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Maize Yield Response in a Long-term Rotation and Intercropping Systems in the Guinea Savannah Zone of Northern Ghana

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Abstract: To sustain crop production, cowpea, groundnut, soybean, sorghum and cassava were compared for their potential in crop rotation or as an intercropping partner to maize over an eleven-year period in Northern Ghana. The trial in each year consisted of 12 treatments arranged in an RCBD with five replicates. There was a gradual decline in maize yield for groundnut-maize, soybean-maize and cassava-maize as compared to a rapid decline in the other rotation combinations over the years. The best combination was maize-groundnut rotation with grain yields above 3.0 t ha^{-1}. Intercropping advantage for most combinations in the first two years was not sustained in later years, except for sorghum-maize and cassava-maize systems. Sorghum-maize combination was the best in terms of crop yield, based on Land Equivalent Ratio (LER). Cassava-maize and soybean-maize systems were the best in terms of energy value and protein yield respectively. Maize yields obtained were comparatively better in rotation than intercrops, underlining the superiority of rotation to intercropping in the long-term, consequently its potential to improve on household food security. The results so far indicate that good cropping system and proper agronomic practices can sustain maize production on the same piece of land for more than 10 years.

Key words: Crop rotation, Ghana, intercrop, LER, maize

INTRODUCTION

The Guinea Savannah zone of Northern Ghana experiences annual burning, which most often is carried out for several reasons including; clearing of land for cultivation, stimulating production of new shoots for livestock fodder and exposing wild game to hunt (NRI, 1996). This burning usually results in a marked, but short-lived rise in nutrient availability; however it raises the soil pH to such high levels that deficiency of iron and other micro-nutrients are induced (Oelsligle *et al.*, 1976). In recent times, as a result of increased pressure on land in most parts of the zone (especially in the north eastern corner) the prevalent farming system of rotating crops - in sole or mixtures - followed by a long bush fallow that lasts 5-10 years or more is no longer the common practice. It has given way to shorter bush or grass fallow that lasts 2-3 years and continuous cropping systems which are more resource demanding. This has affected crop production significantly, since the evolving systems are incapable of conserving soils against wind and water erosion and in restoring soil fertility, thus resulting in deterioration of the resource base of the soil. Consequently, there is the need to identify sustainable cropping systems that allow continuous cultivation on the same piece of land.

In intercropping (i.e., growing two or more crops simultaneously on the same field (Andrews and Kassam, 1976)), the crops are so selected that they take advantage of the different root stratification, varying nutrient requirements and differences in plant architecture so as to maximise resource use.

In cereal-legume rotation or intercrop systems the cereal benefits from the nitrogen fixed by the legume and the decomposition of the nutrient-rich biomass, root and nodules of the legume (Blade *et al.*, 1997). Apart from crop productivity, legume-based cropping systems could also help to increase soil organic matter levels, thereby enhancing soil quality, as well as having the additional benefit of sequestering atmospheric C (Gregorich *et al.*, 2001). Crop rotation (temporal diversification) and intercropping (spatial diversification) strategies reduces weed population density and biomass production (Liebman and Dyck, 1993). These cropping systems ensure more efficient use of land, greater yield stability, spreading of labour input, greater diversity of produce, less dependence on storage, greater market opportunities and better soil and water conservation (Edwards, 1993).

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This experiment was designed to study the long-term effect of the common rotation and intercropping practices on the yields of some important crops in northern Ghana. The objective was to identify suitable preceding crops to maize in rotation and also assess the compatibility of the common cereals (maize and sorghum), legumes (cowpea, groundnut and soybean) and cassava in a mixed cropping system. The aim was to obtain over the long period a better understanding of this complex system and make recommendations to farmers.

MATERIALS AND METHODS

The experiment was carried out at the experimental site of the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Nyankpala in the Guinea Savannah zone of Northern Ghana from 1986 to 1997. The region is classified as dry hot low latitude climate (Aw) according to the Köppens climatic classification. It experiences erratic rainfall with annual variations and monomodal rainy period of 150-180 days as shown for the experiment's duration (Fig. 1).

