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# soybean

A guide to upland cropping in Cambodia

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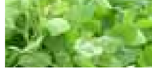

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A guide to upland cropping in Cambodia

Stephanie Belfield, Christine Brown
and Robert Martin

ACIAR
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2011

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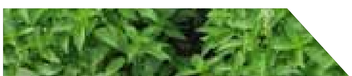
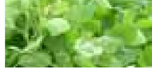




# Foreword

The National Poverty Reduction Strategy (2003–05) of the Royal Cambodian Government committed research centres and extension systems to focus on small-scale farmers and emphasise the use of improved tools and management practices for cropping systems. Priority was given to diversifying and intensifying sustainable agricultural production, with few external inputs, and to developing cost-effective management practices.

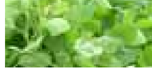
The Australian Centre for International Agricultural Research (ACIAR) took on these challenges in 2003, beginning a project (ASEM/2000/109) to develop sustainable farming systems for a variety of crops. The project focused on maize, soybean, sesame, mungbean, peanut and cowpea in upland areas of Kampong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

The project team conducted 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 retention of crop residues. In 2007, provincial staff from the Department of Agriculture and non-government organisations in Battambang, Kampong Cham and Pailin provinces were trained in implementing on-farm demonstrations of the new technologies and improved practices.

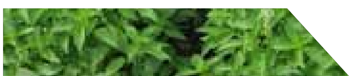
A new ACIAR project (ASEM/2006/130) began in 2008 to increase production and marketing of maize and soybean in north-western Cambodia. The emphasis of the new project is on on-farm adaptive trials to evaluate and improve the technologies and practices initially tested in 2007. The new project has also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

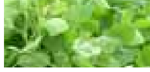
This book is part of a series of publications produced by ACIAR in support of the ongoing roll-out of on-farm demonstrations for upland crops in Cambodia.

**Nick Austin**
Chief Executive Officer
ACIAR

# Contents





# Acknowledgments

The information in this manual is based on research by the Cambodian Agricultural Research and Development Institute (CARDI), the Maddox Jolie-Pitt Foundation, CARE Cambodia and provincial offices of the Department of Agriculture in Battambang, Kampong Cham and Pailin. The research was supported by the New South Wales Department of Primary Industries and the University of New England.

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# Acronyms and abbreviations

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| Al | aluminium |
| Bt | *Bacillus thuringiensis* |
| CARDI | Cambodian Agricultural Research and Development Institute |
| cm | centimetre |
| EWS | early wet season |
| Fe | iron |
| ha | hectare |
| IPM | integrated pest management |
| K | potassium |
| kg | kilogram |
| $m^2$ | square metre |
| mm | millimetre |
| Mo | molybdenum |
| MWS | main wet season |
| N | nitrogen |
| NPV | nucleopolyhedrovirus |
| P | phosphorus |
| S | sulfur |
| t | tonne |
| Zn | zinc |

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# 1 Introduction

Soybean (*Glycine max*) is a tropical legume that can be grown on many soil types under a wide range of climatic conditions. It is a native of eastern Asia and originally grew wild in China, Manchuria, Korea and Japan. This manual outlines how to grow soybean successfully in Cambodia under rainfed upland conditions.

Soybean production in Cambodia has been growing steadily since 1980 (Figure 1) and exceeded 100,000 tonnes per year in 2005. The main soybean production area for the past 30 years has been the province of Kampong Cham. However, in recent years, soybean production has increased in north-western Cambodia, especially in the province of Battambang. Soybean is also grown in other provinces, including Siem Reap, Kandal and Takeo.

Soybean is usually grown in the main wet season, and the crop fits well in an upland rotation in combination with maize, sesame and peanut. The roots of legume crops such as soybean have nodules formed by rhizobium bacteria (*Bradyrhizobium* spp.), which obtain nitrogen from the atmosphere; this nitrogen becomes available to both the soybean and following crops. Rhizobia are not always present in the soil and may need to be added to the seed at sowing time (see Section 8).

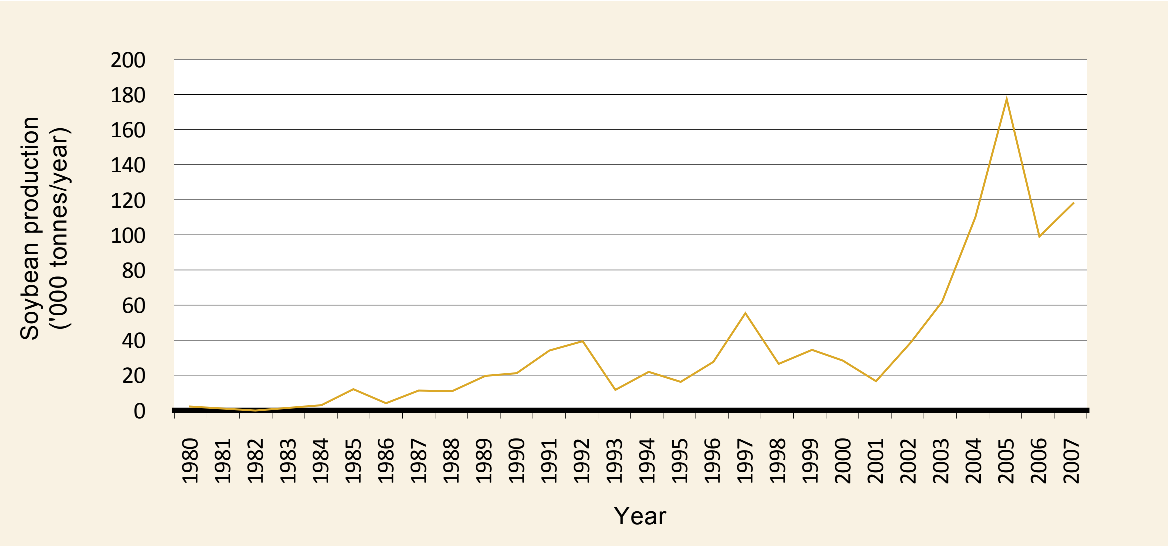



**FIGURE 1.** Soybean production in Cambodia, 1980–2007

The average yield for soybean in Cambodia is 1.5 tonnes per hectare (t/ha), which is low compared with international averages (Figure 2). However, with good management, on the better-quality soils, soybean yields in Cambodia can exceed 3 t/ha (Figure 2).

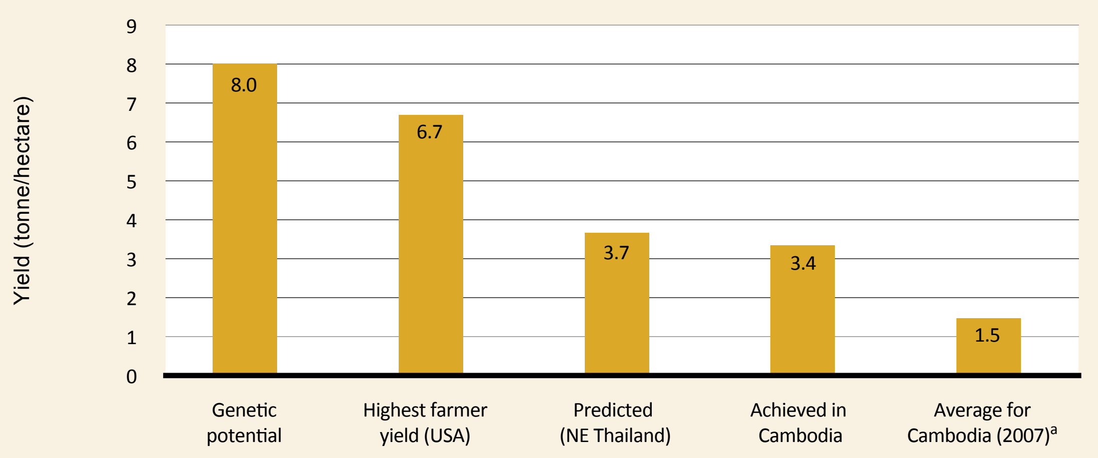
Since global demand for soybean and soy-related products is increasing, oversupply of the market in unlikely to be a problem in the medium term. Most of the Cambodian soybean crop is exported to Vietnam or Thailand (see Section 11).

Cambodian farmers have a good opportunity to increase soybean yields and reduce the risk of crop failure by adopting improved agronomic methods and technologies. This manual provides information that Cambodian farmers can use to increase soybean production.

On-farm experiments and demonstrations were conducted between 2004 and 2010, and information was obtained on:

- variety evaluation
- effect of major insect pests and diseases
- general agronomy and farming systems
- rhizobium inoculation for legumes
- reduced tillage and crop residues
- weed management
- socioeconomic analysis.

A combination of new technologies and improved agronomic methods can produce soybean yields up to 3.4 t/ha (Figure 2), more than double Cambodia's average of 1.5 t/ha. The addition of rhizobium can increase yield by up to 15% compared with farmer practice and has the added benefit of providing residual nitrogen in the soil, which will become available to the following crop. This means that the farmer may not need to apply nitrogen fertiliser to the following crop. As more trials are carried out and new agronomic methods and technologies are adopted, it is hoped that soybean yields in Cambodia will continue to increase towards 4 t/ha.




[a] Statistics Office, Department of Planning and International Cooperation, Ministry of Agriculture, Forestry and Fisheries (Agricultural Statistics Bulletin)

**FIGURE 2.** Actual and potential yield of soybean

# 2 Climate and soils

## Temperature

The optimal temperature for soybean growth is 20–30 °C. Temperatures of 35 °C and above are considered to limit growth. The optimal soil temperature for germination and early seedling growth is 25–30 °C.

Low temperature is rarely a limiting factor for soybean production in Cambodia. Much of the production of soybean is concentrated in the main wet season (MWS), when the risk of high temperatures is lower than during the early wet season (EWS) months of March and April. High temperatures can exceed 38 °C in the EWS, so growing soybeans at this time is not recommended.

## Rainfall

Soybean can grow to maturity with as little as 180 mm of in-crop rain, but this would reduce yield by 40–60% compared with optimal conditions. The ideal rainfall for soybean is 500–1000 mm. Depending on soil type and stored soil moisture, crop failure would be expected if less than 180 mm of rain were received during crop growth. Generally, in Cambodia, the growing season rainfall is inadequate for soybean in the EWS but adequate in the MWS (Table 1).

