NO STARVING BILLIONS:
THE ROLE OF AGRICULTURAL ENGINEERING IN ECONOMIC DEVELOPMENT

by

WESLEY F. BUCHELE
Professor of Agricultural Engineering
University of Ghana and Iowa State University

An Inaugural Lecture delivered on May 9, 1969 at the
University of Ghana, Legon, Accra.
ERRATUM

Page 18, line 9, for “Manufaccure”
read “Manufacture”
NO STARVING BILLIONS: THE ROLE OF AGRICULTURAL ENGINEERING IN ECONOMIC DEVELOPMENT

by

WESLEY F. BUCHELE
Professor of Agricultural Engineering
University of Ghana and Iowa State University

An Inaugural Lecture delivered on May 9, 1969 at the University of Ghana, Legon, Accra.
NO STARVING BILLIONS: THE ROLE OF AGRICULTURAL ENGINEERING IN ECONOMIC DEVELOPMENT

Introduction

The agricultural situation in developing countries is much as it has always been. Using iron age tools and equipment developed long ago, the nomad follows his herd and the peasant farmer shifts from patch to patch.

While the mechanical revolution has little affected his way of life, the chemical revolution is drastically affecting him today. Chemicals, insecticides and drugs, reduced the spread of disease and cured the afflicted. This lowered infant mortality, extended the life of the aged and launched the population explosion. Unless there is a simultaneous explosion in food production, the speedy death by diseases will be replaced by the slow death by starvation.

The news is not so much what the situation is, but that it can be changed, that economic development can take place!

Situation in Developing Countries

The way of life of the rural areas that developed centuries ago is based upon the climate, the productivity of the soils and the available tools and equipment. The animal drawn plough, hand-
hoe, cutlass and head pan are almost universal tools. They were invented locally or were spread by trade or by invading armies.

Developing countries are defined as those in which the great majority of people, often over 80%, live on the land and depend directly on agriculture for their livelihood. The average daily wage is less than one-half cedi per day. The agriculture is largely of the traditional or static type and is powered by human beings and/or animals.

The following is a comparison of the conditions existing in the developing countries and the United States.

<table>
<thead>
<tr>
<th>Developing Country</th>
<th>U.S.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Percent of population engaged in Agriculture.</td>
<td>70 to 80%</td>
</tr>
<tr>
<td>2. Percent of income spent on food.</td>
<td>70 to 80%</td>
</tr>
<tr>
<td>3. Daily wage of farm worker.</td>
<td>NXC0.25 to NXC0.70</td>
</tr>
<tr>
<td>4. Horse power per cultivated acre</td>
<td>.03</td>
</tr>
<tr>
<td>5. Number of off-the-farm persons supplied food &amp; fibre by a farm family</td>
<td>1/4 to 1</td>
</tr>
<tr>
<td>6. Average size farm</td>
<td>3 to 10 acres</td>
</tr>
<tr>
<td>7. Percentage of 20–24 year-olds in College</td>
<td>.05</td>
</tr>
<tr>
<td>8. Average yields of grain pounds per acre per year</td>
<td>900</td>
</tr>
<tr>
<td>9. Average calorie content daily diet</td>
<td>2,200</td>
</tr>
<tr>
<td>10. Percentage of grain lost between field and consumer</td>
<td>30 to 40</td>
</tr>
<tr>
<td>11. Population growth</td>
<td>2.6</td>
</tr>
<tr>
<td>12. Median age of population in yrs.</td>
<td>15</td>
</tr>
</tbody>
</table>

For centuries the population and the food supply of developing countries have both expanded at the rate of 0.1% per year.

Since food production appeared to meet the demand for food, it was concluded that there was a direct relationship between the food production of a country and the number of peasant farmers. With the introduction of chemicals (insecticides and drugs) in the
1950's, the population growth sky–rocketed, by 2.5 to 3%. If the above relationship is true, a geometrical increase of food production should follow population growth by 12 to 15 years. This will happen when the enlarged group of children begin growing food, but there will always be a gap between food produced and food needs in a static agriculture.

Today, the quantity of food consumed by the extra children, saved by the drugs and insecticides, between the time he is born and the time he takes up the hoe is supplied by advanced countries.

Because supply lines, both chemicals and foods from overseas are best in the cities, the urban population is expanding fastest of all. In addition, the number of peasant farmers is decreasing, the rural youth are migrating to the cities. This accelerates the decline in agriculture productivity of the country.

Even if enough food is produced by the peasant farmer, the traditional transportation and marketing system would have a difficult time moving it to the cities fast enough to supply the growing needs.

Need for Economic Development

Many thoughtful people have recognized the collision course of soaring World population and static food supply. One of the latest, Lord C.P. Snow said in 1968, "At best, this will mean local famines to begin with. At worst, the local famines will spread into a sea of hunger. The usual date predicted for the beginning of the local famines is 1975–1980. Many millions of people in the poor countries are going to starve to death before our eyes".

Preventing this prediction from occuring is being accepted as a challenge by intellectual people throughtout the world. They believe that rapid economic development will solve the food problem, raise the standard of living of a country and contribute to nation building.

The developed countries have implemented massive foreign aid programs and the brink–of–disaster nations, have written 5 years economic development plans. They do this because they know the
rise and fall of civilizations have closely paralleled the success of the farmers in producing food. A nation turns to civilization-building only after the farmers have been able to provide an adequate supply of food. The food supply problem was solved by developing the art of carrying out the necessary tillage and cultural practices with a unique set of tools and equipment. The number of people needed for civilization building were released food production, only after the tillage operations and to a lesser extent, the threshing and grinding operations, were powered by slaves, animal or in later years by tractors.

Each plan of the developing countries has directed the nation's resources into either the industrial sector or into the agricultural sector. The next five years' plan of the nation invariably shifted the national effort from the sector presently being emphasized to the other sector and each plan in turn failed to reach its stated goals because the sector not being supported failed to sustain the planned economic growth.

