

# CASSAVA PRODUCTIVITY WORLDWIDE: AN OVERVIEW<sup>1</sup>

Nagib M. A. Nassar<sup>2</sup>  
Hasan Elkholy<sup>3</sup>  
Atyia Eltantawy<sup>3</sup>

## ABSTRACT

Cassava is the most well-known subsistence crop in the tropical world, particularly in northeastern Brazil. Analyzing FAO data on cassava productivity during the last thirty years in South America, Nigeria and India, a constant level of productivity was found in South America (around 12.5 ton/hectare) and around 14.6 throughout the 1960s. In Nigeria, it went from 9 ton/hectare during the 1980s, increasing to 11.5 in the 1990s. In India, the yield increased constantly from 14 t/ha in the early 1970s to 24.5 t/ha in the 1990s. It was concluded that root production in cassava is highly affected by heterosis. Apomixis is an efficient way to preserve heterotic vigour. Moreover, it functions as a filter against accumulation of bacteria and virus on stem cuttings. Interspecific hybridization may provide new genes on which cassava is deficient.

Key words: *Manihot esculenta*, root productivity, polyploidy, heterosis, apomixis, interspecific hybridization.

## RESUMO

### PRODUTIVIDADE DA MANDIOCA NO MUNDO: UMA VISÃO GERAL

A mandioca é a cultura de subsistência mais conhecida no mundo tropical, particularmente no nordeste do Brasil. Analisando os dados da FAO sobre a mandioca nos últimos trinta anos na América do Sul, Nigéria e Índia, verifica-se um nível constante de produtividade na América do Sul (cerca de 12,5 t/ha) e cerca de 14,6 t/ha nos anos de 1960.

---

<sup>1</sup> Accepted for publication on March 6, 2002.

<sup>2</sup> Departamento de Genética e Morfologia, Universidade de Brasília.

<sup>3</sup> Institute of African Studies, Cairo University, Cairo, Egypt.

Na Nigéria, ela cresceu de 9 t/ha, nos anos de 80, para 11,5 t/ha, nos anos de 90. Na Índia, o rendimento cresceu constantemente de 14,5 t/ha, no início dos anos de 70, para 24,5 t/ha, na década de 90. Verificou-se que a produção de raízes na mandioca é altamente afetada pela heterose. A apomixia é um eficiente meio de preservar o vigor heterótico. Ademais, ela funciona como um filtro contra a acumulação de bactérias e vírus nas manivas. A hibridação inerespecífica poderá fornecer novos genes, dos quais a mandioca é deficiente.

Palavras-chaves: *Manihot esculenta*, rendimento, poliploidia, heterose, apomixia, hibridação interespecífica.

## INTRODUCTION

Cassava (*Manihot esculenta* Crantz) ranks fourth among world staple crops, and is consumed by more than 800 million people (4). In some countries, such as northeastern Brasil, Ghana and Nigeria, some islands in Indonesia and in the Pacific Ocean, more than 70% of the calories consumed daily by the population comes from cassava. Among other crops, it is credited with high caloric productivity (3), biological efficiency as an energy producer (3), year round availability and adaptation to suboptimal soil (2). In the early 1970s, the U.S. President warned about a developing country food crisis, appointed a Science Advisory Committee Panel on world food supply to report on food research priorities. It recommended that the agricultural potential for vast areas of uncultivated land, particularly in South America and Africa, be thoroughly evaluated for sustained food production, with emphasis on cassava as a selected crop with the potential for satisfying a huge food demand. Since then, much attention has been given to cassava as a priority crop in the newly created International Centers for Agricultural Research (IARs). The International Center for Tropical Agriculture (CIAT) at Cali, Colombia, was given a mandate for improving cassava throughout the world and in South America, in particular.

## CASSAVA PRODUCTIVITY DURING THE LAST 30 YEARS

Cassava productivity per hectare is the criterion used for assessing crop genetic improvement. Therefore, we have selected three areas around the world which have contributed significantly to world production and have studied its productivity over the last 30 years. These areas are South America, Nigeria and India. The FAO Production Yearbook in 1998 was a source used as of information (4). Based on FAO data of 1998, and previous years, the following can be noted:

1. The total area cultivated in South America during the 1960s (about 2,480,000 hectares) produced 34,400,000 tons. Productivity per hectare was approximately 14.3 tons.

2. Brazil's contribution was 88% of the total production of South America and one third of the worldwide production.

3. Since the early 1972s, productivity per hectare began to decline constantly in South America, dropping from 14.3 t/ha to 11.8 t/ha during the 1980s (Table 1).

4. In Brazil, the major producer all over the world, the decline was also constant during the 1970s and the 1980s. Productivity dropped from 14,6 t/ha in the 1960s to 12.1 t/ha in the 1980s.