Drought can cause patchy crop establishment, death of plants and reduced yields. Periods of more than 5 days without rain occur almost every year in the EWS in Cambodia. Crop water stress often occurs in the EWS, especially on sandy, gravelly or shallow soils that have a low capacity for water storage in the root zone (see below, under 'Soils'). It is therefore recommended that soybean be planted in the MWS, when the chance of adequate rainfall is greater.

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

| Sowing time | In-crop rainfall (mm) |
|---|---|
| April (EWS) | 340–480 |
| May (EWS) | 420–600 |
| July–August (MWS) | 560–690 |

EWS = early wet season; mm = millimetre, MWS = main wet season
Source: Vance et al. (2004)

The impact of drought can be greatly reduced by practising reduced tillage, maintaining crop residues in the field or adding crop residues such as rice straw or maize residue. These practices lower soil temperature and reduce surface evaporation and thus increase moisture storage in the soil. Soybean yield was increased dramatically by adding rice straw mulch to the soil surface (see Table 11 in Section 11). Mulching reduces the risk of crop failure and increases the yield potential of early sown crops.

During the MWS, in-crop rainfall is likely to be within the optimal range. Average MWS in-crop rainfall is approximately 500 mm in Battambang and 580 mm in Kampong Cham for a crop growing season of 80–90 days (Table 1). The monthly distribution of this rainfall for Kampong Cham and Battambang provinces is shown in Figures 3 and 4, respectively.

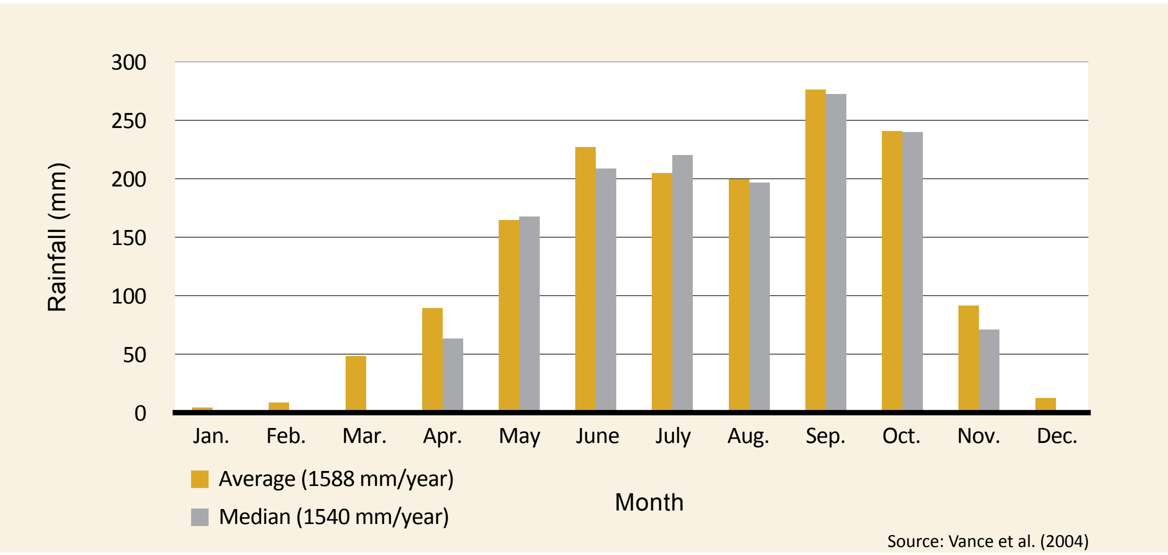



**FIGURE 3.** Monthly rainfall at Chamkar Leu, Kampong Cham

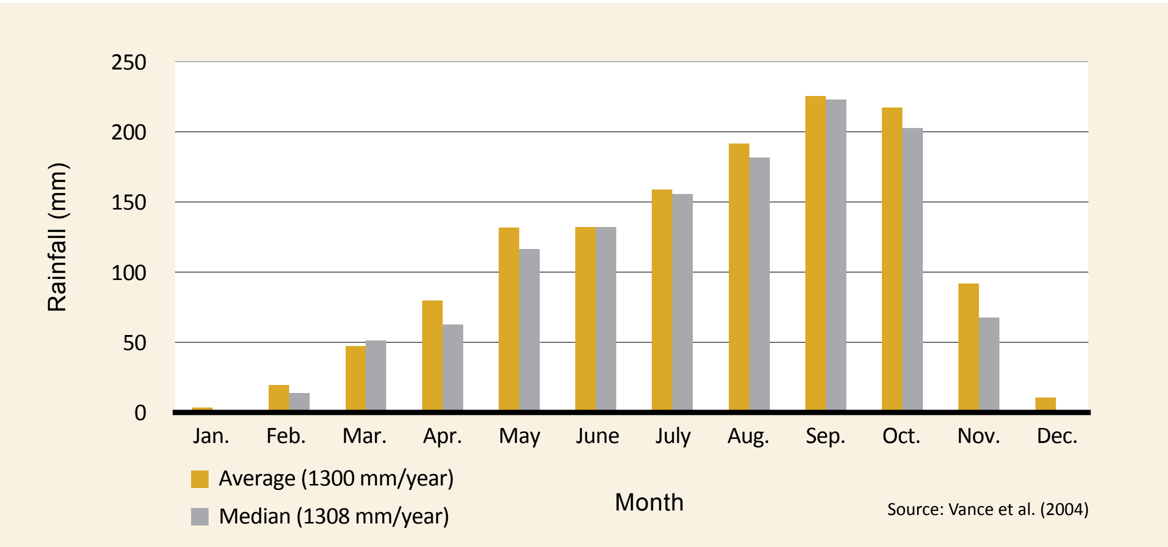



**FIGURE 4.** Monthly rainfall at Battambang City

## Day length

Soybean is a short-day plant. This means that flowering responds to shortening days. Each variety has a different critical day length that must be reached before the plant will start to flower. In Cambodia, day length increases from late December until late June and then decreases until late December (Figure 5). The best time to plant soybean is between late June and mid August.

## Soils

Soybean prefers fertile, well-drained, loamy soils. Such soils are also suitable for a range of other crops, so the decision to grow soybean will depend on its profitability relative to other crop options. Soil organic carbon, total nitrogen, nitrate and pH on Labansiek (Ferrosol) and Kampong Siem (Vertisol) soils in Kampong Cham and Battambang provinces are shown in Table 2. Labansiek soils are red clay soils, which occur on the foot-slopes of hills. Kampong Siem soils are black–grey clay soils; they also occur on the foot-slopes of hills, but usually lower in the landscape than the Labansiek soils (White et al. 2000).

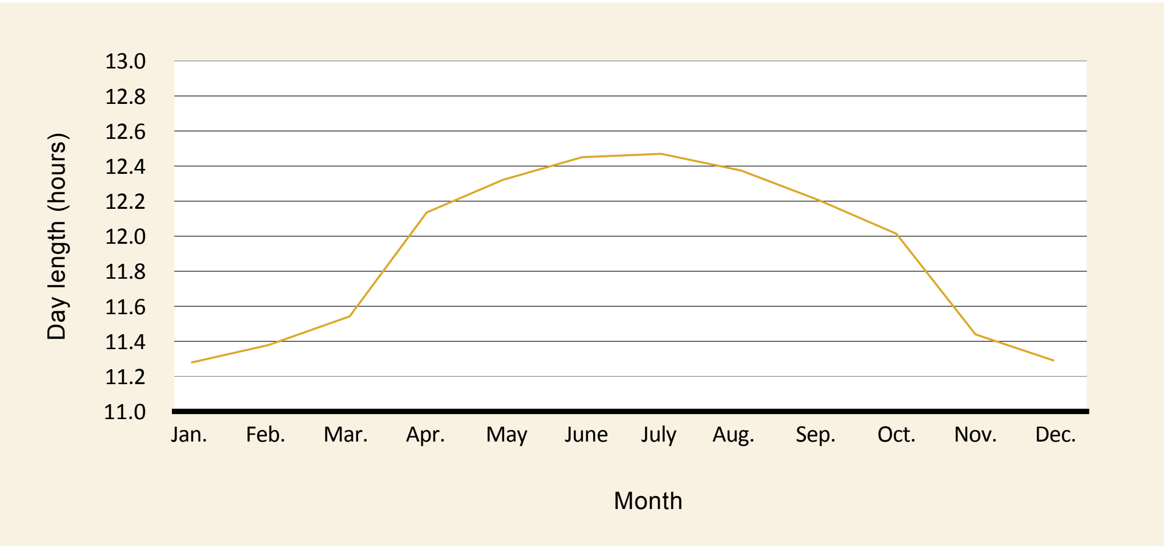



**FIGURE 5.** Average monthly day length at Phnom Penh

**TABLE 2.** Soil organic carbon, total nitrogen, nitrate and pH at a depth of 0–20 cm for 100 sites in Kampong Cham and Battambang provinces

| | | | | Feb.–Mar. 2005 | | July–Aug. 2005 | |
|---|---|---|---|---|---|---|---|
| Province | Soil type | Organic carbon (%) | Total nitrogen (%) | pH | Nitrate (ppm) | pH | Nitrate (ppm) |
| Kampong Cham | Labansiek | 1.45 | 0.128 | 5.5 | 28 | 5.0 | 10 |
| Kampong Cham | Kampong Siem | 2.13 | 0.165 | 5.7 | 20 | 5.4 | 12 |
| Battambang | Labansiek | 2.07 | 0.176 | 5.8 | 20 | 5.5 | 38 |
| Battambang | Kampong Siem | 2.46 | 0.181 | 6.7 | 22 | 6.5 | 50 |

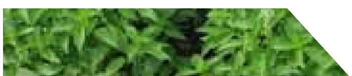
ppm = parts per million
Source: Martin and Belfield (2007)

Soybean does not tolerate drought because the relatively shallow root system limits water absorption during dry periods. Therefore, soybean is not well suited to sandy soils or soils with low water storage capacity, such as gravelly or shallow soils. Good soil moisture is needed at sowing to increase the chance of seed germination and plant establishment on all soil types. Soybean should be grown only in the MWS unless the soil is irrigated or has good stored moisture and residues covering the ground.

Soybean is susceptible to waterlogging between emergence and the four-leaf stage. However, after this stage, it has good tolerance to waterlogging compared with other non-rice crops. This is another reason to grow soybean in the MWS. Soybean may also tolerate flood irrigation more effectively than other crops.