For economic development to succeed, the industrial sector and the agricultural sector must move forward together. This is accomplished when the industrial sector deals with the manufacture and supply of agricultural machinery and when the agricultural sector is geared to use these machines. This happens when agricultural engineers provide the catalytic function in both the agricultural sector and the industrial sector.

The major objective of this paper is to discuss the role of the agricultural engineer in supplying the professional services needed to ensure the successful growth of each sector and to produce an adequate supply of nutritious food.

The Role of Agricultural Engineers

Working in agriculture, the agricultural engineer is needed to:

1. Invent, design, develop and manufacture or to select and test tools and equipment needed by the tropical farmer for tilling the
soil, planting the crop, harvesting the crop, for processing the crop and transporting the product.

2. Design and construct buildings to house the livestock and store the crop.

3. Design and build structures for the control and use of water and for conserving the soil.

4. Conduct research on tillage systems, crop drying, crop storage and processing, irrigation, drainage and methods of conserving water and soil.

The agricultural engineer must not only understand the crops and soils of the area and the job to be done, but he must understand the people and their economic and political environment.

After the designs are established, the agricultural engineer works with local industry to transfer the new ideas from research concepts into commercially produced machines or buildings. The new device must be designed for production under local condition, jigs and fixtures designed and built, manufacturing operations detailed and assembly lines established for manufacturing the machine. The manufactured product is then tested for function and for service life under local conditions.

Lastly, the agricultural engineer is needed in agriculture to help the farmer to understand the use of the new design and help him use the new machine, building, or system profitably on his own farm.

In order to improve further the efficiency and economic position of the local farmer in the world market, the new device must be further developed by the engineer and the selling price reduced.

You may ask the question, if agricultural engineers are so important, why did not the profession develop earlier and why are their numbers so few? The answer is simple; the profession developed and grew up outside the academic community in both the United States and in Europe.

A review of history shows that the founding father of the agricultural machinery industry were blacksmiths. Blacksmithing was an
extensive occupation in the U.S. because horses were used for farm work as well as for transportation on the 19th century farm. The blacksmith shod the horses, built and repaired wagons and manufactured tools. As the need for agricultural machines became evident, it was natural for him to invent and begin the manufacturing of farm machinery.

The agricultural engineering profession developed after the turn of the century in the United States, when men with engineering training were needed to design the increasingly complicated machines and tractors. It did not materially develop in Europe until after World War II. The need for agricultural engineering in developing countries goes far beyond that of providing technical services.

National leaders are needed to formulate and carry out agricultural policy. They must be able to look beyond the improvement of a tool to the development of a completely new crop production system; beyond the design of machines to replace manual labour to the design of new machines that do entirely new jobs now impossible to perform by hand. The specific design of an irrigation ditch turns into planning for the utilization of the land and water resources. Mechanization of import substitution goods changes to the manufacturing of capital generating equipment for the basic industries of agriculture, mining, forestry and fishing.

It may be argued by some that the generalist, the person educated in the arts, is more capable of making these decisions; that the technician cannot see the forest for the trees. This simply is not true. The agricultural engineer has been dealing with developing agriculture production all along. The moment he is allowed to create national policy in mechanization, he will take to it like a duck takes to water. But the problem is that the engineer like anyone else, needs many years of experience in various management tasks before he is thrust into making national policy. Because the people making up the engineering profession of developing countries are relatively young, many will be forced into policy positions long before they have developed a mature view of their professional
responsibility in national development.

This is one area where experienced foreign Agricultural Engineers with a long history in agricultural development can render invaluable advisory service.

**Necessary Conditions for Economic Development**

We have said that for economic development of a country to take place, there must be simultaneous industrial and agricultural development. Industrial development must be primarily concerned with the production and marketing of agricultural tools and equipment.

Agricultural development must be concerned with the use of these tools and equipment in ever increasing numbers for production, processing, storage and transportation of farm products.

When the Agricultural revolution coexists with the industrial revolution, a large number of economic forces come into play by the double revolution. The agricultural machinery industry siphons \(^{(1)}\) off to the city the rural labour supply to build farm machinery.

The farmers are then forced to substitute capital investment in machinery for labour, or pay higher wages.

The money the manufacturer receives for his machinery is used to hire more labour away from the farm and the farm wages rise again to compete with the price of industrial labour.

As the wages rise, the money earned by the labour above that needed for the purchase of food is spent for new goods and services. This creates a sound basis for the development of a consumer goods industry.

As the farmers increase their mechanization, the cost of production decreases and the number of acres that can be farmed increases. This two-fold effect increases the productivity of the mechanized farmer, and a plentiful supply of inexpensive food becomes available for purchase by the urban population.

Using the profits of farming, the mechanized farmer purchases
or rents additional land from the farmer who did not mechanize.

This review shows that economic development was propelled by the agricultural machinery industry, that agricultural revolution coexisted with the industrial revolution and that they each fed on each other.

While this was the model for the 19th century development of America, it is far different from the conventional 20th century foreign aid approach. To get agriculture development moving, the agriculture officers invariably start an activity that has nearly a 100% possibility of success. Using imported fertilizer, insecticides and improved varieties of crops, they demonstrate that yield per acre can be increased.

When it is found that these inputs do return a profit to the farmer, there is an immediate temptation to recommend that the national planner build chemical factories and start producing these inputs to save foreign exchange. Now this may sound logical, but nothing could be more disastrous at the beginning stages of development. Managers, engineers and money already in short supply, are tied up manufacturing something that could be imported.

There is nothing unique about fertilizer that requires it to be under continuous development in a specific country. Once the proportion of nutrients are established in a particular country, the dials can be set and the fertilizer can be produced anywhere in the world.

The available management, engineering and money in the country should be used to establish a farm machinery industry to produce equipment adapted for the local crops and conditions.

Though the above prescription for economic development appears simple and straightforward, it has been missed in nearly every economic development plan put forward by national planning commissions or by Foreign Aid programmes.

We have said that the chances for success increase when the agricultural sector and the industrial sector develop together.
A nation develops when the following conditions (2) are met:

1. The energy used by each individual worker in industry and on the farm is increasing.

2. The percentage of the population employed on the farm is decreasing.

3. The percentage of the worker’s income spent on food is decreasing.

There is a direct relation between the percentage of the population engaged in agriculture and the percentage of the worker’s wages spent on food. The industrial labourer of developing countries spends a very high proportion of a very low wage on food. There is little left in the pay check to buy other goods and services.