In Nigeria, productivity per hectare in the early 1970s was 10.5 t/ha, increasing to 11.5 in the 1980s, dropping to 10.5 by the end of 1980s and recovering in the early 1990s, reaching 11.5 t/ha once again by the late 1990s.

In India, productivity per hectare in the early 1970s was 9.0 ton, increasing in the 1980s to 17.7 t per hectare, and continuing to remarkably increase during the 1990s to, approximately, 24,5 t/ha. (Table 1., Figs.1, 2, 3 and 4).

TABLE 1 - Evolution of cassava yield in the last 30 years in South America, Nigeria and India (ton/hectare)

Year	S. America	Nigeria	India
1960s	14.6	9.3	9.0
1970s	11.7	10.1	16.4
1980s	12.4	10.8	19.2
1990s	12.3	11.3	24.5

Source: FAO Production Yearbook (4).

Cassava productivity drop in South America during the 1970s and the 1980s is due to the following facts: The main producer of the continent, the state of São Paulo in Brazil, contributed with about 1/3 of the total production of the country, with a productivity average of 21 t/ha. This level of productivity was possible due to the techniques followed by the Instituto Agronômico de Campinas (IAC) (Table 2). Since the early 1970s, São Paulo farmers have replaced cassava by other crops, due to the government subsidies policy. Consequently, cassava has not been able to compete (1, 20). Cassava cultivation areas decreased in the country and in the whole continent. In the meantime, cassava cultivars planted in other Brazilian states did not show the good performance the IAC's cultivars showed in São Paulo, thus contributing to reducing cassava productivity in Brazil and in the whole continent.

