals a strong positive association between the population densities and agricultural intensities of a sample of tropical subsistence agriculturalists; the variation in population densities accounts for fifty-eight percent of the variation in the logarithm of agricultural intensities. The addition of subsistence and environmental factors to the model increases the explained variation and suggests several modifications of Boserup's thesis.

ALTHOUGH scholars have observed the influences of population pressure on agricultural intensities for quite some time, the relationship between these two factors has received close attention only recently.[1] Boserup stimulated this attention by contending that population pressure determines agricultural intensity: increases in population pressure cause increases in agricultural intensity; decreases in the former cause decreases in the latter.[2] The thesis is founded on the premise that subsistence farmers are labor-efficient and will choose the intensity of cultivation that will satisfy their agricultural needs with the least amount of work. Extensive systems of agriculture maximize labor efficiency when population density is low. Since total production in such systems is low, however, extensive cultivation cannot support high population densities. Boserup maintains that an increase in population is the key factor that forces a shift from extensive to less efficient, intensive systems of cultivation.

The evidence to support Boserup's thesis of a positive relationship between population pressure and agricultural intensity as it applies to subsistence cultivators has come mainly from field observations.[3] With a few exceptions, no-

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[1] The history of the population pressure thesis is not clear. Several references to the influential role of population pressure on agriculture were made in the early part of this century; O. F. Cook, "Staircase Farms of the Ancients," *National Geographic Magazine*, Vol. 29 (1916), p. 493. A more recent treatment of the topic is H. C. Brookfield, "Local Study and Comparative Method: An Example From Central New Guinea," *Annals*, Association of American Geographers, Vol. 52 (1962), pp. 242–52.

[2] Ester Boserup, *The Conditions of Agricultural Growth* (Chicago: Aldine Publ. Co., 1965). Brookfield's evaluation of the topic preceded Boserup's work by several years. Brookfield did not place his work in a theoretical context and did not treat the topic as broadly as did Boserup. Consequently, Brookfield's excellent work has not received the attention afforded to Boserup's work. Also of note, an argument similar to that posited by Boserup was developed independently by M. B. Gleave and H. P. White, "Population Density and Agricultural Systems in West Africa," in M. F. Thomas and G. W. Whittington, eds., *Environment and Land Use in West Africa* (London: Methuen and Co., 1969), pp. 273–300.

[3] For examples of those who largely concur with Boserup's contentions, see the following: William C. Clarke, "From Extensive to Intensive Shifting Cultivation: A Succession from New Guinea," *Ethnology*, Vol. 5 (1966), pp. 347–59; Robert Mc. Netting, "Ecosystems in Process: A Comparative Study of Change in Two West African Societies," in David Dumas, ed., *Contributions to Anthropology: Ecological Essays*, National Museum of Canada Bulletin 230 (1969), p. 105; Donald E. Vermeer, "Population Pressure and Crop Rotational Changes Among the Tiv of Nigeria," *Annals*, Association of American Geographers, Vol. 60 (1970), pp. 299–314; and Harry

tably Brookfield's comparative study of agricultural intensities among subsistence groups in New Guinea, the relationship between population pressure and agricultural intensity has not been treated systematically.[4] Recently, however, Brown and Podolefsky demonstrated a close statistical relationship between population density and agricultural intensity in highland New Guinea.[5] Although their study primarily addresses the effects that population density and agricultural intensity have on land tenure and group size, it adds considerable insight into our otherwise limited understanding of the strength and nuances of the population pressure–agricultural intensity relationship. Our examination differs from that of Brown and Podolefsky in that 1) the data cover a broader geographical area, 2) agricultural intensity is defined differently, 3) the data are subjected to different modes of statistical analyses, and 4) the emphasis is strictly on the association between population density and agricultural intensity.[6]

This investigation concentrates on the relationship between population density and agricultural intensity as it exists among several groups of tropical subsistence agriculturalists. This emphasis is maintained because 1) subsistence agriculturalists produce most of their own food, a practice that reduces the influences of exogenous factors (such as distant markets) on cultivation; 2) most subsistence agriculturalists live in the tropics; and 3) Boserup derived her thesis, in part, from observations of such cultivators.[7]

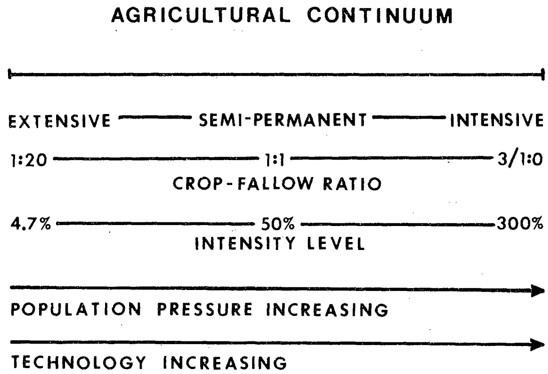

FIGURE 1

DATA

The principal data for this study are the population densities and agricultural intensities of twenty-nine groups of tropical subsistence cultivators (Table 1). These groups maintain different subsistence bases and occupy different tropical environments. Since each of the groups practice various forms of subsistence agriculture, the best measure of the pressure exerted on the intensity of agriculture of each group by its population is the ratio of the population of each group to the total area available to it for cultivation. The data necessary to determine this ratio are not always available in the literature and, as a result, the ratio of the group's population to the principal area of cultivation is used here as the measure of population pressure. This surrogate measure is referred to as population density.

Agricultural intensity is more difficult to determine. Boserup refers to agricultural intensity as the frequency with which a parcel of land is cultivated, and employs the crop-fallow cycle to measure that frequency (Fig. 1).[8] For example, a system in which the land is cultivated for 2 consecutive years and fallowed for 20 consecutive years has a crop-fallow cycle of 2:20. To facilitate comparisons of different frequencies of cultivation, the crop-fallow cycle is converted to a form that expresses the number of

W. Basehart, "Cultivation Intensity, Settlement Patterns, and Homestead Forms among the Matengo of Tanzania," *Ethnology*, Vol. 12 (1973), p. 71. For an example of a modification of the Boserup thesis see H. C. Brookfield, "Intensification and Disintensification in Pacific Agriculture: A Theoretical Approach," *Pacific Viewpoint*, Vol. 13 (1972), pp. 30–48.

4 Brookfield's study was systematic in its approach but did not provide statistical analyses. Brookfield examined many more variables than are examined here. Brookfield, op. cit., footnote 1.