Agricultural workers, using the products designed by agricultural engineers, have a higher work index and direct and use more energy than workers in any other industry. The standard of living of a country closely follows the work index of the agricultural and the industrial workers.

The above three conditions are easily met when the following are happening at the same time:

1. The farms are using more efficient tools and changing the form of power from human to animal to tractor. Instead of doing the job by hand, animal or tractor powered machines are used to till the soil and thresh the grain. The planting, weed control and harvesting are done with improved hand tools or animal or tractor drawn equipment.

2. The farmers are using off-the-farm inputs such as fertilizer, pesticides, and machinery to augment the fertility of the soil, provide pest control and improve the environment of the plants.

3. The agricultural machinery industry is providing repair services for the machinery and other commercial or government organizations have been established to provide advice and supply the off-the-farm inputs.

4. A system of long term and short term credit is available to the farmers.
5. Transporting and marketing systems are moving and selling the farm products.

While it is conceivable that these three conditions mentioned above could be met, and the five simultaneous happenings could take place without professional help, the facts are that they have not taken place in developing countries.

A review of the historical development of agricultural machinery will place the responsibilities for economic development in better perspective, will show that an industry prospers when solving a unique problem and will at the same time show how economic development took place in other countries.

**History of Agricultural Development**

The cultural practices and equipment needed for permanent, powered, profitable agriculture were developed for the semi-arid regions of the middle east (Egypt, Indus Valley, Iran, Iraq) between 3000 and 6000 years ago. Irrigation was invented at that time to provide water for the growing crop. These practices and equipment are used today in the flooded rice culture of the tropical areas.

The cultural practices and equipment needed for permanent, powered, rain-fed farming in the temperate zone were developed during the nineteenth century in the United States and Europe.

The cultural practices and equipment for permanent, powered, profitable farming have not yet been developed for rain-fed farming in the low altitude Tropics. Concentrated research efforts by agricultural scientists and agricultural engineers will be needed during the next two or three generations to develop a profitable tractor-powered system of settled farming on tropical soils.

Because the development of powered farming marked the beginning of economic development in the United States, a review of her development history is genuine to the development of tropical countries. For at the beginning of the 19th century, the United States was one of the most undeveloped nations in the world. Europe
on the other hand had highly developed cities but development was not extended to the rural peasantry until after World War II.

The invention that marks the beginning of the agricultural revolution, took place in England at the beginning of the 18th century. There, Jethro Tull, in 1709, devised the row-system of growing crops and invented the horse-drawn row-crop planter and horse-drawn cultivator. This system of planting in rows slowly began to spread around the world a century later. It is now used almost universally for planting crops except small grains such as wheat or rice.

The equipment however, needed to carry out the practice in many countries did not follow the practice, or were found inadequate to cope with the unique local conditions. Thus many areas of the world, today, engage in row crop farming with human-powered tools and equipment.

The next major step in powered agriculture was the invention of the cotton gin by Ely Whitney in 1793. The impact of this invention had far reaching effects. One of the major needs for slaves throughout the world was for pulling cotton lint from cotton seed. With the invention of machinery capable of replacing hand labour England outlawed the slave trade in 1807. Importation of slaves into the United States was made illegal in 1808. England abolished the slave trade throughout her territories in 1833. Because machinery for harvesting of sugarcane was slow to develop, slavery continued in the sugar growing countries till the 1880's. While the moral indignation of various people popularized the sinful nature of slavery, it was the invention of agricultural machines, such as the cotton gin and other machines to be described later that made slavery uneconomical and spelled the deathknell of the practice in all but the primitive societies of Africa.

Agricultural machinery development in the United States began in earnest in 1819 when a patent was granted to Jethro Wood for a cast-iron mouldboard plough. This plough with replaceable wearing parts, permitted the efficient breaking of virgin soils.

Cyrus K. McCormick invented the reaper for harvesting small
grains in 1831. At that time, the ratio of the rural population to the urban population in the U.S. was similar to that of most developing countries today. Between 80% and 90% of the population lived on the farms. Each farm family provided food for themselves and for about one-half of another person located off-the-farm. Today, the American farm family produces food for themselves and 76 people located off-the-farm. The reaper broke the harvesting bottle-neck. Before this invention, a man could till and plant with a team of oxen more land than he could harvest by hand.

The invention of the reaper was closely followed in 1837 by the invention of the steel-mouldboard plough to replace the cast-iron plough. The development of the plough is a fascinating history of man using his skills and ingenuity to build a soil-working tool from the materials of his age. The cast-iron mouldboard permitted the efficient ploughing of the rocky soils of Eastern United States. But the flat-rich prairie soils of mid-west America, after being ploughed several times, no longer flow smoothly and easily off the cast-iron mouldboard. The moist soil stuck to the mouldboard; it did not scour. During ploughing, the soil flowed over a layer of soil that had adhered to the cast-iron mouldboard. (The adhesion between the cast-iron mouldboard and the prairie soil was greater than that between the steel mouldboard and the soil, the internal strength of the soil was sufficient to move the soil over steel but insufficient to move the same soil over cast-iron.) The cast-iron mouldboard plough pulled hard and did a poor job of ploughing. The steel mouldboard that John Deere fashioned from a broken saw mill blade efficiently ploughed the rich, black, prairie soil, and made farming possible not only on the black-prairie lands of North America but on similar lands on other continents.

Shortly thereafter, Jerome I. Case, began manufacturing threshing machines to efficiently thresh and separate grain from straw and chaff. These men, and many other ingenious men that followed them, wrought a revolution in industry and agriculture that caused development to take place simultaneously in rural and urban areas of North America.
They founded the first large manufacturing industries in North America, developed methods for conducting business, established principles of business management, created the concept of guaranteeing the performance of the product and set up world-wide dealer organizations for selling, servicing and repairing the products of their factories. After many mergers, these companies exist today as manufacturers of farm machinery throughout the world.

