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A GUIDE TO UPLAND CROPPING IN CAMBODIA: MAIZE

A guide to upland cropping in Cambodia: maize

Stephanie Belfield and Christine Brown

NSW DEPARTMENT OF
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Telephone: 61 2 6217 0500
aciar@aciar.gov.au

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This manual provides a comprehensive guide on how to produce maize successfully in upland areas of Cambodia.

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NSW DPI, TAMWORTH AUSTRALIA

Professor Bob Martin
Director Tamworth Agricultural Institute

Ms Fiona Scott, Economist

Ms Natalie Elias, Research Agronomist

Mr John Holland, Research Scientist

MURDOCH UNIVERSITY, PERTH AUSTRALIA

Professor Richard Bell, Environmental Scientist

Ms Wendy Vance, Professional Officer

CARDI, PHNOM PENH CAMBODIA

Ms Chan Phaloeun

Dr Seng Vang, Head of Soil and Water

Mr Hin Sarith, Deputy Head of Soil and Water

Mr Ung Sopheap
Deputy Head Agronomy & Farming Systems

Mr Pin Tara, Project Officer

Mr Pol Chanthy, Entomologist

Mr Nin Charya, Plant Breeder

Mr Sieng Lay Heng, Plant Breeder

Mr Pao Sinath, Agricultural Engineer

UNIVERSITY OF CANBERRA, CANBERRA AUSTRALIA

Professor John Spriggs

Foreword

The Royal Cambodian Government's National Poverty Reduction Strategy (2003–2005) committed research centres and extension systems to focus on small-scale farmers and place emphasis on the use of improved tools and management practices for cropping systems. Priority was given to diversification and intensification of sustainable agricultural production with few external inputs as well as to cost-effective management practices.

The Australian Centre for International Agricultural Research (ACIAR) took on these challenges in 2003 with commencement of a project to develop sustainable farming systems for diversification crops (ASEM/2000/109). The focus was on maize, soybean, sesame, mungbean, peanut and cowpea in upland areas of Kampong Cham and Battambang provinces. The aim of the project was to help reduce poverty and contribute to food security at household and national levels in Cambodia through the development of technologies and opportunities for the production of non-rice upland crops. The research process involved discussion with farmers, validation of local knowledge, documentation of case studies and identifying priorities for field experimentation.

The project team conducted a total of 153 on-farm experiments and demonstrations between 2004 and 2006. This research provided the basis for a demonstration package of new technologies and improved practices for upland crop production. The packages included improved varieties, fertiliser recommendations, *Rhizobium* inoculation, reduced tillage and crop-residue retention. Provincial Department of Agriculture staff and non-government organisations in Battambang and Kampong Cham were trained in the implementation of on-farm demonstrations of the new technologies and improved practices in 2007.

A new ACIAR project commenced in 2008 to enhance production and marketing of maize and soybean in north-western Cambodia (ASEM/2006/130). The emphasis of the new project is on-farm adaptive trials to evaluate and improve the technologies and practices initially tested in 2007. The new project has also been expanded to integrate the production and marketing components of the system.

This book is part of a series of publications produced by ACIAR in support of the on-going rollout of on-farm demonstrations for upland crops in Cambodia.

Nick Austin
Chief Executive Officer
ACIAR

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Introduction

Overview

Maize is a tropical grass that is well adapted to many climates and hence has wide-ranging maturities from 70 days to 210 days. In Cambodia, maize is widely adapted to soils in the higher rainfall upland area. Maize plants are erect and may grow as tall as 3 m, with little tillering capacity. The scientific name for maize is *Zea mays*; it is also commonly known as corn, but for the purpose of this manual it will be referred to as maize.

This production manual is a guide on how to grow maize successfully in upland areas of Cambodia in a rain fed system not under irrigation; however, many principles of agronomy are relevant to both irrigated and rainfed farming systems.

The main maize cash crop currently grown in Cambodia is red maize (also known as yellow maize), which is grown for the stockfeed market, whereas white maize is grown locally for human consumption (see Tables 10 and 11 for production statistics). Historically, however, white (or waxy) maize was the dominant type of maize grown. White maize has been grown in Cambodia since around the 17th century. Maize is now second in importance after rice in terms of cultivated area and production. This field crop manual is focused primarily on producing red maize for grain yield. However, most of the agronomy applies also to white maize.

Maize fits well in an upland crop rotation when grown in combination with mungbeans in the early wet season (EWS). Alternatively, maize can be sown in the EWS and soybeans in the main wet season (MWS) (refer to Tables 3 and 5).

The main production area of both types of maize in Cambodia is the province of Battambang and the Municipality of Pailin. Maize is also grown in Kampong Cham, Kampot, Kandal, Banteay Meanchey and Takeo Provinces.

Maize has been identified as having a large potential for growth in production and profit for Cambodian farmers. Figure 1 shows how actual yields in Cambodia compare to potential yields, given Cambodian limitations and with adequate resources. Maize is one of the world's most important cereal crops after rice and wheat, and because of increasing global demand for stockfeed, especially as China develops a greater demand for meat, it is predicted that maize demand will continue to rise.

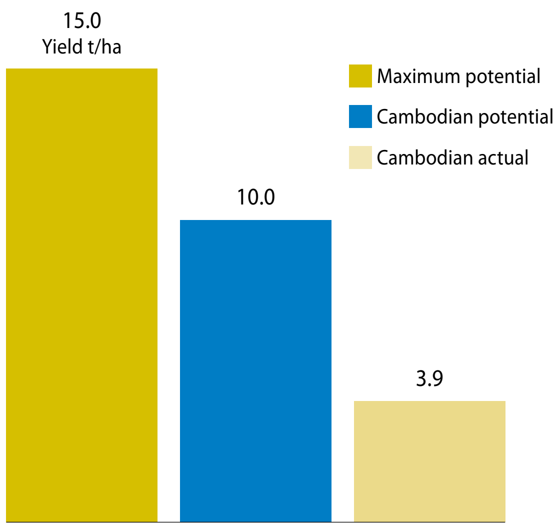


Figure 1. Actual and potential yields of maize in Cambodia

In order to achieve better yields and profitability, farmers may need to adopt other agronomic methods and technology. This manual outlines important maize-crop agronomy and provides information on the methodology and technology that farmers may be able to utilise to grow maize in Cambodia. Preliminary trials have been carried out in Cambodia by the Cambodian Agricultural Research and Development Institute (CARDI) and by parties collaborating on the Australian Centre for International Agricultural Research (ACIAR) project, ASEM/2000/109 *Farming Systems for Crop Diversification in Cambodia and Australia*. This project has provided information on the effects of varietal selection, fertiliser usage, mulching and tillage practices on yield. The difference in yield between current farmer practices and these different agronomic practices is summarised in Figure 2. As can be seen from the graph, a simple change such as adding fertiliser can significantly increase yield. A difference of 0.91 t/ha was achieved in this trial between current farmer practices and a combination of new technology and improved agronomic methods. As more trials are carried out and new agronomic methods and technology are adopted it is hoped that the average Cambodian maize yield will continue to increase up to around 10 t/ha, as shown in Figure 1.

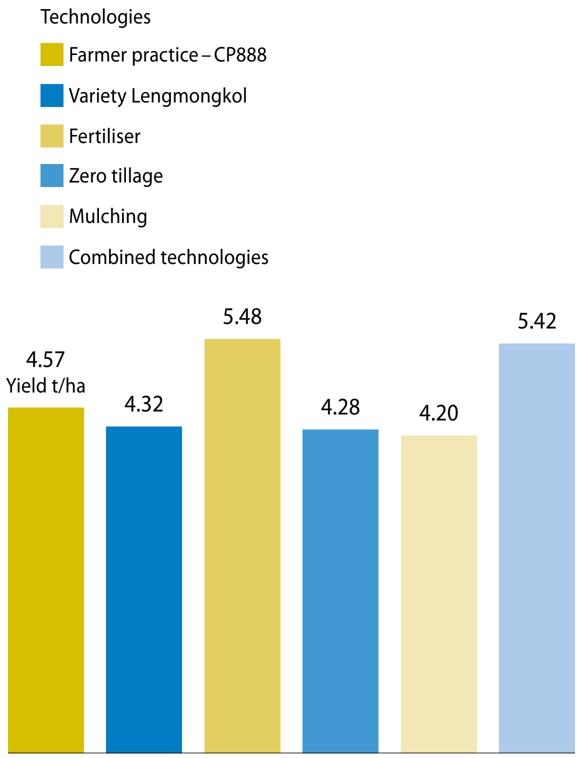


Figure 2. Effect of new technology on yield of maize, EWS 2006

Climate, soils and production areas

Temperature requirements

The optimum temperature for maize growth and development is 18 to 32°C, with temperatures of 35°C and above considered inhibitory. The optimum soil temperatures for germination and early seedling growth are 12°C or greater, and at tasselling 21 to 30°C is ideal.

Low temperature is rarely a limiting factor for crop production in Cambodia. However, high temperatures, which can exceed 38°C in March and April, may be limiting during crop establishment in the EWS, when the plant is most sensitive to heat stress.

Rainfall requirements

Maize can grow and yield with as little as 300 mm rainfall (40% to 60% yield decline compared to optimal conditions), but prefers 500 to 1200 mm as the optimal range. Depending on soil type and stored soil moisture, crop failure would be expected if less than 300 mm of rain were received in crop. Generally in Cambodia the growing season rainfall is less than optimal during the EWS but adequate in the MWS, as outlined in Table 1.

However, through practising reduced tillage, maintaining ground cover or applying crop residues such as rice straw, the impact of drought can be greatly reduced by lowering soil temperature and surface evaporation. In one upland experiment maize yield was increased by 61% by simply adding crop residues to the soil (known as mulching). The results of this mulching trial are shown in Table 13. The effect of mulching aids in lowering the risk of crop failure in the EWS and lifts yield potential.

Table 1. Estimated growing season rainfall for Battambang and Kampong Cham provinces

SOWING TIME	IN-CROP RAINFALL (mm)
EWS – April sowing	340–480
EWS – May sowing	420–600
MWS – July-August sowing	560–690

Source. Vance et al. *2004*

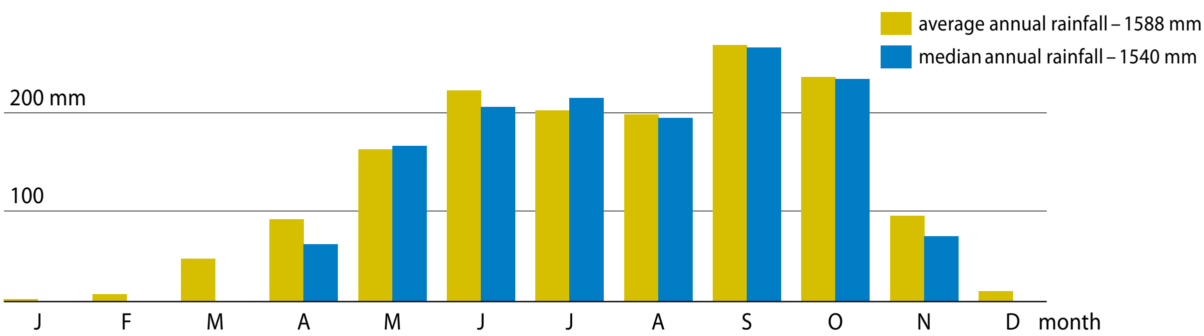


Figure 3. Monthly rainfall at Chamkar Leu, Kampong Cham

Source. Vance et al. *2004*

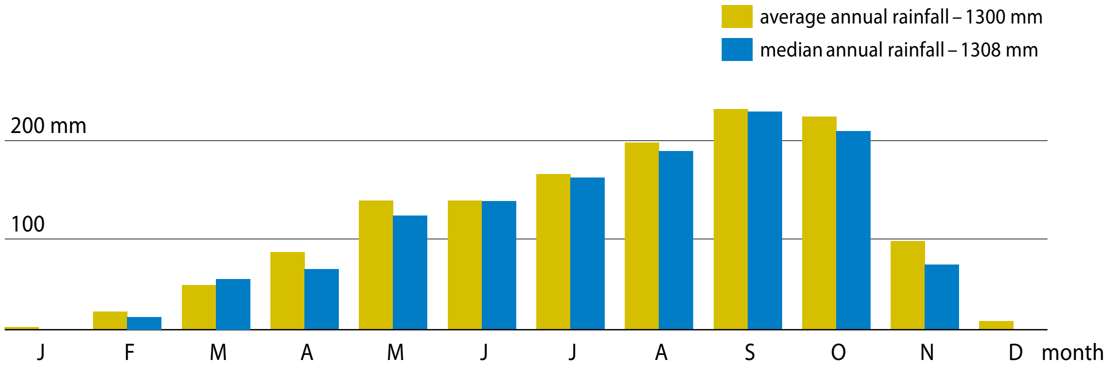


Figure 4. Monthly rainfall at Battambang

Source. Vance et al. *2004*

Monthly rainfall for Kampong Cham and Battambang is shown in Figures 3 and 4, respectively. The onset of the early wet season appears to occur at least a month earlier in Battambang and the variability of rainfall there is also less compared to that in Kampong Cham. Although the annual rainfall is less in Battambang, it would seem that it is more reliable there for EWS upland cropping than in Kampong Cham. However, the potential problem for a dry spell in April is still an issue.