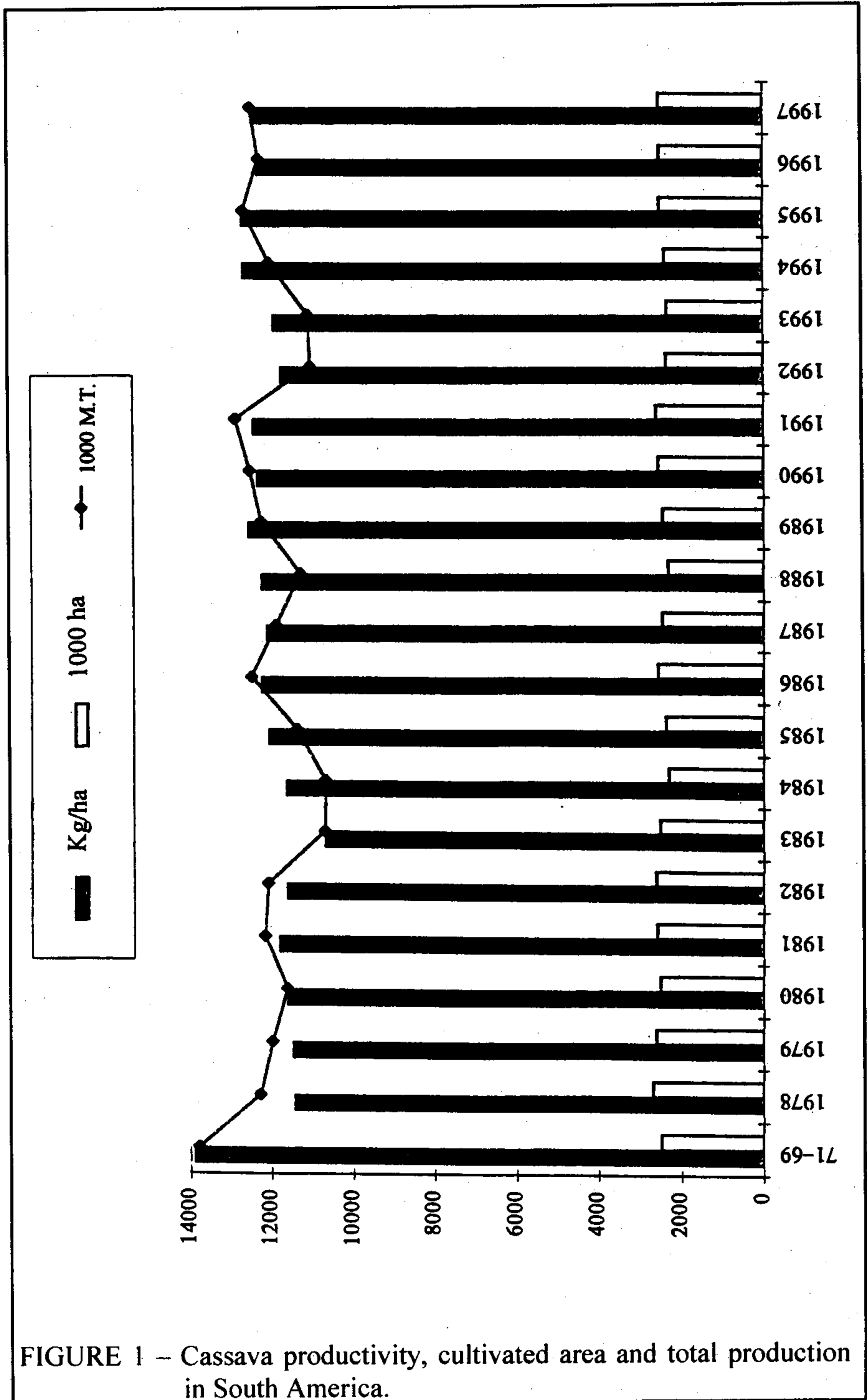


FIGURE 1 – Cassava productivity, cultivated area and total production in South America.

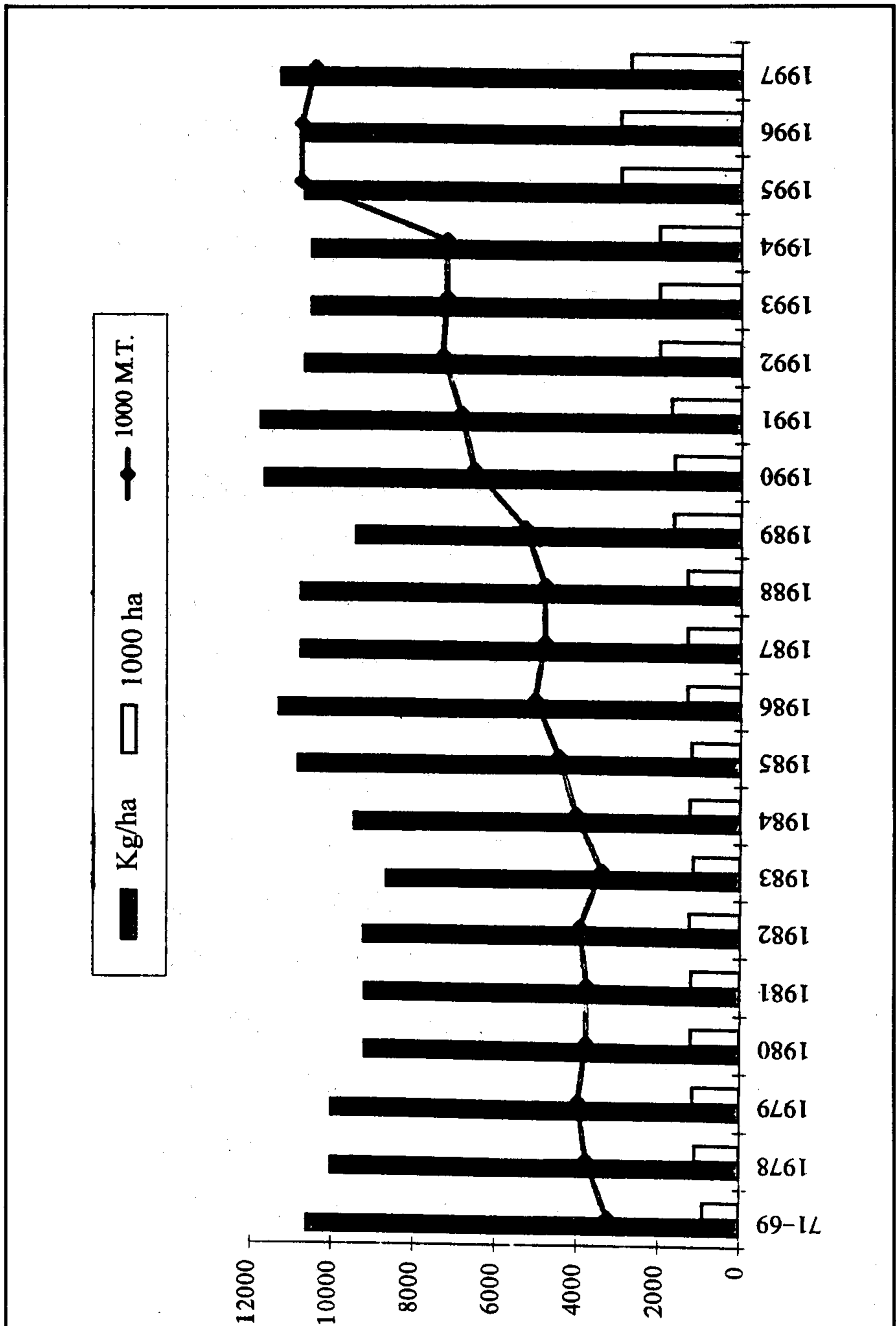


FIGURE 2 – Cassava productivity, cultivated area and total production in Nigeria.