Soybean can be grown on a wide range of soils with pH (in a calcium chloride solution—see Section 7 for details of pH measurement) ranging from 4.5 to 8.5. However, the crop prefers slightly acid soil—the optimal soil pH is in the range of 5.5–6.5. Soybean is not tolerant of strongly acid soils (below pH 4.5), as aluminium and manganese toxicity are likely to occur under such conditions. At the other end of the pH scale, growing soybean in soils with pH greater than 8 is not recommended, as micronutrient deficiencies such as zinc and iron may occur.





# 3 Morphology of soybean

## Seed and seedling

Soybean seeds vary in their appearance but are generally round or oval and have a cream seed coat. The hilum, which is the point where the seed is attached to the pod, may vary from dark brown to yellow (Figure 6). Soybean seeds have a hundred seed weight of 15–25 grams, which means that there are between 4,000 and 7,000 seeds per kilogram.

**FIGURE 6.** Hilum colour in soybean

The seed (Figure 7) is made up of two halves called cotyledons. These organs contain most of the oil and protein in the seed and supply food to the emerging seedling for the first 2 weeks of its life. Between the two cotyledons and attached to them is the embryo, which contains the immature leaves and stems (epicotyl and hypocotyl) and the root shoot (radicle).

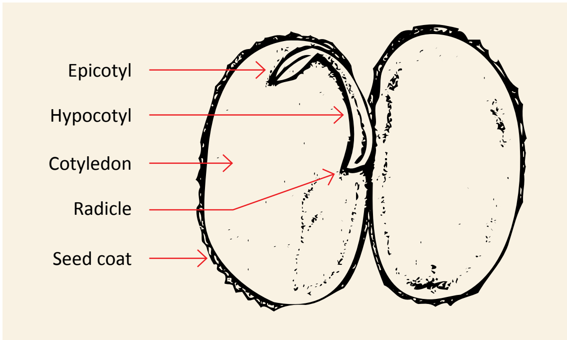



**FIGURE 7.** Soybean seed

Soybean seeds are very delicate. Their only protection from mechanical damage, fungal infection and bacterial infection is the very thin seed coat. Seeds with a cracked coat will not usually develop into a healthy seedling and may not germinate.

## Root system

Soybean has both a branched taproot and fibrous roots; however, the taproot is weak. Strong lateral (horizontal) root growth compensates for this, with lateral roots beginning to develop at emergence of the cotyledons (Figure 8). The lateral root system becomes extensive, reaching 45 cm within 4–5 weeks. As soil dries out, roots may grow deeper into the soil to absorb water and nutrients. As with other legumes, soybean has a symbiotic relationship with the nitrogen-fixing root nodule bacterium *Bradyrhizobium* spp., which forms nodules on the roots (see Section 8).

**FIGURE 8.** Soybean roots

## Vegetative morphology

The first leaves to emerge after the cotyledons are single bladed (unifoliate), opposite and ovate in shape (broad at the base and tapering to the end). The second leaves that emerge are alternate and usually trifoliate—three leaflets make up each leaf. Each leaflet is 6–15 cm long and 2–7 cm wide (Figure 9).

The stems and leaves are usually covered in a mass of fine hairs. The stem has two functions: to support the leaves and flowers, and to transport water and nutrients. Within the stem, the xylem cells carry nutrients and water upwards from the roots to the leaves and the phloem carries sugars around the plant. The major function of the leaves is to photosynthesise. Photosynthesis uses sunlight energy to convert water and carbon dioxide into sugars, which are the building blocks for growth and reproduction.

Soybean plants have an erect, bushy habit. The plant grows to between 60 cm and 140 cm tall, depending on the planting date and the characteristics of the soybean variety.

## Reproductive plant parts

The first flower appears on the main stem at any node (a node is a slight lump and swelling of the stem where a leaf or branch extends from the stem). Flowers are present in groups at nodes along the stem. The plant is in full flower when open flowers can be seen at one of the two uppermost nodes of the main stem (Figure 10; see also Appendix 1).

Flowers are white, pink or purple; most Cambodian varieties have pink flowers. They are small, pea-type flowers, 5–6 mm long (Figure 11), and are borne in a group called a raceme, which is an elongated cluster arrangement. Flowers at the base of the raceme open first.

**FIGURE 9.** Soybean trifoliate leaf

**FIGURE 10.** Soybean plant during flowering

**FIGURE 11.** Soybean flower

Soybean is a self-pollinated plant. The anthers (male organs) mature inside the flower bud and shed their pollen directly onto the stigma (female organ) before the flower opens. Some soybean varieties are indeterminate, which means that the plant continues to produce leaves and stems during the reproductive phase.

Fertilised flowers develop along the stems into hairy pods, which contain the seeds (Figure 12).

The developing seeds are initially small and green. At maturity, there are usually two or three seeds per pod. The pods are 3–8 cm long, and the seeds are creamy yellow in colour (Figure 13). The plant is at full maturity when 95% of the pods are brown. At maturity, the seeds contain approximately 13% moisture. On a dry-weight basis, soybean seeds are made up of 40% protein, 20% oil, 35% carbohydrate and about 5% ash. Soybean seeds comprise approximately 8% seed coat, 90% cotyledons and 2% hypocotyl axis.

**FIGURE 12.** Soybean at full pod with immature pods along the main stem

**FIGURE 13.** Mature pod containing creamy yellow seeds

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# 4 Growth stages of soybean

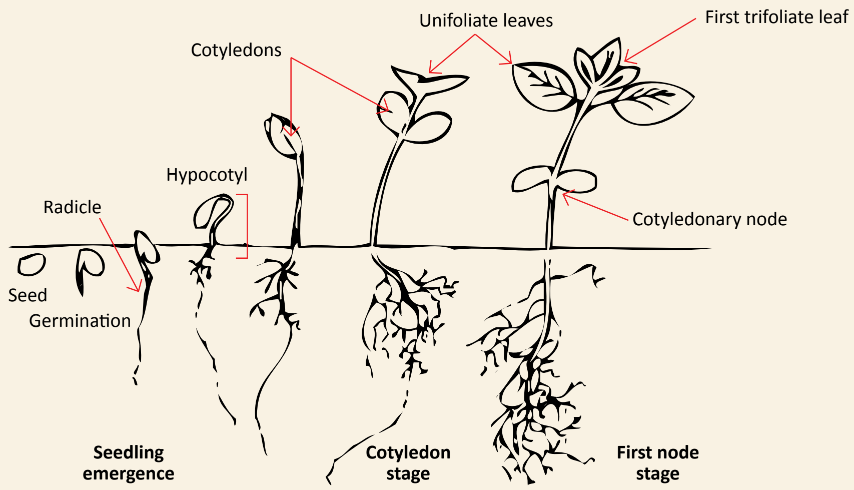
## Germination and emergence

The seed starts absorbing moisture from the soil almost immediately when sown into moist soil, and begins to germinate once it has taken in 50% of its weight in water. Germination begins with the radicle (seedling root) growing downwards (Figure 14). Soon after germination, a shoot (hypocotyl) extends upwards, pushing the cotyledons through the soil surface within 3 to 4 days of sowing. The time to seedling emergence is related to temperature, available moisture and planting depth. Seeds should not be planted deeper than 5 cm as they may not emerge. Emergence may also be reduced if the soil surface is crusted or if insects, rodents or birds damage the growing point.

The two cotyledons change from being organs storing energy for germination in the seed to being greatly enlarged leaves above the ground that photosynthesise and supply energy for development of the first true leaves.

The plant produces two single-bladed (unifoliate) leaves soon after emergence. These are followed by a 5–10 cm gap to the first node and trifoliate leaf.

Root nodule bacteria (*Bradyrhizobium* spp.) enter the seedling through root hairs almost immediately after seedling emergence (see Section 8). Roots begin actively fixing nitrogen by the time the second or third node has developed.




Source: Michigan State University Extension (2000)

**FIGURE 14.** Soybean early growth stages

## Vegetative development

The stem grows rapidly, with a new trifoliate leaf produced at each node of the plant every 3 days. A node is counted as whole when all the leaflets above it are fully opened. When the plant reaches the third node stage, axillary buds are formed at the node. These buds can produce lateral branches that allow the plant to recover from damage, such as insect attack, to the main stem.

Branching of soybean starts when the plant is about 20 cm tall and when six nodes on the main stem have fully developed leaves. The number of branches depends on the soybean variety and plant density. Branches are able to grow larger to compensate for low plant density, or when the growing point is damaged.

## Flowering

An open flower at any node is considered to be the start of flowering. The number of days to first flower depends on day length, temperature and the soybean variety. The soybean plant is sensitive to day length—flowering begins when days become shorter. Each variety has a critical day length that will initiate flowering. Cambodia is close to the equator, so day lengths are relatively short. This means that soybean varieties from higher latitudes produce flowers early and have a shorter vegetative stage, which reduces the potential yield. However, plant breeders have developed 'long juvenile backcrosses' that delay flowering by approximately 10 days, increasing the length of the vegetative stage.

Soybean varieties are either determinate or indeterminate in growth habit. Determinate means that they do not start flowering until the plant reaches full height. Once it reaches this height, a cluster of flower buds forms at the top of the plant, stopping further vegetative growth. Determinate varieties start flowering at all nodes almost at the same time once the plant has reached maximum height. At each node, a raceme is produced and, over a 3–5-week period, flowering progresses from the base of the raceme to the top. At maturity, determinate plants have a number of pods on a terminal raceme.

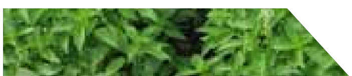
Indeterminate varieties reach about 30–50% of their maximum plant height when flowering starts and less than half the nodes on the main stem have developed. Flowers appear upwards along the stem of the plant as vegetative growth continues. This produces new nodes over a period of 3–8 weeks. The raceme produced by indeterminate varieties is within the leaf canopy.

Indeterminate varieties continue vegetative growth and increase height while flowering, which means that the lower nodes will develop pods while upper nodes are still flowering. These varieties can often recover well from damage as they are able to compensate by producing more vegetation and flowers. However, this can result in flowering over a long period, which can make harvest timing difficult. A prolonged ripening period may also increase the risk of harvest losses from shattering of the pod or moisture damage.

About 60–75% of all flowers produced abort and do not form pods. This means that soybean has a good capacity to compensate for insect attack or drought stress.

