Tennessee Valley Authority

A Method for Estimating World Fertilizer Requirements as Related to Agricultural and Food ~~Requirements~~ Production

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by

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A METHOD FOR ESTIMATING WORLD FERTILIZER REQUIREMENTS AS RELATED TO AGRICULTURAL AND FOOD PRODUCTION

INTRODUCTION

It is generally recognized that fertilizer, properly used, is an important factor in increasing the production of agricultural crops. In turn, the amount of crop production closely determines the amount of food production, since almost all food comes from crops either directly or through agricultural upgradings such as livestock. The worldwide dependence of food on agriculture and of agriculture on fertilizer means that fertilizer requirements of the future will be associated inherently with the agricultural and food production of that time.

This report deals with the estimation of 1980 fertilizer requirements on the above basis. First, a region's 1980 food and agricultural levels are determined by continuing its own past growths of demonstrated consistency. The associated fertilizer requirements for 1980 are based on the region's own relationship of fertilizer use relative to agricultural or to food production. The method is therefore empirical and specific to each region.

In this report the relationship between fertilizer use and agricultural production does not have the customary basing. A common method of relating fertilizer use to agricultural or crop production has been to apply the same relationship to all countries in a region or in the world (3, 5, 6, 8, 9). The fertilizer-crop relationship used has been either a fixed conversion factor or a curve. The conversion factor was usually 10 tons (sometimes 8 tons) of additional crop per ton of plant nutrients; the curve relationship was that of a yield-value index curve (12).

OECD has pointed out difficulties with both the fixed and the curve relationship (7) and these difficulties were encountered in estimating the fertilizer requirements for developing countries (5). Regions and countries were not close enough to the yield-value index curve to avoid a large measure of subjective or arbitrary treatment. The problem is avoided by analyzing each region through its own relationship of fertilizer use to agricultural production.

METHOD OF ESTIMATING

Primary Data

Level of agricultural production is given by the FAO Index of Total Agricultural Production for the 18-year period 1952-69 (1). A country's index for a given year is described (2) as having been determined by listing the net production of each crop (i.e., excluding agriculture's internal consumption) and the production of livestock, multiplying each amount by a weighting factor relative to wheat, adding the products, dividing this sum of products (the aggregate) by the companion figure for 1952-56, and multiplying the quotient by 100. Regional indexes are determined by adding the aggregates of the constituent countries and converting to the index basis. The FAO Index of Total Agricultural Production is a composite measure—it includes industrial crops, food crops, and net livestock production.

Level of food production is given by the FAO Index of Food Production (1). It also covers the period 1952-69 and is expressed on the basis, 1952-56 = 100. Crops used by compounding the food index are those used for total agricultural production excluding the industrial crops, tea, coffee, industrial oilseeds, tobacco, vegetable and animal fibers, and rubber. The food index therefore includes livestock as well as food crops which are used directly. The calculation of the food index is as described for total agricultural production.

Fertilizer use is taken as the FAO tonnages of plant nutrient consumption (4).

Normally, time is taken as the calendar year. The FAO indexes of agricultural and of food production are published on a calendar-year basis, and in this report FAO fertilizer consumption data are put with the appropriate calendar years. Since fertilizer data are listed by FAO under a July-June fertilizer year, the tonnage for the second, or January-June, half of the split year (spring application in the northern hemisphere) is paired with agricultural production for the same calendar year (fall harvest in the northern hemisphere). For example, fertilizer consumption for split 1964-65 goes with agricultural production for calendar 1965. Individual countries are handled according to their specific fertilizer years as footnoted in the FAO consumption tables.

Population growth rates to 1969 are based on United Nations' population data (10). For growth rates to 1980, this report uses rates which lie between the low and medium variants of U.N. projections. Though published in 1966, the U.N. projections were based on assessments in 1963 (11) and they did not fully anticipate the declines in growth which occurred in the developed countries during the latter 1960's (5). The population rates in this report may appear to be conservatively low because of the wide publication (13) of U.N. estimates based on the *high* variant in the same source (11).

Analysis of Data

The estimation of 1980 fertilizer requirements in relation to agricultural and food production is done in two stages. First, a region's 1980 levels of agricultural and food production are estimated; next, the associated fertilizer requirement is determined for these agricultural and food levels.

At the outset, the indexes of agricultural and of food production are plotted against time to show the past patterns. When a region has high consistency of growth for a period of years it is assumed that its near future will be a continuation of its established past, unless there is information to the contrary. The 1980 estimates of agricultural and of food production are therefore extensions of sound-looking past trends. When a departure from consistency occurs, the time and nature of the departure are pointed up for whatever they may mean.

Since food and agricultural production are interrelated inherently, a plotting of one against the other reveals whether a change in relationship has occurred. At the level of a large region, food and agricultural production change together but in an individual country a major change in an industrial crop can put them out of tracking. The cross checking is necessary because fertilizer use is related literally to agricultural production while in many developing sections food production is the item of primary concern. Normally, information is not available on the fertilizer tonnages used specifically on food crops.

As a side observation the rate of growth in food production may be compared with that of population to indicate the per capita situation.