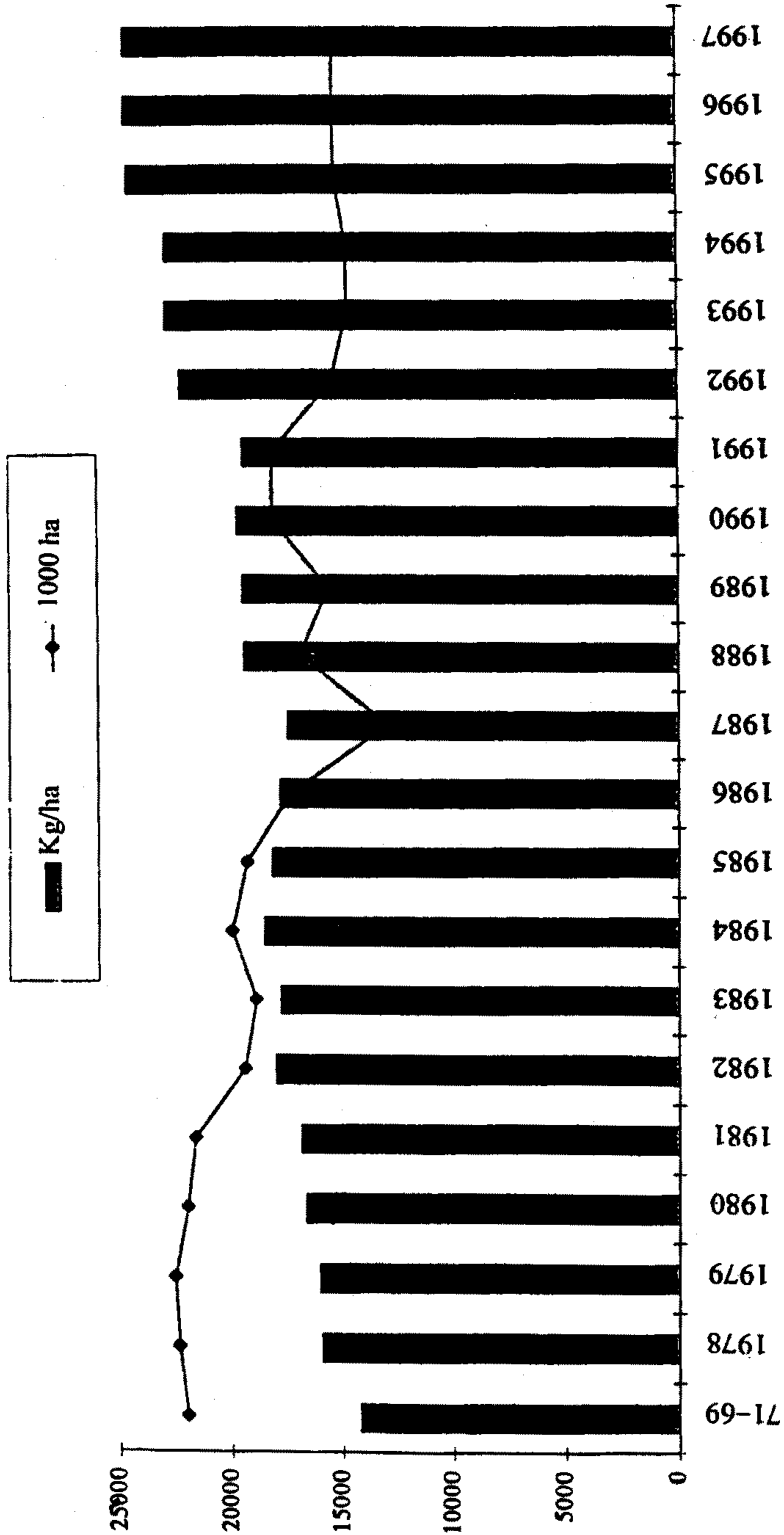
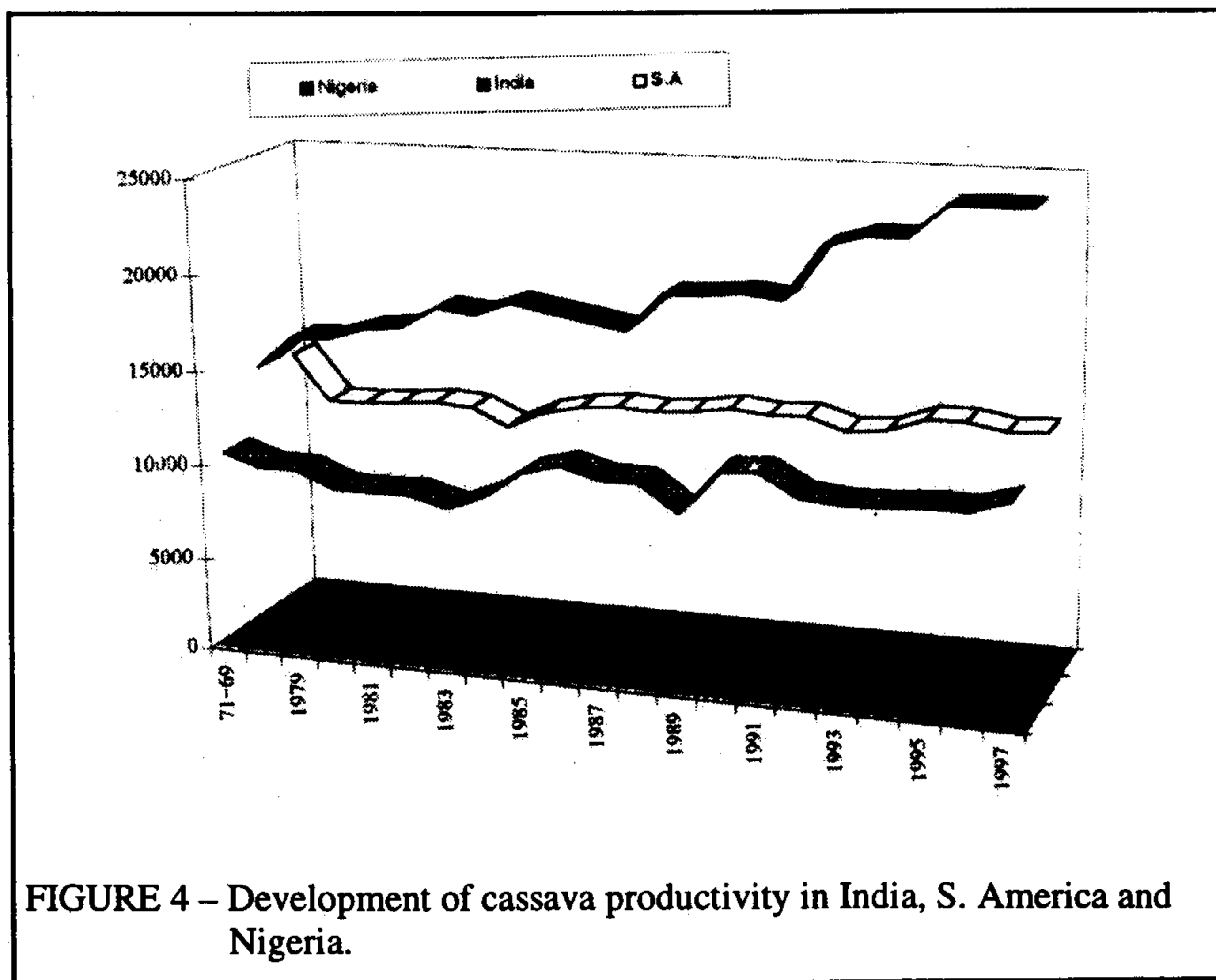