The soybean plant has accumulated 25–30% of its total dry weight by flowering. From then on, dry weight increases rapidly. A well-nodulated soybean plant will acquire most of its nitrogen during this reproductive phase (Imsande 1986).





# Pod and seed development

Pods start to appear 7–10 days after the start of flowering. The beginning of podding is defined as one 5-mm-long pod at one of the four uppermost nodes. Pods may drop off the plant under severe moisture stress. Adequate moisture supply and control of pod-sucking insects are critical during the pod-filling stage.

As the pods and seeds develop, they are less likely to drop off. Usually, two or three of the seeds will grow and eventually fill the pod cavity. The rate of nitrogen fixation in the plant is highest at the beginning of pod filling and drops sharply as seed filling continues. Some of the nutrients in the leaves and other vegetative parts that have accumulated during earlier growth stages are transferred to the seeds.

Full pod is reached when a pod is 2 cm long at one of the four uppermost nodes. This is the beginning of the critical period that determines yield. The start of seed development is when seeds are 3 mm long in a pod at one of the four uppermost nodes. During this time, there is a large demand for water and nutrients. At this stage, the number of seeds per pod, seed size and yield can be affected by heat stress (temperatures greater than 35 °C), moisture stress or lack of nutrients.

The full-seed stage is reached when a pod contains a green seed that fills the pod cavity at one of the four uppermost nodes (Figure 15).

Physiological maturity is reached when seeds obtain their maximum dry weight. Up to this point, the crop is still gaining weight and must have an adequate supply of moisture if optimum yield is to be reached. The following signs help to determine when physiological maturity is reached:

- Nearly all pods are yellow, with up to 50% turning brown (Figure 16).
- Seeds have just started to shrink and are no longer attached to the pod by a white membrane.

**FIGURE 15.** Green seeds filling the pod cavity

**FIGURE 16.** Soybean plants at physiological maturity

- Seeds in the lower pods are creamy yellow in colour (Figure 13).
- For determinate varieties, upper leaves are green while lower leaves are yellow and falling off.
- For indeterminate varieties, most leaves are yellow or have fallen off.
- Seeds have an average of 40–50% moisture.

Full maturity, which occurs about a week after physiological maturity, is when 95% of the pods are brown. A further 5 days of fine weather are required after the plant reaches full maturity before the seeds have dried sufficiently for mechanical harvest to begin (Figure 17).

## Understanding growth stages

Farmers need to be familiar with the growth stages of soybean so that they can use appropriate management practices to maximise yield potential. There is always variation in maturity across a field. A crop is considered to be at a particular growth stage when more than 50% of plants in the field are at that stage. The vegetative and reproductive growth stages of soybean are shown in Appendix 1.

**FIGURE 17.** A soybean crop ready to harvest

# 5 Varieties of soybean

## Selecting a variety

The choice of variety can have a significant impact on yield and quality of the crop. It is important to choose a variety that is suited to the soils, climate and length of season in the region where it is to be grown. Table 3 summarises the features of some varieties that are suitable for planting in Cambodia.

Several point to consider when selecting a suitable variety are discussed below.

### End use

Soybeans in Cambodia are primarily grown for human consumption and exported to processors in Vietnam and Thailand. There are a few smaller companies in Cambodia that also process soybeans for milk, sauce and the feed market (see Section 11). It is important to ensure that the variety chosen is suited to the end-use market that is targeted.

### Maturity

Maturity and planting time need to be considered when selecting varieties, as the time taken to harvest differs between varieties. Farmers should plan to sow their chosen variety in the recommended planting windows outlined in Table 4, ensuring that the expected harvest time of the particular variety does not fall in September, the wettest month of the year. If soybean is planted late, a quick-maturing variety should be grown.

**TABLE 3.** Characteristics of soybean varieties in Cambodia

| Variety | 100 seed weight (g) | Days to 50% flower | Days to harvest | Plant height at maturity (cm) |
|---|---|---|---|---|
| DT84 | 18.4 | 33 | 91 | 59 |
| Chiang Mai 60 | 15.9 | 33 | 98 | 71 |
| B3039 | 14.8 | 42 | 96 | 85 |
| Chakkrabandhu No.1 | 13.3 | 48 | 109 | 64 |
| Asca | 13.6 | 50 | 97 | 80 |

cm = centimetre; g = gram

**TABLE 4.** Recommended sowing times for soybean in Cambodia

| | Early wet season | | | | | | | | | | | | Main wet season | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | March weeks | | | | April weeks | | | | May weeks | | | | June weeks | | | | July weeks | | | | August weeks | | | |
| **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; * = optimal sowing time; > = later than ideal, but acceptable

For example, an early maturing variety such as DT84 takes approximately 90 days to be ready for harvest. If it is sown on 20 June, it may be ready for harvest by 19 September when it is still at great risk of weather damage from prolonged rain. However, if the same variety is sown 4 weeks later, on 18 July, it will be ready for harvest around 17 October, which is a better time for harvest because there is less chance of rain.

Farmers planning to sow in late June or early July are advised to sow a variety, such as Asca, with a longer season. When sown on 20 June, this variety would be ready to harvest approximately 120 days later, on 18 October.

## Breeding

When deciding what variety to grow, farmers should also think about yield; susceptibility to seed shattering at harvest; and specific soybean quality traits such as seed size (Figure 18) and protein and oil content, which may attract a premium price from the trader.

## Logistics

Farmers should plan the size of their soybean crop. A large crop will have a high demand for labour to harvest and thresh it, and to dry the seed, and also needs more space to lay it in the sun. These problems can be reduced by planting two varieties with different times to maturity, so that they do not ripen at the same time (Figure 19). Having crops at different stages of growth during the season could also reduce the risk of losses such as rain damage at harvest, because the crops will be at different growth stages throughout the growing season. It could also reduce the losses from insect damage or disease. Planting more than one variety is therefore a good way to reduce risk and stabilise farm income.

## Standing ability

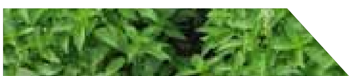
Farmers should select varieties that have well-developed roots and strong stems, and are resistant to root and stalk rot. These features help prevent the plant from falling over (lodging), which can lower the yield and quality of the grain.

## 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. Some diseases, such as soybean mosaic virus (see Section 9), are transmitted in the seed and can be present in the seed at planting. Therefore, it is important to buy certified seed that has been tested and shown to be free from disease.

**FIGURE 18.** Seed size differences between soybean varieties B3039 (small, on left) and DT84 (large, on right)

**FIGURE 19.** Soybean varieties at different stages of maturity



# 6 Sowing soybean

## Planting time

Soybean is not as drought tolerant as other upland crops such as peanut, mungbean and sesame, so good soil moisture at sowing time is required before the crop is planted. It is recommended that the soil is wet to a depth of at least 30 cm before sowing. Soybean should be planted on deeper alluvial soils, where possible.

Because of the requirement for water to maximise yield and quality, the majority of soybean is planted in the main wet season from June to August, when rainfall is more frequent and reliable. Recommended sowing times for soybean in upland areas of Cambodia are given in Table 4 in Section 5.

## Seed quality

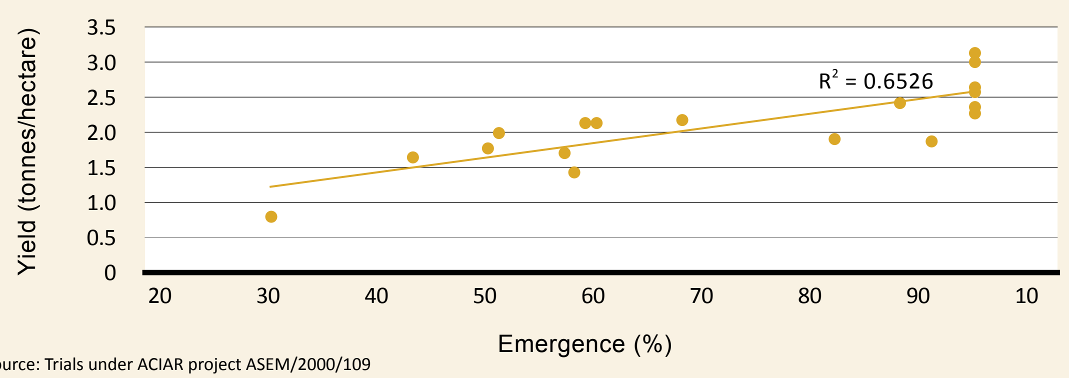
Soybean seed does not keep for very long in storage, often losing germination and vigour after only 2–3 months. Postharvest storage conditions for soybean seed in Cambodia are a big problem, with many facilities not favourable to retaining high-quality seed.

It is important to test the germination and vigour of seed before sowing. To do this, complete the following steps:

- First, look at seeds for signs of weathering, disease or physical damage.
- Two weeks before sowing, do a germination test in soil or sand. Randomly select 400 seeds and sow them 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 that have emerged after 3, 5 and 7 days.

If less than 70% of the seeds have germinated after 7 days, the seed should not be used if another source of seed is available. If fresh seed is not available, planting rates should be increased to compensate for the low percentage of germination.

The seed coat of soybean is very thin and, if it is cracked (during harvest or handling), the seed is unlikely to germinate. A cracked seed coat allows moisture to penetrate very quickly, swelling the seed and breaking the fragile embryo. This results in fewer plants establishing and a patchy, uneven plant stand, thus reducing the potential yield (Figure 20) and increasing weed competition.




Source: Trials under ACIAR project ASEM/2000/109

**FIGURE 20.** Effect of emergence of soybean varieties on yield, Samlout, main wet season 2007

It is also important that planting seed is as pure as possible—that is, it should all be the same variety and not mixed with other varieties. Diseases, such as soybean mosaic virus (see Section 9), can be carried in the seed, so it is essential to plant seed that is free from disease. The seed should also be free from weed seeds and green or immature seeds. A pure line of seed will simplify management and maximise productivity, quality and yields. If possible, farmers should buy certified seed that meets the above criteria and has results of germination and purity tests printed on the bag.

The Food Facility Project (GCP/CMB/033/EC) of the Food and Agriculture Organization of the United Nations and the European Union has distributed air-tight bins, with a capacity of 120 kg, to selected households in Cambodia (Figure 21). These seed storage bins were provided for keeping rice seeds for planting, but are equally useful for storing soybean seed. The bin protects the seed from the moisture instability of the atmosphere, ensuring that the seed is neither too dry nor too moist (which would adversely affect the seed quality and germination rate). When seed is correctly dried and sealed in the bins, it is safe from contamination and spoilage by insects, rodents, birds, moisture fluctuations, heat and water. As a result, the seed will have high germination rates.