5 Paula Brown and Aaron Podolefsky, "Population Density, Agricultural Intensity, Land Tenure, and Group Size in the New Guinea Highlands," *Ethnology*, Vol. 15 (1976), pp. 211–38.

6 Our examination was largely inspired by the absence of statistical treatments of the topic and with no knowledge of the then unpublished work of Brown and Podolefsky.

7 The meanings of the term subsistence range from subsistence production (all production is consumed by the producer) to subsistence living (some production is not consumed by the producer). Here the term refers to all groups that depend primarily on their own production for maintaining a livelihood; Clifton R. Wharton, Jr., "Subsistence Agriculture: Concept and Scope," in C. R. Wharton, Jr., ed., *Subsistence Agriculture and Economic Development*, (Chicago: Aldine Publ. Co., 1965), p. 13.

8 Boserup, op. cit., footnote 2, pp. 15–16.

TABLE 1.—SAMPLE GROUP DATA

Group	Location	Population density (km²)	Average agric. intensity	Average agric. cycle	Major crops[a]	Livestock	Aquatic resources	Mean annual precip. (mm)	Length of dry season (months)	Alluvial/ hydro-morphic soils	Data quality[b]
1. Campa	Gran Pajonal, eastern Peru	1.0	9	1:10	mc,mz	—	—	2000	4	—	2
2. Tsembaga	Madang Dist., New Guinea	26.0	7	1:14	rc	+	—	3277	0	+	2
3. Yaruro-Caño Totudoro	southeastern Venezuela	27.0	20	1:4	mc,mz	—	—	1600	4	—	2
4. Kuikuru	central Brazil	1.1	6	1:17	mc	—	+	2800	0	—	2
5. Chimbu	Naregu, New Guinea	101.0	50	1:1	sp	+	—	2413	0	+	1
6. Baegu	Malaita, Solomon Is.	13.1	16	1:5	sp,t	+	—	2000	0	+	3
7. Bomagai-Angoiang	Ndwimba Basin, New Guinea	14.9	5	1:17.5	sp,t	+	—	4445	0	—	1
8. Aruní	Sabakamada, New Guinea	134.7[c]	100	1:0	sp	+	—	2490	0	+	1
9. Iban	Baleh, Sarawak	3.0	7	1:13	dr	—	—	3000	0	—	2
10. Ngawbe	western Panama	5.7	14	1:6	mz,be	—	—	1500	3	—	3
11. Ngawbe Cerro Mamita	western Panama	7.6	14	1:6	mz,be	—	—	1500	3	0	2
12. Kuma	Wahgi Valley, New Guinea	38.6	20	1:3.8	sp	+	—	2438	0	+	3
13. Ipili	Porgera Valley, New Guinea	25.0	10	1:8.7	sp	—	—	2540	0	—	3
14. Enga-Mae	Kara-Sari Terr., New Guinea	143.0	50	1:1	sp	+	—	2740	0	—	3
15. Yakö	Umor, Nigeria	90.0	16	1:5	y	—	—	2350	2	—	1
16. Gari	Madang Dist., New Guinea	27.5	14	1:6	t	—	—	3000	0	—	3
17. Tiv	Mba Gor, Nigeria	103.0	50	1:1	y	+	—	2000	0	—	3
18. Gwemba Tonga	Mid Zambesi, Zambia	115.8	150	1.5/1:0[d]	so,mt	+	+	2000	8	+	3
19. Ba Dugu Djoliba	Niger Valley, Southwestern Mali	40.2	35	1:1.8	so	—	+	1000	6	+	1
20. Há apaí	Tonga Is., Polynesia	200.0	59	1:0.7	y,ba	—	+	1778	0	—	2
21. Dani-Dugum	Balim Valley, West Irian	50.0	29	1:2.5	sp	+	—	2082	0	+	1

TABLE 1.—*Continued*

Group	Location	Population density (km²)	Average agric. intensity	Average agric. cycle	Major crops[a]	Livestock	Aquatic resources	Mean annual precip. (mm)	Length of dry season (months)	Alluvial/ hydro-morphic soils	Data quality[b]
22. Abelam-Yenigo	Sepik, New Guinea	49.8	10	1:8.5	y,t	+	—	1651	0	—	2
23. Abelam-Stapikam	Sepik, New Guinea	106.2	16	1:5	y,t	—	—	1657	0	+	2
24. Rarak village	western Sumbawa	34.6	22	1:3.5	dr,mz	—	—	1651	0	—	2
25. Amba	Toro Dist., Uganda	140.6	67	1:0.5	ba,mc,sp	+	—	1500	6	—	2
26. Kofyar	Jos Plateau, Nigeria	140.0	100	1:0	mt,so	+	—	1524	3	—	1
27. Kara	Ukara Is., Lake Victoria	233.0	100	1:0	mt	+	—	2000	3	—	1
28. Miskito-Tasbapauni	Nicaragua	15.4	18	1:4.5	mc,ba	—	+	4064	3	—	1
29. Karinya-Bajo Hondo	Venezuela	12.0	70	3.5:1.5	mc	—	—	1200	5	+	2

[a] *Major Crops*: ba—banana (*Musa sapientum*), be—bean (*Phaseolus* spp.), dr—dry rice (*Oryza stiva*), mc—manioc (*Manihot* spp.), mt—millet (*Pennisetum* spp.), mz—maize (*Zea mays*), rc—root crops, so—sorghum (*Sorghum* spp.), sp—sweet potato (*Ipomoea batatas*), t—taro (*Colocasia* spp.), y—yam (*Dioscorea* spp.).

[b] *Data Quality*: Ratings refer only to the population density and agricultural intensity data required for this study: 1—all data based on measurement; 2—one or more of the data based on estimates; 3—data omitted or based on tenuous estimates.

[c] *Aruni*: Includes the terrace section of the Aruní.

[d] *Gwemba Tonga*: Other sources suggest that the major intensity of cultivation for this group is 2/1:0.