FIGURE 3 – Cassava cultivated area and productivity per hectare in India.



### CASSAVA BREEDING

The highly productive, well adapted IAC cultivars are simple products of the cassava breeding program in this Institution. The IAC cassava program began by determining good progenitors from whom new cultivars could be selected on the basis of productivity and resistance to diseases and pests. This was carried out through comprehensive combining ability tests, including the use of clones collected from the states of São Paulo and Minas Gerais. In these states, wild species of *Manihot* normally grow very close to cultivated cassava clones and natural interspecific hybridization frequently occurs between them (8, 9, 13, 15, 20 ). Progeny seedlings of these natural crosses grow simultaneously and some of them are selected by farmers, and are reproduced vegetatively giving rise to new clones. These clones grow in commercial plantations and are subjected to autopollination due to the monoclonal system of plantations (17). Emerging homozygous plants will have genes of wild species introgressed into their genomes. This cycle of hybridization is repeated in nature and inbred clones enriched by high adaptive genes of the wild

species are cultivated by farmers. These type of clones were collected by IAC breeders and used in their combining ability trials. Among them were the most successful clones ever known in the history of cassava: Branca Santa Catarina, Mantiqueira, Engana Ladrão and others.

In its evaluation to release new cultivars, the IAC carried out performance trials of root yield under suboptimal conditions of soil and mineral nutrients to ensure the largest range of cultivar adaptations. Through a number of counties, ranging from 9 to 70, these cultivars showed the highest productivity, compared to those released by other institutions (Tables 2 and 3). The combining ability approach followed by the IAC to produce superior progeny and perpetuate selected individuals by cloning showed more potential and effectiveness than the method of recurrent selection. It seems that nonadditive genes and heterosis are predominant in cassava as modes of gene action.