When a region's fertilizer use is plotted against its index of agricultural production for a period of years the resulting graph is approximately a straight line on semilog paper. In some cases a slightly more representative trend might be given by a more complicated expression but for this report the semilog form is considered adequate for the reliability of the data. As a primary criterion fertilizer use is put against agricultural production rather than against time because the latter is often more irregular in short term. Presumably, bad weather at planting time, the economics within and without the fertilizer industry, and perhaps other factors introduce additional cycling from year to year.

A consistent trend between fertilizer use and agricultural production can be extended to the level of agricultural production previously determined for 1980. The resulting fertilizer requirement is more qualified than an open estimate of actual fertilizer consumption. The 1980 fertilizer "requirement" is associated with a given agricultural production assuming a continuing relation between the two. In developed countries the food significance of a given level of agricultural production changes as foods of animal origin increase while those of plant origin decrease. This occurs as countries change from developing to developed, foodwise, and as they progress up the food scale as developed countries. The straight line treatments in this report do not take such changes into account.

All trend lines are determined by method of least squares.

FERTILIZER REQUIREMENTS AS RELATED TO AGRICULTURAL AND FOOD PRODUCTION

World Less Communist Asia

Agricultural production (figure 1) and food production (figure 2) are highly linear with time over the entire 1952-69 period. Their 1980 extensions are 183.6 and 187.2, respectively. Figure 3 shows that food production grew evenly with agricultural production. At the 1980 level of agricultural production, i.e., 183.6, the food production index would be 187.2 which is the same value as obtained by direct projection of the food index to 1980. The indexes of agricultural and of food production are therefore in tight conformity at the level of World Less Communist Asia and either index could be used for mathematical relation with fertilizer use.

The 1952-69 arithmetic food trend of figure 2 has the decreasing annual percentage gains shown in figure 4. When annual population growths (5) are put on the same scale, a breakeven time between food production and population appears in 1974-75. This does not mean that the world will start starving in 1975. According to the data, the world would stop increasing its per capita food production on the world average but if the rate of population growth by 1980 were 1.8 instead of the estimated 2.1%/year then the breakeven time would be extended to 1980. Figure 4 is a very sensitive portrayal which should be interpreted only generally at the world level where averaging masks local unevenness.

Continuing the determination of fertilizer requirements, figure 5 connects fertilizer use with agricultural production, by giving the trend for the 18-year period, 1952-69, with an extension to the 1980 projection of agricultural production (183.6). The indicated fertilizer requirement is 119.4 million metric tons. The equation for the trend line shows that fertilizer use increases by 2.3% while agricultural production is increasing by one unit, whether from 100 to 101, 140 to 141, etc.

The appearance of the fertilizer use vs. agricultural production trend of figure 5 is shown on arithmetic scale, with coordinates reversed, in figure 6. This curve brings out the fact that agricultural production increases more and more gradually with greater fertilizer use. Conversely, more

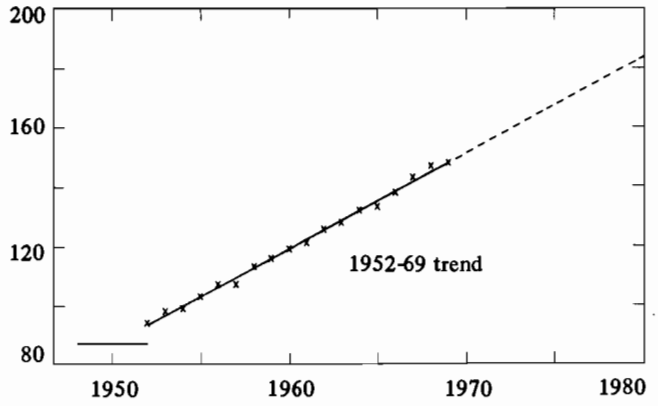

Fig. 1. FAO index of total agricultural production—World less Communist Asia (1952-56=100)

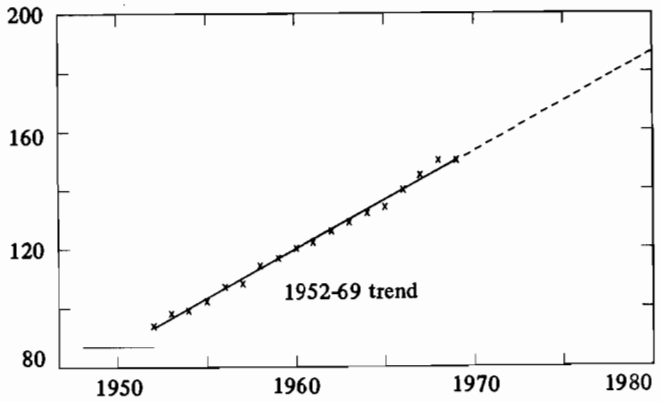

Fig. 2. FAO index of food production—World less Communist Asia (1952-56=100)