**FIGURE 21.** Plastic bins used for seed storage

(Photo courtesy of FAO–EU project GCP/CMB/033/EC)

## Seedbed preparation

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

A good seedbed should have 5–7 cm depth of fine, firm soil that is free from weeds. The rest of the soil profile should not contain hardpans or compacted layers from too much cultivation, as these will reduce moisture penetration and root growth.

To achieve a 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 before planting soybean. Soybean establishes very well under a no-tillage system, where the residues are retained from the previous crop. The field needs to be even and kept free from weeds by hand chipping or spraying, as required. Soybean can be sown directly into the standing stubble, saving the costs of ploughing. This system is possible where maize is grown in the early wet season (EWS) and soybean is planted directly into the maize stubble.

The benefits of retaining crop residues or mulching are reduced soil temperature, reduced crusting of the soil surface, reduced surface evaporation, reduced emergence of weeds, reduced soil erosion, improved rainfall infiltration and increased yield. Mulching can also reduce the risk of crop failure as a result of drought, especially during the EWS.

In experiments in Cambodian upland crops, mulching has provided significant benefits, especially for soybean, with yield increasing from 0.6 t/ha to 1.4 t/ha (an increase of 136%).

# Crop establishment

Having wet soil to a depth of 20 cm at planting will help soybean establish and survive periods of hot, dry weather after seedling emergence. Crop residues on the soil surface help to preserve the soil moisture, and soybean establishes well under these conditions. The crop residue or mulch provides a good microclimate for establishment, allows greater rainfall infiltration and allows more water to be stored in the soil for the crop to use throughout the growing season. As the mulch breaks down, it increases soil organic matter. In the long term, this improves soil structure, water-holding capacity and fertility.

It is important to plant soybean seed at an even depth of 3–5 cm into firm, moist soil. This will ensure good contact between the seed and the soil, and improve moisture uptake and the chance of even germination (Figure 22). If seed is planted at a shallower depth, farmers should ensure that soil moisture is good and check that soil temperatures are not too high, as this might kill the seed and prevent germination.

Plant density and row spacing are critical agronomic factors to get right when sowing soybean, to maximise yield and quality. Crop yield is maximised when plants are evenly distributed across the whole field at an appropriate density. In similar growing environments in Australian coastal areas, with approximately 1,000 mm of rain per year, the recommendation is to aim for 30–40 established plants per square metre.

**FIGURE 22.** No-till disc planter sowing soybean into brachiaria grass mulch, Kampong Cham province (top) and close-up of disc tyne and press wheel (bottom)

If plant stands are too thin, the plants will be short, with pods close to the ground. Very thick crops produce tall, thin-stemmed plants that will lodge easily. Optimum plant populations should result in complete groundcover by the start of flowering, which is important for reducing weed competition, as well as for increasing yield. Sowing rate should be adjusted to take account of the germination percentage and vigour of the seed, but is usually in the range of 70–90 kg/ha for early maturing crops and 45–60 kg/ha for later maturing crops (Table 5 and Figure 23).

For machine planting, a seeding rate of 80 kg/ha will result in a plant population of 40 plants/m$^2$ (400,000 plants/ha) assuming a hundred seed weight of 15 g and an establishment rate of 75%. A seeding rate of 55 kg/ha would result in a plant stand of 28 plants/m$^2$ (275,000 plants/ha).

## Fertiliser application

Fertiliser may be required at sowing to provide the seedling with the major nutrients needed for early stages of development. The main nutrients applied at sowing for soybean are nitrogen (N), phosphorus (P) and potassium (K). On some soil types, sulfur (S) and micronutrients such as zinc, iron and molybdenum might need to be applied. The fertiliser recommendations below can be used as a guide for soybean production in Cambodia. These recommendations have been derived from general fertiliser rates determined for other regions in South-East Asia and adjusted for Cambodia on the basis of expected yield, limited Cambodian trial data and soil analyses of a limited number of profiles.

**TABLE 5.** Hand planting rates and recommended plant densities for soybeans in upland Cambodia

| Variety maturity | Seeding rate (kg/ha) | Distance between rows (cm) | Distance between hills (cm) | Seeds per hill |
|---|---|---|---|---|
| Quick | 55 | 40 | 20 | 3–4 |
| Slow | 80 | 30 | 20 | 3–4 |

cm = centimetre; ha = hectare; kg = kilogram

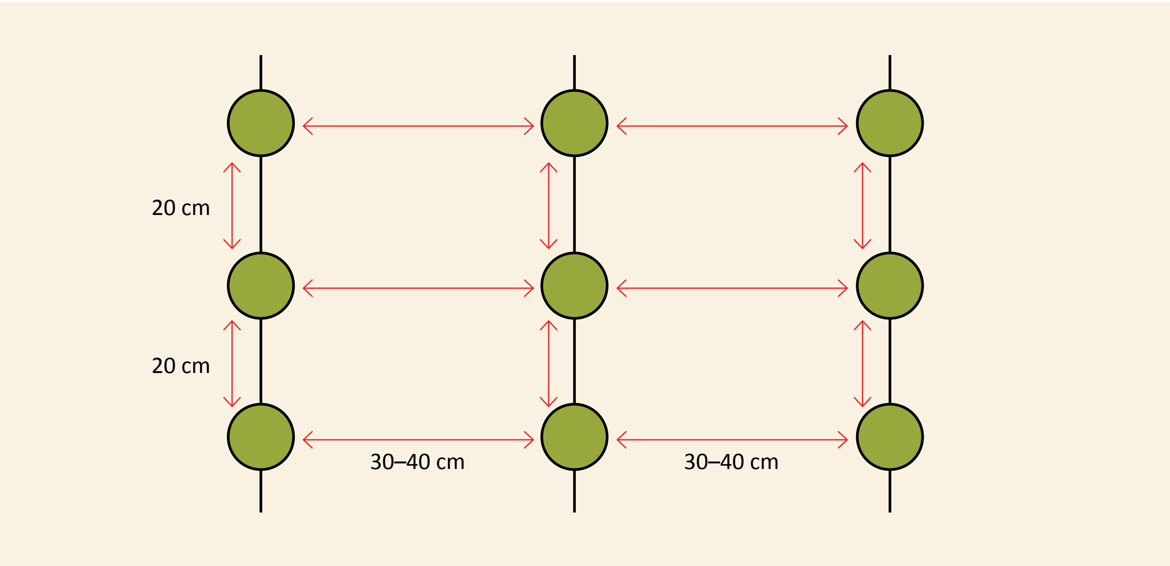



**FIGURE 23.** Recommended planting configuration for soybeans

DAP (diammonium phosphate) should be applied at or before sowing at a rate of up to 100 kg/ha. DAP contains 18% N, 20% P and 1.6% S.

Local rock phosphate is potentially a viable alternative to the increasingly expensive imported P fertilisers such as DAP (White et al. 1999), given the widespread P deficiency in most soils in Cambodia and the low cost of the rock phosphate. New fertiliser products developed from local rock phosphate deposits appear to be effective for rice production in Cambodia. There is potential to trial rock phosphate on upland crops as well as rice.

Research in Vietnam, the Philippines and Australia on acidic red upland soils showed that the best yield response to P fertiliser occurred when the fertilier was applied at 26–39 kg/ha of P at sowing, banded below the seed (Blamey et al. 2002). 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 be limiting crop growth in some acid soils.

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

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

It is very important to follow these recommended methods of fertiliser application to minimise losses of fertiliser nutrients due to volatilisation (N), surface run-off and erosion (P and K). Fertiliser needs to be placed near to, but not in contact with, the seed. Broadcasting fertiliser is not normally recommended because this might promote the growth of weeds as well as the crop. However, if this is the only available method of application, it will suffice.

Nitrogen is essential for crop growth. However, if soybean is inoculated with rhizobia (see Section 8) or is grown in soil that has recently contained well-nodulated soybean plants, additional N from fertiliser, such as urea, may not be required. A basal fertiliser application of 20 kg/ha of N plus rhizobium inoculation is recommended to give the crop a good start.

Finally, fertiliser should be applied after weeding so that weeds do not benefit from it.

# soybean
# soybean

# 7 Crop nutrition

## Soils and nutrient availability

Nutrition is extremely important for soybean, which has a high demand for soil nitrogen (N), phosphorus (P) and potassium (K). It also requires many other nutrients in smaller quantities.

Although many nutrients required to grow soybean can be found in the soil in abundant supply, some essential nutrients have a low availability to plant roots. Low fertility levels can be natural for the soil type or environment, or can be the result of many years of continuous cropping and removal of nutrients from the field in the harvested crop.

A well-nodulated soybean crop will supply most, if not all, of its own N, particularly on low-nitrate soils (see Section 8). However, fertiliser may be required to correct deficiencies of essential elements. This section provides recommendations for overcoming these deficiencies.

Another factor that strongly affects the availability of nutrients is pH, which is a measure of the acidity or alkalinity of the soil. The pH can be measured in a water (5% $H_2O$) or calcium chloride ($CaCl_2$) solution. The pH of soil in $CaCl_2$ can be up to one pH unit lower than the pH in 5% $H_2O$, so it is important to know which test was used.

Soybean can be grown in a wide range of soil pH levels (see Section 2). However, the optimal range is between pH 5.5 and 6.5 (in $CaCl_2$). Nutrient availability is affected by pH. Most nutrients are more readily available in neutral soils but tend towards deficiency or toxicity as soils become more acid or alkaline.

Soil tests at 50 sites in Kampong Cham province and 50 sites in Battambang province in 2004 by project and extension staff from the Australian Centre for International Agricultural Research (ACIAR) showed that Labansiek soils are moderately acidic (see Table 2 in Section 2). In more extensive analysis of soil pH in Tbaung Khmum, Ou Reang Ov and Ponhea Krek districts, some profiles of Labansiek soils were extremely acidic and severely limited soybean production. The soil groups of Prey Khmer, Prateah Lang and Toul Samroung are also acidic and are likely to have reduced P and molybdenum (Mo) availability. Availability of K, calcium (Ca) and magnesium (Mg) could also be affected, although levels of these elements are often not below the critical limit for healthy plant growth. Kampong Siem soils had a wide pH range from 5 (moderately acidic) to 8 (alkaline).