It is not uncommon today for farmers using these machines to do work at a rate equivalent to that done by one or two thousand men.

The grain produced by these new agricultural machines in the United States was shipped in great quantities to the cities of Europe beginning in the 1870’s. Wheat could be grown and harvested in the U.S. and shipped to Paris and sold cheaper than the French Peasant could hand produce the wheat. The tremendous supply of wheat outpouring from the U.S. facilitated the growth of the great European cities in the latter part of the 19th century, just as the same outpouring of grain is now, today permitting the growth of similar great cities in the developing countries. Hongkong, Toyko, Calcutta, Bombay, Accra, are but a few of the cities whose food supply is now supplemented by machine grown and machine harvested grain from another country.

A study of recently organized agricultural machinery companies in developed countries shows that the farmers (2) are still inventors and that engineers are both inventors and developers of machines. In Europe, the self-loading hay wagon was developed by a German farmer and the rotary bar mower was invented by a Dutch farmer; the flail manure spreader and flail forage harvester were invented by Iowa farmers in the U.S.A. This is possible in developed countries because modern, mechanized farmers are skilled in metal working. Most farmers have a workshop equipped with an electric are welder, acetylene gas cutting torch, an electric power drill and a large assortment of junk consisting of old farm machines and automobiles.

The situation appears quite different in developing countries.
The skill needed to invent or develop new machines does not appear to exist at the Peasant farm level. Thus the Agricultural Engineers in developing countries have a much greater responsibility; they must assume the job of inventing and developing needed machines and adapting machinery of other countries so that they will work under the specific tropical conditions.

The agricultural engineering departments of the various Land Grant Universities of the U.S. have become exceedingly active in agricultural machinery invention and development since World War II. The Research Professors or their graduate students have invented and developed nearly all of the machines now used for the total harvesting of maize, for alfalfa leaf harvesting and the brush stripping of cotton. Working with horticulturists, they have invented and developed machines for harvesting tomatoes, grapes, cabbages lettuce, carrots radishes, peaches, plums, dates and English walnuts. Agricultural engineers at the University of Ghana have developed the low cost oil palm press fabricated originally by Gordon (7) and cassava graters and hand maize shellers, maize dryers and maize ridger–planters. Agricultural engineers in India and Tiawan have constructed many new machines such as grain drills, fertilizer distributions and maize planters.

Whether any of the above machines will ever become commercially available remains to be seen. The important point is that new machines are being developed in tropical countries by agricultural engineers.

The largest agricultural machinery manufacturing company in Ghana is owned and managed by an agricultural engineer. He manufactures locally-developed cassava graters and presses, tobacco barn flue pipe and chicken feeders and waterers.

But the development of a machine is only a small part of the problem. It must be commercially manufactured in such a way that it has a long useful life. It must also sell at a price that the machine (within its use pattern) can save the farmer at least the annual cost of ownership which is around 25% of the purchase price of the machine. The cost of introducing a machine on the
market is at least equal to all the money, real and otherwise, spent getting the machine ready for production. The agriculture policy must be carefully structured to promote the development and manufacturing of the new machines. Quantity purchase orders and maximum extension effort are necessary to promote the manufacture and use of farm machines.

Why Agricultural Machinery should be Developed

Agriculture is the major capital generating industry of nearly every nation. It generates capital out of free inputs such as oxygen, water, CO₂, heat and time. The money earned from the sale of the products is used to pay for purchased inputs and return a profit to the farmer. Other examples of capital generating industries are mining, forestry and fishing. Because equipment used in these industries reduces the cost of production and increase productivity, they are considered capital generating machinery. They pay for themselves many times over by either reducing the cost of operation, improving the efficiency of the operation or increasing the productivity of the land or the sea. The agricultural machines maximize the yield by timely planting of uniformly spaced seeds placed at the correct depth, correct placement of fertilizer and pesticides, timely weed control and efficient timely harvest and processing of crops. While a combination of improved varieties and fertilizers may improve the productivity of the land two to four times, machinery not only improves the productivity of the land but also improves the productivity of the farmer.

Agricultural machines are human multipliers, they permit one man, depending on the size of machine and the crop, to do the work of a thousand or more men. The time and energy spent on the initial manufacturing of the tractors and implements is returned to the nations economy again and again as the machine is used through the years of its useful life. For example, if the total time required to build a combine is 300 man-days and the combine, doing the work of 1,000 men, is used 30 days per year for 10 years, the ratio of labour efficiency is 1,000 man-days saved for each day expended. This ratio of labour efficiency in food production permits
a nation to develop its educational, governmental and service systems.

The people released from the food production occupation are available for promoting the arts and fighting diseases and travelling to the moon. The machines so greatly increase the efficiency of the productive farm labour that in spite of the tremendous accumulation of labour in non-productive jobs, the nation as a whole remains productive and solvent.

Local Development and Manufacture of Agricultural Machinery

The reason that the emergence of an indigenous manufacturing industry is an important and necessary ingredient in agricultural development is that the implements must be tailor-made to efficiently operate within the constraints of the climate, crops and soil of each particular area. No country has successfully developed her agriculture with imported farm equipment. World wide machinery manufacturers cannot produce machinery for a local market or condition. Only a few countries including Canada and Israel were able to develop without a tractor manufacturing industry and this is true even though the tractors have been designed to operate and develop traction over a wide range of soil conditions.

Many countries have entered into agreement with World-wide tractor Manufacturing Companies to set-up and operate tractor assembly plants as a means of reducing the drain of foreign exchange.

The review of the development of various agricultural machinery companies showed that each company began with the development of a farm machine that solved a unique problem or suited a local need. The company assumed the obligation of continuous development of the specialized machine. If the job was efficiently done and the crop acreage increased, the company prospered. In other cases, the company remained small as it produced machines for the special local market. But the machine is just as important to the specialize farmer as it is to the general farmer.

The peasant farmer and his family are the major consumer group
in a developing country. There is a vast and untapped market for adapted tools and equipment that will increase the productivity of the farmer. The local machinery companies need to employ Agricultural Engineers and take on the obligations of improving the efficiency of the machines and reducing the cost of operation and selling price.