Sources: Abelam—D. A. M. Lea, "The Abelam: A Study in Local Differentiation," *Pacific Viewpoint*, Vol. 6 (1965), pp. 191–214; Amba—E. H. Winter, Bwamba Economy: The Development of a Primitive Subsistence Economy in Uganda, *East African Studies* No. 5 (Uganda: East African Institute of Social Research, 1955); Aruní—Eric W. Waddell, *The Mound Builders: Agricultural Practices, Environment, and Society in the Central Highlands of New Guinea* (Seattle: University of Washington Press, 1972); Baegu—Harold M. Ross, Baegu: Social and Ecological Organization in Malaita, Solomon Islands, *Illinois Studies in Anthropology*, No. 8 (Urbana: University of Illinois Press, 1973); Ba Dugu Djoliba—William I. Jones, "The Food Economy of Ba Duga Djoliba, Mali," in P. F. M. McLoughlin, ed., *African Food Production Systems: Cases and Theory* (Baltimore: Johns Hopkins Press, 1970), pp. 265–306; Bomagai-Angoiang—William C. Clarke, *Place and People: An Ecology of A New Guinean Community* (Berkeley: University of California Press, 1971); Campa—William M. Denevan, "Campa Subsistence in the Gran Pajonal, Eastern Peru," *Geographical Review*, Vol. 61 (1971), pp. 496–519; Chimbu—Harold C. Brookfield and Paula Brown, *Struggle for Land: Agriculture and Group Territories among the Chimbu of the New Guinea Highlands* (London: Oxford University Press, 1963); Dani—Karl G. Heider, *The Dugam Dani: A Papuan Culture in the Highlands of West New Guinea* (Chicago: Aldine Publ. Co., 1970); Enga—M. J. Meggitt, "The Enga of the New Guinea Highlands: Some Preliminary Observations," *Oceania*, Vol. 28 (1958), pp. 253–330; Gari—Peter Lawrence, *Land Tenure among the Gari: Traditional System of a New Guinea People* (Canberra: Australian National University, 1955); Há apaí—Alaric Maude, "Shifting Cultivation and Population Growth in Tonga," *Journal of Tropical Geography*, Vol. 31 (1970), pp. 57–64; Iban—J. D. Freeman, Iban Agriculture, *Colonial Research Studies*, No. 18 (London: Her Majesty's Stationery Office, 1955); Ipili—M. J. Meggitt, "The Ipili of the Porgera Valley, Western Highlands District, Territory of New Guinea," *Oceania*, Vol. 28 (1957), pp. 31–55; Kara—D. Thornton and N. V. Rounce, "Ukara Islands and the Agricultural Practices of the Wakara," *Tanganyika Notes and Records*, No. 1 (1936), pp. 25–32; Karinya—Denevan and Bergman, op. cit., footnote 15; Kofyar—Robert McC. Netting, *Hill Farmers of Nigeria: Cultural Ecology of the Kofyar of the Jos Plateau* (Seattle: University of Washington Press, 1968); Kuikuru—Robert L. Carneiro, "Slash-And-Burn Cultivation Among the Kuikuru and Its Implications for Cultural Development in the Amazon Basin," in J. Wilbert, ed., *The Evolution of Horticultural Systems in Native South America: Causes and Consequences—A Symposium*, (Caracas: Sociedad de Ciencias Naturales La Salle, 1961), pp. 47–67; Kuma—Marie Reay, *The Kuma: Freedom and Conformity in the New Guinea Highlands* (Melbourne: Melbourne University Press, 1959); Ngawbe—Philip D. Young, Ngawbe: Tradition and Change among the Western Guaymi of Panama, *Illinois Studies in Anthropology*, No. 7 (Urbana: University of Illinois Press, 1971); Rarak—Peter R. Goethals, "Rarak: A Swidden Village of West Sumbawa," in Koentjaraningrat, raden mas., ed. *Villages in Indonesia*, (Ithaca: Cornell University Press, 1967), pp. 30–62; Tiv—Paul Bohannan, Tiv Farm and Settlement, *Colonial Research Studies*, No. 15 (London: Her Majesty's Stationery Office, 1954); Tonga—Thayer Scudder, *The Ecology of the Gwemba Tonga* (Manchester: University of Manchester at the University Press, 1962); Tsembaga—Roy A. Rappaport, *Pigs for the Ancestors: Ritual in the Ecology of a New Guinea People* (New Haven: Yale University Press, 1968); Yakö—C. Daryll Forde, "Land and Labour in a Cross River Village, Southern Nigeria," *Geographical Journal*, Vol. 90 (1937), pp. 24–51; Yaruro—Anthony Leeds, "Yaruro Incipient Tropical Forest Horticulture: Possibilities and Limits," in J. Wilbert, ed., *The Evolution of Horticultural Systems in Native South America: Causes and Consequences—A Symposium*, (Caracas: Sociedad de Ciencias Naturales La Salle, 1961), pp. 13–46.

years of fallow for every year of cultivation. The 2:20 crop-fallow cycle is converted to a 1:10 cycle—an 11 year cycle with one year of cultivation and 10 years of fallow. Boserup's definition of agricultural intensity does not consider cropping techniques, labor, or productivity, although these characteristics relate to agricultural intensity.

We use the proportion of time that each crop-fallow cycle is in the cropping phase as the degree of agricultural intensity. For instance, a crop-fallow cycle of 1:1 (one year of cropping to one year of fallowing) is considered to have fifty percent intensity since each cropping unit is cultivated once every other year. A cycle of 1:0 is taken to have one-hundred percent intensity since each cropping unit is cultivated once every year with no fallow.[9]

Because of the individual characteristics of the agricultural systems, three different methods were employed to calculate the crop-fallow cycles. First, when several variations in the cultivation cycle are present and no cycle dominates the production of the staple crops, the average of the more intensive cycles was used. For instance, a group reported to maintain cropping cycles of from 1:3 to 1:5, 1:4 to 1:5, and 1:7 to 1:8 was taken to have a crop-fallow cycle of 1:4 (the average of the most intensive cycle) and an agricultural intensity of twenty percent. Second, when a specific range in cropping cycles was present, we computed an average cycle. Finally, when a specific cycle dominates the staple crops, it was used even though different cycles may exist for subsidiary crops.

Several critics of Boserup's thesis noted factors that may modify the suspected relationship between population pressure and agricultural intensity.[10] These factors include numerous qualities of the subsistence base of each group and of the physical environment. The data have limited our investigation to the possible modifying factors of staple crop type, livestock and aquatic resources, precipitation characteristics, and soil conditions.

Variances in the productivity and nutritional content of specific cultivars may affect the subsistence base. Since crop types indicate a great deal about agricultural productivity and nutritional standards, each group is categorized according to their major staples, either root crops or cereal crops, regardless of the number and variety of other cultivars.[11] All of the groups examined here fit into either category with the exception of the Amba (No. 25) who have traditionally relied on the production of bananas and plantains (Table 1). The Amba were placed in the root-crop category because they produce enough manioc and sweet potatoes to rival their production of tree crops.

Animal protein and byproducts, either from livestock production or from aquatic resources, may affect the relationship between population pressure and agricultural intensity.[12] If the collection, production, or use of animal resources significantly modifies the total food consumption or the agricultural practices of a group, that group was placed in the appropriate category.