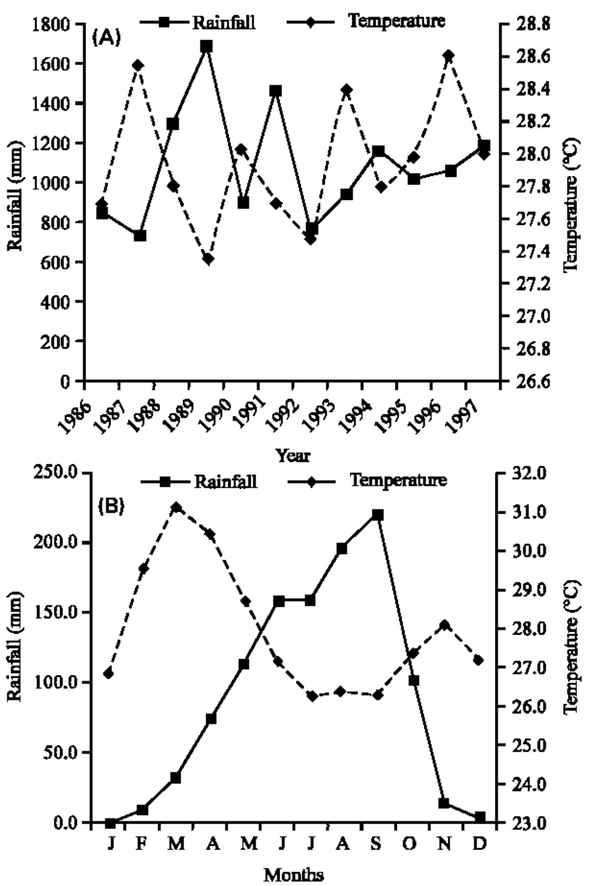

Fig. 1: Mean annual (A) and monthly (B) rainfall and temperature distribution from 1986 to 1997

Year 1	M	G	MG	M	S	MS	M	CA	MCA
	M	C	MC	M+S	G	(M+S)G	M	SOY	MSOY
Year 2	G	M	MG	S	M	MS	CA	M	MCA
	C	M	MC	G	M+S	(M+S)G	SOY	M	MSOY

Fig. 2: Layout of treatment combination for one block (replicate) in alternating years (M = maize, G = groundnut, C = Cowpea, SOY = soybean, CA = cassava and S = sorghum)

The experiment was planted on soils locally referred to as Tingoli series or Haplic lixisol by FAO-UNESCO (1990). The soils are well-drained sandy clay with slightly acidic reaction and low organic matter content (Adu, 1957).

The crops involved in the trial were: cereals (maize and sorghum), legumes (cowpea, groundnut and soybean) and cassava. The crop varieties used were maize (Okomasa), soybean (Salintuya-I), cassava (local), Groundnut (F-mix), sorghum (NSV II) and cowpea (Valenga). There were six main crop combinations: groundnut-maize, sorghum-maize, cassava-maize, cowpea-maize, groundnut-maize+sorghum and soybean-maize in rotation and intercrop. In all there were 12 treatments per block of 18 plots. Each crop combination consists of two treatments, planted on three plots. The three plots were made-up of one permanent intercrop treatment plot and rotation treatment on the two remaining plots as the other treatment. This is shown in Fig. 2 for one block (replicate) in alternating years. This layout repeats itself after every other year.

The experimental units were arranged in a Randomised Complete Block Design (RCBD) with five replications. The plot size used was 10 × 6 m with spacing of 1 m between plots. The crops were planted in a double row with spacing of 75 cm between two pairs of double rows (i.e., middle to middle) and 10 cm within a double row. Plants in a pair of double rows are placed in alternating positions as far as possible. The plant spacing was 75 × 60 cm for maize and sorghum, 75 × 25 cm for groundnut, 75 × 30 cm for cowpea and 75× 10 cm for soybean. In the case of sole crop cultivation, both double rows were occupied by the same crop whiles each partner crop occupied one of the double row in the intercrop. For the combination of groundnut-maize+sorghum, maize plus sorghum replaces the maize crop. Sole cassava was planted at 100 × 100 cm. In the case of maize-cassava intercrop, 5 maize plants m^{-2} were used to replace the cassava plant in alternating positions. All cereal treatments were given Sulphate of Ammonia fertiliser as a starter dose at the rate of 40 kg N ha^{-1} to pure cereal stands and 20 kg N ha^{-1} to intercrops. All plots received 60 kg P_2O_5 ha^{-1} as Single Super Phosphate and 30 kg K ha^{-1} as Muriate of Potash annually. Weed control on the experimental plots was done manually (hoe-weeding) three times before harvesting.