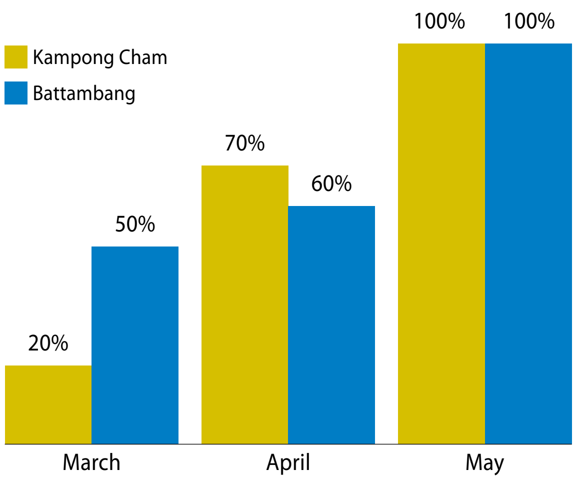


Figure 5. Probability of receiving at least 50 mm of rainfall in Kampong Cham and Battambang

Source. Vance et al. *2004*

Looking at the mean rainfall figures, it would seem that crop planting could commence in March (50 mm average) in Kampong Cham; however, the low median rainfall indicates that rainfall in March is variable. The daily data also shows that a good start in March can often be followed by a dry spell in April. Therefore, sowing in March could be risky, with only a 20% chance of receiving 50 mm (Figure 5). In contrast, farmers are likely to be able to sow earlier in Battambang, where there is a 50% chance of receiving 50 mm of rain in March, which is much more reliable.

Periods of more than 5 days without rain occur almost every year in the EWS. Hence on sandy, gravelly or shallow soils with less than 35 mm water storage in the root zone, crop water stress often occurs in the EWS. Thus it is recommended that, on shallow soils, maize be planted at the end of the EWS when the chance of adequate rainfall is greater. Maize has reasonable tolerance of waterlogging; however, this tolerance is lowest at the tasselling stage.

Photoperiod

Maize is grown globally from 50°N to 40°S, and from sea level up to 4000 m altitude. Maize is a short-day plant with 12.5 hours/day being suggested as the critical photoperiod. Photoperiods greater than this may increase the total number of leaves produced prior to initiation of tasselling, and may increase the time taken from emergence to tassel initiation (Birch 1997). Cambodia lies between latitudes 10.29°N and 14.50°N. The day length range varies from 11 hours and 29 minutes to 12 hours and 48 minutes. Day length increases from January to June and becomes shorter from July until December. Therefore, the same variety of maize planted between mid-May and early August may be slightly slower than if planted outside this period, when daylength is less than 12.5 hours per day.

Soils

In Cambodia, maize is grown on a wide range of soil types. Table 2 outlines some basic soil data for two major upland soil types in Kampong Cham and Battambang provinces where maize is grown. Maize is also grown on lowland rice soils that are hard setting, poorly structured and low in nutrient levels due to leaching. Yields on these soils are very low and maize production is considered uneconomical.

Table 2. Mean soils data (0 to 20 cm) for 100 sites in Kampong Cham and Battambang

				FEB–MAR 05		JUL–AUG 05	
PROVINCE	SOIL TYPE	OC	TN	PH	NO_3	PH	NO_3
Kampong Cham	Lebansiek	1.45	0.128	5.5	28	5.0	10
Kampong Cham	Kompong Siem	2.13	0.165	5.7	20	5.4	12
Battambang	Lebansiek	2.07	0.176	5.8	20	5.5	38
Battambang	Kompong Siem	2.46	0.181	6.7	22	6.5	50

Source. Martin and Belfield 2007

OC – organic carbon; TN – total nitrogen; pH – a measure of the acidity or alkalinity of the solution; NO_3 *– nitrate nitrogen*

The preference of most field crops is for fertile, well-drained loamy soils. Maize is relatively well adapted to a wide range of soils with pH 5.0 to 8.0. It is not as acid tolerant as peanut, but is more tolerant to low phosphorus (P) than soybean. Aluminium toxicity could become a problem on soils with pH less than 5.0 (Al > 40%), which includes sandy soils such as Prey Khmer. Maize is moderately sensitive to salinity, which reduces uptake of nutrients and decreases total dry matter production. However, this has not proven to be a problem in Cambodian soils to date.

Like soybean, maize is not drought tolerant. Hence, low soil water storage is more of a problem for maize than for other crops such as peanut and sesame, and this probably explains why farmers tend to grow maize in the MWS. Sandy, gravelly and shallow soils increase the risk of drought in Cambodia and good yields are unlikely on these soils unless there is supplementary irrigation or favourable rainfall distribution during the growing season.

Maize yields vary a lot depending on the soil type where the crop is grown, as outlined in Table 3. On Labansiek soil, the highest yield of 4.4 t/ha obtained from on-farm trials conducted in the ACIAR project, *Assessing Land Suitability for Crop Diversification in Cambodia and Australia* was well above the average yield in Cambodia. On other soils, the yields were below the national average yield.

Table 3. Yields of maize (t/ha) from on-farm trials on soils of various groups in 2004 and 2005 in EWS and MWS in Battambang, Kampong Cham and Takeo Provinces

SOIL GROUP	EWS 2004	EWS 2005	MWS 2004	MWS 2005	MEAN
KOMPONG SIEM	1.75	na	4.09	2.09	2.64
KEIN SVAY	2.75	1.16	2.85	3.19	2.49
TOUL SAMROUNG	2.25	1.30	1.87	1.92	1.84
KOMPONG SIEM, CALCAREOUS	1.50	2.52	1.40	1.34	1.69
PREY KHMER	1.50	0.28	1.14	1.39	1.08
OU REANG OV	3.00	0.67	1.86	1.78	2.39
LABANSIEK	4.50	na	4.29	na	4.40

Source. Bell et al. *2005, na = no data, owing to failure of crop establishment.*

Morphology of maize

Seedling

The seed of a maize plant is called the kernel and consists of three major parts: the fruit wall, endosperm and embryo, as shown in Figure 6. The kernel is made up of approximately 10% protein, 70% carbohydrate, 2.3% crude fibre and 1.4% ash. It is also a source of Vitamins A and E, riboflavin and nicotinic acid.

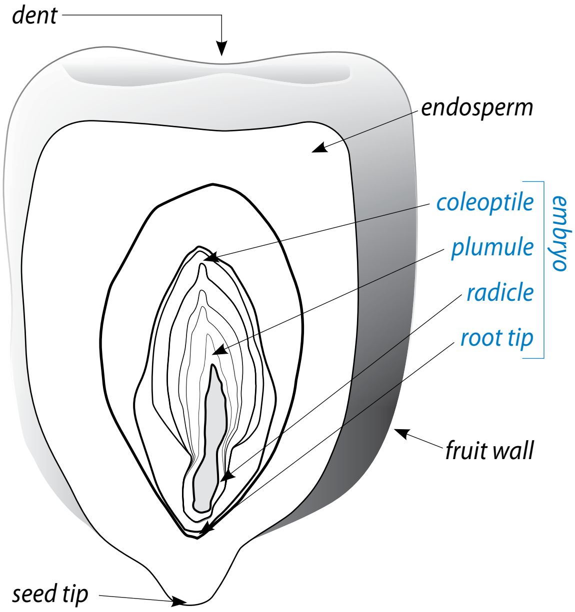


Figure 6. Maize seed anatomy

Once the seed absorbs water, germination commences. The seedling uses seed starch reserves in the endosperm to germinate and a root, called the radicle, sprouts from the kernel, which is illustrated in Figure 7. Soon after emergence of the radicle, three to four lateral roots sprouting from the seed also emerge. At the same time or soon after, a shoot emerges at the other end of the kernel (Figure 7) and pushes through the soil surface. This breaking through the soil surface is called emergence. When the tip of the shoot breaks through the soil surface, elongation of the middle section of the shoot, called the mesocotyl, ceases, and the first leaf, which is termed the plumule, emerges (Figure 8).

The primary roots develop at the depth at which the seed is sown. The growth of these roots slows down after the shoot emerges above the soil surface and virtually stops at about the three-leaf stage. The first adventitious roots (roots other than those growing from the radicle) start developing from the first node at the mesocotyl, which occurs just below the soil surface. These adventitious roots continue to develop into a thick web of fibrous roots and are the main anchorage for the maize plant; they also facilitate water and nutrient uptake.

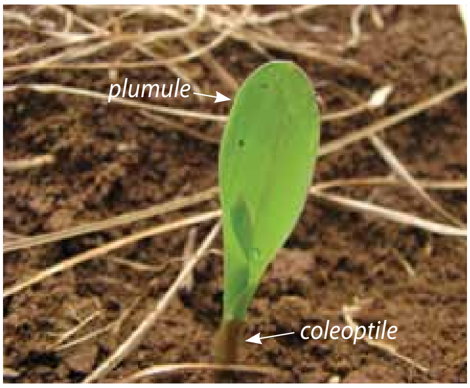


Figure 7. (left) A germinating maize seed illustrating growth of the plumule and radicle

Photo. W Leedham

Figure 8. First true leaf expansion and emergence of the second leaf

Photo. S Belfield

Figure 9. Adventitious roots, including brace roots, growing from the first node

Photo. S Belfield

Some adventitious roots (Figure 9) emerge at two or three nodes above the soil surface and are called brace roots or prop roots. The main function of these brace roots is to keep the plant upright and prevent it from lodging under normal conditions. It is now believed that these roots also help in nutrient and water uptake.

Maize vegetation morphology

In the early growth stages, the leaves and stem are not readily distinguishable. That is because the growing point (whorl) remains underground until the first five leaves have emerged.

Examination of a 1-metre-tall maize plant reveals a series of enlargements that encircle the stem. These are called nodes. The space between two nodes is called an internode. The earliest internodes elongate only slightly, so that the space between internodes is only small. However, internodes of older plants elongate much more and account for height in maize.

Leaves are made up of a blade and sheath. The blade extends from the stem at a node. Below this node the leaf runs parallel to the stem and is called the leaf sheath. The sheath encircles the node, forming a pale collar. Between the stem and the leaf sheath is a prominent ligule, a small, fine, hairy membrane surrounding the stem (Figure 10).

The stem (Figure 10) has two functions: to support the leaves and flowers and to transport water and nutrients. Nutrients are carried in vessels, called xylem and phloem, which are connected to the roots. The xylem transports water and mineral nutrients from the roots up into the plant and can only flow one way. The phloem flows in both directions and transports organic nutrients, especially sucrose, in a water based solution. The major function of the leaves is to carry out photosynthesis for grain production.

New leaves arise from the growing point. Depending upon the variety, 16 to 23 foliage leaves will be produced. The diameter of the stem eventually becomes very large at the base, which usually causes the lower 5 to 7 leaves to break loose and wither.

Problems such as nutrient imbalances, herbicide damage and disease symptoms usually become evident through the leaves. Maize farmers should check the crop for symptoms of these problems by observing the colour, growth, and development of the leaves.

Reproductive structures

Maize is a monoecious plant, which means that each individual plant has both male and female flowers. Male flowers produce pollen and are on the tassel (Figure 11). The tassel arises from the growing point of the plant. It is the terminal structure of the growing point. When the tassel becomes visible, the innermost leaf in the growing point is the last leaf produced. The female flowers receive the pollen and are carried in the ears. The pollinated female flowers develop into the kernels.

Pollen grain and silk

The tassel has a central spike and several lateral branches, each of which has many flowers. The flower, called a spikelet, consists of a pair of functional florets with three anthers, which produce pollen, borne on filaments. The round, slightly sculptured pollen grains begin dropping from the anther two or three days before the silks (styles) on the female flower are ready to receive them. However, the process continues after female receptivity as pollen is shed from the anthers over a five to eight day period.

Figure 10. (left) Maize stem and leaf structures

Photo. S Belfield

Figure 11. A maize crop at the reproductive stage showing both the male (tassel) and female (ears) reproductive organs

Photo. S Belfield

The 'ear' is the female (pistillate) flower which arises at a leaf axis. Although any leaf axis could bear an ear, only one or two ears usually develop. In most maize plants, the primary ear develops about halfway between the ground and the uppermost leaf. The individual female flower is a spikelet similar to that of the tassel, and like the tassel it has two adjacent florets. The difference between the tassel florets and the ear florets is that one of the ear florets never becomes functional and degenerates. The functional ear floret partly encloses the ovule, which contains the embryo sac with the egg inside it.

Pollen from the tassel passes down the silk to fertilise the egg. The embryo sac eventually becomes a maize seed. The endosperm nuclei, which surround the embryo sac, are also fertilised by a pollen nucleus and eventually grow into the starchy food layer (Figures 12, 13, 14).

Figure 12. A maize tassel during pollination

Photos. S Belfield

Figure 13. A maize ear with emerging silks

Figure 14. Maize silks receiving pollen

Growth stages of maize

Figure 15 illustrates the complete life cycle of maize from germination through to maturity and harvest. The growth stages are explained in detail below.