Precipitation characteristics and the use of alluvial or hydromorphic soils also may influence the population pressure–agricultural intensity relationship. Mean annual precipitation and the mean annual number of dry months were computed for each group's locale. A month was considered to be dry if its mean precipitation total was 50 mm or less. When not available in the references, precipitation data were taken from various national atlases. The examination of the important factor of soil has been limited severely by the data to the presence or absence of alluvial and hydromorphic soil conditions. Unfortunately, the data have even prevented the distinction between these two soil conditions,

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[9] Groups that maintain lengthy periods of cultivation and short periods of fallow, such as a 10:1 cycle, are considered to have a degree of intensity of one hundred percent. This assumption is necessary because most scholars refer to such systems as permanent or annual cultivation and do not include the precise agricultural cycle.

[10] Boserup (op. cit., footnote 2, pp. 28–29) does not dismiss the influences that variables other than population pressure have on agricultural intensity. Rather, by arguing that farmers attempt to maximize agricultural output per man-hour of work and by viewing technology as a freely moving variable, she circumvents the necessity of introducing such variables as environment. Brookfield (op. cit., footnote 3, p. 34) and Nell (Edward J. Nell, "The Technology of Intimidation," *Peasant Studies Newsletter*, Vol. 1, No. 2 (1972), pp. 39–44) have questioned the validity of these procedures.

[11] Although root crops take on various growth forms, the concern here is with the major starches that may be categorized as tuberous roots, tubers, and rhizomes.

[12] Although hunting and gathering also may influence agricultural intensity, the data employed here do not address this influence.

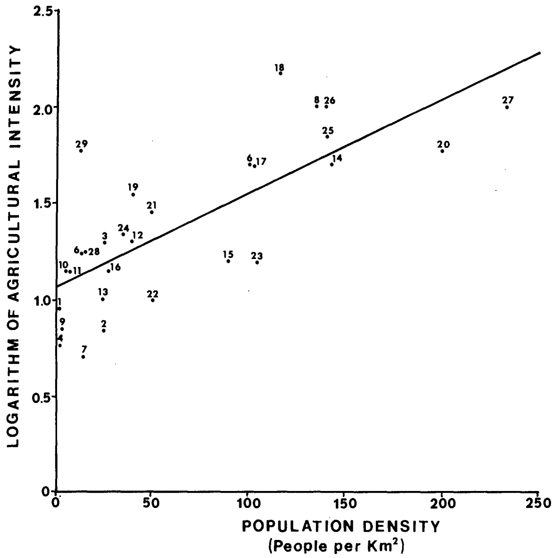

FIG. 2. Population density and agricultural intensity.

both of which may incur problems of inundation.

DATA ANALYSIS

Linear regression and correlation techniques were employed to establish the association between the agricultural intensities and population densities of the twenty-nine groups sampled here. To be consistent with the Boserup thesis, agricultural intensity was chosen as the dependent variable (Fig. 2). Correlation coefficients were calculated for arithmetic, exponential, and power functions. The exponential model gave the greatest amount of explained variation ($r^2 = 0.58$). The form of the model is

$$\log A = a + bP, \qquad (1)$$

where A represents agricultural intensity, and P is population density; a and b are parameters. The resulting equation (and standard error of estimate) are

$$\log A = 1.06 + \underset{(0.0008)}{0.0049P}.$$

The positive regression coefficient, which is significant at the 0.01 level on the basis of a t-test with twenty-seven degrees of freedom, demonstrates that agricultural intensity does increase as population density increases. The association between the two variables is strong, supporting the observations of Pelzer, Grove, Brookfield, Clarke, Vermeer, and others, and the analysis of Brown and Podolefsky.[13]

Data and test inaccuracies explain some of the largest residuals from the regression line.[14] For instance, the Gwemba Tonga (No. 18) maintain a densely settled, intensively cultivated segment of land along the Zambezi River. The data used to derive the population density and agricultural intensity of that group also incorporated segments of less densely settled and more extensively cultivated nonriverine land. The nonriverine segment is included in the calculations in order to adhere to the prescribed method of measuring the variables, but its inclusion lowers the Gwemba Tonga population density more than it lowers their agricultural intensity. In this case, agricultural intensity may have been taken to be higher than it really is, or population density may have been taken to be lower than it really is.

The agricultural intensity of the Stapikam Abelam (No. 23) is based on the average crop-fallow rotation practiced on upland slopes. Though these people also cultivate a section of alluvial soils on a floodplain, the intensity of this cultivation is not reported. If the floodplain cultivation were included in the calculations, the net effect probably would be to raise the level of agricultural intensity and thereby reduce the size of the residual.

The case of the Bajo Hondo Karinya (No. 29) is quite similar to that of the Gwemba Tonga. The Karinya pursue intensive agriculture on small, raised and drained fields within the much larger area they control. The nature of the data, however, makes it difficult to delimit the total area used by that group for subsis-

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[13] Karl J. Pelzer, *Pioneer Settlement in the Asiatic Tropics* (New York: American Geographical Society, Special Publ. No. 29, 1945); A. T. Grove, "Population Densities and Agriculture in Northern Nigeria," in K. M. Barbour and R. M. Prothero, eds., *Essays on African Population* (London: Routledge and Kegan Paul, 1961), p. 115; Brookfield, op. cit., footnote 1; Brookfield, op. cit., footnote 3, p. 310; Clarke, op. cit., footnote 3, p. 357; Vermeer, op. cit., footnote 3, p. 810; and Brown and Podolefsky, op. cit., footnote 5, p. 221.

[14] The lack of standardization in data also creates inaccuracies in computing population densities and agricultural intensities. This problem becomes obvious when comparing the data for several New Guinea groups in Table 1 with similar data produced by Brown and Podolefsky (op. cit., footnote 5, p. 214).

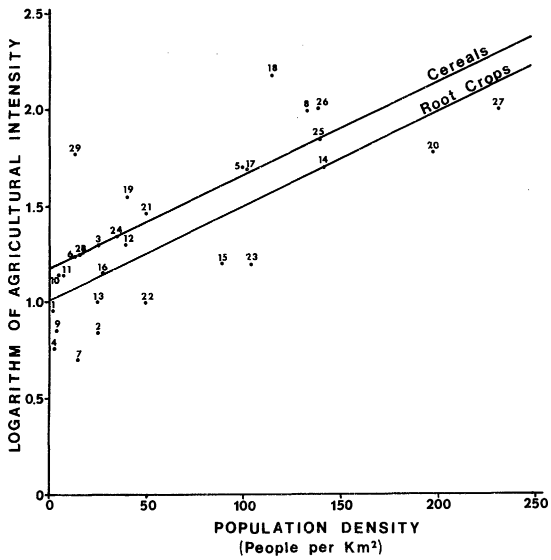

FIG. 3. The influence of major staple types.

tence.[15] To avoid raising the strength of the relationship between population density and agricultural intensity, the size of the area used for subsistence was considered larger than it probably is. As a result, the measure of the population density of the Karinya probably is low, a factor that increases the size of the residual.