TABLE 2 - Productivity of principal clones released by IAC in different counties in the state of São Paulo, without fertilizers

Clone	Ton/ha	Nº of counties	Confidence range
Branca S. Catarina	34.4	71	30.6 – 37.4
Cafelha	33.3	23	26.4 – 40.2
tu	26.5	24	22.3 – 30.7
atu	32.8	12	24.6 – 41.0
AC 5-123	37.2	20	30.6 – 43.8
AC-165	33.0	28	27.9 – 38.1
AC-156	34.5	16	26.4 – 42.6
acema	37.9	18	43.7 – 51.7
antiqueira	47.7	9	43.7 – 51.7

Source: Report on tuber and root section, IAC 1976.

TABLE 3 - Productivity of cassava (ton/ha) clones released by CIAT in different counties of Colombia.

Clone	Palmira	Media Luna	Carimagua
M 309-41	30.4	10.7	3.8
M 342-55	37.6	25.9	5.7
M 308-197	36.9	16.0	1.5
M 426-6	36.0	21.9	7.6
M 440-5	29.2	9.1	4.1
M 471-4	30.7	12.3	0.8
M 451-1	31.2	14.0	3.5
M 321-188	43.8	16.9	1.8

Source: CIAT Annual Report (1980).



Cassava productivity drop in Nigeria in the 1980s was due to the invasion of mealy bug, accidentally introduced in the country in the 1970s, and was controlled by an effective biological program by the late 1980s. The 1990 recovery is an evidence of the superiority of the clones released by IITA(International Institute of Tropical Agriculture).

An extremely impressive fact was the vertical rythm of increased productivity in India in the 1980s and 1990s thanks to the leading work of the Central Root and Tuber Center (CTCRI) at Kerala. Both IAC(Instituto Agronômico de Campinas, Brazil) and CTCRI(Central Tuber Crops Research Institute,India) followed methods based on heterotic effect to increase cassava root production. The best Indian cultivars H-96, H-165, H-226, Sree Visakham and Sree Sohya were of hybrid origin, where a top cross test was applied (2, 29). Thus, it seems that using of hybrid vigour and exploiting heterosis is the best breeding method for this crop.

Transferring seed for use abroad may lead to a heterosis breackdown in future generations. If apomixis genes were introduced to cassava cultivars, this might save superior genotypes from segregation. Apomixis exists in wild species and may be transferred to the cultivar by means of interspecific hybridization (13, 21). Other useful genes can be trasferred also, such as high protein content (24), tolerance to drought and so many others (14, 22, 23). Production of polyploid types may be a promising option for increasing cassava productivity under suboptimal conditions. One of the best productive Indian cultivars, Sree Hansha, is a triploid type. In Brazil, the most drought tolerant cassava clone is a natural triploid called Manebeba Branca. Considering these facts, a cassava improvement plan may be be defined as follows:

1) *Exploration of wild genetic resources.* Cassava originated in the Northern Amazon, South America (8). In various parts of the continent, wild relatives grow naturally and exhibit a vast array of genetic variations yet to be explored and utilized as a source of many genes (8, 10, 11, 12). Many leading scientists have emphasized the valuable sources of wild species in breeding crops(5, 6, 7). Through his program, the first author, at the Universidade de Brasília, has systematically collected, evaluated and manipulated these wild species, incorporating their useful genes for crops improvement (12, 13, 15, 16), such as clones tolerant to drought (28, 29) and high protein content combined with low HCN hybrids (18).

Recent studies show that cassava cultivars are not the typical allogamous material that they were believed to be in the past. They also show genetic poverty through so many characters, that they must be enriched continuously by introgressed genes of wild relatives.

The classical case of exploring *M. glaziovii* by Nichols (27) in the 1940s resulted in the recovery of the crop in East Africa from extinction, due to devastation of the African mosaic.

Interspecific hybrids of cassava with wild species showed high productivity under semiarid conditions in Brazil (19). This country, which is responsible for about 88% of the cassava production in the continent, has vast areas of uncultivated savanna (cerrado) with the greatest potential for cassava production, if well utilized, like the IAC model implanted in São Paulo state, using highly productive cultivars. If introgressed genes of vigorous wild *Manihot* species, native of the cerrado, were introduced to cassava cultivars, this would contribute significantly to increase the production in the entire continent. Wild species, native of the cerrado (Central Brazil savanna) and those native of the caatinga (Northeastern Brazil savanna) were well evaluated by the first author and have had their useful genes incorporated to the cultivate (15). The following is a summary of the breeding trials conducted:

*M. pseudoglaziovii* Pax & Hoffmann. Natural hybrids with cassava have deep fibrous roots, tolerant to drought. When the hybrid backcrossed to cassava it produced a progeny, from which clones adapted to arid conditions were selected.