At harvest, data was taken on yield of component crops. Estimate of intercropping advantage of the intercropping system was determined by Land Equivalent Ratio (LER) and nutritive values (i.e., energy value and protein yield) were made.

The LER was calculated based on the method of Mead and Willey (1979) as follows:

$$LER = Y_{12}/Y_{11} + Y_{21}/Y_{22}$$

Where, Y_{12} is yield of crop 1 in mixture; Y_{11} is yield of crop 1 in sole; Y_{21} is yield of crop 2 in mixture; and Y_{22} is yield of crop 2 in sole.

Yield for intercrops were adjusted to that of sole crop for ease of comparing intercrops and rotation. This was done based on the population in intercrop as compared to that of the sole crop and LER as follows:

$$Y_{ia} = (PP_s/PP_i) \times LER \times Y_i$$

Where, Y_{ia} is the adjusted intercrop yield, Y_i is the actual intercrop yield, PP_s is the plant population in sole and PP_i is the plant population in intercrop.

The nutritive values were estimated based on data provided by Watson (1971) on nutritive value of some Ghanaian foodstuffs. For soybean the energy value was estimated based on the feed units of soybean and energy value of oats (Kalachnikov *et al*., 1985).

RESULTS AND DISCUSSION

The results presented here are those for 11 years from 1986-1997, with the exception of that of 1995 which is not available. It includes yield data on crop rotation, intercrop, LER and nutritive values of the different crops and combinations.

Rotation effect on maize yield: Yield of maize in rotation (as preceded by the other crops) was on the average in excess of 2 t ha^{-1} except for sorghum-maize rotation (Fig. 3). The 11-year mean yield of maize - i.e., excluding that of 1995 - indicated that the best preceding crops for maize in descending order were: groundnut (3.81 t ha^{-1}), cassava (3.47 t ha^{-1}), soybean (3.42 t ha^{-1}), cowpea (3.20 t ha^{-1}), maize+sorghum after groundnut (2.84 t ha^{-1}) and sorghum (1.87 t ha^{-1}). This mean trend has been consistent since the beginning of the experiment, except cowpea that changed position as the second best in 1986 - 1990 to the fourth best in 1991-1997. Yield variations were mainly due to year-to-year variability in weather conditions (Fig. 1A) and probably declining soil fertility such as P-levels as observed by Porter *et al*. (2003).

Since 1991 soybean has been superior to cowpea - except in 1996 - as a better preceding crop to maize. The emergence of soybean as a better preceding crop for

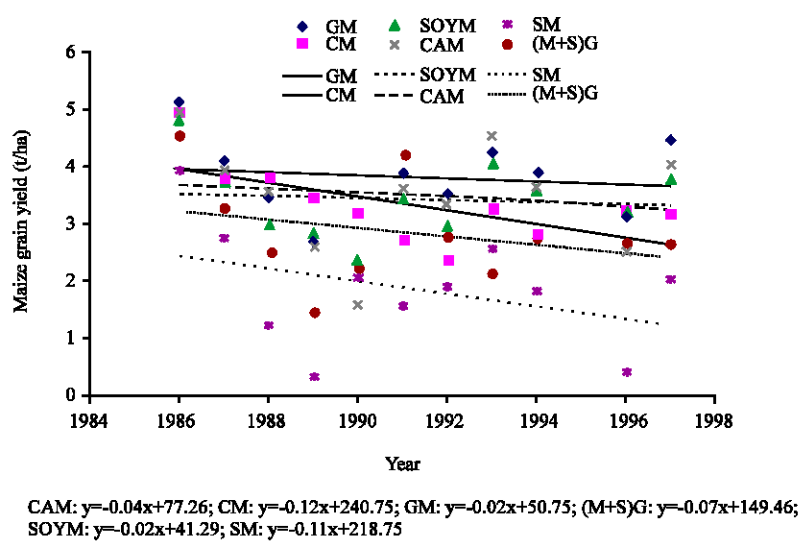

Fig. 3: Maize (M) grain yield as influenced by preceding groundnut (G), cowpea (C), soybean (SOY, sorghum (S) and cassava (CA) in rotation from 1986 to 1997, except 1995