That the correlation between agricultural intensity and population density is highest when the exponential model is used suggests that the rate of increase in agricultural intensity itself increases as population density rises. This result may reflect the influences of diminishing returns on the relationship. A point is reached at which a unit increase in population density will necessitate more than a unit rise in agricultural intensity if the production standards are to remain constant.

Subsistence Base Factors

The greater agricultural intensities associated with cereal-crop cultivators than with root-crop cultivators at any population density suggested that the type of staple may affect agricultural intensity. A dummy variable, C, representing this dichotomy was introduced into equation (1), both in direct form and in interaction with population density, to test for a difference in the relationship between each of these two types of cultivators and agricultural intensity. The parameters of the following equation were estimated:

$$\log A = a_0 + a_1C + (b_0 + b_1C)P. \quad (2)$$

The result of the calculation is

$$\log A = 1.17 - \underset{(0.11)}{0.15}\, C + \underset{(0.0008)}{0.0048}P$$
$$R^2 = 0.61.$$

The regression coefficient for C is significant at the 0.20 level (d.f. = 26) and the result indicates that agricultural intensities are generally higher for cereal-crop cultivators than for root-crop cultivators at any level of population density, although our confidence in this conclusion is not strong because of the high probability of making a type 1 error (Fig. 3).

Root crops in the tropics have a different relationship with agricultural intensity than do cereal crops because tropical root crops provide more calories per unit of cultivation. Jones' calculations indicate that millet provides from 1.3 to 2.6 million calories per hectare; maize, from 2.4 to 5.0; and padi rice, from 2.8 to 5.5. On the other hand, yams and sweet potatoes provide from 5.6 to 8.6 million calories per hectare and manioc produces from 7.1 to 14.2.[16] Furthermore, root crops, especially manioc, tend to produce more calories per labor input than do cereals. Estimates from central Africa show that manioc requires approximately 3.42 man-days (five hours) to produce one million calories of food energy, whereas maize requires 10.67.[17]

[15] The calculation of the variables for the Bajo Hondo Karinya are based on personal communication with William M. Denevan and on William M. Denevan and Roland W. Bergman, "Karinya Indian Swamp Cultivation in the Venezuelan Llanos," *Yearbook*, Association of Pacific Coast Geographers, Vol. 37 (1975), pp. 23–37.

[16] William O. Jones, *Manioc in Africa* (Stanford: Stanford University Press, 1959), p. 25. Also see, Bruce F. Johnston, *The Staple Food Economies of Western Tropical Africa* (Stanford: Stanford University Press, 1958), pp. 91–123; D. E. Yen, *The Sweet Potato in Oceania: An Essay in Ethnobotany* (Honolulu: Bishop Museum Press, 1974), pp. 49–50; and Daniel R. Gross, "Protein Capture and Cultural Development in the Amazon Basin," *American Anthropologist*, Vol. 27 (1975), p. 527.

[17] Data to support this statement have been collected by J. Noyen in the Congo region of Africa and reported in Jones (op. cit., footnote 16, p. 263). Noyen also reports that manioc produces more calories per man-days required in processing than maize; Jones, op. cit., footnote 16, p. 264.

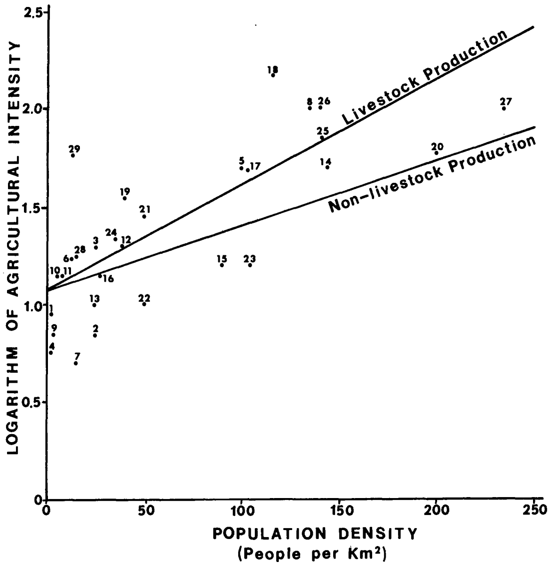

FIG. 4. The influence of livestock production.

Root crops also produce better in marginal soils and resist droughts and pests, especially locusts, more effectively than do cereal crops.[18] As a consequence, larger and perhaps more staple productions result when the land is devoted to root crops rather than cereals, no matter what the level of agricultural intensity. At any population density, one should expect a lesser intensity of cultivation when root crops are the staple than when cereal crops are the staple.

A disadvantage of root crops is their low protein and vitamin content. Moreover, indigenous techniques of food preparation, such as the soaking of maize in lime water to release body-essential vitamins, apparently cannot mitigate this drawback.[19] The protein and vitamin content of the diets of the various groups can be increased, however, by gathering, hunting, fishing, and producing livestock. These activities affect the diets and, probably, the intensities of agriculture of the groups that practice them.

Data scarcity prevents an assessment of the impact of gathering and hunting on agriculture. Several groups, however, produce livestock or procure aquatic resources (Table 1). The points representing groups that place significant emphasis on aquatic resources (Nos. 4, 18, 19, 20, and 28) and the points representing groups that do not appear to be random (Fig. 2). There was no distinctive difference in the agricultural intensities of the two groups.

The residual pattern for the groups engaged in major livestock production (Nos. 2, 5, 6, 7, 8, 12, 14, 17, 18, 21, 22, 25, 26, and 27) suggests that these groups maintain somewhat greater agricultural intensities than their counterparts (Fig. 2). A dummy variable, L, representing the dichotomy between livestock oriented groups and nonlivestock oriented groups was introduced into equation (1) in the following manner:

$$\log A = a_0 + a_1L + (b_0 + b_1L)P. \quad (3)$$

The result is

$$\log A = 1.07 + \underset{(0.0012)}{0.0033} + \underset{(0.0012)}{0.0021L)P}$$

$$R^2 = 0.62.$$

The regression coefficient for LP is significant at the 0.10 level (d.f. = 26). A relationship exists between livestock rearing and agricultural intensity, but only as a result of the interaction between the former and population density. In other words, the rate of increase in agricultural intensity brought about by a rising population density is greater for groups that rear livestock than for groups that do not (Fig. 4).

