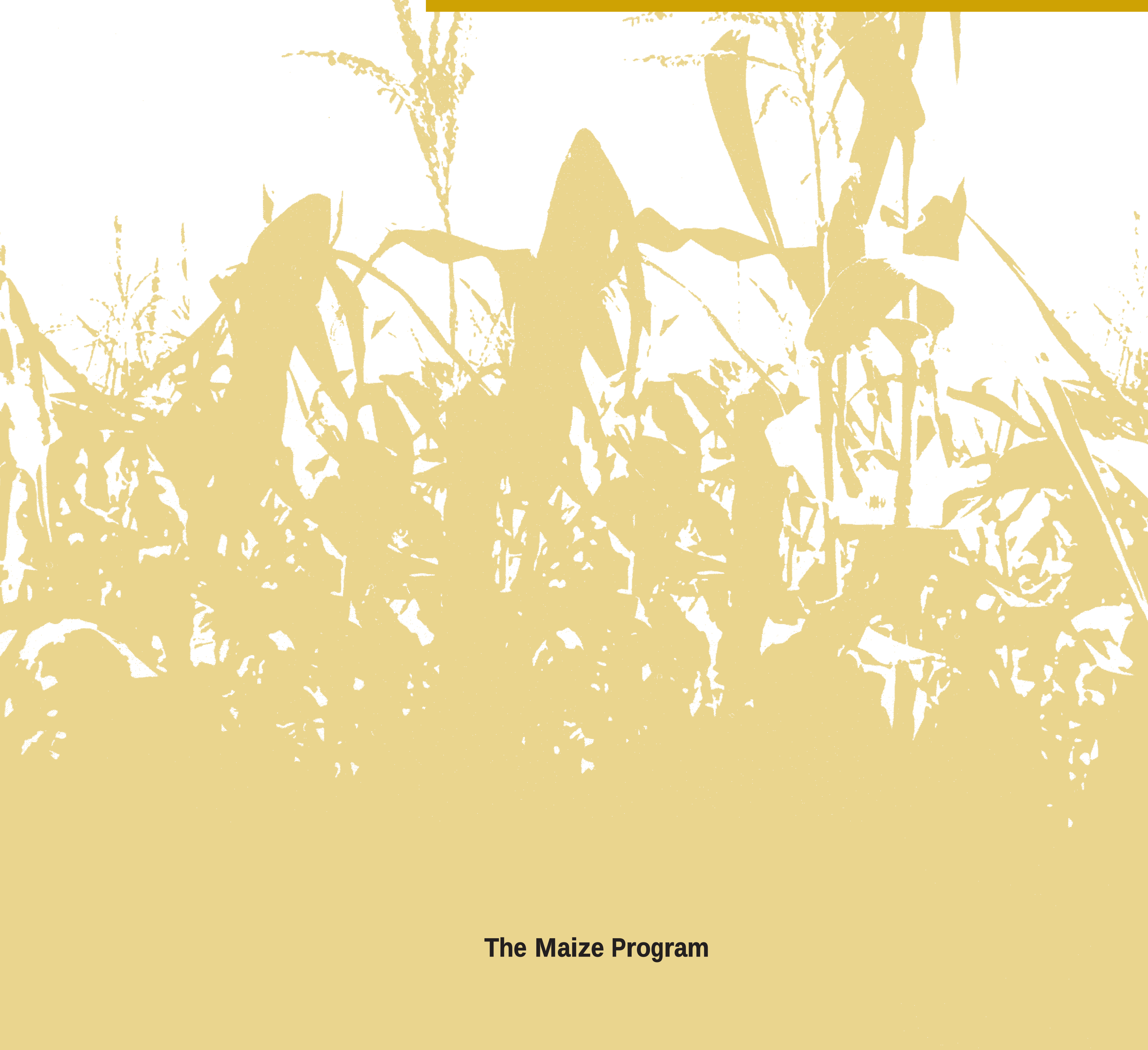
Development, Maintenance, and Seed Multiplication of Open-Pollinated Maize Varieties

2nd edition



The Maize Program

CIMMYT (www.cimmyt.mx or www.cimmyt.cgiar.org) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center works with agricultural research institutions worldwide to improve the productivity, profitability, and sustainability of maize and wheat systems for poor farmers in developing countries. It is one of 16 similar centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR comprises over 55 partner countries, international and regional organizations, and private foundations. It is co-sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP). Financial support for CIMMYT's research agenda also comes from many other sources, including foundations, development banks, and public and private agencies.

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Abstract: The procedures for the production of maize hybrid seed and maintenance of parental lines are well documented. However, not much has been written on the development, maintenance, and multiplication of improved open pollinated maize varieties (OPVs). This bulletin provides appropriate, user-friendly procedures and guidelines for variety development, evaluation and variety release systems, characterizing open-pollinated varieties, maintenance and seed production (breeder's seed, foundation seed, certified seed), isolation standards for seed production, standards for maintaining varietal uniformity, as well as for keeping reserve stocks, choosing sites for seed multiplication fields, and determining necessary quantities of seed.

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Preface

The availability of higher yielding maize materials in the developing world has grown dramatically over the past decade. With this research progress, more effective seed production systems will become increasingly important, if national research programs are to transfer improved maize technology to farmers. In many countries considerable investments are still needed to create the necessary infrastructure to produce and deliver quality commercial seed to farmers in a timely fashion. Adequate procedures will also have to be instituted to maintain quality and efficiency standards in the seed production process. Although documentation exists for the production of hybrids, little information has been published on proper procedures for the development and maintenance of open-pollinated maize varieties. Hence, these guidelines for the development, maintenance and seed production of open-pollinated maize varieties.