Often, as the machine is developed, a higher quality of product is harvested by the machine. For example, second-picking machine-picked cotton grades higher than second-picking hand-picked cotton.

Because Agricultural Engineers in every country are continuously improving the efficiency of farm machinery and reducing the selling price, no farmer can remain economically solvent when continuously using one particular model of machine. An agricultural machine becomes functionally and/or economically obsolete in 10 to 15 years. This means that because of improvements in design, increase in efficiency, changes in speed of operation or size, it is uneconomical for the farmer to continue to use the old machine. A new machine will literally pay for itself out of savings accrued from using the new machine instead of the older, obsolete machine. A farmer operating outdated machinery is a poor competitor with a farmer using the newest model machine.

Tractors and to a lesser extent harvesting machinery, can be imported into the country but the tillage, planting and cultivation machinery will have to be locally produced.

Does Agriculture Machinery Cause Unemployment?

Whenever mechanization of farming is discussed, the question of the machinery putting men out of work arises. It is pointed out that developing nations are short of capital but have an abundant supply of surplus labour and that labour-intensive systems of farming should be recommended by the extension service. This conclusion shows little knowledge of the actual farming situation.

There are critical times in the year when there are severe shortages of labour. The scarcity of labour may occur during any one or
more of the following seasons: 1. Land clearing, 2. Land preparation, 3. Planting, 4. Weed control or 5. Harvesting. The number of acres of land farmed is determined by the area that can actually be covered by the labour available during the critical season.

Millikan and Hapgood (11) in their book *No Easy Harvest* state; "machinery may sometimes be the only way to raise yields and far from saving labour, such machines as tractors (and adapted farm machines) are often labour-complementary — that is, their use increases, rather than decreases, the demand for labour". They go on to say, "Multicropping may in some cases be possible only with powered machinery. This is true if planting dates are critically short... Often the time during which a crop must be planted for maximum yield is no more than a few days per year. When machinery permits double cropping, or larger plantings of a crop such as rice that is labour intensive in other stages as well as planting, the effect is to increase the demand for labour. What happens is that the farmer's effective labour is increased at those key times when he is fully employed in any case. His larger crops then require more labour at other times of the year".

One might ask, "why not plant any time during the growing season?" This would be courting disaster. Because of the attacks of birds, animals and human being on his crops, the farmer does not want to be caught feeding all of the neighbourhood pests from his fields that ripens either ahead or behind that of his neighbours.

Irrigation pumps are another form of labor-complementary machinery. They make intensive cultivation and double or triple cultivation possible and raise the demand for labor.

**Advantage Accruing from Mechanization**

Mechanization promotes timeliness of planting in rain-fed farming and reduces the time land is idle in irrigation farming.

In the U.S., one day delay in planting maize causes a reduction of 1 bushel per acre and if soyabees ½ bushel per acre. In the
Sudan, disease infestation drastically reduces the yield of late planted cotton.

In the Phillipines, Loyd Johnson (10) found that a human powered farmer uses 20 to 30 man-days to single-spade his land. When the "productivity land-time" of rice is 10 lbs a day, the cost of delay of tillage is 200 to 300 lbs of rice per acre. The delay is made even more serious because weeds will have grown back on the first tilled land. He found that one animal used to pull the plough and comb harrow will reduce the cost of delay due to tillage 40 to 70 lbs per acre. The cost of delay of 10 days in irrigated areas will be more than the pay for hiring the tillage done by a custom tractor ploughman.

Giles (9) reviewed the literature concerning the effect of mechanization on the yields of various crops. He found a delay in planting, because of slow tillage and/or slow planting operation, caused a 1% loss in yield for each day delay beyond the 10 to 15 day optimum period. He found evidence that showed an increase in yield of 35 lbs per acre from every extra ploughing up to 9 ploughings with a "country" plough. Using traditional animal power methods of ploughing one acre per day and "productive land-time" of 10 lbs per acre per day, the net gain in production for a day's work would be 25 lbs of wheat per acre per day.

Superior soil manipulation in the Raipur district of India increased yields 40% over the traditional ploughing. He found that the peak labor period in the Punjab was November when the maize was harvested and wheat was planted. Double cropping the land is only possible after the farmers have mechanized the tillage and the sowing of the wheat.

A three-row grain and fertilizer drill in India pulled by a pair of bullock, gave a 12.5% increase in yield of wheat and a 39.5% decrease in labor over plots planted by hand at the same time. If used on 15 acres of land, the increase in yield alone would pay for the drill. A one-row maize and fertilizer planter increased yields 40% and reduced labor 36%.
When fertilizer is machine-placed in the soil as compared to broadcasting by hand, yields are increased 50%.

Timely and efficient harvesting maximizes the yield of all crops. Too early or too late harvest lowers both the quality and quantity of products. Studies in Burma show a 2% loss of rice per day of delay in harvest. Improved harvesting, drying and milling practices increased the out turn of whole kernel rice from 58% to 70%.

**Competition Among Farmers**

The farmers of the world compete with each other, whether they live in the same country or in different countries. Wherever he lives, the human powered farmer competes with the tractor powered farmer. The peasant farmer operates to minimize the risks in the event of crop failure or low prices. He pays little or no rent, uses his own seed and labor. The worst that can happen during failure or poor prices is that he and his family have little or no income but they will not starve.

Loyd Johnson of the International Rice Research Institute showed that the quantity of energy required to till the land is approximately the same irrespective of the size of the prime mover and the tillage machine.

Because the time between primary tillage and planting can be condensed with tractor drawn machinery, secondary tillage can often be eliminated and farming costs reduced. The type of soil and the environment influence the cost of tillage. The net income the farmer receives is depended on the cost of producing the energy needed to till the soil, plant, control weeds, harvest, dry, process, store and transport his crop. The greater the energy used per acre, the larger the machines and the greater the expense of ware and tare and cost of farming.

Agricultural engineers not only help with the design and manufacture of the engines that develop the energy and the machines that use the energy but also work with the farmers to minimize
the expense of using the machines and maximize the productivity of soil.