The greater increases in the agricultural intensities of groups engaged in livestock production than of groups not engaged in such production may result, in part, from the subsistence needs of livestock.[20] Land devoted to grazing or fodder production limits the area available for subsistence agricultural expansion. To

[18] Jones, op. cit., footnote 16, pp. 15, 17, 23. Also see the appropriate sections of Yen (op. cit., footnote 16). Taro is one root crop that may not be particularly resistant to drought.

[19] S. H. Katz, M. L. Hediger, and L. A. Valleroy, "Traditional Maize Processing Techniques in the New World," *Science*, Vol. 184 (1974), pp. 765–73. For further information concerning the nutritive composition of root crops see: H. C. P. C. Oomen et al., "The Sweet Potatoe as the Staff of Life of the Highland Papuan," *Tropical and Geographical Medicine*, Vol. 13 (1961), pp. 55–66; and *Food Composition Table for Use in Latin America*, compiled by Woot-Tsuen Wu Leung (Bethesda, Md.: National Institutes of Health, 1961).

[20] Livestock may be maintained for ritualistic needs as are pigs in the highlands of New Guinea where numerous groups in our sample reside. In such circumstances, an increase in the human population may result in an increase in the livestock population for ritualistic reasons. Regardless of the reasons for production, the increase in livestock may affect agricultural intensities.

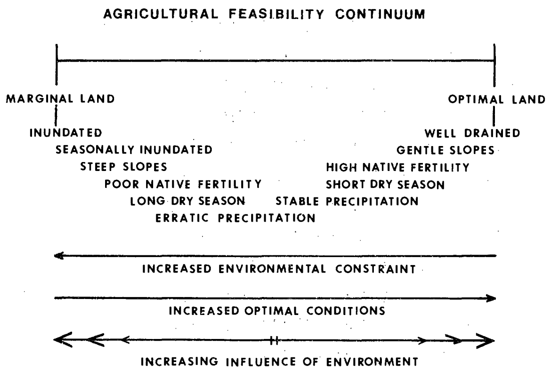

FIGURE 5

compensate, groups that utilize livestock may increase agricultural intensity as noted by Boserup.[21] Livestock production may also heighten agricultural intensity because animals often fertilize fields with their excrement and turn and loosen soils while foraging in cultivated plots. The results do not suggest that livestock increase agricultural intensity by facilitating the use of technology, such as the plow. Few of our groups use either draft animals or plows for cultivation.

Environmental Factors

Boserup held environmental factors constant in order to illuminate the relationship between population pressure and agricultural intensity. In so doing, the influence of environmental factors on agricultural intensity is minimized, although it is recognized that environment plays a role in the relationship.[22] Brookfield offered an alternative which incorporated environmental influences into the relationship.[23] Brookfield views the environment as offering:[24]

> a series of constraints that have the effect of providing "threshold levels" of intensity below which no continued cultivation is feasible. In an environment offering minimal constraints, it is possible to sustain cultivation by very simple means over long periods of time, under moderate population densities, and even quite high densities where conditions are unusually good. . . . Where constraints are more severe, it remains possible to support very low densities of population by simple means, but rising densities demand a measure of intensification if the land is to continue in production, and the ecosystem be not destroyed. Constraints of a higher order present occupiers with no alternative but to adopt some special techniques, even at a low population density.

With minor revisions in Brookfield's scheme, all land may be viewed in terms of a continuum of agricultural feasibility (Fig. 5). The poles of the continuum are designated as optimal land (requiring minimal preparation for cultivation and little upkeep), and marginal land (requiring major preparations for cultivation and a great deal of upkeep).[25]

Optimal land—such as a well-drained river valley that receives an annual deposition of alluvium of volcanic origin—may provide such excellent physical conditions that increases in the intensity of cultivation may be obtained with minimal decreases in labor efficiency; the amount of increased labor necessary to raise agricultural intensity is minimal.[26] A 1:0 crop-fallow cycle (one hundred percent agricultural intensity) may be as labor efficient under optimal conditions as a 1:4 crop-fallow cycle (twenty percent agricultural intensity) under more marginal conditions. In such circumstances, subsistence farmers may choose to cultivate the same plot with a greater frequency rather than shift plots. This choice exaggerates agricultural intensities relative to population densities.

Swamps, which may not be cultivated without drainage or the construction of raised fields, provide an example of marginal agricultural land. Such land limits the extent of cultivation because the labor and time involved in land preparations cannot be justified unless some minimal intensity of cultivation (Brookfield's threshold level) is established as a counterbalance to the costs. This constraint creates a higher intensity of cultivation per population

21 Boserup, op. cit., footnote 2, pp. 4–5.

22 Ester Boserup, personal communication.

23 Brookfield (op. cit., footnote 3, pp. 38–39) also contends that social production influences agricultural intensity, an argument that we do not address at this time.

24 Brookfield, op. cit., footnote 3, pp. 41–43.

25 Our reference to zones of environmental constraint or optimal land applies only to microscale levels of investigation and does not reinforce the erroneous concept that certain environs, such as the humid tropics, limit agricultural growth.

26 In contrast to temperate regions, alluvial soils in the tropics vary considerably in native fertility and, therefore, all river valleys are not necessarily optimal lands, even when the soils are properly drained; C. H. Elderman and P. K. J. Van Der Voorde, "Important Characteristics of Alluvial Soils in the Tropics," *Soil Science*, Vol. 95 (1963), pp. 258–59.

density than is found in more moderate circumstances.

Moderate conditions for cultivation characterize most lands occupied by agriculturalists. Population density should have its strongest effect on agricultural intensity where such conditions occur. Therefore, when population density is held constant, one would expect that agricultural intensity would be greater where major environmental constraints and optimal conditions prevail than where more moderate environmental conditions exist.[27]

Agricultural intensity may be constrained by extremes in temperature, precipitation, and soil quality. Temperature rarely is a major constraint in the zones occupied by the group in our sample, but precipitation and soil factors are.[28] Insufficient rainfall and a lengthy dry season may require considerable land preparation to ensure adequate yields. On the other hand, adequate moisture and a short dry season may create optimal agricultural conditions that facilitate continuous cultivation with minimal preparations.