Over the past three years, several CIMMYT staff have presented papers at conferences and symposia on the subject of production and maintenance of open-pollinated maize varieties. This bulletin is a synthesis of these various efforts and special recognition is given to Drs. Alejandro Ortega and Surinder Vasal for their contributions.

In the sections describing variety development, specific numbers are given for quantities of progeny to be grown and selection intensity to be exercised. Similarly, variability standards have been given for various classes of seed. These numbers are to be used only as guidelines, however, and not as sacred and inviolable tenets of maize variety breeding. The variability found within a variety, the resources available for seed production, and the quantity of seed required may alter the number of progeny grown and the selection intensity utilized. Variations, no doubt, will also exist from country to country in the breeding methodology and in the form that national seed programs will take. However, the efficient development and distribution of improved varieties to farmers must remain the central goal. It is our hope that the pages following will contribute to its achievement.

Shivaji Pandey
Director
CIMMYT Maize Program

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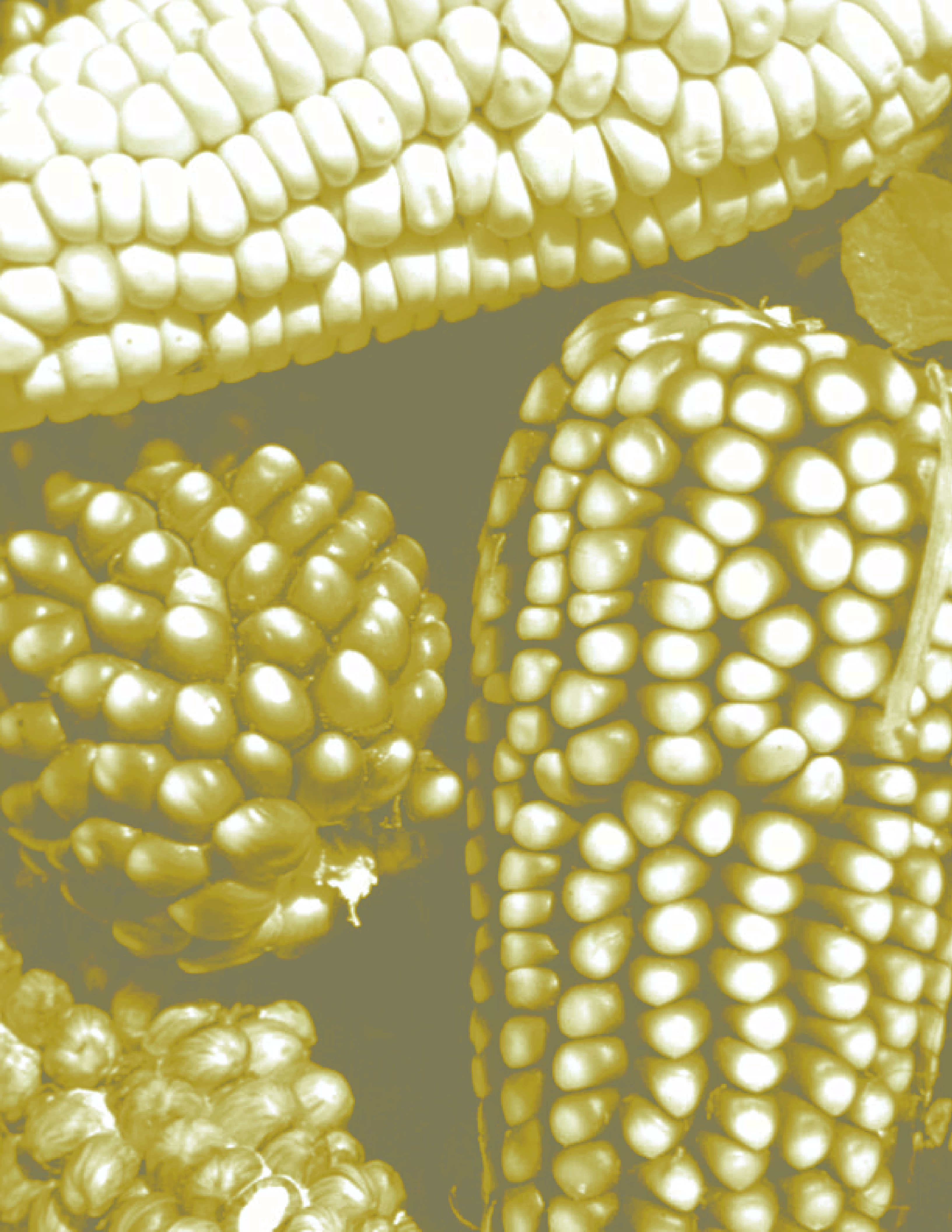


Introduction

Maize (*Zea mays*, L.) is grown on approximately 140 million hectares (M ha) worldwide: 97 M ha in developing countries, 34 M ha in the high income countries, and 9 M ha in the Eastern Europe and the former Soviet Union (CIMMYT, 1994). Maize is a staple food for several hundred million people in the developing world. The average inhabitant of eastern and southern Africa consumes 80 kg of maize each year; in Mexico, Central America, and the Caribbean, 170 kg. Annual per capita maize utilization averages 100 kg in East Asia and more than 190 kg in the Southern Cone of South America, largely as animal feed in both cases. Unfortunately, developing countries do not produce enough maize to meet their needs and must therefore import approximately 30 million tons of maize annually. Use of improved cultivars and management practices should help increase maize yields and reduce imports in developing countries.