*M. glaziovii* Muell. Arg. Its hybrids and backcrossed generations with cassava were produced by the first author (22). The introgression of resistance to mosaic genes from this species by Nichols in the 1940s (27) gave the most impressive example of the utilization of wild species.

*M. anomala* Pohl. Hybrids and backcrossed generations were obtained by the first author. Hybrids of this species with cassava show adaptation to shadow, and may be a potential for use in associated cropping of cassava with other crops. They also show resistance to the mealy bug, a very dangerous pest in West Africa.

*M. oligantha* Pax & Hoffmann. Its hybrid with cassava showed high protein content, twice that of the common cultivars (24). The evaluation of the hybrid for protein content, during approximately 15 years, showed constant high protein content combined with low HCN. This hybrid is being propagated now to be distributed to farmers by the Brazilian Corporation for Agricultural Research.

*M. neusana* Nassar. Its hybrid with cassava is very vigorous and has tremendous leaf and vegetative growth, making it a candidate for use as forage. The hybrid shows high frequency of meiotic restitution, which may lead to production of triploid and trisomic hybrids in the second generation (16, 23). It is also a source of apomixis genes (21, 23, 26).

2) *Production of polyploid hybrids.* Tetraploid and triploid cultivars of vegetatively-reproduced crops have been successfully used by plant

breeders. Trials of chromosome doubling in cassava were made early in the 1960s, by using colchicine. However, this attempt has not led to the development of tetraploid or triploid cultivars, probably due to instability of the chimera produced.

Interspecific hybrids of cassava with the wild species exhibit a meiotic irregularity accompanied by high frequency of meiotic restitution, leading to the production of  $2n$  hybrid diploid gametes (25). The first author has manipulated this phenomenon to produce a productive triploid tolerant to drought conditions (19). In addition to this triploid, the first author proceeded to the production of a trisomic hybrid, which show high yield combined to adaptation to savanna conditions (23).

Polyploidy is also apt to restore fertility in the interspecific hybrids. If interspecific hybrids were polyploidized, they would restore fertility and be able to cross with diploid cultivate producing triploids that are vigorous, due to both heterosis and ploid level. Ployploids have been achieved in several and different interspecific hybrids by this author; trials of their crosses with cassava are under way.

3) *Development of apomictic true lines.* Since cassava is vegetatively propagated by means of stem cuttings, it is considered to be a labor intensive crop. Vegetative cuttings are also often responsible for the spread of diseases and pests throughout the tropics. Nassar and O'Hair (17) proposed the idea that the use of true seeds instead of stem cuttings for cassava production would eliminate these problems and potentially reduce production costs. One limiting factor, though, is the lack of quick and uniform seed germination. Another difficulty is the genetic segregation and lack of true breeding lines. If apomictic easily germinated lines could be developed, this idea would have been successful.

Since 1983, the first author has been involved in the use of mass selection to gradually modify the cassava population with respect to seed dormancy and has obtained an easily germinated seed population. During the last years, by the use of molecular, cytogenetic and embryonic techniques, facultative apomictic clones have been selected and developed among this easily germinated seed population. Molecular and embryonic studies have confirmed the transference of apomictic gene from both *M. neusana* and *M.dichotoma* to cassava (21, 26). Seeds of these facultative clones have been provided to CIAT, IITA, and CTCRI.

Another advantage of apomictic clones, rather than preservation of genetic superiority, is that it acts as a filter for virus and bacterial germs which accumulate year after year on cassava vegetative growth, through the use of contaminated cuttings. By using of apomictic clones, we would have avoided the extinction of excellent clones, similar to what occurred

to the best Brazilian ones ever known in the history of the crop: Vassourinha, Guaxupé and many others.

### Acknowledgement

This work is partially supported by the Brazilian Nacional Council for Research Development (CNPq). The living collection was established at the Universidade de Brasília with the help of the International Development Research Center (IDRC), Ottawa, Canada, to whom the first author is grateful.