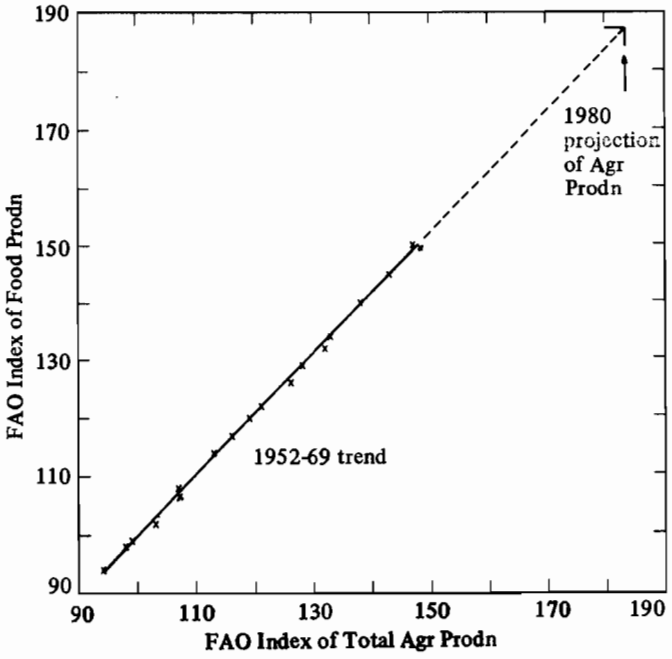

Fig. 3. FAO index of food production vs. FAO index of total agricultural production—World less Communist Asia (1952 rising through 1969) (1952-56=100)

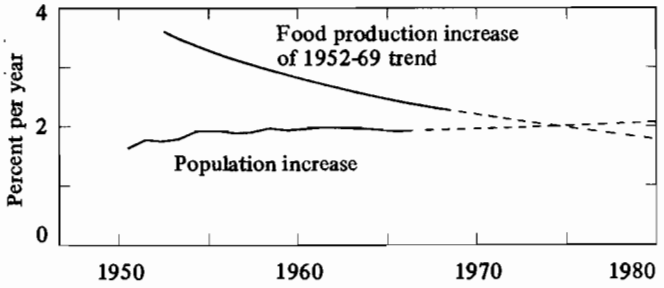

Fig. 4. Rates of increase in food production and population—World less Communist Asia

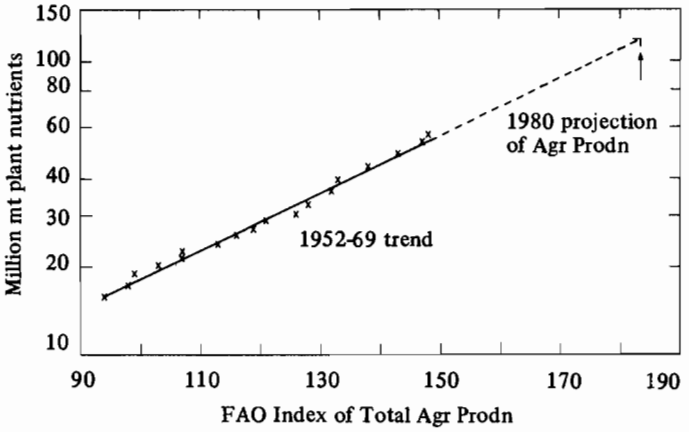

Fig. 5. Fertilizer use vs. FAO index of total agricultural production—World less Communist Asia (1952 rising through 1969)

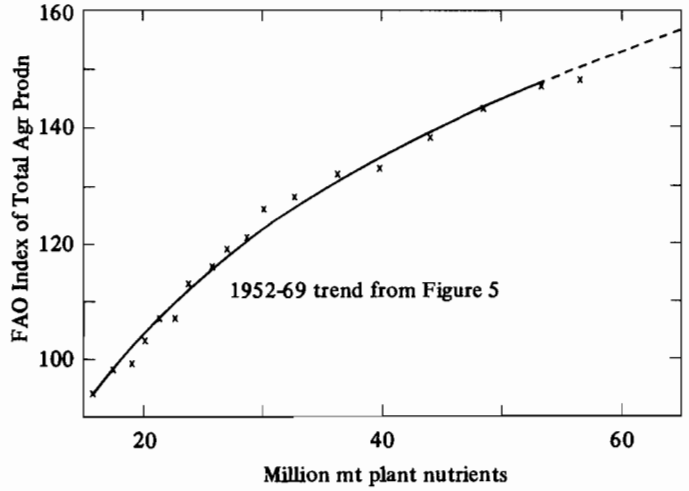

Fig. 6. FAO index of total agricultural production vs. fertilizer use—World less Communist Asia (1952 rising through 1969)