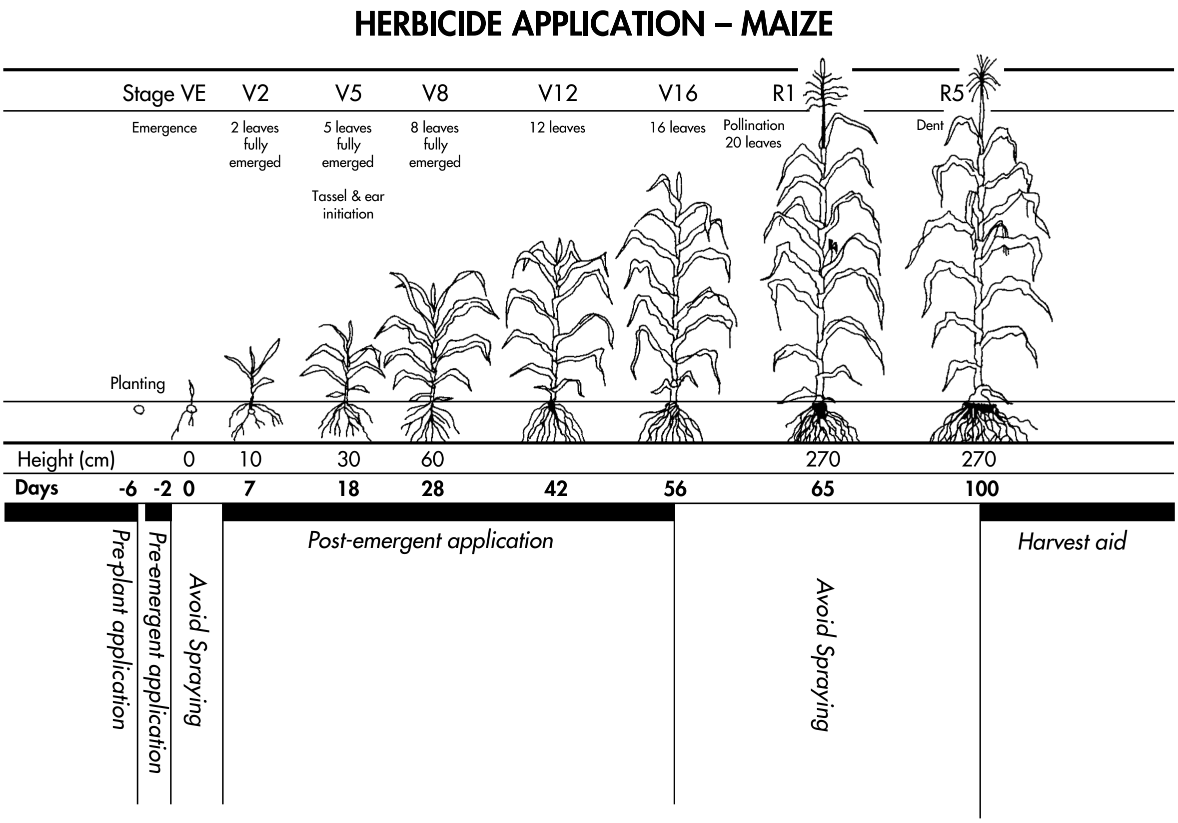


Figure 15. The growth stages of maize

Source. NSW Department of Primary Industries

Germination and emergence (stages VE to V2 in Figure 15)

When maize seed is sown in soil with a temperature above 21°C and adequate moisture, it rapidly absorbs water and emerges within 2 or 3 days. If the soil temperature is low (less than 18°C), germination slows and radicle emergence may take as long as six to eight days. In addition, radicle emergence is slow if the depth of sowing is deeper than 8 cm. On the other hand, under rainfed conditions when the seed is sown in dry soil awaiting rain, high soil temperature and inadequate moisture can cause the seed to die.

Nutrient reserves in the seed feed the emerging seedling for the first week until the primary roots develop and begin to supply the plant with water and nutrients from the soil. The stem's first internode grows rapidly until eventually the seedling emerges, usually 4 or 5 days after sowing, provided there is enough moisture in the soil and temperature is optimal.

Early vegetative development (stages V3 to V10 in Figure 15)

The adventitious root system develops from the first stem node below the soil surface and takes over the main root function approximately 10 days after emergence (stages V3 to V4 in Figure 15).

All the leaves the plant will ever produce are formed by a single growing point below the ground during the first 2 to 3 weeks. As the growing point is below the ground, young maize plants are susceptible to damage from waterlogging, especially when combined with high temperatures. However, if later conditions are favourable, the plant can recover well from damage during this stage.

Three weeks after emergence the growing point is at the soil surface and, having formed all the leaves, develops an embryonic tassel (stage V5). At this stage, leaf formation is at its fastest stage of production and at 4 weeks eight leaves are fully emerged (stage V8).

Late vegetative development (stages V11 to V16 in Figure 15)

This is one of the most critical stages in the development of the maize plant. The plant grows and the stem elongates rapidly, with a high demand for water and nutrients nitrogen (N), phosphorus (P) and potassium (K). Leaf enlargement is complete by 5 weeks (V12) and the roots quickly fill most of the root zone.

Ears begin to form within the plant soon after tassel initiation (V5); however, over a 2-week period in weeks 5 to 7 (V11 to V16), the highest one or two ears start rapidly developing and ear size is determined. The number of rows per ear is determined first, then kernels per row. At about 7 weeks the tassel reaches full size (V16).

Any adverse effect suffered at this stage, such as nutrient or water shortage, insect damage, or too high a plant population, will significantly affect yield. Furthermore, damage to pollen or ear structures in this period will be permanent, with little chance of compensation later.

Flowering (stage R1 in Figure 15)

At this stage plants will have finished producing all 20 leaves. Tassels fully emerge (R1) and pollen sheds 40 to 50 days after emergence, with the length of time depending on variety and environmental conditions. Silks emerge from the uppermost ear and sometimes from the second ear. Pollination and fertilisation of the ears occurs. During this period there is a high demand for water, and the uptake of N and P is rapid, although K uptake is almost complete.

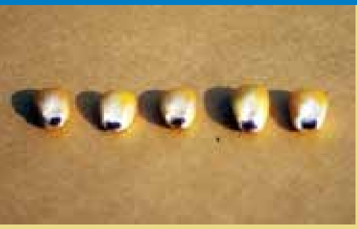


Figure 17. (left) A black layer at the tip of the maize kernel indicates physiological maturity

Photo. Mississippi State University Extension Service, http://msucares.com/crops/corn/corn7.html

Figure 18. Maize cobs at harvest

Photo. S Belfield

As pollen supply is abundant, poor seed set is usually due to nutrient or water deficits that either delay silking or result in kernel abortion after pollination. If maize is flowering during hot, dry weather this places extra stress on the plant's resources and the silks may wither and burn off before the pollen reaches the ear. Hence fertilisation does not occur for all kernels and seed set is greatly reduced. This is commonly referred to as pollen blasting.

Cob and kernel development

Cobs, husks and shanks are fully developed by day 7 after silking. The plant is now using significant energy and nutrients to produce kernels on an ear. Initially the kernels are like small blisters containing a clear fluid; this is referred to as the kernel blister stage. As the kernels continue to fill, the fluid becomes thicker and whiter in colour. This is called the 'milk stage'. Next is the 'kernel dough stage', at which point the fluid within the kernels becomes thicker as starch accumulates. During these kernel filling stages N and P uptake continues at a rapid rate. As the number of ears and kernels has already been determined, it is the kernel size that is affected by conditions during this stage. A low kernel weight will reduce yield. Denting of the grain (Figure 6) occurs around 20 days after silking; this is an indicator that the embryos are fully developed. Initially at denting a line can be seen which slowly moves to the tip of the kernel through until physiological maturity. This line is called the 'milk line' and marks the boundary between the liquid (milky) and solid (starchy) areas of the maturing kernels (Figure 16).

Maturity

Approximately 30 days after silking the plant has reached the maximum dry weight, a stage called physiological maturity. This is where a 'black layer' (a dark mark; Figure 17) is noticeable at the tip of each kernel, where cells die and block further starch accumulation into the kernel. At this stage the milk line has completely disappeared. Kernel moisture at physiological maturity is around 30%.

The grain and husks begin losing moisture while healthy stalks remain green. Eventually the leaves will dry off. Harvesting can commence when grain moisture is below 20% (Figure 18). The grain is dried down to 14% for delivery to storage or market.

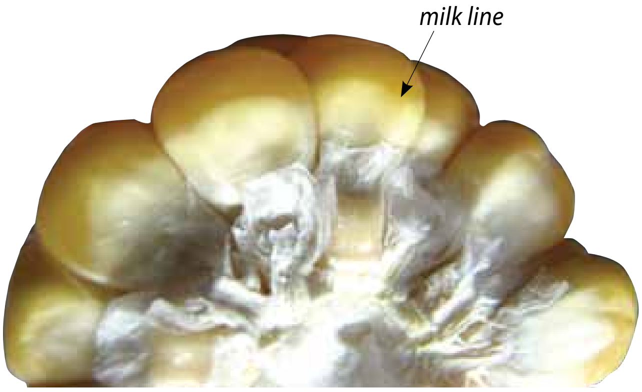


Figure 16. Maize cob cross section showing milk line at mid development

Photo. S Belfield

Maize varieties

Selecting varieties

Varietal choice can have a significant impact on the yield and quality of the crop. Table 4 summarises the features of the range of varieties suitable for planting in Cambodia. Consider the following points when selecting a suitable variety:

1. *End-use*

Maize is primarily grown for stockfeed which is exported to Thailand. However, there are also varieties available that are suitable for silage and human consumption. Ensure the variety you grow is suited to the end use market you are aiming for.

2. *Maturity*

Farmers should plan to sow their chosen variety in the recommended planting windows outlined in Table 5, ensuring the expected harvest time (days to harvest) of the particular variety falls outside of September, the wettest month of the year. It is also important to ensure harvest will not be far into the dry season as prolonged drought will encourage the onset of aflatoxin in maize, a fungus that produces a carcinogenic substance (see the disease section on page 28).

3. *Breeding*

Both open-pollinated and hybrid maize varieties are available in Cambodia. Hybrid maize is high yielding with current hybrids possessing good resistance to downy mildew, the major maize disease in Cambodia. Seed of hybrid maize cannot be kept for planting seed. Open-pollinated varieties can however be kept for planting seed, yet they are lower yielding than the hybrid lines.

4. *Logistics*

If farmers are planning to sow a large area of maize, which will have a substantial demand at harvest for labour, threshing logistics and seed drying, it is advisable to select two varieties to plant, with differing maturities so they do not ripen at the same time. This also spreads the risk of unfavourable seasonal conditions, because the crops will be at different growth stages throughout the growing season. For example, rain at harvest on an early variety will lead to lower quality, yet may be beneficial (by filling large kernels) in a longer maturing variety, so the whole crop will not be downgraded. Spreading seasonal risk aids not only in stabilising production but also maintains a stable farm budget.

5. *Standing ability*

It is recommended that farmers select varieties that have well developed roots, strong stalks, and are resistant to root and stalk rot. These features help prevent the plant from falling over, which can lower the yield and quality of the grain.

6. *Insect and disease resistance*

A variety may be known to have resistance to a disease or insect common in the area where the crop is to be grown. This may help farmers to maximise yield potential.

Table 4. Varietal characteristics and yields of maize

VARIETY	SEED COLOUR	BREEDING	MATURITY	DAYS TO SILKING	DAYS TO HARVEST	PLANT HEIGHT AT MATURITY (m)	YIELD POTENTIAL t/ha	DISEASE RESISTANCE TO DOWNY MILDEW
CP888	Yellow semi-flint	Hybrid	Medium	50–55	105–110	1.8–2.1	9.0–13.5	R
CP999	Yellow semi-flint	Hybrid	Early	52	90–95	1.6–1.8	9.0–13.5	R
LEUNG MONGKOL	Yellow	Open-pollinated	Medium	53–55	100–106	1.54–2.48	4.2–10.6	n/a
SUWAN 5	Yellow	Open-pollinated	Medium	53–57	110–115	1.87	3.32	R
CPAAA	Yellow semi-flint	Hybrid	Early	52	90–95	1.6–1.8	9.0–13.5	R
30B80	Yellow semi-flint	Hybrid	Medium	60	110	2.45	6.7	n/a
COMPOSIT	White	Open-pollinated	Early	40–48	90–100	1.75–1.95	1.02–6.35	n/a
SOR CHEY	White	Open-pollinated	Medium	53–55	104–112	1.56–2.36	4.1–8.7	n/a
GLUTINOUS MAIZE	White	Open-pollinated	Early	40–44	80–90	1.0	0.7–2.40	n/a

Note. The information contained in this table should be used only as an indication of varietal characteristics. These figures are based on limited Cambodian data and also may vary depending on many factors such as sowing time, seasonal conditions and site variation.

The sowing operation

Planting time

Maize is not as drought tolerant as some of the other upland crops such as mungbeans and sesame, so good soil moisture at sowing time is required before the crop is planted. It is recommended that there be at least 30 cm of wet soil throughout the soil profile before sowing. Aim to plant maize on deeper alluvial soils where possible.

Because of this higher water requirement, the majority of corn is planted in the MWS when rainfall is more reliable and there is more of it. However, in Battambang Province a lot of maize is successfully grown in the EWS as their early break of season is more reliable than in other parts of Cambodia. Table 5 illustrates recommended sowing times for maize in the upland provinces.

Table 5. Recommended sowing times for maize in Cambodia

	EWS												MWS											
	MARCH				APRIL				MAY				JUNE				JULY				AUGUST			
PROVINCE	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
BATTAMBANG			<	*	*	*	*	*	*	*	>				<	*	*	*	*	>	>			
PAILIN	<	*	*	*	*	*	>									<	*	*	*	*	>			
KAMPONG CHAM					<	*	*	*	*	>	>					<	*	*	*	*	*	>	>	

*< Earlier than ideal, but acceptable; *Optimum sowing time; > Later than ideal, but acceptable.*

Seed quality

If farmers choose to grow an open-pollinated maize variety, the seed may be kept for sowing the next season with no adverse effects on yield or quality. However, if the farmer is growing hybrid seed, such as CP888, seed must not be harvested and kept for sowing the next season. If second-generation hybrid seed is sown, it will yield at least 20% less than first generation commercial seed. Colour will also be variable in second-generation seed. If this second-generation seed is kept, the decline in yield potential will continue in subsequent years.

It is important to test the germination and vigour of your planting seed before sowing. The following processes should be undertaken:

- First look at seed for signs of weathering, disease or physical damage.
- Subsequently, 2 weeks before sowing, it is advisable to do your own germination test in soil or sand. Randomly select 400 seeds and sow at a depth of 5 cm in a prepared area of the field or in a container at home (placed in the sun). Count the number of seedlings emerged after 3, 5 and 7 days. If less than 70% germination after 7 days then seed should not be used if there is an alternative source available, or planting rates should be increased to compensate.

Seed should be plump and free from visible damage such as broken seed coats and chipped crowns. Even microscopic breaks in the seed coat can allow seedling rots to develop, especially when the soil is cool and damp. It is advisable to always buy certified seed.

Figure 19. No-till disc planter sowing into brachiaria grass mulch. (right) Close-up of disc tyne and press wheel.

Photos. R Martin

Seedbed preparation

Maize needs to be planted carefully and accurately to achieve the best germination and emergence possible. If the soil is too wet or too dry or the maize seed is planted too deep, seeds will be slow to emerge or fail to germinate at all.

A good seedbed should consist of 5 to 7 cm of fine firm soil that is free from weeds. The rest of the soil profile should not contain hardpans and compacted layers from over-cultivation, which can reduce moisture penetration and root growth.