Cost of Farming By Human, Animal and Tractor Power

Dynamometer tests have been run to measure the power developed by working human beings. These tests show that a man can develop between $\frac{1}{10}$ and $\frac{1}{20}$ of a horse power. It is reasonable to expect a man working $7\frac{1}{2}$ hours per day in the Tropics to develop and direct approximately $\frac{1}{2}$ horse power-hour of energy per day.

Based on a minimum wage of 70 new pesewas per day in Ghana, the cost of a directed human-developed horsepower-hour is N\$1.40. The efficiency of the human being in applying the energy he developed is assumed to be 100%.

The cost of a directed tractor-developed horse-power-hour is approximately, N\$0.07 in Ghana, only slightly more than N\$0.05 in the U.S.A.

If the efficiency of the machine in using tractor-developed energy is considered 20%, then the cost of a directed tractor-developed machine horse-power-hour is N\$0.35. (If the machine was 40% efficient, the cost would be N\$0.175 per horse power-hour).

It is thus obvious that the cost of energy the tractor farmer uses is 25% of the cost of energy to the human-powered farmer. The cost of ploughing land with a tractor is calculated to be approximately N\$2.37 per acre based on 1969 prices and an annual use of 800 hours per year for the tractor and 200 acres per year for the plough. Wadhwa (12) found that the cost of human powered primary tillage was N\$9.30 per acre (93 hours per acre at N\$0.10 per hour). The cost of ploughing by bullocks power was N\$5.70 per acre and by two wheel tractor N\$5.90 per acre on 10 acre farms.

He found that human-powered farming was cheapest for farms below 3.5 acre. He found bullocks were the cheapest source between 3.5 and 15 acres, a two-wheel tractor was the cheapest source of energy between 15 acres and 40 acres of cultivated land. Above 40 acres, the four wheel tractor was most economical. It is interesting
to note that this conclusion concerning the cost of energy compares favourably with the situation as found by Haldore Hanson, West Africa representative for the Ford Foundation. "A farmer with a hoe," he said "manages 2 to 3 acres, whether he is Japanese or Indian or West African. A farmer with a water buffalo, or a bullock or a camel or a pair of donkeys manages 10-15 acres whatever his nationality."

The question might be asked, "why doesn't the human powered farmer hire labourers and farm more land?" The total cost of permanent farming with hired labourers is at least N\$34.50 per acre. If the yield is 5 bags per acre and the selling price is N\$8 per bag, the profit per acre would be only N\$5.50 per acre. This profit could be wiped out if the yield or price fell or he had to pay interest on the money. The laborer would receive N\$61.50 for his years work for farming three acres. The farmer would receive N\$16.50 per hired laborer minus interest charges.

Wadhwa found that when the human labor was supplemented with tractor powered mechanical operations such as tillage, each farm laborer must handle 18 acres of maize in order for the farmer to break even based in the above data of yield and price.

Thus the human powered farmer cannot afford the risks involved to hire laborers to increase the area farmed. On the average, he produces enough food to feed his family and sells enough food off-the-farm to feed one person.

The average daily gross income of the human-powered farmer is thus determined by what the farmer receives for one daily food ration consumed by the off-the-farm person, plus the cocoa sales and other cash crop. In Ghana, the farmer receives approximately N\$0.30 for a daily ration or N\$109.50 per year. If he grows cocoa or non-food cash crops, his annual gross income may be more.

**Effect of Large Farming Schemes on Economic Development**

Large farming schemes have little to do with the economic development of a nation. They are often encouraged by governments
because of what the scheme promises:

1. That it would import large sums of hard currency to start the project. 2. That the product has a ready export market. 3. That it would provide new employment opportunities, and 4. That the scheme has innovation value in developing new markets, new farming methods and new product processing techniques.

The problem lies in the fact that large schemes do not encourage the development of local agriculture service industries. Farm machinery and farm supplies are purchased by overseas contracts. Because the scheme begins large, the service needs at the beginning are large. To meet the immediate need, the scheme, itself establishes its own service facilities. Local service industry does not get the chance to grow with the scheme.

Because the scheme starts large, there is no chance for determining the best equipment and cultural practices by experimentation. The theory is that the scheme is going to grow maize like they do in Iowa or sugar cane like they do in Hawaii, and they are going to grow thousands and thousands of acres the first year. But farming in the Tropics is not that simple. Before the local workers have mastered the operation of the machines, before a set of cultural practices that can be mechanically carried out by the imported equipment have been developed, before the managers have developed the ability to manage the new machines and the new workers in the new conditions of climate and soil, the scheme will have turned sour. The expatriate management team will have lost their zeal because of the ravages of constant sickness and diseases. The land, so costly and laboriously cleared of bush and forest, will in turn become infested with weeds and grass. The soil will have become compacted under the constant tillage operations carried out to control the grass and weeds. Because of the compaction of the soil, the yields, even under high fertilizer applications, will have fallen far short of projected yields and will become less each year. The vast sums of money allocated to start the project will have been spent and each day sees the scheme sinking deeper and deeper into debt.
The author has not found one settled, powered, profitable settled farming scheme in the rain-fed, sea level, Tropics of Africa. A.H. Bunting (3) reached the same conclusion in 1967, "I am the last to say that large scale mechanization is technically impossible; it could even be economically successful, given the right sequence of survey, research, pilot scale operations, economic assessment, logistic planning and training. Nevertheless, it has not succeeded in fact in any instance known to me. Africa is littered with cemeteries in which tractors, dreams and ambition have rotted away together in the tall grass."

Planning ability seems in short supply in the Tropics. Yet history records that considerable planning was done on the semi-arid Gezira Scheme of the Sudan. The first survey of the Blue Nile area was conducted in 1904. A considerable number of small scale irrigation tests were conducted in the teens and the Sennar Dam was not finished until 1925.

The Wanji Sugar Estates of Ethiopia successfully farmed in Indonesia before being forced to leave that country. The sugar and pineapple companies of Hawaii have enjoyed spectacular success in mechanized farming.