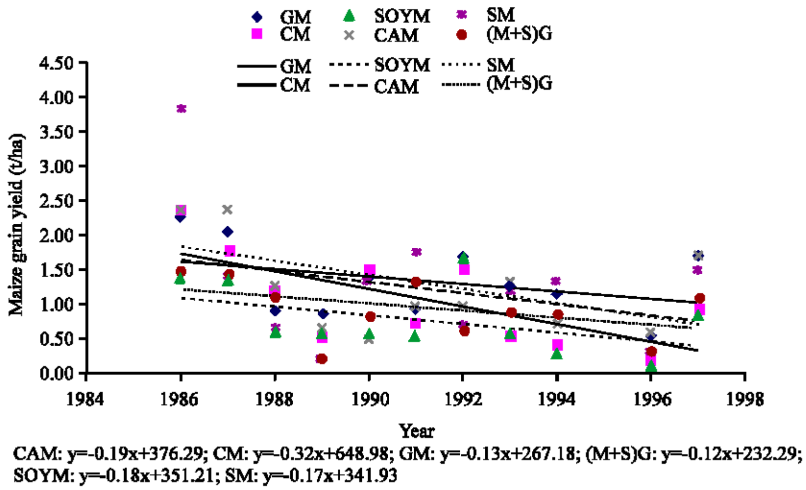

Fig. 4: Maize (M) grain yield as influenced by intercropping with groundnut (G), cowpea (C), soybean (SOY, sorghum (S) and cassava (CA) from 1986 to 1997, except 1995. Maize yield in intercrop was adjusted to that of sole crop (based on population in intercrop as compared to that of sole crop and LER)

maize in comparison to cowpea may be due to its higher biomass production and the relative build-up of specific *Bradyrhizobia* species that now infect the soybean crop, resulting in greater N-fixation, which may be an advantage to the maize (Ennin and Clegg, 2001).

Maize yields in the rotation declined on the average over the 12-year period (Fig. 3). The decline was gradual for groundnut-maize, cassava-maize and soybean-maize as compared to cowpea-maize and sorghum-maize combinations. Riekert and Henshaw (1998), working in Northern Ghana, observed that higher maize yield in a maize-groundnut rotation was due to lower nematode association with groundnut as compared to cowpea or soybean. The sharp decline in maize yields when preceded by cowpea-maize and sorghum-maize combination may be due to the build-up of cowpea pest and the cereal-cereal (i.e., maize-sorghum) combination that is less efficient in nutrient recycling. Sauerborn *et al.* (2000) also observed lower maize yields when maize follows sorghum. Horst and Haerdter (1994) indicated that yield decline in maize monocropping might be due to allelopathic effects. Groundnut and sorghum consistently proved to be the best and the least favourable preceding crops to maize, respectively.

Intercropping effect on maize yield: The decline in maize yield in the first four years (Table 1) was steeper than the 11-year trend (Fig. 3 and 4) for both intercropping and rotation systems. In the intercropping system maize yields declined less steeply than the rotation combination up to the fourth year before stabilising at lower yield values (Table 1). On the average the best intercropping partners to maize in terms of maize yield in descending order were groundnut (1.34 t ha^{-1}), sorghum (1.3 t ha^{-}),^{1} cassava (1.22 t ha^{-1}), cowpea (1.08 t ha^{-}), maize+sorghum intercrop with groundnut (0.94 t ha^{-1}) and soybean (0.78 t ha^{-1}). The more rapid decline in maize yields experienced in the intercropping system as compared to the rotation (Fig. 3 and 4) could be due to a more rapid depletion of nutrients under intercropping compared to rotation as a result of increased competition for nutrient and sunlight. Another reason may be the low return of crop residue to the soil, since most are transported off the fields to be used as animal feed or household fuel. Sauerborn *et al.* (2000) observed after a three year trial on farmers' field in Northern Ghana that yield of maize preceded by cotton, cowpea, groundnut, soybean or sunflower was better than in the conventional cropping of mixed stands of maize-sorghum or maize-groundnut.