To achieve this fine seedbed, traditional farmer practice is to plough the land once or twice followed by one or two harrowings. However, it is not always necessary to cultivate the soil in order to plant maize. Maize establishes very well under a no-tillage system where the stubble is retained from the previous crop, providing the field is relatively even and kept free from weeds by hand-chipping or spraying as required. The maize is then sown directly into the standing stubble without the associated costs of ploughing.

The benefits of retaining crop residues or mulching are reduced soil temperature; reduced crusting of soil surface; reduced surface evaporation; reduced emergence of weeds, reduced soil erosion, reduced sandblasting damage to seedlings, improved rainfall infiltration and increased production. Mulching has the potential to reduce the risk of crop failure as a result of drought, especially during the EWS. A pilot experiment was established in Tbaung Khmom District, Kampong Cham, in 2005 to determine the effect of rice straw mulch for increasing the yield of upland crops – maize, soybean, mungbean, peanut, sesame and cowpea.

The response to mulching was highly significant, especially for maize, with yield being increased from 2.9 t/ha to 4.7 t/ha (a 61% increase). This resulted in an increase in the gross margin from approximately US $28/ha to almost US $176/ha.

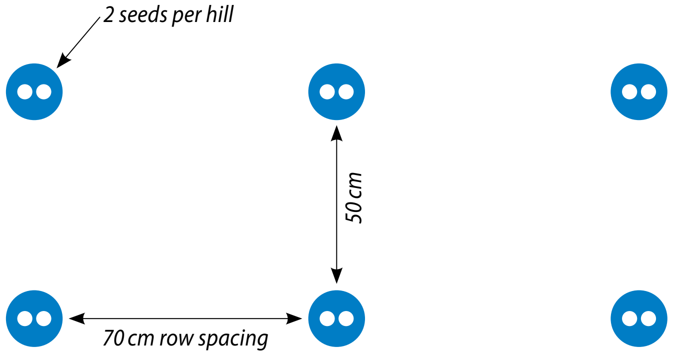
Crop establishment

As already mentioned, maize establishes well in a no-tillage system where stubble is retained. The stubble provides a good microclimate for establishment and allows greater rainfall infiltration, so more water is stored in the soil for the crop to use throughout the growing season.

It is important to plant maize seeds at an even depth of 2 to 5 cm into firm, moist soil to ensure good seed-to-soil contact for moisture uptake and subsequent germination (Figure 19). If planting shallow, ensure moisture is sufficient and check soil temperatures are not too high as this will effectively cook the seed and germination will not occur.

Plant density and row spacing are critical agronomic factors to get right when sowing maize to maximise yield. The highest yielding crops have an evenly distributed plant population across the whole field of approximately 53 000 to 66 000 plants/ha. Sowing rate, which depends on the germination and vigour of the seed, is usually 15 to 20 kg/ha with two plants/hill on 70-cm row spacings and 50 cm between hills (Figure 20).

Figure 20. Recommended planting configuration for maize



Maize generally has a single stem, which means it does not compensate well under adverse conditions. If plant stands are too thin yield will be limited, whereas very thick crops produce tall, thin-stemmed plants that will lodge easily with only one cob per plant. Therefore, it is important to establish an even plant population at the correct density.

Fertiliser recommendations for sowing

The use of fertiliser at sowing provides the seedling with the major nutrients required in the early stages of development. Nitrogen (N) and phosphorus (P) are particularly important, and potassium (K) may also need to be applied before planting if levels are low. The following preliminary fertiliser recommendations have been developed as a guide for maize production in Cambodia.

DAP (diammonium phosphate) should be applied at or before sowing at up to 100 kg/ha. This rate has been derived from general fertiliser rates determined for elsewhere in SE Asia and has been adjusted for Cambodia on the basis of the yield expected, limited Cambodian trial data, and soil analyses of a limited number of profiles. DAP contains 18% N, 20% P and 1.6% S (sulfur).

Research in Vietnam, the Philippines and Australia on red acid upland soils showed the best yield response to phosphorus fertiliser was achieved with the application of between 26 and 39 kg P/ha at sowing and banded below the seed (Blamey *et al*. 2002). The application of 100 kg/ha of DAP will result in 20 kg/ha of P being applied at sowing, which is a good basal rate. However, according to these findings P could still limit crop growth in some acid soils.

Fertiliser should be placed approximately 5 cm below and to the side of the seed and be covered with soil prior to planting to minimise losses. Alternatively, basal fertiliser can be broadcast 1 or 2 days before sowing to avoid burning the seed.

Potassium can also be applied before sowing if the soil is likely or known to be deficient. Muriate of potash (KCl) contains 50% K and can be applied at 60 to 100 kg/ha. This can also be applied prior to final cultivation or may be broadcast before rain.

It is very important to follow these recommended methods of fertiliser application in order to minimise losses of fertiliser nutrients due to volatilisation (N), surface run-off and erosion (P and K). Following these methods will also prevent the fertiliser directly contacting with the seed and will maximise effectiveness and improve efficiency.

Finally, fertiliser application should be carried out after weeding so that weeds do not benefit from applied fertilisers.

Nutrition

Soils and nutrient availability

Nutrition is extremely important when growing a maize crop as it has a high demand for nutrients, which the soil cannot always provide. Achieving high maize yields requires high levels of soil fertility.

Although many nutrients required to grow maize can be found in the soil in abundant supply, some essential mineral elements may exist in only low levels. Low fertility levels can be natural for the soil type or environment, or can be the result of many years of continuous cropping and removing product from the field. Later in this section there are recommendations for overcoming these deficiencies.

Another factor that strongly influences the availability of nutrients is pH (Figure 21). pH can be measured in a water or calcium chloride solution. The pH_{CaCl} can give a reading of up to one pH unit lower than pH_{w}. Therefore, it is important to know which test is carried out.

Maize usually grows well over a pH range of 5.5 to 7.8. Outside this range, availability of nutrients to maize plants can be strongly affected, causing a reduction in plant growth (Lafitte, 1994). The following chart shows this relationship between pH and nutrient availability.

Soil tests taken at 50 sites in Kampong Cham and 50 sites in Battambang Provinces in 2004 by ACIAR project staff and extension staff indicate that Labansiek soils are moderately acidic (see Table 2). The soil groups of Prey Khmer, Prateah Lang and Toul Samroung are also acidic. This would be likely to reduce P and molybdenum (Mo) availability. It may also affect K and magnesium (Mg) availability. We found that Kompong Siem soils had a wider pH range: from 5.0 (moderately acidic) to 8 (alkaline).

Low pH is also associated with high aluminium (Al) levels, which restrict root growth and yields. If Al toxicity is suspected, check roots for stunting and 'clubbing'. Manganese (Mn) toxicity can also be a problem on acid soils and may lead to poor crop growth and even plant death. Symptoms include thin stems, yellow-green foliage and small reddish-brown spots on older leaves. The mid-vein and surrounding area turn silver-green, which can be used as a diagnostic tool to indicate toxicity in low pH soils (English & Cahill 2005).

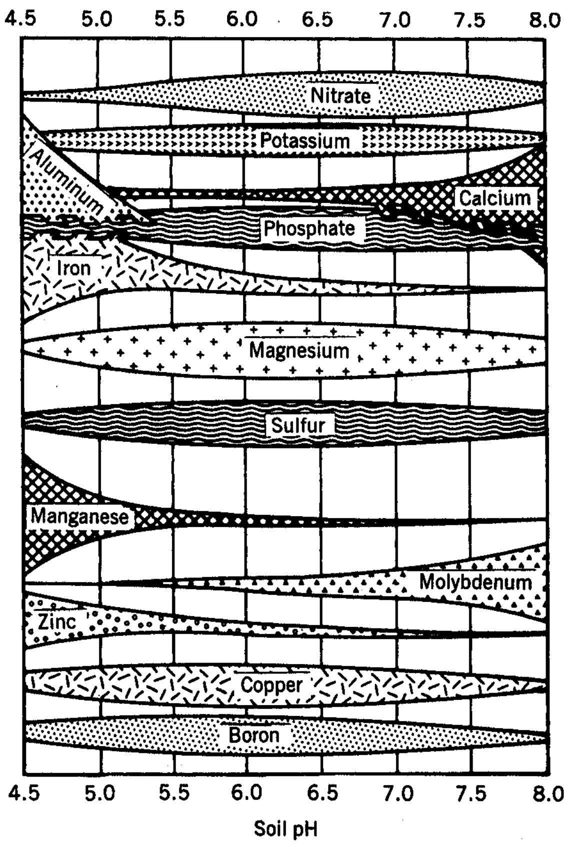


Figure 21. Influence of pH on nutrient availability

Source. University of Kentucky 1970

Figure 22. (left) Maize with nitrogen applied (left side) and maize without nitrogen applied (right side) showing deficiency symptoms

Photo. R Martin

Figure 23. Maize intercropped with mungbean

Photo. S Belfield

If acidity is a problem, lime can be applied to slowly increase pH. Lime is best applied a few months before sowing to allow time for the lime to move through the profile and change the pH in the root zone. Incorporating with tillage may also increase the rate of pH change. Where soils are acidic, lime should be applied once every two or three crops, depending on the soil pH changes after lime application. It is recommended that lime ($CaCO_3$) be used on Labansiek soil and dolomite if available ($CaMg[CO_3]_2$) on Prey Khmer soils, as the latter soil type tends to be low in magnesium.

If soil pH_w is above 7, soils are alkaline, as is the case with some of the Kompong Siem soils around Battambang. Slightly alkaline soils may have low Mn, iron (Fe), zinc (Zn) and boron (B) levels. Kompong Siem and Labansiek soils also tend to have high P retention; this means that P is strongly adsorbed in the soil and is thus relatively unavailable for plant uptake.

Crop nutrition requirements

Uptake and nutrient removal

Nutrient uptake by maize is closely related to dry matter production. Table 6 shows typical amounts of N, P and K removed in the grain of a healthy maize crop. Clearly, on sites that are consistently high yielding, proportionately higher levels of nutrients will be taken up and removed in harvested grain.

Table 6. Uptake and removal of essential nutrients N, P and K by a healthy hybrid maize crop

ELEMENT	TOTAL N, P, K UPTAKE BY PLANTS (kg/ha) (Above-ground biomass of a 4.5 t/ha yielding maize crop)	NUTRIENT REMOVAL IN GRAIN (kg nutrient/t grain harvested)
N	115	16
P	20	3
K	75	4

Source. Dierolf et al. *2001*

Macronutrients

There are a number of nutrients required by maize in large quantities and these are referred to as macronutrients. Nitrogen, phosphorus and potassium are three important macronutrients and are discussed below.

Nitrogen (N)

Nitrogen is an important element for maize, and the one that most often limits yield. N increases vegetative growth and the photosynthetic capacity of the plant. Nitrogen determines the number of leaves the plants produces and the number of seeds per cob, and therefore determines yield potential. About two-thirds of the N absorbed by the plant ends up in the kernels at maturity.

Soils contain nitrogen in various forms. Nitrate nitrogen (NO_3) is the form that can be taken up by plants. Various chemical reactions occur in the soil to change nitrogen from other forms into this plant available form.

If plants are deficient in nitrogen (Figure 22) the common symptoms are: leaves become pale green or yellow, premature yellowing starts at the tip and moves along the middle of leaf, and lower leaves appear burnt. Additionally, ears are small and protein content is low, and kernels at the tip of the cob are not filled.

To achieve a target maize yield of 8 t/ha, up to 256 kg/ha of nitrogen is required. There are various ways of obtaining this nitrogen requirement.

1. *Rotational cropping*: If the previous crop was a legume that was well nodulated, such as soybeans, peanuts or mungbeans, there may be fixed additional nitrogen in the soil that can be utilised in this maize crop. This, therefore, lowers the amount of fertiliser N required to be applied, hence lowering costs of production.

Figure 24. (left) P-deficient maize seedling; (centre) close-up of P-deficient maize leaf; (right) P-deficient maize crop

Photos: R Martin

2. *Green manure crops*: If the previous crop was green manured this will increase organic matter in the surface soil layers, add N to the soil and act as a mulch to preserve soil moisture. While no crop is harvested, the benefits of this extra N and soil moisture are utilised by the following maize crop and less N needs to be applied.
3. *Intercropping with a legume such as mungbean EWS and soybean MWS*: The inoculated legume grown in between the maize rows may possibly provide a small amount of nitrogen to the plant as it grows. It will also prevent erosion and run-off of applied fertiliser N in the heavy storms often experienced in the MWS (Figure 23).
4. *Fertiliser application*: The most common sources of N are urea, which is 46% N, and DAP, which is approximately 18% N. DAP is used at sowing to provide nutrients to the seedling. Urea can be applied as a split application (apply the total amount required in two or more applications) as a side dressing.

Phosphorus (P)

Maize is also a demanding crop for P and is quite sensitive to low P availability, especially in the early growth stages. Fertiliser P should be applied at sowing, as most of the P is taken up early in the life of plants, particularly as it is required for healthy root development. For this reason, P fertiliser should be placed where it is available to the roots quickly and the best location for this is banded below the seed at sowing.

Maize response to P application varies widely as soils vary in available P, as well as in their capacity to tie up added phosphate into insoluble forms unable to be taken up by the plant. Significant amounts of P can be made available if organic matter levels and rates of mineralisation are favourable. P that is mineralised from organic matter is more beneficial than adding inorganic fertiliser P as organic P is available for longer in the soil solution for plant uptake. A method of increasing the amount of organic P in the soil is to plant a green manure crop in the EWS before planting maize in the MWS. Sometimes P uptake can also be improved if mycorrhizae are present in maize roots. Mycorrhizae are a symbiotic relationship between fungi and roots of plants and can improve the uptake of nutrients.

P deficiency symptoms (Figure 24) are: stunted growth, dark green or reddish-purple leaves, particularly at the leaf tips in the young plant, and delayed flowering and ripening. In P-deficient maize, ears are small, often twisted and have undeveloped kernels.

Potassium (K)

Maize takes up potassium (K) in a relatively large amount. About 86% of K taken up has accumulated by silking and only 19% of this K is contained in the ear and shank portion. Therefore, most of the K absorbed remains in the stubble, and is then recycled through crop residues for subsequent crop production.