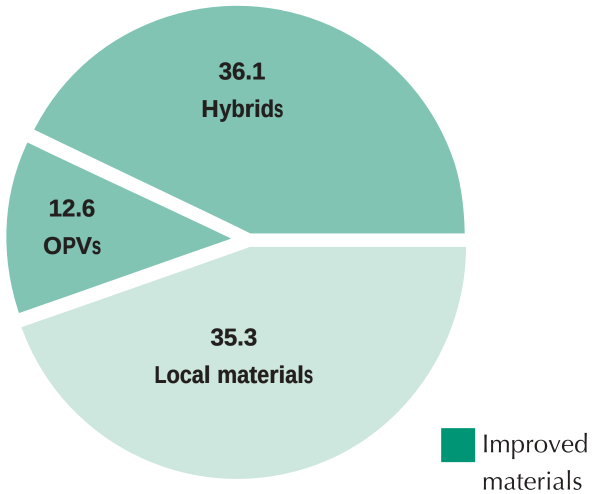
Appropriateness of OPVs

Approximately 58% of the maize area in developing countries is planted to improved maize: 44% to hybrids, 14% to improved open-pollinated varieties (OPVs), and 42% to unimproved OPVs (Fig. 1) (Pandey and Gardner, 1992; CIMMYT, 1994). In contrast, nearly 100% of maize area in the developed countries is planted to hybrids. Thus, OPVs occupy an important place in maize culture in developing countries. Improved OPVs are easier to develop than hybrids, their seed production is simpler and relatively inexpensive, and subsistence farmers who grow them can save their own seed for planting the following season, reducing their dependence on external sources. Since input requirements of OPVs and management practices used for them are similar to those for the landraces that poor farmers currently grow, adoption and farmer-to-farmer seed movement of OPVs are relatively easier. Perhaps this is why improved OPVs occupy more maize area in some developing countries than any single hybrid; e.g., BR-106 in Brazil, ICA-156 in Colombia, INIAP-526 in Ecuador, Marginal-28 in Peru, etc.

Substituting *better* OPVs for currently used OPV and landrace cultivars will help increase maize yields. In addition, increased use of seed of improved OPVs by farmers should encourage investments by private and public seed enterprises, resulting in the eventual adoption and use of hybrids in the developing countries.

The procedures for the production of hybrid seed and maintenance of parental lines are well documented. However, not much has been written on the development, maintenance, and multiplication of improved OPVs. In this bulletin, we present some of the more appropriate and user-friendly procedures for development, maintenance, and seed production of improved OPVs.

Figure 1. Types of maize planted (millon hectares) in developing countries.



Source: CIMMYT, 1994.

Changes in the concept of OPVs

Since maize is an open-pollinated crop, it exhibits high genetic variability. Genetically diverse maize types are routinely crossed to develop maize populations (composites, gene pools, and advanced generations of varietal crosses, etc.) which are then improved through recurrent selection. A bulk from the improved population is often released as an improved OPV for cultivation.

Unfortunately, many released OPVs are not sufficiently uniform in agronomic characteristics, which reduces their acceptance by farmers. This situation largely resulted from the somewhat looser definition of “variety” that prevailed until recently. More recently, however, a variety has come to be redefined as an assemblage of relatively uniform phenotypes that is different, relatively uniform, and stable. An OPV is “different” if it possesses traits that distinguish it from other known varieties and define its identity. It is relatively uniform and stable over time for important agronomic traits in its area of adaptation. If constituted by intermating 8-10 selected families or lines of similar maturity, plant and ear height, and other morphological traits, an OPV will be more uniform, more acceptable to farmers, and easier to maintain and produce seed for.

Variety Development, Evaluation, and Characterization

Before describing procedures for varietal maintenance and seed production, we briefly review those involved in the development, evaluation, and characterization of an OPV.

Variety development procedures

Since outstanding families identified during a recurrent selection program are normally used in the formation of OPVs, development of OPVs is influenced by the recurrent selection scheme used to improve maize populations. The families used to form an OPV differ in their genetic complexity, depending on the population improvement method used.

The inbreeding level of the population from which the families are selected, the number and type of families selected, and the procedure employed in intermating them to form an OPV have a direct effect on the level of inbreeding of the resulting OPV. Use of fewer families makes it easier to ensure that they are truly superior and similar in morphological traits. However, the fewer the families intermated, the greater the inbreeding depression.