### REFERENCES

1. AGRO EUROPE BRITISH PUBLICATION. Brazilian manioc growing encouraged by end of wheat subsidies. London, 1999. 49p. (N° 1564).
2. CENTRAL TUBER CROPS RESEARCH INSTITUTE. Annual Report. Thiruvandrum, 1989. 86p.
3. COURSEY, D. & HAYNES, P. H.. Root crops and their potential as food in the tropics. *World Crops*, 22:261-5, 1979.
4. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. FAO Production yearbook, 52:31-2, 1998.
5. HARLAN, J.R. Genetic resources in wild relative crops. *Crop Science*, 16:329-32, 1976.
6. HAWKES, J. G. The importance of wild germplasm in plant breeding. *Euphytica*, 26:615-21, 1977.
7. MONACO, L.C. & CARVALHO, A. Transfer of rust resistance from *Coffea canephora* to *C. arabica*. *Ciência e Cultura*, 23:101-2, 1971.
8. NASSAR, N.M.A. Conservation of the genetic resources of cassava (*Manihot esculenta* Crantz): Determination of wild species localities with emphasis on probable origin. *Economic Botany*, 32:311-20, 1978.
9. NASSAR, N.M.A. Hydrocyanic acid content in some wild *Manihot* (cassava) species. *Canadian Journal of Plant Science*, 58: 577-8, 1978.
10. NASSAR, N.M.A. Microcenters of wild cassava *Manihot* spp. diversity in central Brazil. *Turrialba*, 28: 345-7, 1978.
11. NASSAR, N.M.A. Some further species of *Manihot* with potential value to cassava breeding. *Canadian Journal of Plant Science*, 58:915-6, 1978.
12. NASSAR, N.M.A. Wild *Manihot* species of central Brazil for cassava breeding. *Canadian Journal of Plant Science*, 58: 257-61, 1979.
13. NASSAR, N.M.A. A study of the collection and maintenance of the germplasm of wild cassavas. *Manihot* spp. *Turrialba*, 29: 221, 1979.
14. NASSAR, N.M.A. Three Brazilian *Manihot* species with tolerance to stress conditions. *Canadian Journal of Plant Science*, 59: 533-55, 1979.
15. NASSAR, N.M.A. Natural hybrids between *Manihot reptans* Pax and *M. alutacea* Rogers & Appan. *Canadian Journal of Plant Science*, 64: 423-5, 1984.
16. NASSAR, N. M. A. *Manihot neusana* Nassar: A new species native to Paraná, Brazil. *Canadian Journal of Plant Science*, 65: 1097-100, 1985.
17. NASSAR, N.M.A. & O'HAIR, S. K. Variation among clones in relation to seed germination. *Indian Journal of Genetics*, 45:429-32, 1985.
18. NASSAR, N.M. A. Genetic variation of wild *Manihot* species native to Brazil and its potential for cassava improvement. *Field Crops Research*, 13:177-84, 1986.

19. NASSAR, N.M. A. Production of triploid cassava, *Manihot esculenta* Grantz by hybrid diploid gametes. *Field Crops Research*, 13: 173-82, 1991.
20. NASSAR, N.M.A. Cassava in South America: A plant breeder viewpoint. *Ciência e Cultura*, 44:25-7, 1992.
21. NASSAR, N. M. A. Selection and development of cassava apomictic clones. *Ciência e Cultura*, 41:168-71, 1994.
22. NASSAR, N. M. A. Development of cassava interspecific hybrids for savanna conditions *Journal of Root Crops* 22:9-17, 1995.
23. NASSAR, N.M. A. Cassava, *Manihot esculenta* Crantz genetic resources: Their collection, evaluation, and manipulation. *Advances in Agronomy*, 69:179-230, 1999.
24. NASSAR, N.M.A. & DOREA, G. Protein contents of cassava cultivars and its hybrid with *Manihot* species. *Turrialba*, 32:429-32, 1982.
25. NASSAR, N.M.A. & FREITAS, M. Prospects of polyploidizing cassava. *Manihot esculenta* Crantz, by unreduced microspores. *Plant Breeding*, 116:195-7, 1997.
26. NASSAR, N.A.; VIEIRA, M.A.; VIEIRA, C. & GRATTAPAGLIA, D. Molecular and embryonic evidence of apomix in cassava (*Manihot esculenta* Crantz). *Euphytica*, 102:9-13, 1998.
27. NICHOLS, R.F.W. Breeding cassava for virus resistance. *East Africa Agriculture Journal*, 12:184-94, 1947.
28. PAPADAKIS J. Crop ecology survey in West Africa (Liberia, Ivory Coast, Ghana, Togo, Dahomy, Nigeria). Rome, FAO, 1966. 72p.
29. RAJENDRAN, P.G.; RAVINDRAN, C.S.; NAIR & NAYAR, T.V.R. True cassava seed (TCS) for rapid spread of the crop in non traditional areas. Thiruvananthapuram. *Central Tuber Crops Research* 2000. 22p. (Tech. Bull. Nº 28).
30. VRIES, C.A.; FERWEDS J.D. & FLACH, M. Choice of crops in relation to actual and potential production in tropics. *Netherlands Journal of Agricultural Science*, 15:241-6, 1967.