The native fertility and the moisture balance are key qualities of soil that may constrain or facilitate agricultural intensity. Under ideal conditions moist, fertile soils may be cropped intensively without much preparation or upkeep, whereas dry or inundated, less fertile soils may require extensive preparations and thus they act as environmental constraints.[29] Since our data did not permit precise distinctions between alluvial and hydromorphic soil conditions, the two soil types were treated as if they were the same. Ten of the twenty-nine groups farm on alluvial or hydromorphic soils (Nos. 2, 5, 6, 8, 12, 18, 19, 21, 23, and 29).

[27] This argument is not to be confused with environmental determinism. The emphasis here is on environmental modification of the population pressure–agricultural intensity relationship, not on the determination by the physical environment of agricultural intensity.

[28] Low temperatures may influence cultivation among several of our groups that are located in the highlands of New Guinea, especially the Aruni (No. 8).

[29] The influences of extreme soil conditions, either excessively wet or dry, on systems of agriculture and, hence, agricultural intensities have long been recognized; E. C. Jul. Mohr, "The Relation Between Soil and Population Density in the Netherlands East Indies," *Comptes Rendus du Congrèss International de Géographie Amsterdam*, Vol. 2, Sec. IIIc (1938), pp. 483–84.

Each of the environmental variables was introduced separately into equation (1) and the parameters were estimated by least squares regression. The three equations were as follows:

$$\log A = a_0 + a_1M + (b_0 + b_1M)P \quad (4)$$

where M represented the mean annual precipitation;

$$\log A = a_0 + a_1D + (b_0 + b_1D)P \quad (5)$$

where D represented the length of the dry season; and

$$\log A = a_0 + a_1S + (b_0 + b_1S)P \quad (6)$$

where S is a dichotomous variable that indicates whether or not the group cultivates an area of alluvial/hydromorphic soils.

The estimated parameters for equation (4) produced the following results:

$$\log A = 1.42 - \underset{(0.0062)}{0.015M} + \underset{(0.0008)}{0.0045P}$$
$$R^2 = 0.66.$$

The regression coefficient for M is significant at the 0.05 level (d.f. = 26); an inverse relationship exists between the mean annual precipitation of the locale in which a group lives and the agricultural intensity of that group. The results of equation (5) were:

$$\log A = 0.94 + \underset{(0.017)}{0.063D} + \underset{(0.0007)}{0.0049P}$$
$$R^2 = 0.72.$$

The coefficient for D is significant at the 0.01 level (d.f. = 26). There is a strong direct relationship between the length of the dry season and agricultural intensity. The results of equation (6) were:

$$\log A = 0.98 + \underset{(0.099)}{0.23S} + \underset{(0.0008)}{0.0050P}$$
$$R^2 = 0.66.$$

The coefficient for S is significant at the 0.05 level (d.f. = 26). Groups that cultivate alluvial or hydromorphic soils maintain higher agricultural intensities at any level of population density than groups that cultivate other types of soils (Fig. 6).

The evidence indicates that when population densities do not vary, groups that cultivate areas with small amounts of precipitation, long dry seasons, and alluvial/hydromorphic soils maintain higher agricultural intensities than groups

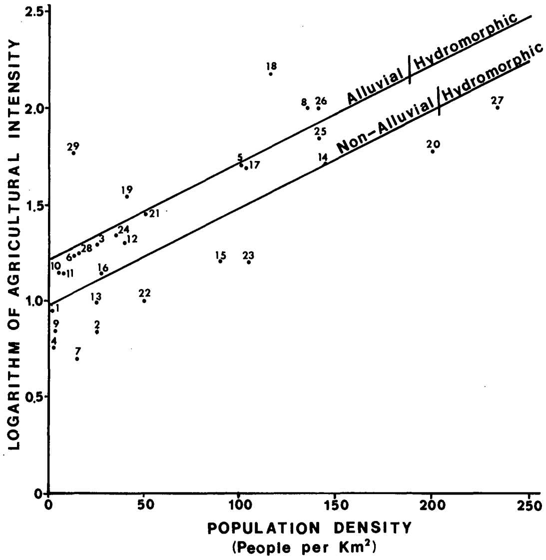

FIG. 6. The influence of alluvial/hydromorphic soils.

cultivating areas that do not display these characteristics. This result supports the hypothesis that in the tropics, at any given level of population density, agricultural intensities tend to be higher where the environment either greatly constrains or facilitates cultivation. The evidence does not suggest that environmental influences operate by means of interacting with population density; none of the coefficients for the interaction terms in equations (4) through (6) were significant on the basis of the *t*-test.

The evidence also suggests that poor agricultural land can be made productive and that the combined influences of constraint and optimal conditions elevate agricultural intensities. This situation may explain some of the largest residuals, especially No. 18 (Gwemba Tonga) and No. 29 (Bajo Hondo Karinya). The Gwemba Tonga cultivate a floodplain which receives an annual deposition of alluvium, but which may incur up to an eight month dry season. The alluvial soils may provide optimal agricultural conditions after the flooding period and probably promote intensive cultivation, at least on an annual basis (one hundred percent agricultural intensity). The lengthy dry season limits cultivation, a fact that probably encourages the adoption of irrigation. Such hydraulic techniques promote further intensification by enhancing the possibility of double-cropping (two hundred percent agricultural intensity).

General Model

The regression analyses indicate that environmental factors explain more of the variation in agricultural intensity not explained by population density than do subsistence base factors, although neither increase statistical explanation very much. The increase attributed to the major staple type is three percent; to the interaction between livestock production and population density, four percent; to the mean annual precipitation, eight percent; to the soil type, eight percent; and to the length of the dry season, fourteen percent. These figures refer only to the contributions of each variable in isolation from the remaining factors.

The relative importance of the variables can be gauged by placing them into a general model:

$$\log A = a_0 + a_1C + a_2L + a_3M + a_4D + a_5S + (b_0 + b_1C + b_2L + b_3M + b_4D + b_5S)P. \quad (7)$$

The coefficients of this model were estimated by stepwise regression. The results for the fifth step show that population density (P), the length of the dry season (D), alluvial and hydromorphic soils (S), the interaction between livestock and population density (LP), and the interaction between the length of the dry season and population density (DP) combine to account for eighty-seven percent of the variance in the logarithm of agricultural intensity (Table 2). The results for subsequent steps are not considered because the standard error of the estimated coefficients exceed the value of the coefficients for each of the remaining variables entered.