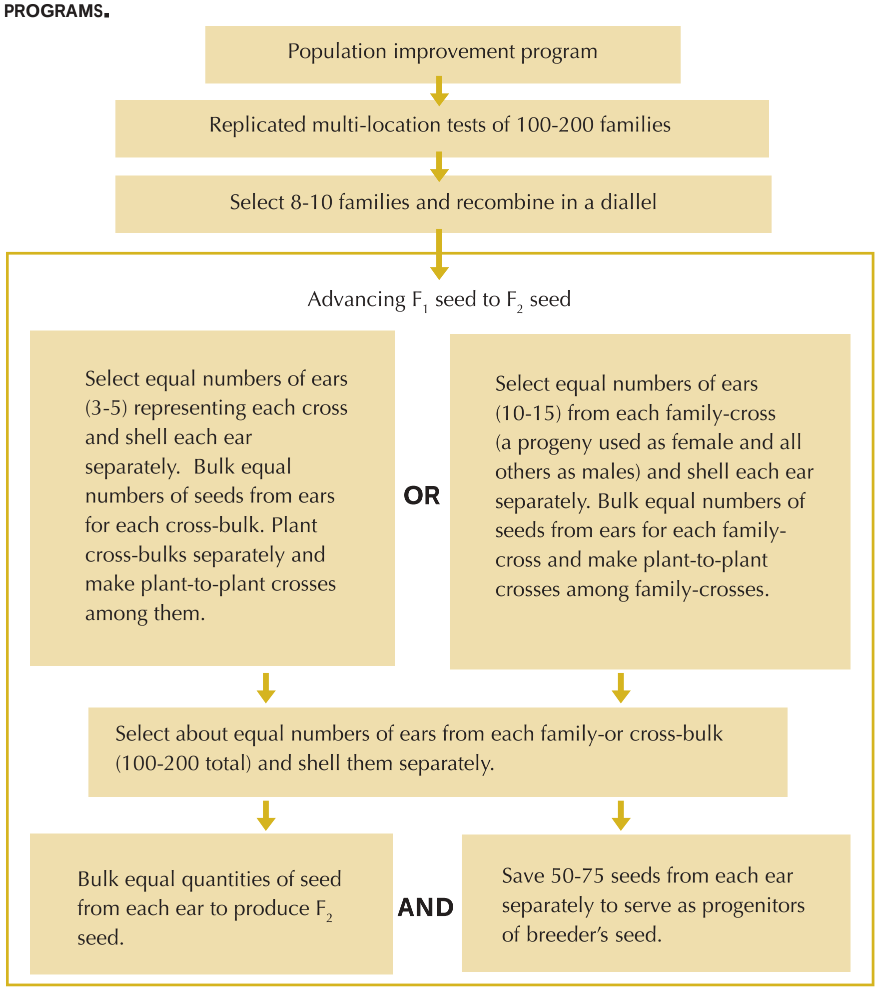
Regardless of the recurrent selection scheme employed, 8-10 superior families should be identified based on their performance in multi-location tests (Fig. 2). Using their remnant seed, the selected families should be intermated by making plant-to-plant diallel crosses among them to form an OPV. Diallel crossing among 10 or fewer genotypes is easily accomplished, permits more complete recombination, and reduces inbreeding (Hallauer and Miranda, 1988). In the crossing block, if a family looks different from other families during any stage of its growth and development, it can be discarded before or after pollination. Plants of other families fertilized with pollen from the undesirable family must also be discarded.

Superior OPVs can also be developed by recombining elite inbred lines not derived from a population improvement program. In this case, it is desirable to select 8-10 lines with high general combining ability and intermate them as described before. High-yielding OPVs have also been developed by crossing among four or five single- or two or three double-cross hybrids. We recommend that the parents of the hybrids — that is, the inbred lines — be selected and used instead of the hybrids themselves to form an OPV. This is because general combining ability is more important in the performance of OPVs than specific combining ability (which plays a greater role in the performance of hybrids).

The F_1 seed should be advanced to F_2 by hand-pollination using any of the following two procedures to provide enough seed for the evaluation and maintenance of the OPV and to reduce heterotic effects (Fig. 2):

- Assuming that 10 families were used to form the OPV, there would be 45 two-parent crosses. A roughly equal number (three to five) of ears selected from each cross can be shelled individually and equal amounts of seed from each ear bulked. Each of the 45 cross-bulks can be planted separately, represented by about 20 plants. Plant-to-plant crosses can be made between cross-bulks using healthy and vigorous plants. If a cross-bulk is found undesirable, all crosses involving either of its parents can be discarded.

Figure 2. Variety formation and obtaining F_2 seed from recurrent selection programs.



- For each family involved in the formation of an OPV, select roughly equal numbers (10-15) of ears from crossing the family as female with all other families as male. Ears should be shelled individually and equal amounts of seed from each ear involved in each family-cross bulked to prepare separate family-bulks. Thus, if 10 families were involved, there would be 10 family-cross bulks. These bulks can be planted individually and plant-to-plant crosses should be made among them. Any bulks exhibiting undesirable attributes can be discarded at any stage of plant development. This procedure does not preclude the presence of a poor family in the OPV, as the family would have contributed its pollen to seed used to prepare other family bulks.

In both procedures, 100-200 hand-pollinated ears are selected and an equal quantity of seed from each ear bulked to produce the F_2 seed. Selection for uniformity at this stage will prove useful in the subsequent stages of seed multiplication and varietal maintenance. From each ear, 50-75 seeds can be saved separately to serve as progenitors of breeder's seed for use during the maintenance and seed production of the variety.

The first procedure outlined in Figure 2 for advancing F_1 seed to F_2 is superior to the second, as it is more effective in ensuring that only superior families are included in the OPV. Whichever procedure is used, at least two sets of seed should be prepared, in case one is lost by accident.

Evaluation and variety release systems

Evaluation and variety release systems vary by country. The evaluation system should facilitate rapid identification of OPVs superior to checks; release and seed certification regulations should facilitate efficient delivery of the OPVs to the farmers (Fig. 3). Data from about 25 properly conducted trials at research stations and in farmers' fields, under farmers' own management and under improved management conditions, should be enough to determine the performance, stability, and suitability of an OPV. Simple agronomic trials conducted in farmers' fields can form the basis for agronomic recommendations to accompany the OPV. An OPV should be stable in the expression of its morphological traits and yield to be acceptable to farmers.