Very acidic soils can inhibit nodule formation. Low pH is also associated with high aluminium (Al) levels, which restrict root growth and yields. The impaired root growth, apart from reducing nodulation, may increase susceptibility to a range of nutrient disorders and to drought stress. Rhizobium survival will be reduced in soils with a low pH that have restricted access to Ca and Mo and the potential for toxic Al and manganese (Mn) levels. Soybean plants affected by Al toxicity generally have thickened, stubby and distorted roots, and overall growth is restricted if the plant survives at all.

Manganese is required in small quantities for enzyme activity. However, Mn toxicity can be a problem on acidic soils. Soybean suffering from Mn toxicity will commonly have reddish brown spots on old leaves. In addition, the young leaves develop interveinal yellowing, followed by crinkling and cupping of the leaf. These toxicities can be expected on acidic Labansiek soils and may lead to poor crop growth and even plant death.

If acidity is a problem, lime ($CaCO_3$) can be applied to increase pH. Lime is best applied a few months before sowing to allow time for the lime particles to move through the soil profile and change the pH in the upper root zone. Where soils are acidic, lime should be applied once every two or three crops, depending on soil pH changes after application of the lime. Use of lime is recommended on Labansiek soil. Dolomite ($CaMg(CO_3)_2$), if available, is recommended for Prey Khmer soil, which tends to be low in Mg.

If soil pH (5% $H_2O$) is above 7, the soil is alkaline. This is the case with some of the Kampong Siem soils in Battambang province. Alkaline soils may have low Mn, boron (B), iron (Fe) or zinc (Zn) levels.

Iron is necessary for photosynthesis. Strongly alkaline soils may have limited availability of Fe, which may result in stunted, spindly crops with interveinal yellowing of young leaves and low vigour. Soybean variety DT84 is moderately efficient at absorbing Fe from alkaline soils. Other varieties may be less susceptible to low Fe, but it is not possible to recommend a more suitable variety for growing in low Fe soils with the current level of knowledge of differences between cultivars grown in Cambodia. Iron deficiency may also inhibit nodulation.

Kampong Siem and Labansiek soils tend to have high levels of P. However, this P is strongly held in the soil particles and is relatively unavailable for uptake by plants.

# Uptake and removal of nutrients

Nutrients are removed when the harvested soybeans or trash from the soybean crop are removed from the field. Continuous cropping can deplete the soil reserves so that nutrients must be added to overcome depletion and ensure that essential nutrients are available to crops. Table 6 shows typical amounts of nutrient removed in a moderate-yielding (1.5 t/ha of seed) soybean crop.

**TABLE 6.** Nutrients removed by a moderate-yielding soybean crop

| | Nutrient | | | | |
|---|---|---|---|---|---|
| | N | P | K | Ca | Mg |
| Seed content (%) | 6.9 | 0.38 | 1.28 | 0.59 | 0.21 |
| Removed in a 1.5 t/ha crop (kg) | 103.5 | 5.7 | 19.2 | 8.85 | 3.15 |

ha = hectare; kg = kilogram; t = tonne
Source: Sale and Campbell (1980)

# Macronutrients

Macronutrients are those required by the plant in large quantities. Four essential macronutrients are N, P, K and sulfur (S).

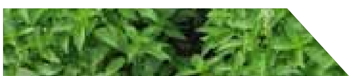
## Nitrogen

Nitrogen is a major essential nutrient used by soybean. It has many roles, including use in the production of proteins. Nitrogen is critical for the production of new plant material during soybean growth and has a major role in determining the number of pods and seeds produced by the plant. It is contained in the seed in relatively large amounts.

As a legume crop, soybean has the capacity to fix its own N. Nitrogen fixation is carried out by bacteria that attach to the root hairs and form nodules. These bacteria are able to convert N in the air into ammonium, which supplies the plant with N. This is explained in greater detail in Section 8. It is important to note that N supply will vary depending on the amount of nodulation that occurs. Nodulation requires adequate levels of the correct N-fixing bacteria in the soil.

In on-farm experiments in Kampong Cham and Battambang provinces, rhizobium inoculation increased soybean grain yield by an average of 12% compared with uninoculated treatments. Rhizobium survival is poor in acid soils, and liming may be required to increase the survival of rhizobia after inoculation. Rhizobia may not be present in soils where soybean has not been previously grown, and inoculation may be required for the first few soybean crops sown.





Provided that the plant has effective nodules, it should have an adequate supply of N. However, the application of low rates of N at sowing can ensure that N is not a limiting factor during seedling development. Although poor nodulation usually results in less N for the plant, an in-crop application of N is rarely recommended or economical. Ensuring effective nodulation is a more desirable N management option for soybean.

On acid soils, Al toxicity and Mo deficiency may inhibit nodule formation and thus N fixation. When such conditions exist, the crop may appear pale green and stunted from N deficiency. If this occurs, supplementary N fertiliser may alleviate the problem for that crop. As mentioned above, over the long term, liming should be considered to correct the acidity problem.

## Phosphorus

Soybean requires a relatively large supply of P to achieve good yields. One tonne of soybean seed contains approximately 7 kg of P (Table 6). Phosphorus is an essential macronutrient for plant growth and plays a key role in many physiological processes, such as energy transfer, photosynthesis, breakdown of sugar and starches, and nutrient transport within the plant. Phosphorus also has specific roles in nodule initiation and growth. It is particularly important in the early growth stages for healthy root development, which is why it should be banded below the seed at sowing for quick availability to the roots.

The availability of P varies between soil types and is strongly related to pH. As pH increases, P availability to the plant decreases, with a rapid decline above pH ($CaCl_2$) 7.0. Significant amounts of P can be made available if organic matter levels and rates of mineralisation are favourable. Phosphorus that is mineralised from organic matter is more beneficial than added inorganic fertiliser P because it is available for plant uptake for longer. A method of increasing the amount of organic P in the soil is to plant a green manure crop in the early wet season before planting soybean in the main wet season.

Sometimes P uptake can be improved if mycorrhizae are present in soybean roots. Mycorrhizae provide a symbiotic relationship between fungi and plant roots and can improve the uptake of P, copper and Zn.

Unlike some other crops, soybean takes up P throughout the growing season, until 10 days before the seeds reach full maturity. Phosphorus deficiency symptoms include retarded growth and small leaflets. In the early stages, the leaves are dark green or bluish green, which may confuse farmers by giving the impression of a healthy crop (Colton et al. 1995). As the deficiency develops, older leaves may appear to have dark-green mottling and may even develop brown spots and purpling along the stems and petioles (English et al. 2003).

## Potassium

After N, the nutrient absorbed in the largest quantity by soybean plants is K. Potassium is essential for crop growth and has many functions in the plant. Its primary role is to regulate the movement of water in the cells of leaf and stem tissue. It is also involved in protein synthesis, enzyme activation, photosynthesis and carbohydrate translocation in plants.

When grown in sandy soils, which are inherently low in nutrients, soybean commonly suffers K deficiency. Most other soils are less likely to be K deficient. However, deficiency may occur in other situations, particularly if there has been a long history of cropping without regular K fertiliser use.

Potassium deficiency appears first in old leaves, with yellowing of the leaf margins, which extends between the veins, possibly resulting in leaf death. Symptoms may first appear during periods of moisture stress and may not be evident on new leaves following rain.

To protect against K deficiency, fertiliser can be applied before sowing if the soil is deficient or likely to be deficient.

### Sulfur

Sulfur is used by the soybean plant in the synthesis of proteins, nitrogen fixation, formation of chlorophyll (where photosynthesis is carried out) and enzyme functioning.

Sulfur deficiency occasionally occurs in soils that are low in organic matter or acidic, sandy and leached of sulfates. Some soils with a long cropping history may also be deficient. Sulfur-deficient plants are pale green, especially in younger leaves. This contrasts with N deficiency, which is expressed as pale green foliage over the whole plant, especially older leaves. Stems in S-deficient plants are thin, hard and elongated.

## Micronutrients

Many nutrients—referred to as trace elements or micronutrients—are required by soybeans in small amounts. Iron, Mo, B and Zn deficiencies are common in soybean.

### Iron

Iron is important in enzyme function, particularly in the formation of chlorophyll. Iron deficiency is common in soybean grown on alkaline soils. Plants that are deficient in Fe have yellowing between veins on younger leaves, as iron is an immobile nutrient in the plant and is not readily moved from older leaves to new leaves.

### Molybdenum

Molybdenum is needed by legumes such as soybean for N fixation. Rhizobia use the enzyme nitrogenase to convert atmospheric N to a form that is available to the plant. Nitrogenase contains an atom of molybdenum at its core that is crucial for the reaction, and soils deficient in molybdenum cannot sustain effective N fixation. Monitoring soil for this element is important to ensure effective N fixation.

Plants that are deficient in Mo may appear pale green or yellow, similar to plants suffering from N deficiency, as Mo deficiency decreases N fixation. Molybdenum-deficient nodules are pale or green and stunted. Molybdenum deficiency can be expected on the acid soil groups: Prey Khmer, Prateah Lang, Labansiek and Toul Samroung. Adding Mo to a starter fertiliser at sowing or to superphosphate can minimise Mo deficiency. Alternatively, Mo can be applied as a foliar spray. Applying lime to raise the soil pH can also increase Mo availability over the longer term. Seed harvested from soils with adequate Mo levels may contain enough Mo for the growth of an entire crop without addition of Mo fertiliser.

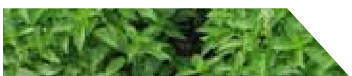
### Zinc

Zinc has many functions in soybean plants and is a component in several enzymes. Zinc deficiency commonly occurs on alkaline soils. Deficiency symptoms include yellowing between the veins of young leaves and stunting of the main stem and leaves. However, marginal Zn deficiency can result in yield loss without any apparent symptoms. Severe deficiency will stunt plants, cause death of leaf margins, and result in many empty pods and substantial yield loss (Colton et al. 1995). If soil Zn levels are low, a fertiliser containing Zn should be applied as part of a basal fertiliser at sowing, or as a foliar spray within 2–4 weeks of sowing.