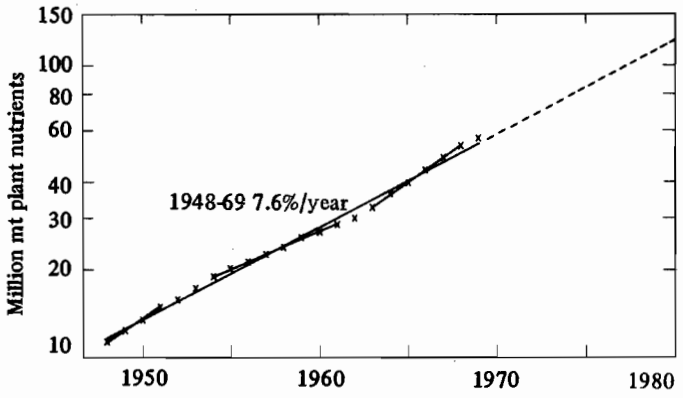

Fig. 7. Fertilizer use—World less Communist Asia

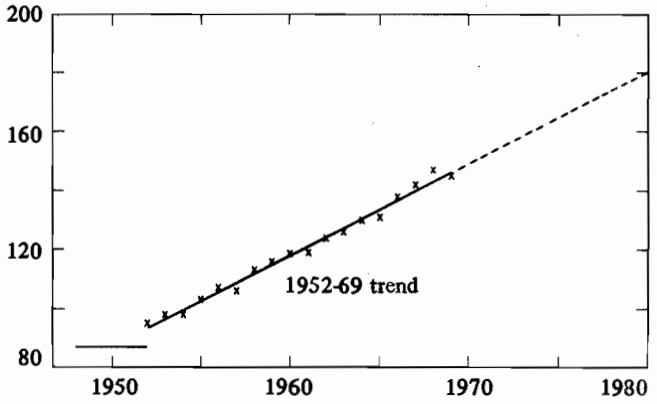

Fig. 8. FAO index of agricultural production—Developed continents plus Israel, Japan, S. Africa (1952-56=100)

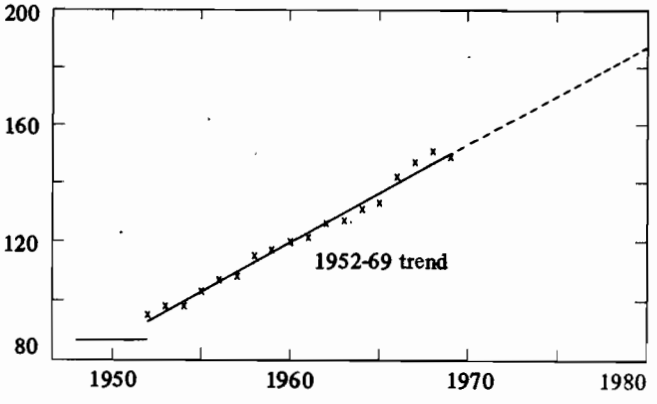

Fig. 9. FAO index of food production—Developed continents plus Israel, Japan, S. Africa (1952-56=100)

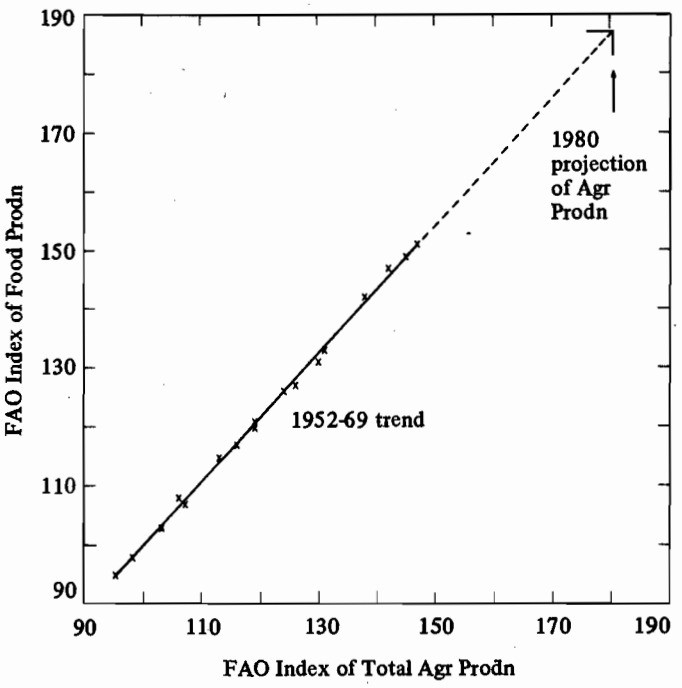

Fig. 10. FAO index of food production vs. FAO index of total agricultural production—Developed continents plus Israel, Japan, S. Africa (1952 rising through 1969) (1952-56=100)

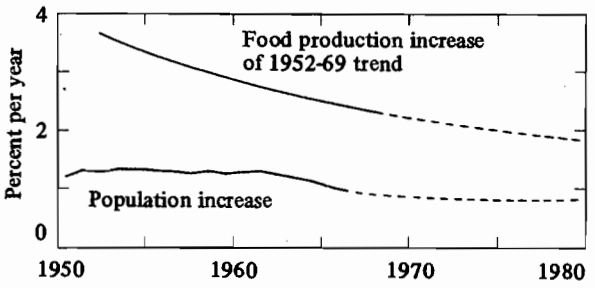

Fig. 11. Rates of increase in food production and population—Developed continents plus Israel, Japan, S. Africa

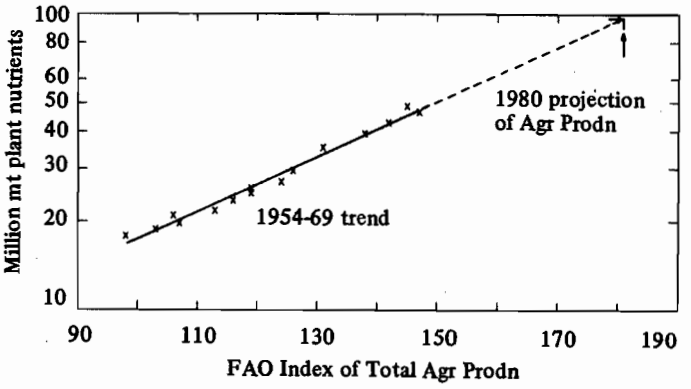

Fig. 12. Fertilizer use vs. FAO index of total agricultural production—Developed continents plus Israel, Japan, S. Africa (1954 to 1969)

and more fertilizer is required per incremental increase in agricultural production as higher production levels are achieved.