Characterizing an open-pollinated variety

When an OPV nears the release stage, it should be described for salient attributes in the area of its adaptation to guide its maintenance and seed certification in the future. It should possess some genetic feature(s) to distinguish it from other OPVs. Characters such as adaptation, maturity, plant height, ear height, stem pigmentation, tassel color, tassel size and configuration, leaf orientation, midrib color, silk color, ear shape, cob color, kernel color, kernel texture, kernel shape, and tolerance or resistance to pests and pathogens should be considered in varietal descriptions (Table 1).

When quantitative characters are used to describe an OPV, expected standard deviation from means should be given to indicate the acceptable variation within the variety (e.g., ± s). For qualitative characters, the expected variation may be given in percentages (e.g., ± %). In this case, setting acceptable upper limits for the variation would be desirable (e.g., pink cobs 5%). Quantitative descriptors are of value in the maintenance of OPVs and production of breeder's seed. Qualitative traits are more useful during seed multiplication and certification.

An important attribute of a good OPV is its uniformity. However, even though elite and relatively similar genotypes are recombined to produce it, an OPV will seldom be as uniform as a single-cross hybrid for most morphological traits. Therefore, certification standards for OPVs should be flexible, realistic, and appropriate for the conditions prevailing in a given country.

Table 1. Characteristics used to define a variety.

	Qualitative	Quantitative
Stem	Color	Height No. of nodes No. of tillers
Leaves	Color of leaves Color of central vein Color of leaf sheath Pubescence of sheath	No. of leaves No. leaves above ear Leaf angle Width ear leaf Length ear leaf
Tassel	Color of glumes Color of anthers Compact or open Color of stigmas Color of dry husks	Length of peduncle Length of central axis No. of branches Days to 50% plants with pollen No. per plant Insertion angle
Ear	Husk pubescence Husk texture Ear shape Kernel row arrangement Cob color	Length of ear peduncle No. of kernel rows Length Diameter Weight Shelling percentage Cob diameter
Seed	Color of pericarp Color of aleurone Color of endosperm Texture (dent, flint, etc.)	Length Width Weight 1000 seeds Thickness of seed

Maintenance and Seed Production

The maintenance and seed production of OPVs can be managed through three stages of seed multiplication: breeder's seed, foundation seed, and certified seed. The breeder's seed field should show the minimum variation for morphological traits; the certified seed field will have more variation; and the foundation seed field will be intermediate between the two. The certification standards should be established carefully for these seed categories to help guide quality control during multiplication but not impede seed production and distribution.

An important consideration during maintenance and different phases of seed production of an OPV is the number of plants or ears to be used. This is particularly important during the production of breeder's seed and of the progenitors of breeder's seed. Two issues interact to determine the number: the number of plants or ears required to adequately represent an OPV and the quantity of seed required of a given phase to meet its future needs, without having to reproduce it too frequently.

The number of plants or ears to represent an OPV depends on the genetic variability present within the OPV. Theoretical considerations and experiences and practices of national programs indicate that 100-200 plants and ears would normally be sufficient to represent an OPV and provide adequate breeder's seed and seed of the progenitors of the breeder's seed for future maintenance and seed production (Authors' experience; A.R. Hallauer and C.O. Gardner, 1996, personal communication). However, both the number of ears selected and the number and size of rows planted with them can be adjusted, if greater quantities of seed are required for future use.

It is recognized that some selection and inbreeding during these phases are inevitable but their effects should be minimized. Any selection during different phases of maintenance and seed production should focus on the identification of plants and ears that best represent the OPV.

Breeder's seed

Breeder's seed is produced from breeder's seed itself and/or from the progenitors of breeder's seed. The responsibility for maintaining the purity of breeder's seed as long as the OPV is in production rests with the breeder. To maintain the highest level of purity, the breeder's seed plot should be small and manageable. To ensure that the OPV does not show excessive variation in succeeding generations, morphological traits of the plants and ears selected for breeder's seed should fall within ± 0.7*s* (standard deviation) for quantitative traits. For qualitative traits, the acceptable range of variation can be ± 3%. When a released OPV is replaced by a superior one, maintenance of the old OPV is discontinued.