The symptoms of K deficiency (Figure 25) are: poor root growth and stalk breakages, as well as yellowing and drying along the tips and edges of lowest leaves. Ears show poorly filled tips and loose chaffy kernels.

If soil is deficient in plant-available potassium, consider applying muriate of potash (KCl) before sowing. Muriate of potash (KCl) contains 50% K and can be applied at 60 to 100 kg/ha. This should be applied prior to final cultivation or may be broadcast prior to a rain event before sowing.

Figure 25. (left) Potassium-deficient maize crop (right) Potassium-deficient maize plants

Source. Iowa State University Department of Entomology, www.ent.iastate.edu

Micronutrients

Many nutrients are required by maize in small amounts. These are referred to as trace elements or micronutrients. Zinc (Zn), boron (B) and molybdenum (Mo) deficiencies are common in maize.

Zinc deficiency is common on alkaline soils that are found in Battambang. If maize is deficient, the young leaves show symptoms first, appearing pale with white streaks. If soil zinc levels are low, a fertiliser containing Zn should be applied as part of a starter fertiliser at sowing.

There is a slight risk of boron deficiency in some Cambodian soils, including Prey Khmer, Prateah Lang and Kompong Siem. Symptoms include stunting with short, thickened stems and lateral roots. The cob leaves remain closed, inhibiting emergence of the silks, and tassels fail to emerge. If a deficiency is known, a foliar fertiliser can be applied when symptoms appear. Care must be taken to apply the correct amount; otherwise toxicities can be a problem.

A risk of molybdenum deficiency exists on the acid soil groups: Prey Khmer, Prateah Lang, Labansiek and Toul Samroung. Deficiency may be apparent in seedlings, with the tips of the lower leaves turning yellow and dying and plants being stunted or even dying. Adding Mo to a starter fertiliser at sowing or to superphosphate can minimise molybdenum deficiency, or Mo can be applied as a foliar spray. Applying lime to raise the soil pH can also increase Mo availability over the longer term.

Fertiliser

Fertiliser application for maize is often required to correct deficiencies of essential nutrients and to replace nutrients removed in harvested crop products. In particular, fertiliser can be applied to provide the main essential nutrients, including N, P and K. Micronutrients can be applied as solids in a mix with other solid fertilisers, as a seed coat dressing (Mo), or by foliar application.

The rates of nutrients to be supplied to a crop depend on soil type, pH, climate, cultivar, targeted yield, soil moisture and management practices. It is important to know the fertility of the soil and make sure there are enough nutrients to grow the crop. Demand for fertilisers can be assessed by soil and plant analysis and by visual symptoms of nutrient deficiencies.

Soil can be sampled from the top 20 cm of the profile using a hand held auger. Take a number of samples across the area (range 10 to 25), mix these together, and then take a sub-sample from this. For accuracy, ensure all equipment is clean and that the area avoids any atypical samples such as tree stumps and old fence lines. The samples must be tested as quickly as possible and kept cool. Samples can then be tested at a laboratory or simple field tests can be used to provide an indication of pH, plant-available nitrate nitrogen (NO_3), and organic carbon (OC) (see Table 2).

It is advisable to test soils to determine their nutrient status two months before sowing in order to calculate how much additional fertiliser is required to meet target maize yields.

Once the farmer knows what nutrients are needed, it is then important to determine the amount of additional nutrient required. Farmers are then able to select the best product to use and determine what rate to apply. Farmers who do not have access to soil testing can use basal rates of fertiliser application as suggested in this manual.

Table 7 shows some of the fertilisers commonly available at markets in Cambodia and how much of the nutrients N, P, K and S are contained in each. The percentage of nutrient must be known in order to calculate the amount of fertiliser to apply.

Table 7. Common fertilisers available in Cambodia, and their chemical analysis

FERTILISER PRODUCT	COMMON NAME	NITROGEN %	PHOSPHORUS %	POTASSIUM %	SULFUR %
Urea	Urea	46	0	0	0
DAP*	Diammonium phosphate	18	20	0	1.6
NPK 15,15,15	NPK	15	15	15	0
KCl (muriate of potash)	Potassium chloride	0	0	50	0

**This standard starter fertiliser can have trace elements added.*

Calculating N fertiliser requirement

If we know how much nitrogen there is in the soil, we can calculate the crop's needs. To do this, either measure the amount of nitrate-N in the soil profile or estimate this figure using the total N in the soil. The following example is based on average nitrate levels of approximately 25 ppm NO_3 in the top 20 cm of soil across 100 sites sampled in 2005 (18 ppm in Kampong Cham and 33 ppm in Ratanak Mondul).

Before you can proceed to determine the amount of fertiliser needed, you need to convert the NO_3 ppm reading from our nitrate meter to mg/kg N. The atomic weight of nitrogen is 14 and that of oxygen is 16. Therefore, each unit of NO_3 contains 0.226 units of N i.e. N = 14 ÷ (14 + (16 × 3)) = 0.226.

In our soil tests, we add 50 g of wet soil to 100 ml of water; shake, and extract the sample for analysis. We assume the soil moisture content is 0.25 g/g of soil solution and that the bulk density is 1, but you can use the actual values if you have them. The next calculation is:

N (mg/kg) = ppm NO_3 × 0.226 × 100 ÷ [soil weight ÷ (1 + 0.25)]

= 25 × 0.226 × 100 ÷ [50 ÷ (1+0.25)]

= 565 × 40

= 14.125

N (kg/ha) = (mg/kg N × bulk density × sample depth) ÷ 10

= (14.125 × 1.0 × 20) ÷ 10

= **28.25**

We assume that the crop will also access N from further down the soil profile. If there is 28.25 kg N/ha in the top 20 cm, we assume there is also more N in the subsequent depths down the soil profile. As the actual amount of nitrate at depth is unknown, we will assume that levels halve at each 20 cm segment down the profile due to leaching and current farming practices. Therefore, we can assume that nitrate at depth equals 14.13 kg (20 to 40 cm), 7.06 kg (40 to 60 cm) and 3.53 kg (60 to 80 cm), giving a total for the profile of 53 kg N/ha.

We also allow for in-crop mineralisation in the top 20 cm of soil equivalent to 80% of the amount in the topsoil at sowing. For our example this would be 22.6 kg N/ha (28.25 × 0.80 = 22.6 kg N/ha). Therefore we estimate that the soil in this example could provide approximately 53 + 22.6 = **75.6** kg nitrate-N/ha in the soil profile to a depth of 80 cm. This estimate should be reduced accordingly on shallower soils.

The amount of nitrate-N required to produce 1 tonne of maize grain is 16 kg/ha. Therefore a 2-t/ha crop will require 32 kg/ha, a 3-t/ha crop will require 48 kg/ha and a 4-t/ha crop will require **64** kg/ha. However, the maize can take up only about 50% of the available soil nitrate-N and therefore the crop would need twice as much N applied so that it is able to uptake the amount required through the roots (Table 8).

Table 8. Maize requirements for soil nitrate-N

GRAIN YIELD (t/ha)	1	2	3	4
SOIL NITRATE-N NEEDED (kg/ha)	32	64	96	128

So a 4 t/ha maize crop would need **64** × 2 = **128** kg/ha of nitrate-N available in the soil. If the farmer applies DAP (18% N) at 100 kg/ha at sowing, and allowing for 20% loss of N from volatilisation and tie-up in the soil, this would supply 100 × 0.18 × 0.8 = **14.4** kg N/ha. Therefore with 75.6 kg/ha being supplied from the soil and **14.4** kg/ha from the DAP, the amount that needs to be applied as urea is: **128** – **75.6** – **14.4** = **38** kg/ha of N.

As mentioned previously, when fertiliser is applied there are losses from volatilisation (N converts to a gas and moves into the atmosphere) and tie-up (into soil structures and organic compounds) in the soil, so only an **80%** conversion from fertiliser N to plant-available N should be assumed. We have taken this into account in estimating the fertiliser N required for a 4-t/ha maize crop and the amount of N required becomes **38** × **1.25** = **47.5** kg N/ha.

It is recommended that farmers use urea in-crop to supply this requirement. Urea is 46% N, so the amount of urea required would be **47.5** × (1 ÷ 0.46) = **103** kg in-crop to achieve the target grain yield of 4 t/ha for maize.

You can use a look-up table to read off urea rates required to achieve yield targets of 1, 2, 3 and 4 t/ha for a range of soil NO_3 readings from 0 to 60 ppm. For maize yields of 4 t/ha or less, no urea would be required for readings above 60 ppm. These calculations are based on a soil water content of 25% and a soil bulk density of 1.0. The Merck meter reading for NO_3 (ppm) is used to read off the amount of fertiliser urea required to achieve target maize yields (1, 2, 3, 4 t/ha).

Table 9. Urea required to supplement nitrogen requirements to a maize crop at varying soil nitrate levels

	EXPECTED GRAIN YIELD OF MAIZE			
	1	2	3	4
NO_3 (ppm)	UREA (kg/ha)			
0	48	135	222	309
5	7	94	181	268
10	0	53	140	227
15	0	12	99	185
20	0	0	57	144
25	0	0	16	103
30	0	0	0	62
35	0	0	0	21
40	0	0	0	0
45	0	0	0	0
50	0	0	0	0
55	0	0	0	0
60	0	0	0	0

Using the look-up table (Table 9), if you refer to the example we worked through above, you will see we started with 25 ppm nitrate N in the soil. Reading off Table 9, we can see that a 1- or 2-t/ha crop of maize would not require urea but that a 3-t/ha crop would require 16 kg urea/ha and a 4-t/ha crop would require 103 kg urea/ha. If you are in the blue area, you won't need to apply urea and if you are in the green, read off the amount of urea required to reach the target yield.

In-crop fertiliser application methods

Application method and timing is critical to ensuring maximum benefit from using fertiliser. The following is a list of recommendations for post emergent fertiliser application.

- Application of urea should be split between two in-crop applications. The in-crop applications are best applied at early vegetative stage when five to eight leaves are fully expanded and then again at late vegetative stage when 12 to 16 leaves are fully expanded to ensure nitrogen availability does not limit yield potential. If soil water is limited during crop growth, yield potential is also likely to be reduced, so topdressing is not recommended, particularly a late vegetative stage application.
- Urea (N) fertiliser should only be applied when there is sufficient soil moisture to allow efficient uptake by the plant, ideally within 24 hours before a rain event.
- Urea placed too close to young seedlings may scorch the roots and shoot base and if granules are lodged in the plant leaves, damage may occur.
- Fertiliser application should be carried out after weeding so that weeds do not benefit from applied fertilisers.
- Mix all fertilisers thoroughly before each application. Do not delay application after mixing since this can result in large losses of nutrients and mixture can become caked or cemented, making them unusable.

Major diseases and insect pests of maize in Cambodia

Integrated pest management (IPM)

Maize production can be significantly reduced in the absence of effective management of diseases, insects and weeds. There are a number of tools and strategies that farmers can use for managing pests. These include:

- ensuring the maize crop is as healthy as possible to compete with the pest
- planting early in the sowing window to avoid the high insect populations that are experienced with late sowings
- monitoring pest levels to determine whether they are causing economic damage or are below critical thresholds
- monitoring and preserving beneficial organisms that provide biological control and should be utilised as the first line of defence in IPM
- using pesticides strategically if required and rotating chemical groups to minimise the risk of organisms developing resistance to specific chemical groups
- controlling host plants such as volunteer maize and grass weeds to reduce the habitat available for pests to survive and multiply. Alternative crops that host the same pests should be avoided in the crop rotation program
- planting a trap crop (a crop that the pest prefers) to concentrate the pest population away from the maize crop, thus reducing the area requiring insecticide control
- communicating with neighbours and other farmers in the area to incorporate area-wide management of pests where possible
- selecting varieties that display good pest resistance.

Area-wide management is the development of a pest management strategy to control pests to below economic threshold levels across a whole area (commune) in the most environmentally and economically sustainable manner possible. This strategy is employed by farmers working together using the same techniques at a similar time to control the pest on a broader scale than the individual farm basis. In order for this strategy to function successfully, excellent cooperation, co-ordination and communication are required.

Integrated Pest Management (IPM) involves using all of these tools and strategies in managing pest populations to minimise reliance on insecticides in an economical way. It is important to be able to identify various insects, diseases and weeds in order to determine an effective IPM strategy. The following sections give an overview of some of the pests that are currently or potentially a problem in Cambodia.

Diseases

It is difficult to determine the extent of maize yield losses in Cambodia as a result of disease. However, maize diseases can reduce yield potential, interfere with normal physiological development, lower grain quality and cause lodging, which affects harvest. The occurrence and impact of a disease depends on a number of factors such as climatic conditions and the health, abundance and varietal resistance of the host plant.

It is important to identify diseases in order to implement management strategies during the season and for subsequent crops. The following is a list of diseases that infect maize crops and may be a problem if conditions are favourable to the disease spreading. Diseases can be difficult to identify and should be diagnosed by a suitable plant pathologist or crop specialist.

Peronosclerospora spp. (downy mildew)

Downy mildew (Figure 26) is still considered the most damaging disease of maize in South Asia (Kim *et al*. 2006). There are numerous types of the disease, several of which may be present in Cambodia.

Symptoms

Maize is most susceptible to downy mildew from seedling to anthesis stages. Symptoms include white and yellow striping of leaves and leaf sheaths and stunting of the whole plant, which produces no yield. The other major symptom is downy growth on or under the leaf due to conidia formation.

Management

It is advisable to choose resistant varieties. Late plantings also favour the disease, so plant on time. Avoid planting maize after maize in the same field.