When relating increased fertilizer use to increased agricultural production, fertilizer typifies other agricultural inputs as well as having its own merit. Agricultural production depends on many factors including water conditions (with irrigation as necessary), crop factors (varieties, planting density, etc.), protection (by insecticides, herbicides, etc.), soil conditions (with liming for control of acidity), nutrition (micronutrients, secondary nutrients, proper primary nutrients), machinery (for better and more timely work), farming practices and management, and perhaps other inputs. These factors reinforce each other and their whole package is implied by constructive advance in the use of fertilizer.

A direct plotting of fertilizer use against time (figure 7) has an overall 1948-69 rate of 7.6%/year for a 1980 projection of 120.9 million metric tons. The 1952-69 rate is 7.5%/year for a 1980 projection of 119.8 million metric tons. This tonnage compares favorably with the 119.4 projection via agricultural production for the same period, 1952-69. Figure 7 has three highly consistent subperiods of greater or less than average growth. The most recent, 1963-68, is steeper than the long-term rate, allowing for a time of slower growth to cycle down to or below the 18- or 22-year norm.

Developed Continents Plus Israel, Japan, South Africa

The recent FAO publication of index numbers for food and agriculture (1) places Israel, Japan, and South Africa in the developed group. This reclassification has little effect on the growth rates in the developed regions as a whole but it gives a sharper focus on the developing regions. In 1969 South Africa used 35% of the fertilizer consumed in all Africa while Israel plus Japan accounted for 35% of the fertilizer consumption in noncommunist Asia.

In figures 8 and 9, the 1952-69 plottings of agricultural and of food production fall reasonably balanced along arithmetic trend lines with 1980 projections of 180.5 and 187.2, respectively. Food production has stayed in a definite relation with agricultural production (figure 10) and at the 1980 level of agricultural production the food index would be 187.2. This value is the same as when the food index was projected directly to 1980 and the agreement interlocks the two indexes.

Since 1963 the annual growth in food production has maintained its margin over population growth (figure 11). The margin will narrow only slightly during the 1970's unless there is an unforeseen change in the rates of food production and/or population. Production surpluses will be available for export, for upgrading of domestic foods, or for additional storage. In the developed regions as a whole, the market for synthetic foods is likely to continue to be largely from discretionary purchasing rather than to fill basic needs of quantity.

Fertilizer use relative to agricultural production has had a compounded increase over 1954-69 (figure 12). At the 1980 projection of agricultural production (180.5) the fertilizer requirement would be 96.7 million metric tons. Its increase per unit of agricultural production has been 2.2%.

Timewise (figure 13), fertilizer use in these developed regions experienced a 5.5%/year growth during 1954-62 and a 9.1% rate during 1962-69. If the 1954-69 rate of 7.1%/year were followed to 1980 the metric tonnage would be 100.6; via agricultural production the tonnage was 96.7. It seems reasonable that 1962-69 was a limited-term period of higher than normal growth rate.

Developing Continents Less Communist Asia, Israel, Japan, South Africa

Transferring Israel, Japan, and South Africa from the developing group removes 27% of the 1969 fertilizer use and a related amount of fertilizer-based agriculture. The resulting group is more truly of less-developed status.

Figures 14 and 15 show impressively linear growths in agricultural and in food production; their 1980 projections are 188.6 and 187.2, respectively. They increase in close conjunction (figure 16) giving a 1980 value of food production of 187.2 whether projected directly against time or by way of agricultural production. However, population growth overtook the expansion in food production in 1964-65 (figure 17) and no signs of substantial reversal have appeared in the data of actual results. In figure 18 the growths in food production and in population are shown in direct comparison for the world and its two main subdivisions. While actual levels of food production were quite different among the three regions, their rates of annual increase were almost identical. Population growth is the item which has grown out of bounds in the developing regions while in the developed regions its lowering has been instrumental in maintaining a favorable food to population position in the 1960's with latitude for the 1970's.

For 1954-69 there is a balanced overall trend of compounded growth between fertilizer use and agricultural production (figure 19). It gives 3.6% more fertilizer per unit of agricultural production and projects to 26.0 million metric tons at the 1980 level of agricultural production. Taken directly against time (figure 20), fertilizer use has grown at 12.8%/year during the 1954-69 period with a 14.7% rate for 1962-69. The 1954-69 growth would amount to 26.6 million metric tons in 1980.