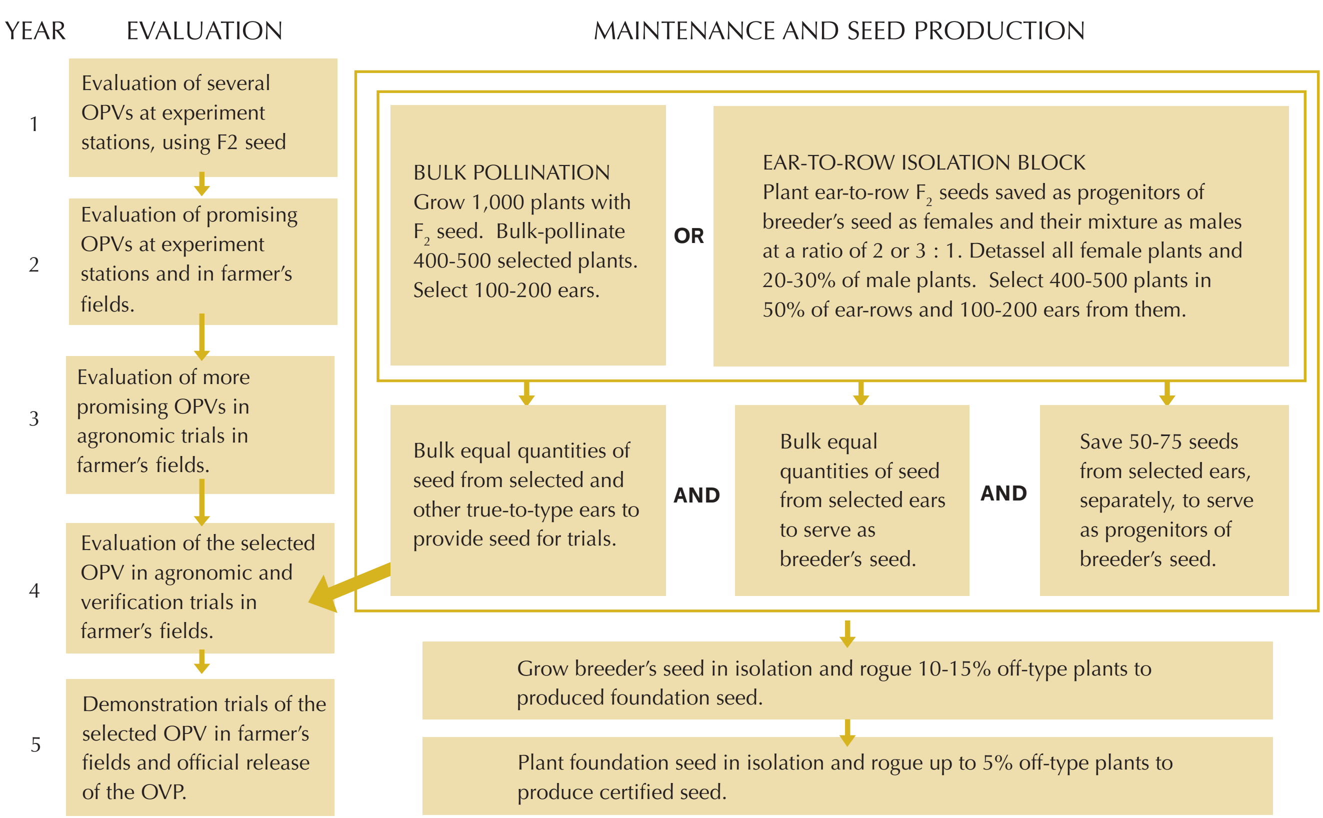
Either of the two procedures described in Figure 2 may be used in the maintenance of the OPV and in production of its breeder's seed.

Bulk pollination

Approximately 1,000 plants can be grown from the F_2 seed bulk or from a balanced bulk of the ears saved as progenitors of breeder's seed and 400-500 plants that fit the phenotypic description of the variety selected. Pollen from the selected plants can be bulked to pollinate these same plants. At harvest, 100-200 ears, meeting the ear and kernel characteristics of the variety, are selected from the selected plants. A seed bulk of equal quantity from each ear is prepared to serve as breeder's seed. Approximately 50-75 seeds from each selected ear can be saved separately to serve as progenitors of breeder's seed for use during future varietal maintenance and seed production.

If the demand for breeder's seed cannot be met by sampling the ears selected, seed can also be saved from other true-to-type ears produced on selected plants but not used as progenitors of breeder's seed. A representative sample from the selected ears as well as seed from other true-to-type hand-pollinated ears can be used for evaluation of the OPV.

Figure 3. Varietal evaluation, maintenance, and seed production program.



Isolated half-sib ear-to-row crossing block

This is a simple and effective procedure for maintaining a variety and producing breeder's seed. It requires isolation and can be initiated with the seed of individually shelled 100-200 F_2 ears, saved as progenitors of the breeder's seed (Fig. 2). Seed from these ears is planted as individual female rows (ear-rows) in a half-sib crossing block. The male rows are planted with a bulk made up by compositing equal quantities of seed from all ears.

A planting system of 1 male : 2 or 3 females is used. All plants in the female rows are detasseled before they shed pollen. Up to 20-30% of the plants in the male rows that do not fit the description of the OPV can also be detasseled, depending upon the ratio of females to male used in planting. In this manner, better control can be exercised on the pollinator (male) rows. If detasseling is done carefully, the female rows will produce more seed of better quality. The male rows provide a good indication of environmental variation in the field. This facilitates selection among and within the female rows for those plants which conform to the varietal description.

Prior to harvest, 4-8 plants in approximately 50% of the ear-rows that meet the varietal description for plant traits are selected and tagged. Two-to-four ears that best fit the ear and grain characteristics of the OPV are selected from the tagged plants in each family, to provide a total of 100-200 ears. Seed from these ears and other true-to-type ears can be used for breeder's seed, progenitors of breeder's seed, and for varietal evaluation, as described for the bulk pollination procedure.

Foundation seed

The first increase of breeder's seed is usually referred to as foundation seed. The responsibility for producing foundation seed often rests with a seed production agency, with assistance from the breeder(s) responsible for maintaining the purity of the variety. The foundation seed should be produced through open-pollination in plots away from any source of pollen contamination. Up to 10-15% of the off-type plants can be rogued before flowering. Roguing for ear and seed traits is done at or after the harvest. The personnel responsible should ensure maintenance of genetic and morphological purity of the OPV through careful supervision.

To ensure that the OPV does not show excessive variation in succeeding generations, morphological traits of the plants and ears selected for foundation seed should fall within ± 1.55*s* (standard deviation) for quantitative traits. For qualitative traits, the acceptable range of variation can be ± 5%. A second generation of foundation seed can be produced using foundation seed, when it is required in large quantities.