Diehl (1992) remarked that the cropping patterns in the Guinea Savannah changes in the course of cultivating a piece of land for several years. After fallow demanding crops like yam are grown followed by crop-combinations

Table 1: Maize grain yields rate of decline for both crop rotation and intercropping in the first four years

Crop combination	Crop rotation Slope	Crop rotation r	Intercropping Slope	Intercropping r
Groundnut-maize	-0.80	0.99	-0.54	0.93
Cowpea-maize	-0.45	0.89	-0.60	0.99
Soybean-maize	-0.67	0.95	-0.31	0.91
Cassava-maize	-0.74	0.98	-0.63	0.95
Sorghum-maize	-1.23	0.95	-1.16	0.93
Groundnut-(maize + sorghum)	-1.01	0.99	-0.41	0.91

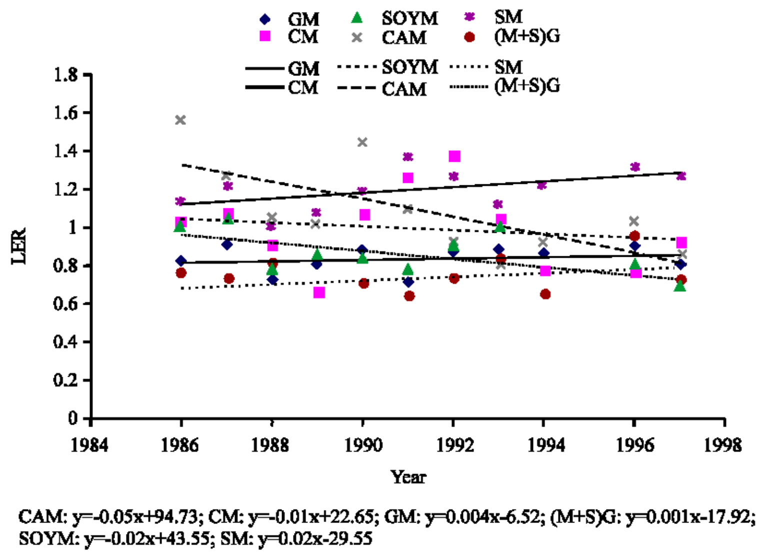

Fig. 5: Total Land Equivalent Ratio (LER) for groundnut-maize, cowpea-maize, soybean-maize, cassava-maize and sorghum-maize in rotation and intercrop over 11 years

with maize for two or three years, maize yields decline and combinations like millet and groundnuts are grown. Farmers, observing such crop sequences, adapt to the deterioration in soil productivity rather than using crop rotation as a means to maintain it.

Land Equivalent Ratio (LER): From the 11 years results the mean LER for maize only was 0.42 for groundnut-maize, 0.42 for cowpea-maize, 0.35 for soybean-maize, 0.44 for cassava-maize, 0.43 for maize+sorghum-groundnut and 0.60 for sorghum-maize. Only sorghum-maize showed an intercropping advantage for maize with LER more than 0.50. The total LER of the various intercropping combinations are shown in Fig. 5.

In the first two years, four combinations (i.e., sorghum-maize, cassava-maize, cowpea-maize and soybean-maize) out of the six showed an advantage in intercropping (i.e., LER > 1). This emphasises the fact that intercropping is only advantageous in most of the crop combinations in the first couple of years. Cowpea-maize and cassava-maize gave LER of more than one in six and seven out of the eleven years respectively. However, only cassava-maize showed an intercropping advantage (i.e., mean LER > 1.0) in addition to sorghum-maize in the long term. The mean LER for 11 years depicts the best intercropping system in descending order as: sorghum-maize, cassava-maize, cowpea-maize, soybean-maize, groundnut-maize and maize+sorghum-groundnut. Cereal-legume combinations are the most frequently encountered in the farming systems of the Guinea Savannah zone. With the exception of the south-eastern parts of the zone, maize, sorghum and millet mixed with groundnuts and/or cowpea is the most common combination found on farms (Diehl, 1992; Andah *et al*., 1999). Among the cereal-legumes mixtures the traditional combination of maize, sorghum and groundnuts covers about 70.5% of the cultivated area followed by a combination of maize, millet and groundnuts with 16.2% (Donhauser *et al*., 1994). These combinations have not been productive in the long-term as shown in this work and also by Diehl (1992). The mean LER values explain the decline in maize yields observed by farmers after two or three years of cropping mixtures with maize on the same piece of land.