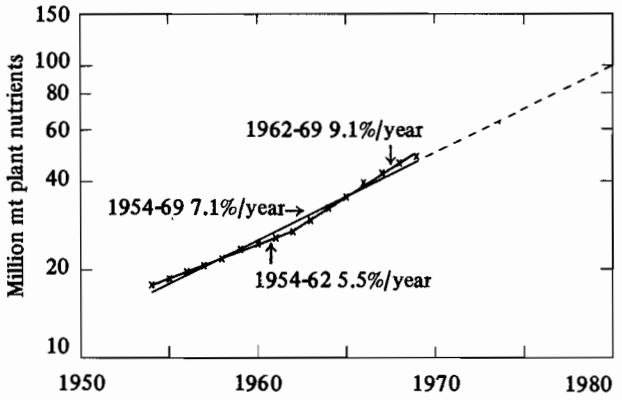

Fig. 13. Fertilizer use—Developed continents plus Israel, Japan, S. Africa

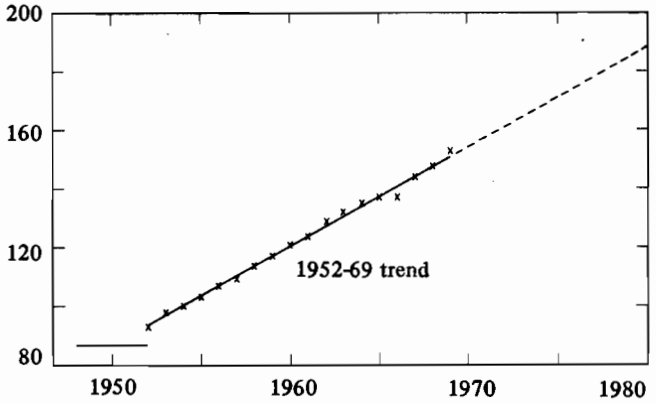

Fig. 14. FAO index of total agricultural production—Developing continents less Communist Asia, Israel, Japan, S. Africa (1952-56=100)

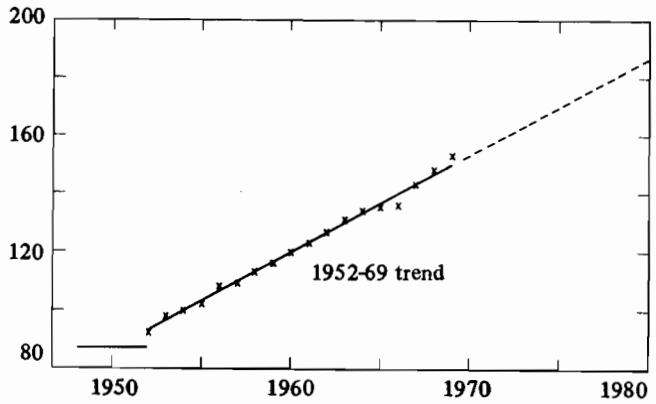

Fig. 15. FAO index of food production—Developing continents less Communist Asia, Israel, Japan, S. Africa (1952-56=100)

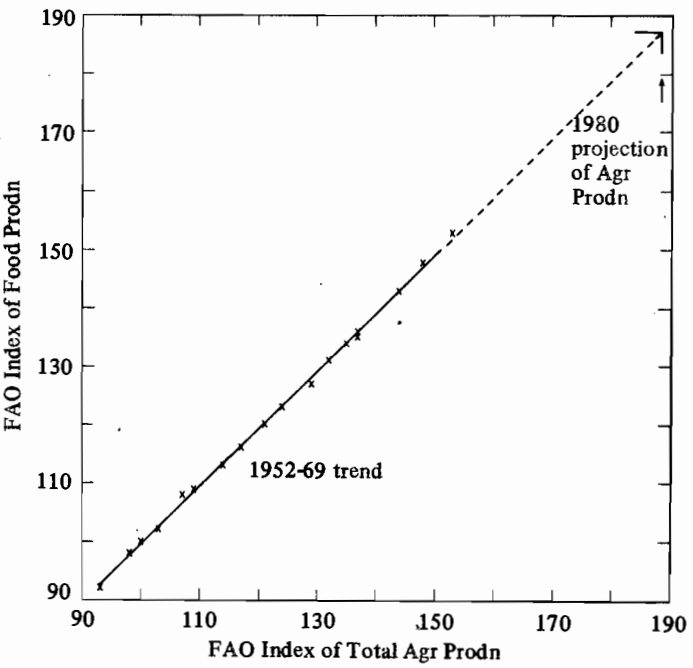

Fig. 16. FAO index of food production vs. FAO index of total agricultural production—Developing continents less Communist Asia, Israel, Japan, S. Africa (1952 rising through 1969) (1952-56=100)

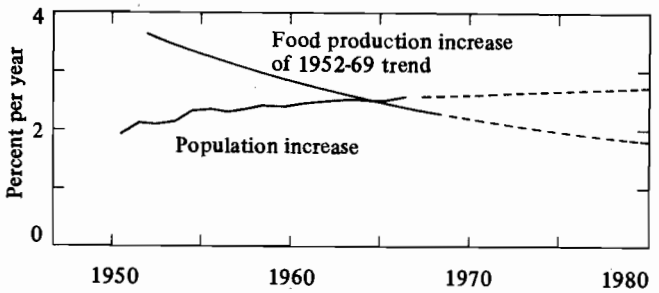

Fig. 17. Annual increases in food production and population—Developing continents less Communist Asia, Israel, Japan, S. Africa