Certified seed

Certified seed is the last stage in the seed multiplication process and is generally produced from foundation seed. It should be grown in isolated plots. Up to 5% of the off-type plants should be rogued before flowering. Roguing for the ear and seed traits is practiced at or after the harvest. To ensure that the OPV does not show excessive variation, morphological traits of the plants and ears selected for certified seed should fall within ± 1.96*s* (standard deviation) for quantitative traits. For qualitative traits, the acceptable range of variation can be ± 8%.

The certified seed should be produced by selected seed growers or at seed farms, under close supervision and coordination of public or private enterprises responsible for seed multiplication and distribution, to ensure production of good quality certified seed. Slightly lower than optimum plant density would help produce better quality seed. The certified seed should be properly processed and treated with insecticides and fungicides before it is sold to farmers.

Isolation standards for seed production

To maintain genetic purity and avoid varietal deterioration, seed multiplication fields of OPVs should be adequately isolated. Isolations can be arranged by distance or by dates of sowing. A 300-meter separation from other maize fields flowering about the same time is considered adequate for breeder's seed and 200-meters for foundation seed, but the greater the distance, the better. Field experience, the differential maturities of materials, known trends of prevailing winds at flowering, and natural or artificial barriers should be considered in determining safe distances for isolation.

Isolation by time of sowing allows planting an isolation block close to other isolation blocks or maize fields. Planting of the isolation block is done either sufficiently earlier or later than nearby maize plantings to ensure that stigma emergence and pollen-shed in one material is over before tassels in the nearby materials emerge. A combination of both, dates of sowing and distance, can also be used in planning isolations. When several isolations need to be arranged in the same field, reliable information on number of days to pollen-shed of the materials is necessary. A time isolation can easily be inserted between two distance isolations with an adequate interval, so that their flowering does not coincide.

Other Considerations in Planning Seed Production

In addition to the proper maintenance and seed production of an OPV, other factors that influence timely provision of quality seed in adequate quantities to the farmers include maintenance of reserve stocks, choice of seed multiplication fields, and determination of quantity of seed to be produced.

Reserve stocks

The need for saving and storing enough reserve seed to guard against losses from crop failures is well recognized in a seed production program. The reserve stocks help ensure continuity of a seed program. Sufficient reserve seed from the progenitors of breeder's seed, breeder's seed, and foundation seed should be kept under cold storage conditions for at least two generations. For certified seed, any surpluses can be stored for up to a year, under proper conditions.

Choosing locations for seed multiplication fields

Maintenance of an OPV and production of its foundation seed should be done in its area of adaptation, where reproduction of all plants is possible. Rapid shifts in the genetic make-up and phenotypic characteristics of OPVs may occur if they are multiplied in areas outside their adaptation. This restriction is less important for certified seed, particularly if its production is only two generations away from the breeder's seed. The maintenance and seed production of different seed categories in their area of adaptation and under proper management also helps produce greater quantities of high quality seed.

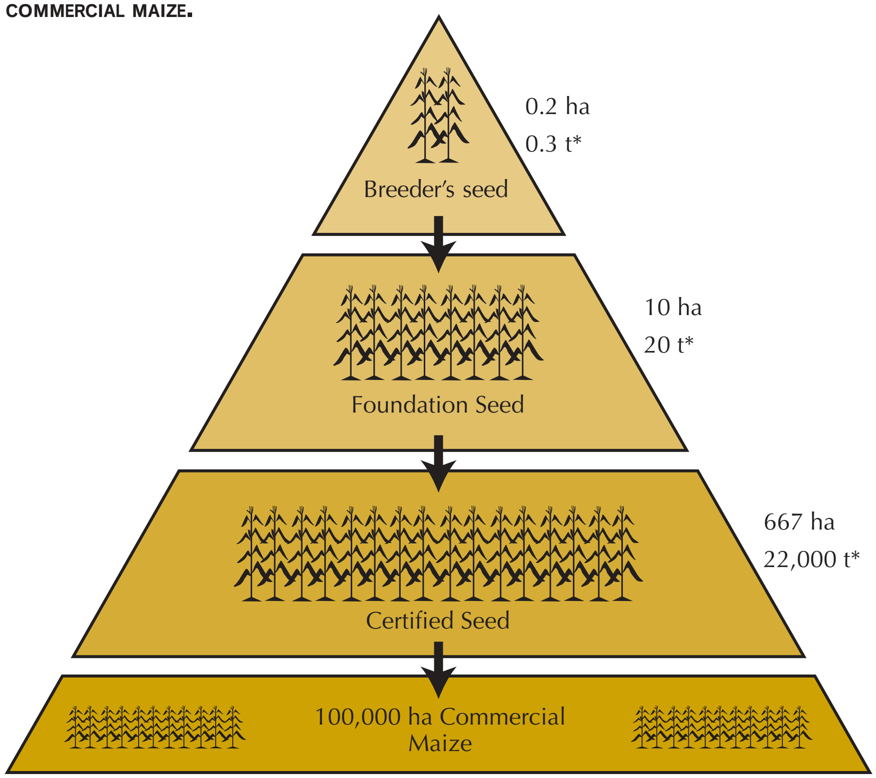
Guidelines for determining seed qualities

Adequate planning is necessary to avoid the possibilities of large shortages or surpluses in the supply of seed. The following factors help determine requirements of different seed categories:

- Potential requirement for certified seed (based on area to be planted with the OPV), which in turn determines the requirements for foundation and breeder's seed.
- Mode of production of certified seed — seed generations needed to produce certified seed.
- Land requirements for the production of different categories of seed, based on their yield, considering male : female ratios and roguing.
- Seeding rate (usually lower than that used in commercial grain production) for production of breeder's, foundation, and certified seed.
- Seed replacement interval — one, two, or three years.