The innovation value of large scheme may be overrated. The Wanji Sugar Estates has little effect on the surrounding farming area. The relation between the sugar plantation and traditional farming outside the gate is similar to the relation between space shots and the hunting of wild animals with a bow and arrow.

When the large scheme is successful and makes a profit from the scale of products within the country, there is a constant drain of foreign exchange as the company withdraws the profits as permitted under the inducement contract.

**Effect Of Land Tenure On Mechanization And Land Development**

There is a direct relationship between the status of land tenure and the productivity of the farmer.

Usufructuary rights in stool land and remote landlords are
synonymous with low productivity and subsistence farming. Under these conditions, approximately 80% of the people live on the farm and produce only a portion of the food needed by the people living in the cities.

The management expertise and monetary inputs needed to inspire the tenant farmer to match the productivity of the land-owning farmer appear to be astronomical. The Russian peasant is 38 times more productive on his private plot of land than he is on the collective farms or state farms.

The Kibbutz of Israel and the Gezira scheme of the Sudan are the few examples of commercially successful ownerless farming. The former succeeds because they are bound together by a common objective and are highly motivated. The later succeeds because of extremely low operating costs of the Gezira Board brought about by an unbelievable large number of favourable conditions in a semi-arid land. There is a vast level expanse of uniformly sloping land, vast quantities of water supplies by the adjacent Blue Nile and weather conditions favouring the growth of a high value long staple cotton crop that has a good overseas market. By having more than 70,000 farmers using the same types of inputs and extension advice, the cost per farm is minimized. Coupled with this is the high probability of absolute failure of the crop when management instructions are not followed.

A high proportion of land-owning farmers are necessary to the development of a country. The privately owned land provides the physical as well as the economical base upon which a farmer may build his farm enterprise. It provides a handy source of collateral for long term loans of money for purchasing buildings, machinery, fencing, agricultural inputs such as seed, fertilizer and pesticides, establishing irrigation systems or for purchasing more land. Without collateral for long term loans, the farmer falls prey to high-interest, short-term money lenders that sap up the money earned each year without permitting the development of the farm and the farmstead.
Another sociological factor that drastically reduces the incentive of developing the land is the matrilineal inheritance system. Why should the farmer's sons encourage the construction of an efficient grain drying and storage system on the farm when the nephews of their dead father will displace them as they inherit the improved farm.

The development of a land tenure system is the "first must" in nation development. All other activities such as crop and animal breeding, enlargement of educational system and creation of industry are of little or no value to a peasant landless farmer who must deal with a remote, disinterested land owner. The research results gained by years of costly experimentation will accumulate in the libraries and lie there unused. The use of research results normally require increasing the number and quantity of agriculture inputs used on the farm and agriculture inputs cost money.

As I have indicated, when all of the land is tenant-farmed, the amount of agriculture inputs provided by the government or managerial board needed to make agriculture a success are extremely large. It is doubtful that if any developing country will ever be able to attract enough foreign aid, both in technical talent and money, to offset the liability of landless farmers.

The peasant farmer will use free inputs or inputs supplied under governmental credit plans, but will return to shifting cultivation when the inputs are no longer supplied. He will do this rather than tie himself to the local credit merchants.

The traditions of communally-held land are such that there is a strong bias against the development of the land. The farmer can use the land but he cannot own the land. He can herd cattle on the land but he cannot fence the land. He can clear land and burn the land but he cannot mortgage the land.

As the percentage of people living in the city increases above 20% of the population, food must imported to feed the increasing urban population. In Ghana, where 30% of the people now live in the
cities, the foreign exchange earned from the export of cocoa, gold, lumber, and diamonds has been increasingly used alongside of increasing foreign aid grants to increase the importation of food to feed the increasing urban population. The situation will grow worse as the percentage of urban population increases.

For a nation wanting economic development to take place, this is an expensive price to pay for a non-working land tenure system. A nation blessed with the rich natural resources of Ghana can feed herself. When she does, the foreign exchange earned from mining, lumber and agricultural cash crops would then be available for economic development.

One further word must be said about the accumulation of the unemployed educated youth in the cities. They migrate to the cities because there they can own property and use it to establish an economic base of operations.

It is axiomatic that when the land has no marketable value, the nation will be economically and politically urban-oriented as wealth can accumulate there and the ambitious will congregate in the cities to lay hold of the economic wealth and the political power.

**Increasing The Quantity And Quality of Food**

The foregoing discussion has clearly delineated the problems of mechanizing developing countries. The title of this paper hints that there is a solution to the food problem. It is now time to face that problem head-on.

As earlier indicated, unless the land tenure problem is solved, further discussion is fruitless. A country with valueless land will always be poor. We have agreed that inputs of fertilizer and pesticides will increase the productivity of the land. We have also shown that there is a two-fold effect from mechanization, that of increasing the productivity of the land increasing the productivity of the farmer himself, often a thousand-fold.

Mechanization coupled with the use of the other agricultural inputs such as fertilizer, pesticides and improved varieties of crops
will more than offset the effect of the migration to the cities. Supplying these inputs including machinery, fuel, grease and agriculture service is a way, as Loyd Johnson (10) puts it, for the urban population to contribute "non-food energy" products to the production of food. This exchange results in the establishment of a market for both urban and agricultural products.

Two of the major objectives of economic development is to increase the daily calorie intake of the population and to improve the quality of protein in the diet. The average daily food intake of developing country is approximately 2100 calories a day or approximately 400lbs of grain per year. (The food-exporting developing countries such as Mexico and Burma have a daily calorie intake of 2500.)

The average American consumes 3100 calories of food a day. On a yearly basis, this consists of approximately 200 lbs of grain consumed directly and 14000 lbs consumed by domesticated animals. Thus he, himself, chews approximately ½ lb of grain products per day and asks his animal to chew 3½ lbs of grain per day and in return, give him palatable, high protein foods such as milk, meat and eggs to complete his diet.