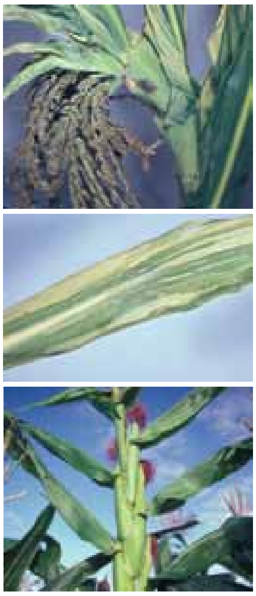


Figure 26. Downy mildew-infected maize. (top) Leaf streaks and malformed tassel (middle) Yellow chlorotic and necrotic leaf streaks (bottom) Stem elongation with multiple cobbing. *Source. Queensland Department of Primary Industries and Fisheries*

Bipolaris maydis, Helminthosporium maydis (southern maize leaf blight)

Symptoms

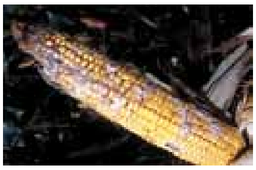
Leaves are affected by lesions which when they first form are small and diamond shaped and elongate as they mature (Figure 27). The final lesion is rectangular and 2 to 3 cm long. Each lesion is light brown with a reddish-brown border and a light yellow ring around it. Lesions may merge, producing a complete burning of large areas of leaf. This may lead on to stalk and cob rot, which can cause significant yield loss.

Management

It is advisable to choose resistant varieties. If varieties are not resistant, farmers must at least plant disease-free seed, as the disease is seed borne. Do not plant maize after maize in the same field.

Figure 27. Southern leaf blight symptoms. *Source. North Carolina State University Centre for Integrated Pest Management: http://ipm.ncsu.edu/corn/diseases/corn_diseases.html#S_Blight*

***Fusarium* spp. (stalk rot and ear rot)**
Symptoms These different species of fungi produce stalk rots, ear rots and seedling blights (Figures 28 and 29). Whitish-pink cottony fungal growth develops on and between the kernels and sometimes on the silks. Infected plants are weakened and can break easily during strong winds and rains. Mycotoxins, which are harmful to humans and livestock, are also produced.
Management These diseases can be controlled by the use of resistant varieties together with the use of optimum plant populations and nitrogen applications.
Figure 28. (top) Fusarium ear rot-infected maize. *Source. Iowa State University Department of Entomology www.ent.iastate.edu* Figure 29. (bottom) Fusarium stalk rot. *Source. S Belfield*

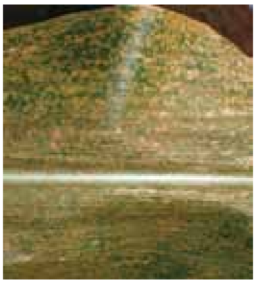


Maize dwarf mosaic virus
Symptoms Light and dark green patches form a mosaic pattern on leaves, with some ring spots. Highly susceptible varieties may have many yellow leaves as well. Plants infected early are very stunted, with significant yield loss.
Management The spread of the virus is due to aphids transmitting the virus from one infected plant to another. Control volunteer grasses such as Johnson grass, which is a host for the virus. Avoid having plants at seedling stage during peak aphid flight time. Grow more tolerant varieties.

***Heterodera zeae, Pratylenchus subranjani, Meloidogyne hapla* (nematodes)**
Symptoms Patches of stunted, drought-stressed plants across the field. Roots are stunted and have small nodule-like cysts and sometimes dark lesions. The nematodes are too small to see and they live inside the roots.
Management Control weeds, which may act as hosts for the nematodes in between crops. Clean equipment well before using on a different field as nematodes are spread by dirt, water and plant material.

Aspergillus flavus (aflatoxin)
Symptoms Masses of yellow to dark green spores develop on kernels, which may be slightly enlarged (Figure 30). Crop symptoms include terminal drought stress such as permanent wilting of the foliage, receding canopy cover between rows, and leaf drop.
Management Aflatoxin is a fungus toxic to humans that affects maize kernels. It affects not only the quality of the crop but also the safety of anyone who consumes affected kernels. Its onset is encouraged by drought (see Figure 5). Growing maize during the MWS should decrease the chances of aflatoxin becoming a problem as there is reduced likelihood of drought during this period. If growing maize in the EWS, do not delay harvest.
Figure 30. Aflatoxin spores on maize kernels. *Source. Iowa State University Department of Entomology www.ent.iastate.edu/*

Puccinia polyspora (tropical corn rust)
Symptoms Small round to oval, brown or orange pustules distributed uniformly over the upper leaf surface (Figure 31). Brown to black circles may appear around the pustules. Severely affected leaves turn yellow and die early. Ears on severely affected plants are much lighter than normal and the seeds are pinched and loose on the cob.
Management Control volunteers and other grass weeds that may act as a host to the fungus. Avoid planting two maize crops in a row. Plant resistant varieties if available.
Figure 31. Tropical corn rust leaf symptoms. *Source. R Martin*



Insect pests

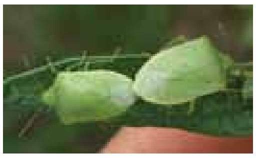
The first step in managing insect pests is to identify the insect and determine the numbers present. Crops should be checked regularly to determine the extent of an insect infestation and assess the damage it is causing. This information can then be used to determine whether control is required and to decide on the most suitable management method. The following is a list of the major maize insect pests in Cambodia and a brief description of the damage they cause. For further details on other insects in maize, see the field guide for insect identification (*Insects of Upland Crops in Cambodia*, to be published in ACIAR's Monograph series).

Macrotermes **(termites)**	***Importance: high***
Insect description Three separate genera of termites have currently been identified as a problem in Cambodian maize crops, including *Microtermes* sp., *Hypotermes* sp., *Globitermes* sp. and *Macrotermes gilvus. Hypotermes* sp. and *Globitermes* sp. build short, broad based, dome shaped mounds in the field whilst the other two species build their nests entirely below ground. Termites are small, white and honey coloured insects with a soft body and live in colonies in the soil. You will always find them in groups and the termites may be different sizes. The workers are the smallest and soldiers are significantly larger.	 
Damage Traditionally termites are fungus producers and they harvest plant material to feed the fungus which they then feed on themselves. In Cambodia, the termites chew maize roots and dry the plant out, usually resulting in patches of crop death. They may also tunnel up the inside of the stem, resulting in crop lodging and significant yield loss.	
Figure 32. (top) Termite-damaged maize roots (bottom) Root termites. *Photo. W Leedham*	

Helicoverpa armigera **(heliothis)**	***Importance: high***
Insect description Hatchlings are pale with dark heads. As they grow, dark spots become clearer (Figure 33). Medium larvae have lines running down their body and their colour varies depending on what they are eating. White hairs are evident on their head and when medium sized, they develop a dark band on the fourth segment back from the head.	
Damage Larvae mainly damage the maize ear, feeding soon after emergence, working on the silk channels. They not only cause direct damage to the kernels but also allow infections to occur if conditions are conducive by ear-rot pathogens.	
Figure 33. *Helicoverpa armigera* larvae. *Photo. W Leedham*	

Ostrinia furnacalis **(Asian maize borer)**	***Importance: high***
Insect description Young larvae are pink or yellow grey with black heads. Older larvae are whitish and spotted (Figure 34). Eggs are laid in clusters on the top side of the leaf or husk and turn black just before hatching.	
Damage Young larvae hatch from an egg mass and eat maize leaves still rolled up in a whorl. Older larvae bore into the stalk behind the leaf sheath, which causes significant damage when the plant has elongated and is at risk of lodging.	
Figure 34. Asian maize borer. *Photo. P Chanthy*	

Spodoptera litura (armyworm)	Importance: high
Insect description As larvae grow they develop obvious black triangles along each side of their body. Larvae grow up to 3 cm long and are narrowest at the head (Figure 35). Eggs are laid in clusters of up to 300.	
Damage Mass hatchings of armyworms begin feeding on leaves, scraping the surface off and creating a 'window pane' effect. The damage becomes progressively worse, starting at the margins and moving inward, with the armyworms eating entire leaves or defoliating plants.	
Figure 35. Armyworm. *Photo. W Leedham*	

Nezara viridula (green vegetable bug)	Importance: high
Insect description Adults are 15 mm long and bright green all over. Nymphs go through five different instar stages where they change colour and pattern. They start by being orange and black, then black, red and yellow patterns develop and eventually green is dominant (Figure 36).	
Damage Adults and nymphs pierce and suck developing seeds and cobs, which may be lost, deformed or have dark marks on them.	
Figure 36. (top) 5th instar green vegetable bug nymph (bottom) Adult green vegetable bugs. *Photo. S Belfield*	

Beneficial insects

There are some beneficial insects, including predators and parasitic wasps that commonly occur in maize crops. Farmers should be able to distinguish these insects from maize pests and use them as a tool in integrated pest management. When present in high numbers these beneficial insects may be effective in controlling pests and preventing yield loss.

Oechalia schellenbergii (spined predatory shield bug)	
Insect description Adults are 15 mm long, shield-shaped with obvious spines sticking out either side of their shoulders and a light mark in the middle of their backs (Figure 37). Nymphs are almost black with a red ring on their backs.	
Impact on pests The adult and nymphal stages of this predator use their beaks to pierce insects, especially heliothis, loopers and other caterpillars, and suck out the body contents.	
Figure 37. Spined predatory shield bug. *Photo. W Leedham*	

Predatory ants

Predatory ants	
Insect description Ants consist of workers, soldiers and queens. Soldiers have large heads and are in charge of defence and protecting the queen. Workers are smaller and have smaller heads, and there are more of them. Queens are obviously larger than all other ants (Figure 38). Predatory ants will have conspicuous ant mounds in the field or nearby.	
Impact on pests Predatory ants attack termites, wireworms, moth eggs, small larva and leafhoppers.	
Figure 38. Predatory ants. *Photo. W Leedham*	

Earwigs

Earwigs	
Insect description Adults are approximately 25 mm long with a flat, brown body. They have lighter coloured legs, a pale cream panel on either side of the thorax and a pair of distinctive curved pincers at the end of the body. They hide on the plant or in the ground during the day, becoming active at night (Figure 39).	
Impact on pests Earwigs commonly occur in field crops such as maize and mungbeans as a predator of caterpillars, pupae and wireworms.	
Figure 39. Earwig. *Photo. W Leedham*	

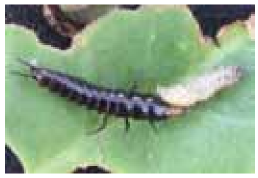
Lady beetles (various species)

Lady beetles (various species)	
Insect description Lady beetles have four distinct growth stages – egg, larval, pupae and adult. Adults are 5 to 8 mm long with two pairs of wings and are oval in shape with obvious spots or lines on their backs in black, red, orange or yellow.	
Impact on pests The adults and larvae of ladybirds are important predatory insects in field crops. Adults mainly feed on helicoverpa eggs and aphids, whilst nymphs will also eat helicoverpa hatchlings (Figure 40). Two or more per plant may make a useful contribution to IPM.	
Figure 40. (top) Lady beetle adult (bottom) Lady beetle larva. *Photo. W Leedham and S Belfield*	

Figure 42. Lemon basil

Photo. J Holland

Calleida sp. (ground beetle)
Insect description Beetles are long and thin with a shiny black shell divided into definite segments (Figure 41).
Impact on pests Both nymphs and adults are predators. The larvae of this beetle walk from plant to plant in the crop to prey on *Spodoptera* sp., *Heliothis* sp. and other defoliating caterpillars.
Figure 41. Ground beetle attacking prey. *Photo. W Leedham*



Companion planting

Lemon basil (*Ocimum basilicum citriodorum*) repels aphids, tomato hornworm, mosquitoes and whitefly. Lemon basil (Figure 42) has small, pale green serrated leaves, with a distinctive point to their end. It originated in Indonesia and, as the name suggests, has a lemony taste and aroma. In Thailand it is promoted as a natural insecticide. The leaves are crushed and mixed with water and applied to other crops as a pest repellent to leaf-eating insects.

Some farmers in the Chamkar Leu district in Kampong Cham intercrop lemon basil with soybean in the MWS. The lemon basil seed is sold to Vietnam for use as a beverage. However if this plant has insect repellent properties it could be useful as a companion plant in an upland crops IPM strategy, with the dual purpose of providing cash income.

Weed management

Weeds can be a problem in the production of upland crops because they reduce yield by competing for essential growth resources such as water, nutrients and light. Weeds can also make it difficult to harvest the crop, and seeds of some species can contaminate the sample and reduce the quality and price of the grain.

In upland crop situations, water is often the most critical factor in potential crop yield. Crops often fail due to drought, especially in the EWS when rainfall is variable and unreliable (see Figure 5). Good weed control is essential under these conditions, especially prior to sowing, to avoid loss of soil moisture.

Farmers should use an integrated approach for the management of weeds that combines all available options. The aim is to keep the weed numbers low and prevent them from producing seeds throughout the cropping cycle. However, many of the weeds in the upland situation can be used for animal fodder or as a vegetable. Therefore, a balance may be required for weed management that provides for these uses without reducing the profitability of the upland crop.

The farmer needs to consider how he is going to manage the weeds well before the crop is sown. This means preventing weeds from setting seeds in the previous crop and controlling weeds around the field edges, along waterways and in adjacent uncropped areas. Special attention needs to be given to weeds that grow from underground tubers or rhizomes such as nut grass (kravanh chruk). They are spread by cultivation and re-grow after the crop is sown.