Figure 4 illustrates quantities of seed of various categories necessary to produce sufficient certified seed to plant 100,000 ha. If a seed rate of 20 kg/ha is used for commercial production, 2,000 tons of certified seed would be needed. Under appropriate environmental conditions and adequate field management, 2,000 tons of certified seed can be produced on 667 ha by planting 10 tons of foundation seed at a seeding rate of 15 kg/ha. Twenty tons of foundation seed can be produced on 10 ha, using 150 kg of breeder's seed. The figures allow for retaining half the breeder's and foundation seed as reserve stock. This example shows the rapidity with which certified seed can be produced and farmers are never more than two generations away from the breeder's seed.

Figure 4. Area and production of different seed classes for 100,000 ha of commercial maize.



* Half of seed saved as reserve stock.

Conclusion

The publication has dealt briefly with the extensive topic of the development, maintenance, and seed multiplication of maize OPVs, providing essential information on user-friendly procedures. While the superiority of hybrids over OPVs in most production environments can no longer be seriously questioned, superior hybrids and the necessary infrastructure for their production and marketing are still not available in many developing countries. CIMMYT believes that superior OPVs have an important role to play in the developing world, mainly because they are easier to develop than hybrids, their seed production is relatively simpler and inexpensive, and resource-poor farmers who grow them can save their own seed for planting the following season.

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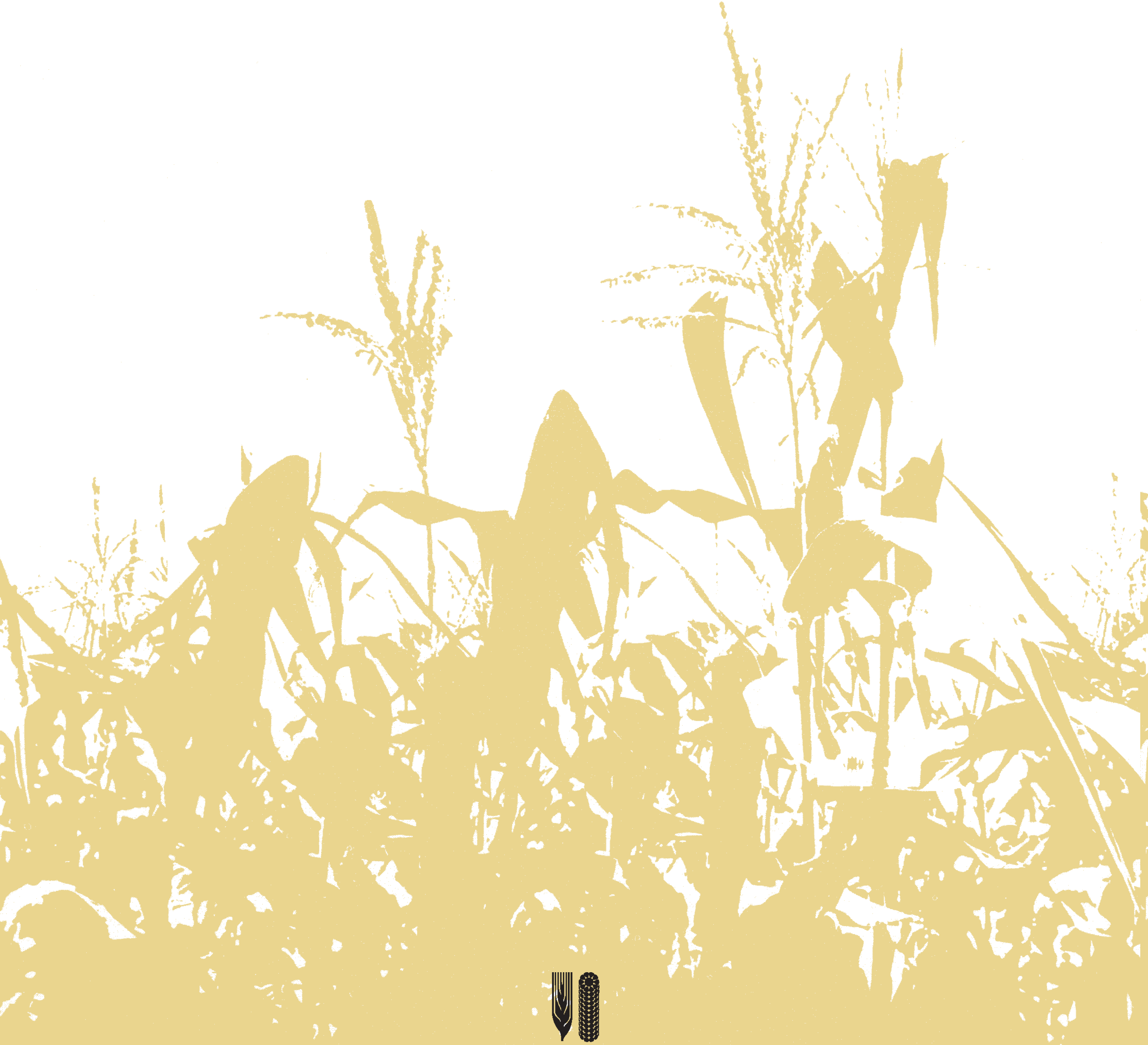

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