The above analysis shows that a diet high in animal products is an expensive diet. The efficiency of animals in salvaging protein and energy from feed ranges from 6 to 27%. Any nation aspiring to duplicate the American diet (to upgrade their diet from 2100 to 3100 calories per day by increasing the proportion of animal products) must first secure a four-fold increase in production of grain or grain equivalent products. This can only take place by mechanizing the farms and using improved varieties, fertilizers, good management, and, where needed, irrigation. But because of population growth, the number of people will double in 25 years so that a nation desiring an improved diet by 1985 will have to produce an eight-fold increase in grain supplies (domestic and imports) over 1960.

The domestic animals vary in the degree they compete with humans for food. In small numbers, they convert waste products
such as the un-eatable parts of human foods and the pickings around the farm into useable nutritious products. When the numbers increase, however feed must be supplied to the animals. It is at this point that the chicken and pig, while among the most efficient salvagers of protein from feed, nevertheless compete directly with the human for consumption of grain (maize). The chicken and swine industry is wholly dependant on a cheap supply of grain. Ruminant animals, cattle, goat and sheep, while less efficient, do salvage the protein found in grass which the human cannot consume and do have a larger place in the 20th century agriculture. Their digestive systems convert waste into nutritious, palatable foods, and upgrade the incomplete proteins salvaged from the grass and give the proteins in foods such as meat or milk.

The cinderella crop of the Tropics is hybrid sorghum (9) The perpetual growing season of the Tropics allow the sorghum crop to demonstrate its fantastic yield potential by ratoon regrowth. Fields in the Phillipines have produced three harvest of grain totalling 18,000 pounds per acre and three crops of fodder. This was after a rice crop had been harvested from the same field in the same year. Cameron (4) conducted small plot and field trials with four varieties of hybrid sorghum at the University of Ghana, with interesting results.

Farmers in the U.S. and India have harvested 10,000 lbs of grain per acre and 8 tons of silage from a single harvest of the crop. This crop, is more tolerant to insects, diseases heat and drought than maize, and is at home in the tropical and temperate zones. It promises to provide the food to feed extra mouths of the year 2000 A.D. The hybrid guinea corn will supply the needed grain and fodder for an expanded livestock enterprise needed to upgrade the diet at that time.

Another practical solution to the problem of supplying an adequate quantity of high quality protein for the diet is being presented by the newly created spun-vegetable protein-fibre industry of the United States (4). This industry short circuits the animal protein cycle. Instead of feeding animals feed containing soybean meal
and expecting the animals to upgrade the protein, this industry is producing a product with the looks, taste and texture of meat. These foods are nutritious and palatable and contain complete high quality proteins made from soybeans and other high protein seeds at a relatively high efficiency. This development has far-reaching effects. The textured proteins have a long unrefrigerated shelf life and are relatively inexpensive in price.

The development of the textured protein fibre industry will directly affect chicken and pig production and to a lesser extent the cattle production.

Agricultural engineers will be needed to design the housing for the livestock and establish and operate the meat processing and the spun-protein fibre processing plants.

In areas where soybeans cannot be grown, the plant breeders of the United States are promising new varieties of high-lysine, higher-protein maize and other cereal grain.

The problem of feeding the population has reached university tenure. It is now a proper subject for discussion in the most learned professions.

This paper has shown that with the proper application of human intellect, no one need go hungry. The best of thinking and energy of all people must be brought to bear on the problem to solve it. But even then, the increased food supply must be considered a stop gap measure until the human family learns to limit its own numbers. It is hoped that men can, with the help of best chemicals, drugs, techniques and equipment learn to do this within the time that their total numbers double once again.
APPENDIX

Laws of Machines

The analysis of the design and use of machinery in agriculture for 30 years has led me to state certain fundamental laws, concerning the operation and use of machines.

1st Law of Machines: Any operation performed by human hands can be performed by a machine or series of machines.

This law is self-evident; machines have been replacing hands at an increasing rate since the days of Watt and Cartwright. In mechanized society, machines milk our cows, pick our corn, weave our cloth etc. Of course, little used processes will not be mechanized because the profits from their sale would not support the cost; at this stage of progress, who would want a machine to operate on his heart? We are, however, pleased that the surgeon does use special instruments (in themselves machines), has a mechanical heart and lung standing by or in actual use during the operation. He also uses machines to oxygenate the air the patient breathes and to monitor the heart beat and blood pressure. The continuous, almost annual design and development of new models leads to the statement of the second law of machines.

2nd Law of Machines: Any operation performed by a machine or a series of machines can be done faster and/or cheaper and/or with an improvement in quality of product by another machine or series of machines.

This law is an optimistic law, it states that continued progress is assured. Once the new ideas are designed into a machine and the machine has been manufactured and used, it is immediately apparent to the engineers and to the layman that a new machine incorporating new ideas could be designed which would either do the job faster than the old machine, do it cheaper or perform the

33
process in such a way that the quality of the product would be better maintained or improved. The law in effect says "engineers will have jobs the rest of their lives designing and manufacturing machines and salesmen will have jobs selling the new machines" Continued development of a mechanized society is assured.

The 3rd Law machine deals with the effect of a machine upon the supply of a product or service when the supply of energy and raw materials used in the manufacturing of the machines is unlimited.

3rd Law of Machines: Any uncontrolled mechanized, profitably produced product or service will be in over production.

This law has been tested over the past 30 to 40 years in industry and in agriculture. It says that once a society mechanizes, the supply will outstrip the demand.

Industry of most countries have essentially established enough control over themselves to prevent the widespread over-production that existed in the late 1920's. In the U.S.A., the congress assumed the obligation, in the early 1920's. In the U.S.A., the Congress assumed the obligation, in the early 1930's, of preventing agricultural over-production, but at the same time, of keeping agriculture profitable without placing rigid controls on the number of units the American farmers could produce. To date, the U.S. Congress had scored a string of approximately 29 failures, a number of stand-offs during the war years and two near successes in matching production and consumption of agricultural products.

The operation of the above three laws are such that our engineered world has turned over the performance of nearly all processes to machines that produce cheaper and cheaper products of higher and higher quality. Even under these conditions of manufacture, the primary cost of production is the labour cost.
REFERENCES