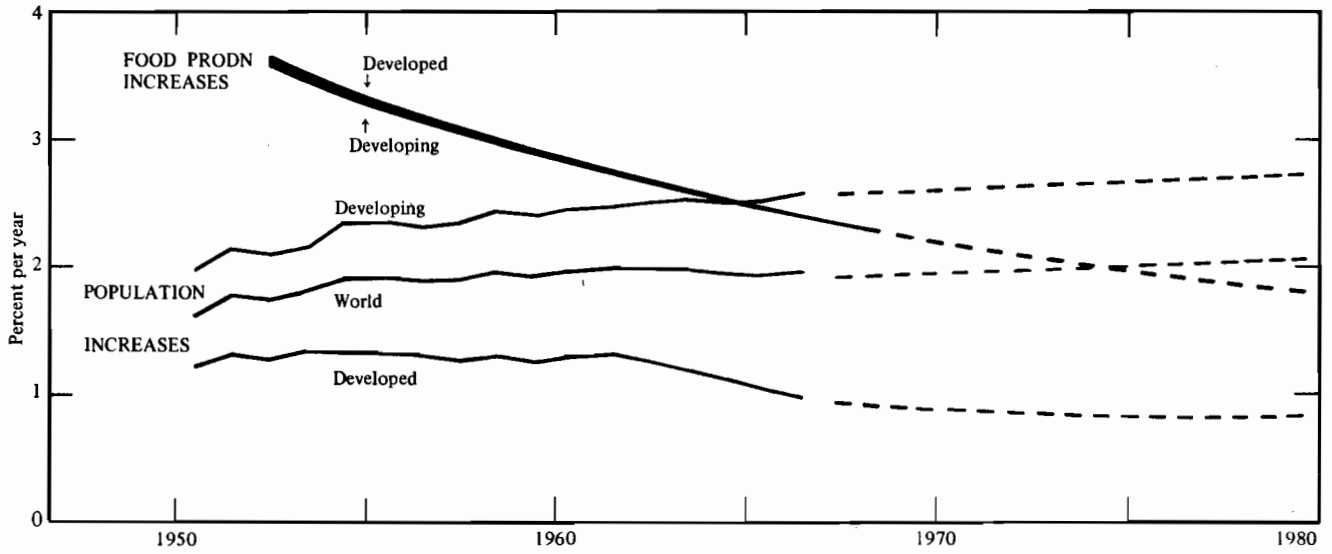

Fig. 18. World and regional food production and population increases (consolidation of figs. 4, 11, 17)

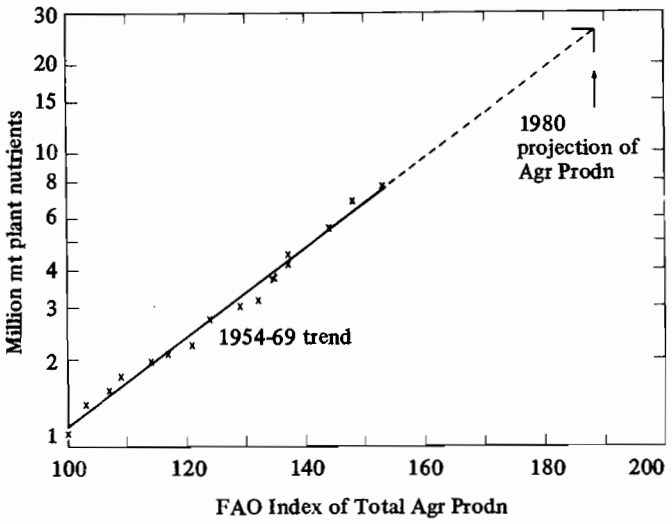

Fig. 19. Fertilizer use vs. FAO index of total agricultural production—Developing continents less Communist Asia, Israel, Japan, S. Africa (1954 rising through 1969)

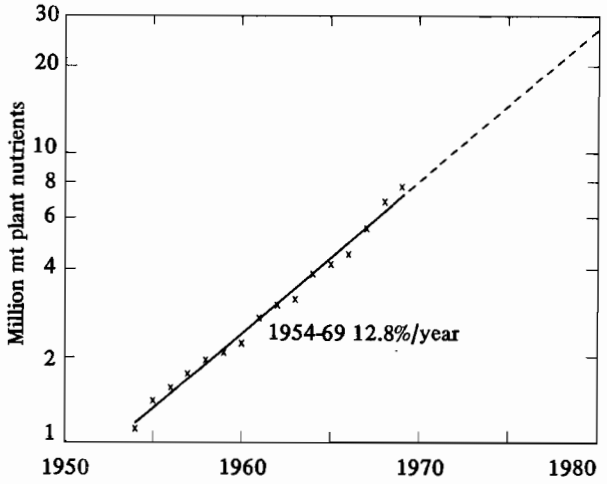

Fig. 20. Fertilizer use—Developing continents less Communist Asia, Israel, Japan, S. Africa

The food outlook can be given as a three-way expression among the 1980 projections of fertilizer use, dietary improvement, and population growth (figure 21). In the background calculations the 1969 index of food production is increased or decreased to correspond to several amounts of dietary change and of population growth. The fertilizer requirement for each index of food production is determined from the relationship of fertilizer use to food production. The dietary effect of using more or less than the estimated fertilizer tonnage can be read from the chart and the controlling influence of population growth is apparent.