Practices that can be used in an integrated weed management program include:

- *Feeding to livestock*. Weeds, especially annual grasses, can be grazed or hand harvested to feed livestock. However, it is important that the weeds are prevented from producing seeds. It should be noted that there may be a trade-off to consider between the amount of soil water used by the weeds and the soil water required by the crop. This is important in the EWS, when water stored in the soil pre-sowing could prevent crop failure and establishment problems due to drought. It may be more profitable to keep the fallow area free from weeds, storing the limited moisture to help ensure success of the crop.
- *Good agronomic practice*. Good agronomic practice includes making sure the crop seed used for sowing is clean and free of weed seeds and has a high germination percentage. Good seedling vigour is important because fast growing, vigorous seedlings are more competitive with weeds. The sowing rate of maize is important as it is vital to establish a uniform plant population that is optimal for the conditions (see page 15).
- *Timely weed control*. Traditionally, cultivation has served the dual purpose of killing weeds and preparing a seedbed. However, cultivation can also reduce the amount of soil water available to the crop. Some upland soil types such as Labansiek and Kompong Siem are friable and self-mulching and may require little or no cultivation to prepare a seed bed. In this case, a pre-sowing cultivation can be replaced by an application of herbicide such as glyphosate, which controls the weeds without loss of soil moisture. Cultivation is also less effective in controlling weeds when the soil is wet, as many weeds transplant and continue to live and set seed. Herbicides can be used as an alternative under these conditions. Farmers must follow label directions when using herbicides.
- *Grazing or burning*. Heavy grazing or burning is often used to control weeds and to make conditions easier for cultivation. These practices have the disadvantage of reducing ground cover, increasing soil surface temperature, reducing soil moisture and causing soil degradation. Burning also reduces soil organic matter content. Preserving soil residues and even adding mulch such as rice straw can reduce the emergence of weeds; it will also conserve soil moisture, reduce the soil temperature and increase soil organic matter.

Weed species differ in their response to management practices because they have different life cycles, nutrient requirements and modes of reproduction. They also vary in their response to cultivation and their susceptibility to herbicides. It is therefore important for the adviser and farmer to be able to recognise different weed species and understand their weaknesses. A field guide for identification of weeds of upland crops in Cambodia has been produced for this purpose (*Weeds of Upland Crops in Cambodia*, Martin & Pol 2007, to be reprinted in ACIAR's Monograph series).

Figure 43. Portable hand-thresher for maize

Photo. R Martin

Harvesting

Harvesting

Traditionally, when red maize cobs have dried down and it is time for harvest, the cobs are handpicked, hand shelled and dried in the sun. This is very labour intensive, which has a significant impact on the gross margin for maize. Another option is to machine harvest when moisture levels drop below 18% to 24% and then dry down to below 14% for delivery or storage.

Harvesting by machine

There are three methods of harvesting maize by machine, with the first option being the most preferable:

1. The harvester picks and threshes the cobs, and the kernels are emptied into the truck
2. The harvester picks the cob from the stem and de-husks the cob, which is then sent to the truck
3. The machine cuts the stems, cobs and all, which are then emptied into the truck. Cobs have to be manually removed from the stalk later and threshed.

The following factors need to be considered for machine harvesting:

- plants and cobs need to be at similar heights across the field
- the stem must not be too dry or too green
- the fruit needs to be big enough for harvesting and threshing
- the plants need to have strong roots and erect stems.

Currently in Cambodia, maize harvesting machines are only available at some research stations.

Harvesting by hand

In Cambodia, most farmers harvest maize by hand, plucking cobs from the plant and piling them at the end of the row. In dry seasons, when the maize matures evenly, farmers pick the maize and transport it by oxen carts or trucks for storage at home. In the wet season, when rain is almost a daily occurrence, farmers attempt to harvest their maize when there is a break in the weather, preferably after two to three days without rain.

Grain threshing

Threshing is usually done by hand in the village. Hand-threshing has a high labour requirement. It can be done with a sheller, where the maize cob is held with one hand and rotated against a stationary shelling device held in the other hand. The sheller has teeth that engage and remove the grain from the cob.

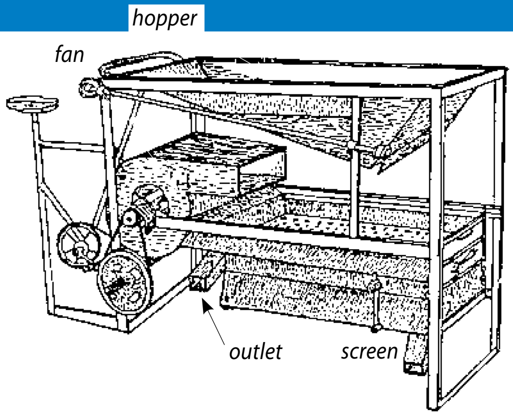
Hand-threshing has the advantage of being cheap, especially as the sheller can be made from local materials. There is minimal damage and loss to the kernels; however, this advantage is offset by the low output of 8–15 kg/hour, which makes it suitable for only small scale farms.

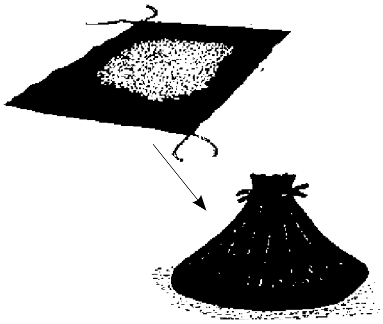
Another option is a small portable hand-thresher, which is mounted on a stationary stand or bench for stability (Figure 43). The thresher has an opening into which a single cob is fed. A hand-operated lever rotates a spike disc against the maize cob. This presses the cob downward and at the same time rotates the spikes of the disc against the cob, which removes the grain. In the Chamkar Leu district (Kampong Cham Province), this is the method normally used by farmers to thresh their maize as the equipment is particularly suitable for small farmers. The machines are effective and usually quite robust, producing up to 100 kg/hour or more of grain, depending on the design (Figure 43).

Alternatively, if the crop is machine harvested, the harvesting and threshing is carried out in one operation as mentioned previously.

Grain cleaning

It is important that the resulting maize grain sample is as clean as possible to increase the attractiveness of the product to the grain trader. The sample needs to be free from dust (especially red dust, which can stain the grain), dirt, stubble, insects and cracked grains. If





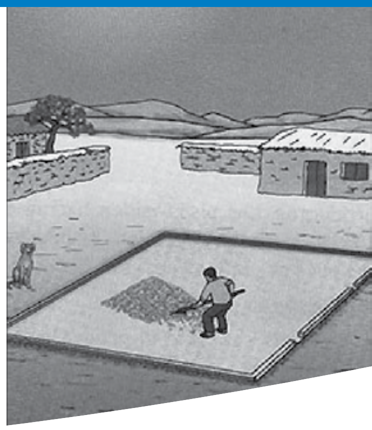


Figure 44. (left) Pedal-operated air screen grain cleaner

Figure 45. (centre) Drying sheet

Source. FAO/GCP/Bol/032.Net

Figure 46. (right) Concrete slab for drying maize

Source. FAO/GCP/Bol/032.Net

the sample does not meet the trader's requirements, the farmer may receive less money for their product.

There are manual and mechanised grain cleaners to aid in producing a clean sample, as illustrated in Figure 44.

The pedal-operated screen grain cleaner in Figure 44 separates dust, dirt, stones, chaff, and broken and smaller grains from agricultural products including maize kernels. Separation occurs due to the difference between the grain size and weight of the product compared to those of the unwanted materials. The uncleaned or ungraded grain is kept in the hopper on top and from there it drops by gravity against an air blast produced by the pedalling action. Different sized screens separate the grain into two grades and the chaff gets blown off by the air blast. Productivity of the equipment is 350–600 kg/hour, with the variation depending on the type of grain.

Drying

After threshing, the maize kernels are dried in the sun either on mats, plastic tarpaulins or on a cement pad until the moisture content is below 11%, when the kernels are ready for sale. During the drying process the kernels are raked across the pad to ensure even drying. The moisture level in maize must remain below 11% if the maize is stored for long periods, otherwise aflatoxin may develop, producing toxic side effects for consumers of the grain (see page 28).

Drying methods

a) Plastic sheets

Commercial plastic sheets can be laid out and the crop spread out on them for drying and can be used with both maize cobs and shelled kernels (Figure 45). Likewise, heavy-duty polythene sheeting or sheets made from opened-out nylon sacks can be used. Care should be taken to avoid contamination of the grain sample by dust or soil. Grain stained by soil may receive a lower price.

b) Concrete slab

This is a layer of concrete on the ground that keeps the grain clean. Concrete also heats up quickly, allowing faster drying time. This system is good for small upland farmers or villages, as all the different upland crops can be dried in this manner, saving the cost of multiple drying systems. Concrete slabs are easy to build and cost effective.

Concrete slabs (Figure 46) are usually 5 × 5 m or 10 × 10 m and can be enlarged depending on requirements. As they use only solar energy for drying, they are environmentally friendly and low maintenance. In clear, sunny weather, a 5 × 5 m slab can dry 1 tonne of maize in one day and a 10 × 10 m slab can dry up to 4 tonnes of grain in one day. As concrete slabs rely on the sun for drying the grain, wet or humid weather is a problem with this system; it works best in the dry season.

c) Commercial machine drying

In western Cambodia there are now five large, modern grain drying and storage facilities for maize. These depots are fully mechanised and have the capacity to receive and store up to 30 000 tonnes of wet maize and the ability to dry up to 30 tonnes per hour.

These facilities receive maize from farmers and collectors to dry and store the grain for subsequent sale to Thai traders or direct to CP Foods. Farmers can deliver their freshly harvested wet maize direct to the drying plant, a system that reduces the labour required for drying and cleaning the grain and results in quicker payment to the farmer.

Storage

Traditionally in Cambodia, farmers have stored maize seed in plastic or steel containers. They spread ash underneath and on top of the maize kernels in each container and then seal the container. At a small rural farmer level, the maize may be stored as cobs or shelled grain, which some farmers will treat with pesticides to deter insect pests.

Maize stored in these containers is susceptible to infestation from pests; therefore it can be difficult to keep seed viable for planting the following season. In order to overcome this problem, some maize harvested at the end of the wet season is planted only a few months after harvest, during the dry season or EWS. This is then harvested 3 or 4 months later, just before the MWS sowing window. Although yields from this interim crop are low, the seed then has a much greater chance of being viable for planting in a large area for the MWS sowing window.

Storage pests

Stored maize is susceptible to infestation by insect pests and attack by diseases and can also be damaged by rodents and birds. It is important to fumigate or periodically expose grain to the sun to kill storage insect pests such as the lesser grain weevil. Cleaning of the grain store to remove all traces of previous crop, preferably by disinfecting the structure before use, is important. It is also necessary to monitor the condition of the stored grain throughout the storage period for insect pests, disease, temperature and moisture.

Insects that commonly occur in stored maize in Cambodia are listed below.

Sitophilus oryzae **(lesser grain weevil)**
Insect description Adults are 2 to 3 mm long, with a long snout and four reddish spots on the wing covers. The larvae spend all their time inside the grain.
Damage Management of this insect is very important. The larvae chew large irregular holes in the kernel and when adults emerge they make an irregular shaped hole about 1.5 mm in diameter.

Tribolium castaneum **(red flour beetle)**
Insect description Adults are reddish brown with a flat, oval body 2.5–4.0 mm long with wings. Larvae are mobile in the grain sample.
Damage Larvae prefer feeding on the grain germ. Damage is particularly serious in grains such as rice and wheat, which have either been dehusked or processed into other products. When infestation is severe, these products turn greyish-yellow and become mouldy with a pungent odour (CPC 2000).

Tribolium confusum (confused flour beetle)
Insect description *T. confusum* is almost identical to the red flour beetle, which has a more curved thorax and abruptly clubbed antennae with three-segmented clubs.
Damage The Canadian Food Inspection Agency (2005) lists *T. confusum* as a common and harmful pest of prepared and processed cereal products. The beetles are a secondary grain feeder in that the adults do not attack sound grain, but feed on broken, damaged or milled products, including flour.

Oryzaephilus surinamensis (saw-toothed grain beetle)
Insect description Adults are 2.5 to 3.0 mm long, with a slim, grey body with distinct ridges on the thorax and teeth-like projections on each side.
Damage Adult beetles of *O. surinamensis* can be seen moving rapidly over stored food, but the immature stages are inconspicuous (CPC 2000). They are a major pest of stored grain and milled products, as they can easily eat through packaging.

Araecerus fasciculatus (areca nut weevil)
Insect description This is a fungus weevil that is a mottled dark brown all over its 3- to 5-mm long body.
Damage Maize is a primary host of these grain-boring insects. Infestation may cause stored grain to be hollowed out or tunnelled by the larvae. Adults bore circular holes when they emerge from the grain. Adult feeding causes irregular ragged patterns of damage, particularly if feeding occurs on a commodity previously damaged by larvae (CPC 2000).

Economics and marketing

Maize production, distribution and usage

With an average annual production of just over 280 000 tonnes between 2002 and 2006, maize is the third largest crop produced in Cambodia, behind rice (4.9 million tonnes on average) and cassava (706 000 tonnes on average) (MAFF Cambodia 2006).

Both red (yellow) maize and white maize are produced in many provinces in Cambodia. Red maize is mostly grown as livestock feed for pigs, chickens and ducks. Its production is concentrated in ten provinces.

White or 'sticky' maize is mainly grown for human consumption by the farmers themselves and for roadside sale and in local food markets. White maize has accounted for just over 50% of maize production in Cambodia in recent years (Table 10) and is grown in 24 provinces.

Table 10. Maize production in Cambodia

	WHITE MAIZE			RED (YELLOW) MAIZE			TOTAL	
YEAR	AREA (ha)	(tonnes)	YIELD t/ha	AREA (ha)	(tonnes)	YIELD t/ha	AREA (ha)	(tonnes)
2002–03	71 594	148 897	2.08	50 265	117 344	2.33	121 859	266 241
2003–04	83 953	314 601	3.75	65 556	287 664	4.39	149 509	602 265
2004–05	77 304	256 665	3.32	57 418	223 656	3.90	134 722	480 321

Source. MAFF Cambodia 2002–03, 2003–04, 2004–05

Red maize is mainly grown in the western provinces with the majority exported to Thailand. For this reason, mainly Thai varieties are grown. The remainder is sold into the local market in Phnom Penh or sent to Vietnam. The provinces of Battambang, Banteay Meanchey and Pailin accounted for about 91% of red maize production in 2004–05 (Table 11).