The general model confirms our initial conclusion that population density maintains the strongest relationship with agricultural intensity (Table 2). Further confirmation is provided by the fact that subsistence base and environmental factors by themselves account for only forty-nine percent of the variation in the logarithm of agricultural intensity. Environmental factors have a stronger association with agricultural intensity than do the subsistence base factors. The negative coefficient for the interaction of the length of the dry season and population density (DP) indicates that the rate at which the logarithm of agricultural intensity changes with a unit change in population density becomes less as the dry season lengthens (Step 5, Table 2). This result, which did not emerge from the previous regression analyses,

TABLE 2.—STEPWISE REGRESSION RESULTS: COEFFICIENTS OF THE GENERAL MODEL, EQUATION (7)

Independent variables[b]	Steps[a] 1	2	3	4	5
C					
L					
M					
D		0.0635[c] (0.0174)	0.0639[c] (0.0152)	0.0612[c] (0.0147)	0.1090[c] (0.0237)
S			0.2343[c] (0.0772)	0.2240[c] (0.0745)	0.2151[c] (0.0679)
P	0.0049[c] (0.0008)	0.0049[c] (0.0007)	0.0049[c] (0.0006)	0.0037[c] (0.0009)	0.0042[c] (0.0008)
CP					
LP				0.0015[e] (0.0009)	0.0026[c] (0.0009)
MP					
DP					−0.0007[d] (0.0003)
SP					
Constant term	1.0590	0.9403	0.8564	0.8740	0.7899
R^2	0.58	0.72	0.79	0.83	0.87
d.f.	27	26	25	24	23

[a] Standard errors are in parentheses.
[b] See text for explanation of symbols.
[c] Significant at the 0.01 level.
[d] Significant at the 0.05 level.
[e] Significant at the 0.10 level.

implies that the influence of population density on agricultural intensity diminishes for those groups that inhabit areas with long dry seasons. This conclusion is consistent with the argument of the role of environmental constraint on agricultural intensification.

DISCUSSION

A strong positive relationship exists between population density and agricultural intensity among tropical subsistence agriculturalists. This result and the results provided by Brown and Podolefsky support the premise implicit in the Boserup thesis. While a strong positive association between the two variables may appear self-evident, the statistical analyses define the strength of the relationship and the effect of other factors on that relationship. The amount of explained variation in agricultural intensity was increased by adding subsistence base and environmental factors to population density. Several of these variables support Brookfield's proposed alterations of Boserup's thesis.

Boserup views agricultural technology, including tools, as a dependent variable that is governed by the system of land use—the combination of environmental conditions and the intensity of cultivation.[30] In this scheme, a positive and direct relationship should exist between agricultural intensity and agricultural techniques if environmental conditions are held constant. A general relationship of this nature is detectable from various data concerning tropical cultivators.[31] We were unable to test this relationship and the effect of environmental factors on technology, however, because of the quality of the data.[32]

Another possible technological influence on the relationship emerged from the finding that the rate of increase in agricultural intensity itself increases as population density rises. While

[30] Boserup, op. cit., footnote 2, pp. 23–27.

[31] Brown and Podolefsky, op. cit., footnote 5, p. 217; H. C. Brookfield and Doreen Hart, *Melanesia, A Geographical Interpretation of an Island World* (London: Metheun and Co., 1971), pp. 98–99; Heinz-Dieter Ludwig, "Permanent Farming on Ukara," in Hans Ruthenberg, ed., *Smallholder Farming and Smallholder Development in Tanzania* (Munich: Weltforum Verlag, 1968), pp. 92–93.

[32] In those instances where precise technological data are available the agricultural cycles are presented in a manner not suited for our method of measure. We found the data on agricultural technology in our sources to be too erratic to make statistical comparisons.

this result was expected and may be partially explained by diminishing returns, the rate of increase that was encountered may reflect the method in which agricultural intensity was measured. Following Boserup, our measure included only the frequency of cultivation. It has been assumed that the technology utilized to increase this frequency also increased the amount of production per harvest. This assumption may be valid for less intensive systems of cultivation. Among more intensive systems, however, a percentage of production may be associated with technology (or other factors) that is not directly related to the increase in intensity.[33] The failure of our measure to account for this factor may explain some of the larger residuals from the regression line (Fig. 2). It also may explain the weaker relationship between population density and agricultural intensity among both the more densely populated groups and those groups that inhabit more arid environs. This observation has led us to question the applicability of our system of measuring agricultural intensity and to explore other measures such as the one proposed by Brookfield and Hart.[34]

We assumed that population pressure (population density) is the principal cause of agricultural intensity among the groups examined. Alternative views of this relationship have been proferred by others. Brown and Podolefsky, for instance, are of the opinion that "the relationship between population density and agricultural intensity is interactional and that neither can be consistently antecedent to the other."[35] Our examination neither supports nor negates their argument. Indeed, as Brown and Podolefsky note, the verification of a causative relationship between population density (or any other factor) and agricultural intensity awaits examinations that incorporate a temporal element.[36]

We focused on the growth of agriculture as a response to rising population pressure. In fact, various alternatives, both agricultural and nonagricultural, usually are available to groups of subsistence farmers confronted with population growth.[37] Some agricultural responses, other than intensification, have been discussed—for example, the adoption of more productive crops, the acceptance of a less nutritional or lower caloric diet, and the expansion of the area cultivated. These alternatives generally are available as population pressure increases among subsistence farmers. Nonagricultural responses include birth control (even infanticide), migration or group splintering, and coercive practices to obtain more food.

Finally, this study was limited to subsistence agriculture and does not take into account market agriculturalists. The influence that population densities have on agricultural intensities may not be as strong among market-oriented agriculturalists as it is among subsistence agriculturalists because the local population is not the prime recipient of the produce. In such circumstances production pressure—the sum forces that determine the amount of agricultural production—may be an alternative measure to population pressure, although production pressure in a market situation may ultimately be linked to world population pressure.

33 This conclusion has been offered by others. See Bashir A. Datoo, "Relationship Between Population Density and Agricultural Systems in the Uluguru Mountains, Tanzania," *Journal of Tropical Geography*, Vol. 41 (1976), pp. 1–12.

34 Brookfield and Hart, op. cit., footnote 31, pp. 89–92.

35 Brown and Podolefsky, op. cit., footnote 5, p. 229.

36 Brown and Podolefsky, op. cit., footnote 5.

37 For a more thorough discussion of these alternatives see D. B. Grigg, "Population Pressure and Agricultural Change," in Christopher Board, et al., *Progress in Geography*, Vol. 8 (London: Edward Arnold, 1976), pp. 135–76.