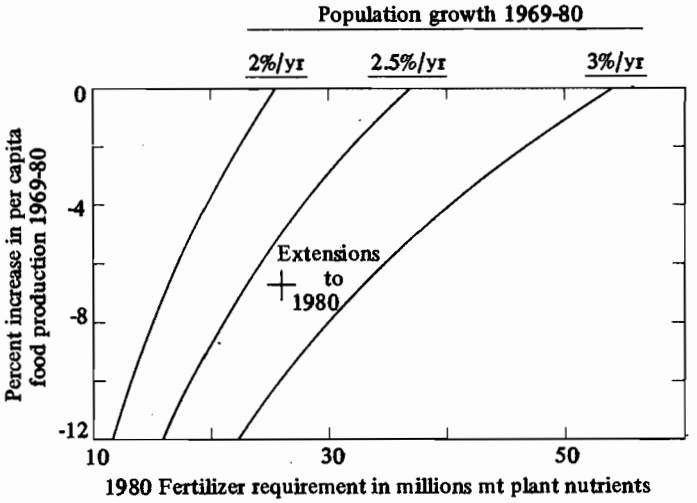

Fig. 21. Fertilizer-food-population balances—1980—Developing continents less Communist Asia, Israel, Japan, S. Africa

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APPENDIX

Equations for Trend Lines (Method of Least Squares Determination)

World Less Communist Asia

Figure 1. Index of Agricultural Production vs. Year
1952-69 Agr Prodn = 93.25 + 3.226 (Year−1952)

Figure 2. Index of Food Production vs. Year
1952-69 Food Prodn = 92.88 + 3.367 (Year−1952)

Figure 3. Index of Food Production vs. Index of Agricultural Production
1952-69 Food Prodn = -4.48 + 1.0440 (Agr Prodn)

Figure 5. Fertilizer Use vs. Index of Agricultural Production
1952-69 log (Fert Use) = 0.2858 + 0.009757 (Agr Prodn)
Fert Use = $1.931 \times 1.0227^{\text{Agr Prodn}}$

Figure 7. Fertilizer Use vs. Year
1948-69 log (Fert Use) = 1.0655 + 0.03178 (Year−1948)
Fert Use = $11.63 \times 1.0759^{\text{Year}-1948}$

1952-69 log (Fert Use) = 1.1950 + 0.03155 (Year−1952)
Fert Use = $15.67 \times 1.0753^{\text{Year}-1952}$

Developed Continents Plus Israel, Japan, South Africa

Figure 8. Index of Agricultural Production vs. Year
1952-69 Agr Prodn = 93.39 + 3.111 (Year−1952)

Figure 9. Index of Food Production vs. Year
1952-69 Food Prodn = 92.94 + 3.366 (Year−1952)

Figure 10. Index of Food Production vs. Index of Agricultural Production
1952-69 Food Prodn = -8.17 + 1.0826 (Agr Prodn)

Figure 12. Fertilizer Use vs. Index of Agricultural Production
1954-69 log (Fert Use) = 0.3136 + 0.009262 (Agr Prodn)
Fert Use = $2.059 \times 1.0216^{\text{Agr Prodn}}$

Figure 13. Fertilizer Use vs. Year
1954-62 log (Fert Use) = 1.2507 + 0.02325 (Year−1954)
Fert Use = $17.81 \times 1.0550^{\text{Year}-1954}$
1962-69 log (Fert Use) = 1.4358 + 0.03794 (Year−1962)
Fert Use = $27.28 \times 1.0913^{\text{Year}-1962}$
1954-69 log (Fert Use) = 1.2268 + 0.02983 (Year−1954)
Fert Use = $16.86 \times 1.0711^{\text{Year}-1954}$

Developing Continents Less Communist Asia, Israel, Japan, South Africa

Figure 14. Index of Agricultural Production vs. Year
1952-69 Agr Prodn = 93.36 + 3.402 (Year−1952)

Figure 15. Index of Food Production vs. Year
1952-69 Food Prodn = 92.92 + 3.368 (Year−1952)

Figure 16. Index of Food Production vs. Index of Agricultural Production
1952-69 Food Prodn = 0.479 + 0.9902 (Agr Prodn)

Figure 19. Fertilizer Use vs. Index of Agricultural Production
1954-69 log (Fert Use) = -1.4473 + 0.015174 (Agr Prodn)
Fert Use = $0.2801 \times 1.0356^{\text{Agr Prodn}}$

Figure 20. Fertilizer Use vs. Year
1954-69 log (Fert Use) = 0.0677 + 0.05217 (Year−1954)
Fert Use = $1.168 \times 1.1277^{\text{Year}-1954}$

Figure 21. Underlying Equation of Fertilizer Use vs. Index of Food Production
1954-69 log (Fert Use) = -1.4571 + 0.015344 (Food Prodn)
Fert Use = $0.2865 \times 1.0360^{\text{Food Prodn}}$