Table 11. Maize production in western Cambodia in 2004–05

PROVINCE	WHITE MAIZE (tonnes)	% OF TOTAL PRODUCTION	RED (YELLOW) MAIZE (tonnes)	% OF TOTAL PRODUCTION
BANTEAY MEAN CHEY	10 489	2	10 082	5
BATTAMBANG	155 030	32	150 409	67
PAILIN	43 354	9	43 151	19
SUBTOTAL	208 873	43	203 642	91

Source. MAFF Cambodia 2004–05

Figure 47. Pailin drying plant, showing weighbridge front right, grain cleaner front left and drying shed in the background

Photo. R Martin

Markets and quality

Quality characteristics preferred by buyers include grain of good even colour with no mould or soil contamination. Price is influenced by crop quality as well as market demand. Grain can be damaged by insects before harvest, resulting in poor quality grain and low prices.

Currently, maize exports from Cambodia consist entirely of the raw commodity and almost all ends up at Charoen Pokphand-Cambodia (C.P.-Cambodia) feed processing facilities in Thailand. Within Cambodia, the only feed processing that occurs is at a C.P.-Cambodia facility in Phnom Penh, where feed is produced for local livestock consumption.

Until recently, most farmers sold wet maize at harvest to collectors, who then sold it to Thai traders, who in turn sold it on to CP Foods in Thailand. However, in the last few years, five large, modern, grain drying and storage facilities (Figure 47) have been established in western Cambodia at Sampov Loun, Malai, Kamrieng, Pailin and Phnom Proek. Each facility has the capacity to receive and store up to 30 000 t of wet maize and the ability to dry up to 30 t/h. These facilities receive maize from farmers and collectors to dry and store the grain for subsequent sale to Thai traders or direct to CP Foods.

These facilities were set up mainly to handle maize; however, other crops, particularly soybeans, are also stored at the facilities for subsequent sale.

Gross margins

A gross margin is the gross income from a crop less the variable costs incurred in growing it. The calculation of a gross margin is the essential first step in farm budgeting and planning. It enables you to directly compare the gross margins expected from similar crops and is a starting point in choosing an overall combination of crops to grow. Gross margins can also be used to analyse actual crop performance by monitoring costs and returns from year to year.

Income per hectare is calculated by multiplying the yield per hectare (in tonnes) by the price (per tonne). US dollars are used as the basic currency for the budgets.

In order to calculate costs, for each input, the product name, rate applied per hectare and methods of application are all required. The usual method is to multiply the amount per hectare used by price per unit. For example, if the seed costs US $0.75/kg, seed at 20 kg/ha multiplied by US $0.75 equals US $15.00/ha. The cost of labour and hired machinery per hectare must also be included.

A series of farmer workshops were held in upland districts in July and August 2005 and the profitability summary shown in Table 12 was estimated from information farmers provided at these meetings and at an extension workshop at CARDI in February 2006.

Table 12. Average profitability summary for maize in upland Cambodia

DISTRICT	YIELD (t/ha)	PRICE ($/t)	INCOME	COSTS	GROSS MARGIN/ha
RATTANAK MONDUL	4.30	80	344	199	145
KAMRIENG	4.30	80	344	203	141
SAMPOV LOUN	4.30	80	344	234	110

Figure 48. Improved maize growth (left side) where mulch has been used

Photo. S Belfield

A trial was conducted on maize in the EWS 2005 by ACIAR project ASEM 2000/109 in Tbaung Khmum district, Kampong Cham Province, to observe the effect of spreading crop residues on the soil (Figure 48). As discussed on page 15, retaining crop residues has many advantages, including increased water infiltration and moisture retention, and reduced weed populations. Also, as the crop residues gradually decompose, the humus and nutrients in them provide benefits to the following crops. The practice of using crop residues as mulch contributes towards maintenance of soil fertility over a long period of time, in addition to benefiting the physical structure of the soil and providing shelter that increases seedling survival.

In this experiment, rice straw was applied at a rate of 3 t/ha after planting, which was estimated to cost US $18/t, including transport and spreading. There were large yield increases due to the use of the rice straw. Maize grown without rice straw yielded 2.93 t/ha, while maize grown with rice straw mulch yielded 4.72 t/ha, a 61% increase in yield.

The other costs involved in growing the maize in the trial (Table 13) were higher than average farmers' costs for growing maize, as shown in Table 12. This was due to the extra land preparation required, the extra fertiliser required for the soil type where the trial was undertaken, and the extra hand weeding that was required due to high weed burdens.

The estimated gross margin returns in the trial increased significantly with the addition of rice straw: from US $28/ha without rice straw mulch to US $176/ha with rice straw mulch, as shown in Table 13. Because of this result, and similar results experienced in other countries producing agricultural commodities, it is recommended that crop residues be retained in as many situations if possible.

Because crop residue mulch increases moisture conservation, it allows growers to sow on time in the EWS and take advantage of the start of the EWS rains to establish a successful crop on limited moisture. This can make the difference between a profitable EWS maize crop and crop failure due to drought. However, the MWS is often too wet for the mulch to be of benefit.

Table 13. Comparison of maize grown with and without rice straw mulch

CROP: MAIZE, WITHOUT MULCH

AREA: 1 HECTARE

YIELD AND INCOME

2.933 **t/ha ×** 120.00 **US D/t = TOTAL INCOME (A)** $352.00

CROP COSTS		MACHINERY/LABOUR		SEED/FERTILISER/CHEMICALS			
Operation	Month	Details	Total US $/ha	Rate/ha (kg)	Cost US $	Total US $/ha	Total Cost US $/ha
Land preparation		disc plough twice	40.00				40.00
Land preparation		harrow once	3.65				3.65
Fertilizer – Mo Superphosphate		before planting, with KCl		114	0.34	38.76	38.76
Fertilizer – KCl		1 person/ha/day	1.25	50	0.36	18.00	19.25
Planting and seed	June/July	planting	15.00	40	2.86	114.40	129.40
Fertilizer-topdressing urea		1 person/ha/day	1.25	50	0.32	16.00	17.25
Thinning		10 people/ha/day	12.50				12.50
1st hand-weeding		15 people/ha/day	18.75				18.75
2nd hand-weeding		15 people/ha/day	18.75				18.75
Harvest	Nov/Dec	20 people/ha/day	25.00				25.00
						Total costs (B)	323.31
						Crop Gross Margin (A-B)	28.68

CROP: MAIZE, WITH MULCH

AREA: 1 HECTARE

YIELD AND INCOME

4.720 **t/ha ×** 120.00 **USD/t = TOTAL INCOME (A)** $566.40

CROP COSTS		MACHINERY/LABOUR		SEED/FERTILISER/CHEMICALS			
Operation	Month	Details	Total US $/ha	Rate/ha (kg)	Cost US $	Total US $/ha	Total Cost US $/ha
Land preparation		disc plough twice	40.00				40.00
Land preparation		harrow once	3.65				3.65
Fertilizer – Mo Superphosphate		before planting, with KCl		114	0.34	38.76	38.76
Fertilizer – KCL		1 person/ha/day	1.25	50	0.36	18.00	19.25
Planting and seed	June/July	planting	15.00	40	2.86	114.40	129.40
Spread rice straw*				3	18.00	54.00	54.00
Fertilizer – topdressing urea		1 person/ha/day	1.25	50	0.32	16.00	17.25
Thinning		10 people/ha/day	12.50				12.50
1st hand-weeding		15 people/ha/day	18.75				18.75
2nd hand-weeding		15 people/ha/day	18.75				18.75
Harvest	Nov/Dec	30 people/ha/day	37.50				37.50
						Total costs (B)	389.81
						Crop Gross Margin (A-B)	176.59

Note: Rice straw or mulch costs are subject to change; the cost to farmer may be lower. In upland areas, other crop residues such as soybean or mungbean may be available.

Appendix: Guide to pests of maize in Cambodia

SCIENTIFIC NAME	ENGLISH COMMON NAME	KHMER COMMON NAME
Achaea janata	Castor oil looper	Dangkov bak khnoung
Acherontia styx	Eastern death's head hawk moth	Dangkov sneng
Cletus bipunctatus	Spined legume bug	No Khmer name
Conogethes punctiferalis	Yellow peach moth/ castor borer	No Khmer name
Helicoverpa armigera	Heliothis, Corn earworm	1. Dangkov kbal roeung 2. Chnot khmao
Hypomeces squamosus	Gold dust weevil	No Khmer name
Microtermes sp., *Hypotermes* sp., *Globitermes* sp., *Macrotermes gilvus*	Root-cutting termite	1. Kondea cut rhu 2. Kondea sirus 3. Kondea cut kol
Nezara viridula	Green vegetable bug	1. Sroeung san dek 2. Sroeung klen tea 3. Sroeung kloun veng
Omoides abstitalis	Legume webspinner	No Khmer name
Ostrinia furnacalis, Sesamia inferens	Asian maize borer	Dangkov kbal khmao
Riptortus sp.	Brown bean bug	1. Sroueng kloun veng 2. Sroueng klen tea
Rhopalosiphum maidis	1. Green peach aphid	No Khmer name
Myzus persicae	2. Maize aphid	
Spodoptera litura	Cluster caterpillar	1. Dangkov vorng 2. Dangkov paoa
Spoladea recurvalis	Beet webworm	Dangkov mousleuk

References and further reading

Bell, RW, Seng, V, Schoknecht, N, Vance, W and Hin, S 2005. Assessing land suitability for crop diversification in Cambodia. *Proceedings of the Land Resource Assessment Forum*, held at CARDI, Cambodia 23–26 September 2004 (in press). Distributed initially as CARDI Soil and Water Science Technical Note No. 1.

Birch, CJ 1997. *Temperature and Photoperiod Sensitivity of Development in Five Cultivars of Maize (Zea mays L.) from Emergence Tassel Initiation*. The University of Queensland, Gatton College, Australia and QDPI/CSIRO, Agricultural Production Systems Research Unit, Toowoomba, Australia.

Blamey, FPC, Bell, MJN, Moody, PW 2002. *Management of Phosphorus for Sustainable Food Crop Production on Acid Upland Soils in Australia, Philippines and Vietnam*. ACIAR Project Final Report LWR1 1994/014, University of Queensland, Brisbane, Australia.

Canadian Food Inspection Agency 2005. Web page URL: http://www.inspection.gc.ca/francais/sci/surv/data/elsampf.shtml.

Colless, JM 1982. *Maize Growing*, Department of Agriculture, Orange, Australia.

CPC, 2000. Crop Protection Compendium—Global Module, Second Edition. CAB International, Wallingford, UK. URL: http://www.cabicompendium.org/cpc.

Dierolf, T, Fairhurst, T, Mutert, E 2001. *Soil Fertility Kit: A Toolkit for Acid, Upland Soil Fertility Management in Southeast Asia*, Singapore Potash & Phosphate Institute (PPI), ProRLK, GTZ GmbH.

English, M, Cahill, M 2005. *Maize Disorders: The Ute Guide*, Department of Primary Industries and Fisheries, Queensland, Australia.

FCRI, 2001. *A Guide Book for Field Crop Production in Thailand*, Field Crops Research Institute, Ministry of Agriculture and Co-operatives, Bangkok.

Joner, EJ & Jakobsen, I 1995. Uptake of ^{32}P from labelled organic matter by mycorrhizal and non-mycorrhizal subterraneum clover (*Trifolium subterraneum* L.), *Plant Soil* 172, pp. 221–227.

Kim, SK, Yoon, NM, Kim, HJ, Kim, YB, Chhay, N, Kim, SM, Oeun, KS, Bora, P, Glaudino, N, Fontes, L, Tam, TT, Cho, MC 2006. *Severe Epidemics of Downy Mildew (Peronosclerospora sorghi) on Maize in Cambodia, East Timor and Vietnam*, Kyungpook National University and the International Corn Foundation, Daegu, South Korea.

Lafitte, HR 1994. *Identifying Production Problems in Tropical Maize: a Field Guide*, Mexico, D.F.: CIMMYT, International Maize and Wheat Improvement Centre.

Llewellyn, R 2000. *Sweet Corn Insect Pests and their Natural Enemies*, Bioresources Pty Ltd, HRDC, Greenridge Press, Toowoomba, Australia.

MAFF Cambodia 2002–03. *Agricultural Statistics 2002–2003* Statistics Office, Dept of Planning, Statistics and International Cooperation, Ministry of Agriculture, Forestry and Fisheries, Cambodia, Agricultural Productivity Improvement Project ITF Credit N0110-KH and IFAD Loan 423-KH

MAFF Cambodia 2003–04. *Agricultural Statistics 2003–2004*. Statistics Office, Dept of Planning, Statistics and International Cooperation, Ministry of Agriculture, Forestry and Fisheries, Cambodia Agricultural Productivity Improvement Project ITF Credit N0110-KH and IFAD Loan 423-KH

MAFF Cambodia 2004–05. *Agricultural Statistics 2004–2005*. Statistics Office, Dept of Planning, Statistics and International Cooperation, Ministry of Agriculture, Forestry and Fisheries, Cambodia, and Japan International Cooperation Agency, Cambodia.

MAFF Cambodia 2006. Web page URL: http//:www.maff.gov.kh/en/statistics/crops.html#a5

Martin, R, Belfield, S 2007. *Improved Technology Practices for Upland Crops in Cambodia: Technical Methods Demonstration Manual.* New South Wales Department of Primary Industries, Orange, Australia.

Martin, R, Pol, C 2007. *Weeds and Upland Crops in Cambodia*. NSW Department of Primary Industries.

Pioneer Hi-Bred Australia Pty Ltd 2002. *Maize Workshop: Growing Maize for Profi*t, Pioneer Hi-Bred Australia Pty Ltd, Toowoomba, Australia.

PNB Krishi 2007. *Maize (Technical)* Punjab National Bank, New Delhi.

University of Kentucky 1970. Soil Handbook, in Foth, HD & Ellis, BG 1997 *Soil Fertility*, 2nd edn, CRC Press, Boca Raton, Florida, USA, ISBN 1-56670-243-7.

USDA Foreign Agricultural Service Cambodia 2006. Grain and feed: grain industry in Cambodia, *GAIN Repor*t CB6001, 29 March, United States Department of Agriculture.

Vance W, Bell R, Seng V 2004. *Rainfall analysis for the Provinces of Battambang, Kampong Cham and Takeo, The Kingdom of Cambodia*, School of Environmental Science, Murdoch University, Australia.

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