## Fertiliser

Nutrients need to be supplied in sufficient quantities to allow the crop to achieve its yield potential. In particular, fertiliser can be applied to provide the main essential nutrients discussed above, including N, P, K and S. Micronutrients can be applied as solids in a mixture with other solid fertilisers, as a seed-coat dressing (e.g. Mo) or by foliar application. The most suitable form to use will depend on the particular nutrient that is targeted, as well as factors such as the timing of application, crop health, soil moisture, climate and availability of product.





The rate (quantity per hectare) of nutrients required by the crop depends on target yield, soil moisture, soil type, pH, climate, variety and management practices. For a legume such as soybean, it is important to determine whether the crop is well nodulated, as this influences the requirement for N and affects the choice of a suitable fertiliser regime.

It is important to know the fertility status of the soil and to ensure that the soil has enough nutrients to grow the crop. Crop demand for fertilisers can be assessed by soil and plant analysis and by observing visual symptoms of nutrient deficiencies.

Soil can be sampled from the top 20 cm of the profile using a hand-held auger. A number of samples (10–25) should be taken across the area and mixed together, and then a subsample taken from this mixture. For accuracy, all equipment should be clean, and atypical areas, such as tree stumps, animal camps and old fencelines, should be avoided. The samples must be tested as quickly as possible and kept cool. Samples can be tested at a laboratory, or simple field tests can be used to provide an indication of pH and the nitrate and organic carbon available to the plant (Table 2 in Section 2).

It is advisable to test soil to determine its nutrient status 1–2 months before sowing, to calculate how much additional fertiliser is required to meet target soybean yields.

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

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

**TABLE 7.** Chemical analysis of common fertilisers available in Cambodia

| | Analysis on the bag (%) | | | Actual nutrient (%) | | | |
|---|---|---|---|---|---|---|---|
| Fertiliser | N | $P_2O_5$ | $K_2O$ | N | P | K | S |
| Urea (46:0:0) | 46 | 0 | 0 | 46 | 0 | 0 | 0 |
| DAP (18:46:0) | 18 | 46 | 0 | 18 | 20 | 0 | 1.6 |
| MAP (12:61:0) | 12 | 61 | 0 | 12 | 26 | 0 | 0 |
| 15:15:15 | 15 | 15 | 15 | 15 | 6 | 12 | 0 |
| 16:16:00 | 16 | 16 | 0 | 16 | 7 | 0 | 0 |
| 16:20:00 | 16 | 20 | 0 | 16 | 9 | 0 | 0 |
| 20:20:15 | 20 | 20 | 15 | 20 | 9 | 12 | 0 |

K = potassium; $K_2O$ = potassium oxide; N = nitrogen; P phosphorus; $P_2O_5$ = phosphorus pentoxide

# Fertiliser application strategies

As very few upland farmers in Cambodia currently use fertiliser to grow upland crops, preliminary fertiliser recommendations have been developed as a guide for soybean production in Cambodia. Soil testing is needed before more definitive values can be proposed. These recommendations have been determined using generalised fertiliser rates determined for elsewhere in South-East Asia and adjusted for Cambodia based on the expected yield, limited Cambodian trial data and soil analysis of a limited number of profiles.

DAP (diammonium phosphate) should be applied at 100 kg/ha at planting time to ensure that the plant has adequate P available in the early stages of development. DAP will also supply a small amount of N to the developing seedling. If P availability is likely to be very limited, monoammonium phosphate (MAP), if available, should be used, as it has half the N concentration of DAP and can be applied at high rates—up to 200 kg/ha—without burning the soybean seed. A rate of 200 kg/ha of MAP would supply P at 44 kg/ha and N at 20 kg/ha.

If soil is deficient in K, MOP (muriate of potash, which is 50% K) should be supplied at 50–100 kg/ha. If available, sulfate of potash could be a viable option, as it provides both K and S (if sulfur is also limiting). These fertilisers are best applied at sowing, either before a rain event or before the final cultivation, to incorporate the fertiliser and thus reduce losses and move the fertiliser into the root zone.

Sulfur in the form of sulfate (which can be taken up by plants) is contained in many fertiliser compounds. A basal rate of 20 kg/ha of S could be applied for moderate S deficiency. A small quantity of S should be applied each year to replace nutrient removed in seed and maintain soil fertility levels.

Iron deficiency can be managed by applying foliar ferrous Fe or by using chelated Fe in both soil and foliar spray. Foliar spray would need to be applied every 10–15 days to ensure sufficient Fe for new leaves (English et al. 2003). Varietal selection is a better strategy for overcoming Fe deficiency.

Molybdenum deficiencies can be overcome by applying a Mo seed dressing before sowing.

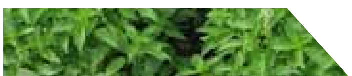
Zinc deficiency is possible on alkaline soils throughout Battambang province. Farmers should consider adding a Zn fertiliser (e.g. zinc sulfate monohydrate) to the starter fertiliser (DAP with 2% Zn) at sowing. Zinc deficiency also occurs in acid sandy Prey Khmer soils in Tram Kak district.

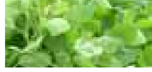
# In-crop fertiliser application

Application method and timing are critical to ensure maximum benefit from using fertiliser. The following is a list of recommendations for fertiliser application:

- Mix all fertilisers thoroughly before each application. Do not delay application after mixing since this can result in significant losses of nutrients, and mixtures can become caked or cemented, making them unusable.
- Place fertilisers in or beside the planting hole and cover them with soil before planting the seed to minimise contact with seed and reduce fertiliser loss due to volatilisation (N) and surface run-off (P and K).
- Apply fertiliser after weeding so that weeds do not benefit from applied fertilisers.





# 8 Rhizobium inoculation and nitrogen fixation

## Legumes in farming systems

Soybean can have an important role in farming systems, due to its ability to supply its own nitrogen (N) as well as to produce valuable seed. Soybean supplies its own N through a process known as biological nitrogen fixation (simplified to‘N fixation’), which can supply a soybean plant with most or all of its N requirements without the addition of N fertiliser.

Non-legume crops grown after soybean may also benefit by having access to the N left in the soil after the soybean crop has been harvested and the crop residues have broken down. The amount of N added to the soil by a legume crop varies and will depend on a range of environmental variables.

## Role of rhizobia

The N fixation process results from the symbiotic relationship between the soybean plant and a special group of bacteria in the soil called rhizobia (*Bradyrhizobium* spp.). The plant helps the rhizobia by providing them with sugars for energy, and the rhizobia help the plant by providing it with N for growth. The rhizobia enter the plant via the root. Special tissue develops around the rhizobia after they enter the root, causing the root to swell and a lump or nodule to develop (Figure 24). The N fixation process takes place inside these nodules.

**FIGURE 24.** Rhizobium nodules on soybean roots

## Biological nitrogen fixation

Eighty per cent of Earth's atmosphere is nitrogen gas ($N_2$), but plants cannot use N in this form. Rhizobia, with the help of the enzyme nitrogenase, can convert $N_2$ into ammonia ($NH_3$), which the plant can readily use. This conversion of $N_2$ to $NH_3$ by rhizobia is known as N fixation.

For a soybean plant to form nodules and fix N, it needs to make contact with rhizobia in the soil. However, there are different species and strains of rhizobia, and they cannot all infect and nodulate soybean plants. Rhizobia are grouped according to the legume plant they can infect and nodulate. Some groups of rhizobia can infect several species. For example, the group of rhizobia that infect mungbean also infect cowpea, but they cannot infect soybean. To maximise the amount of N made available to the plant, it is very important to match the right rhizobium group with the right legume crop. Soybean can be inoculated with manufactured inoculants such as Group H rhizobium, strain CB1809 (Becker-Underwood).

Within a soybean rhizobium group, different strains vary in their effectiveness at N fixation. Some strains are good and some are poor at fixing N. The better or more effective the rhizobia are at fixing N, the more N is provided to the soybean plant and the better it will grow. Soils may naturally contain rhizobia that survive on organic matter. These native rhizobia may be able to infect a soybean crop and form nodules. This is why soybeans are sometimes found with effective nodules in soils that have never had rhizobia added to them. Often, however, the numbers of native rhizobia are very low, and few nodules are formed. Therefore, the best practice is to ensure that high numbers of good N-fixing rhizobia are available to the soybean plant by inoculating the seed with rhizobia obtained from a reliable source.

Soil, climate and biological interactions can affect the rhizobium symbiosis. Waterlogging, drought, very acidic soil and nutrient deficiencies will reduce N fixation. The optimal temperature range for enzyme acitivity in the N fixation process is 25–35 °C. Light availability is also essential to ensure an adequate supply of photosynthate (sugars produced by the plant) to the nodules. Shading will reduce N fixation, as will insect and nematode attack. The plant's health and ability to provide energy to the nodules affect the plant's capacity to fix N.

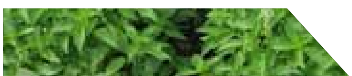
## Survival of rhizobia in the soil

The survival of soybean rhizobia in the soil depends on many factors. For example, survival is influenced by the length of time since soybean was grown in a field. If a long time has passed since soybean was grown, or it has never been grown before, rhizobia are likely to be present in very low numbers or not at all. In these cases, it is best to add effective rhizobia. Environmental conditions will also affect the survival of rhizobia. If there have been extended periods of hot, dry weather, numbers of rhizobia will decline. In this case, it is recommended that rhizobia be added to the seed when the soybean crop is planted.

## Inoculation

Rhizobia can be commercially produced in laboratories and bought by farmers to apply to their fields. A variety of materials or 'carriers' can be used to carry the rhizobia to the soil. The most common carrier is peat. The rhizobia are added to the peat and produced as commercial inoculants (Figure 25), which may then be added to the seed or applied directly to the soil. The most common method is to coat the seed in a peat inoculant just before sowing.





## Peat inoculants

The steps for inoculating soybean seed with peat-based inoculum are outlined below. As the peat is a dry powder, it does not stick to the seed very well, so a sticker solution needs to be added to help it adhere to the seed. A simple sticker solution can be prepared by dissolving 10 g of sugar in 100 mL of cold water.

The sticker solution is then combined with the inoculant to help it stick to the seed, and then spread evenly over the surface of the seeds (Figure 26). It is recommended that seeds be coated with inoculant immediately before planting to minimise rhizobium death. Leaving the coated seed in full sun or hot, dry conditions for more than 20 minutes will result in death of rhizobia, reducing the numbers added to the soil.