Nutritive value: The cassava-maize and sorghum-maize combinations in rotation gave the highest and least total energy values respectively indicating the best and least compatible crops to maize in rotation in terms of energy value (Fig. 6). When the rotation and intercropping systems are combined, the energy values in descending order are cassava-maize, groundnut-maize, cowpea-maize, soybean-maize, maize+sorghum-groundnut and sorghum-maize systems.

The combined protein yield for rotation and intercrop of the different crop combinations in descending order are soybean-maize, cowpea-maize, groundnut-maize, maize+sorghum-groundnut, cassava-maize and sorghum-

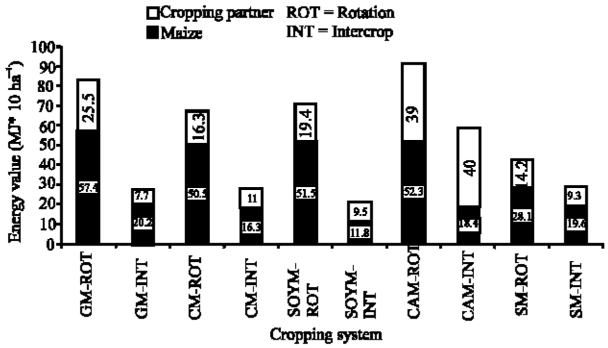

Fig. 6: Mean energy value of groundnut-maize, cowpea-maize, soybean-maize, cassava-maize and sorghum-maize in rotation and intercrop over 10 years

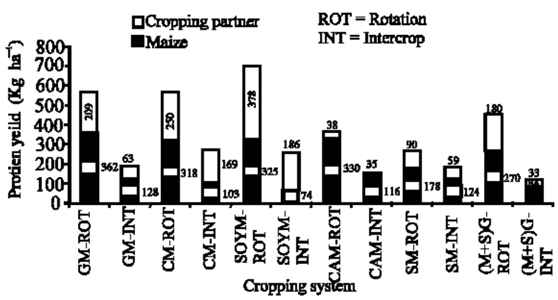

Fig. 7: Mean protein yield of groundnut-maize, cowpea-maize, soybean-maize, cassava-maize and sorghum-maize in rotation and intercrop over 10 years

maize systems (Fig. 7). On the average the rotation system gave higher protein content than their corresponding intercropping system.

Maize grown in rotation has the potential to ensure household food security than when grown as an intercrop component. Farm households in the Guinea Savannah zone grow the partner crops used in this experiment mainly as cash crops and maize as a major subsistence crop. Donhauser *et al.* (1994) computed annual household food requirements in the farming systems of Northern Ghana as 38591 MJ of energy and 212.4 kg of protein. Using these food requirements as a benchmark, from a hectare of land, maize in all the rotation treatments with the exception of sorghum-maize rotation gave on the average an energy self-sufficiency ratio above 1.0 (1.31-1.49) and a protein self-sufficiency ratio of 1.27-1.70.

The intercrops, which are the traditional cropping systems in the zone revealed a problematic situation with respect to household food security with self-sufficiency ratio in energy and protein values < 1. This substantiates the common shortage of food (cereals) experienced in these parts of Ghana two-three months before the first harvest, which has come to be known as the "hunger gap".

CONCLUSIONS

The results so far obtained indicate the best rotation system as groundnut-maize combination. This combination gave a consistently high maize yield over the 12-year trial period. It also provided a high-energy value and protein yield.

In intercropping, although sorghum-maize gave an overall positive intercropping advantage its nutritive value (i.e., energy value and protein yield) is comparatively low, making cassava-maize a better option. In terms of absolute intercrop maize yield, groundnut-maize combination was the best. Sorghum is recommended as the best intercropping partner for maize in the drier parts of the Guinea Savannah zone and cassava in the wetter parts spanning from Bole in the west through Damongo, Buipe, Yapei and Salaga to Kpandai in the East. Maize grown in rotation has the potential to ensure household food security than when grown as an intercrop component. This work has indicated that through a good cropping system couple with proper agronomic practices maize production can be sustained on the same piece of land for more than 10 years.

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