### Steps for inoculating soybean seed with peat inoculant

1. **Weigh the amount of seed to be sown.**
2. **Calculate the amount of inoculant needed, using the following formula:**

   **Inoculant needed (g) = weight of seed (kg) × 5**

   It is better to have too much inoculant than not enough. ***There is no such thing as too much inoculant.***

   For 20 kg of soybean seed, the amount of inoculant required would be 20 × 5 = 100 g.
3. **Calculate the amount of sticker solution required, using the following formula:**

   **Sticker solution needed (mL) = weight of seed (kg) × 10**

   It is important to use the right amount of sticker to evenly coat all soybean seeds.

   For 20 kg of soybean seed, the amount of sticker solution required would be 20 × 10 = 200 mL.
4. **Thoroughly mix the inoculant and sticker solution together. This is called the slurry.**
5. **Place the seed in a large mixing bowl and slowly add the slurry, while mixing. Keep mixing until all seeds are evenly coated. Allow to dry briefly before sowing.**

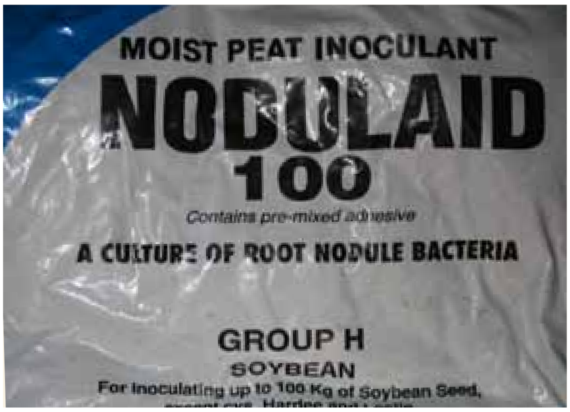



FIGURE 25. Commercial peat-based rhizobium inoculant produced by Becker-Underwood in Australia

FIGURE 26. Soybean seed with good coverage of peat-based rhizobial inoculant

### Liquid inoculants

Liquid rhizobial inoculants can be obtained from the Suranaree University of Technology at Nakhon Ratchasima, north-eastern Thailand (Figure 27). If ordered in advance, the university can produce inoculants in lots of up to 5,000 bottles at one time. The university can produce inoculants for mungbean, peanut, soybean and forages such as *Glyricidia* spp. and *Stylosanthes* spp. The cost in 2010 was 20 baht for 100 mL—enough for 10 kg of soybean seed.

The steps for applying liquid inoculants are as follows:

1. Into a clean mixing container, pour one bottle (100 mL) of liquid inoculant onto 10 kg of soybean seed.
2. Gently mix the inoculant with the seed. You can mix with your hands, but use rubber gloves if you prefer.
3. Spread the mixture on a clean ground sheet in the shade to allow the inoculant to dry on the seed (keep out of the sun at all times).

## Storing inoculants

Rhizobia are living organisms and are susceptible to extreme conditions, such as hot, dry weather, which can cause the rhizobia to die before they reach the soil. To avoid death of rhizobia, it is recommended that the inoculant is stored in a cool place, between 4 °C and 26 °C. If refrigeration is not available, it should be stored in a cool place out of direct sunlight.

## Response to inoculation

A simple method to evaluate if inoculation has been successful is to carefully dig up 10 soybean plants at the start of flowering and look for nodules on the roots. Counting the number of nodules on the roots and giving them a score from 1 to 5, as guided by Table 8, may be used as a measure of nodulation.

Where the level of soil N available to plants is low, the crop depends heavily on good nodulation for its N supply, and a score of 4–5 is desirable (Table 8). A high score indicates that the crop will yield well and conserve soil N for use by a following crop. A low score suggests that the crop will yield poorly and will deplete soil N. If the crop scores between 0 and 2, immediate application of urea may be required to provide enough N for the crop to meet its yield potential.


**FIGURE 27.** Liquid rhizobial inoculants from Suranaree University of Technology, Thailand

**TABLE 8.** Nodulation scoring system for measuring the success of inoculation of a flowering soybean plant

| Score | Number of nodules/plant |
|---|---|
| 1 | 0–10 |
| 2 | 10–30 |
| 3 | 30–60 |
| 4 | 60–100 |
| 5 | >100 |

Although the number of nodules is important, it is also important to break open some nodules and note the colour of the flesh inside. Figure 28 shows healthy, pink nodules that are fixing N for the soybean plant. These are called effective nodules. Small nodules that are green, white or brown in colour are not fixing N and are called ineffective nodules.

Successful inoculation practices can improve nodule numbers on soybean roots and increase the amount of N available to the plant. Increased N may increase yield and seed protein and reduce input costs.

Sometimes there is no visible benefit from inoculation. Many environmental factors affect the number of nodules formed and the amount of N fixed by a legume plant. N fixation will be limited if soybean is planted in a field with high N fertility. This is because the soybean plant is 'lazy' and uses the N that is already in the soil rather than obtaining its own through N fixation. If a field has a high level of N fertility, it may be better to grow a cereal crop such as maize, which is not able to fix its own N. It is more economical to plant soybean in fields with low N and take advantage of the ability of soybean to fix N. This saves money on fertiliser for the soybean crop and possibly the next crop as well.

Nitrogen fixation is also related to the growth stages and N requirements of plants. Fixation peaks during early pod development and declines during late pod fill. In addition, poor plant growth due to disease, poor nutrition or lack of soil moisture will reduce the N requirement of the crop and therefore reduce nodulation and N fixation. Thus, it is important to ensure good field selection and crop agronomy to maximise the N fixed by legume crops such as soybean. With good nodule growth and favourable soil and weather conditions, a soybean crop can fix up to 280 kg of N per hectare.

**FIGURE 28.** Liquid rhizobial inoculants from Suranaree University of Technology, Thailand

soybean

soybean

# 9 Crop protection

## Integrated pest management

Soybean yields can be significantly reduced if diseases, insect pests and weeds are not managed effectively. Farmers can use a number of tools and strategies to manage pests, including:

- ensuring that the soybean crop is as healthy as possible to compete with pests
- 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—these organisms are the first line of defence in integrated pest management (IPM)
- using pesticides strategically, if required, and rotating chemical groups to minimise the risk of organisms developing resistance to specific groups
- controlling host plants, such as volunteer soybean and 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 soybean crop, thus reducing the area that requires pesticide control
- communicating with neighbours and other farmers in the area to incorporate area-wide management of pests, where possible
- selecting soybean varieties that have good resistance to pests and diseases.

### Area-wide management

Area-wide management is the development of a pest management strategy to control pests to below economic threshold levels across a whole area (village or 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. Excellent cooperation, coordination and communication are required for this strategy to function successfully.

### Basic rules of IPM

Just because pests are in the crop does not automatically mean that control is needed. Farmers need to:

- check if damage is significant
- monitor levels and interactions of pests and beneficial organisms.

If pest control is necessary, non-chemical control methods should be considered before pesticides.

Use of a broad-spectrum synthetic pesticide (e.g. alpha cypermethrin) is a last resort when pests are above thresholds and there are no effective natural (‘soft’) options. Examples of pest-specific soft options include *Bacillus thuringiensis* (commonly called Bt) and nucleopolyhedrovirus (NPV).

IPM is using all the tools and strategies listed above in managing pest populations to minimise reliance on pesticides in an economical way. It is important to be able to identify various insects, diseases and weeds to determine an effective IPM strategy. Sections below give an overview of some of the pests that are currently or potentially a problem in upland crops in Cambodia. A field guide to identifying pest and beneficial insects of upland crops in Cambodia is available online (Pol et al. 2010).

## Beneficial organisms

The key to IPM is to preserve the 'beneficials'. These are organisms such as ladybirds, lacewings and bacteria that feed on or parasitise pests of the crop. Types of beneficials are described below.

### Predators

Predators actively capture their prey. They include ladybirds, hoverflies, earwigs, predatory shield bugs, praying mantids, wasps and spiders, as in the following examples:

- Most ladybirds are beneficial as both adults and larvae, feeding primarily on aphids. They also feed on mites, small insects and insect eggs.
- Adult hoverflies feed on pollen and nectar, while the larvae feed on aphids and other soft-bodied insects.
- Predatory wasps are often important predators of caterpillars. The social paper wasps harvest caterpillars, which are chewed up and then fed to developing larvae at the nest.
- The predatory shield bug, *Oechalia schellenbergii*, has piercing and sucking mouthparts and preys mainly on caterpillars.
- The larvae of most lacewing families are predators. Many eat aphids and other pest insects.

### Parasitoids

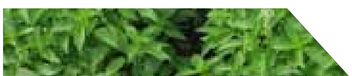
Parasitoids are insects with an immature life cycle stage that develops on or within a single insect host, ultimately killing the host.

Tachinid flies, which can reach large numbers, parasitise the larvae and eggs of a wide range of insects, including important pests such as *Helicoverpa*. They usually lay their eggs close to the head of the pest larva, and sometimes in the egg chamber of the host. They do not kill the host until after the caterpillar has finished feeding, and therefore do not prevent crop damage by that generation of the pest. However, tachinid flies can help reduce the size of following *Helicoverpa* generations and thus reduce future damage.

*Trichopoda* is a genus of small, brightly coloured flies that range in size from 5 to 13 mm. The flies have a distinctive fringe on the hind legs. The eggs are laid on adult or late nymphal stages of *Nezara viridula* (green vegetable bug). On hatching, the maggot bores into the body of the host and feeds on the host's fluids for about 2 weeks. When fully grown, the maggot emerges, killing the host, and pupates in soil. The adult fly emerges after about 2 weeks. *Trichopoda* species have been released as a biological control for *N. viridula* in various parts of the world. Parasitism rates can be as high as 50%, but there is conflicting evidence of the effectiveness of biological control by this parasite.

### Pathogens

Pathogens are viruses, fungi or bacteria that naturally infect insects. Many naturally occurring diseases infect and kill insects. Insect larvae can be infected by pathogens such as NPV and the fungal pathogens *Metarhizium*, *Nomurea* and *Beauvaria*.



Two pathogens are available commercially to control insect larvae: NPV and the bacterial toxin from Bt. Bt is used as a microbial insecticide (e.g. Dipel) for effective control of many types of butterfly and moth larvae, including some, such as cabbage loopers, that are hard to control by other means. Bt products are generally considered safe for people, bees, predatory and parasitic insects, predatory mites and spiders, and the environment.

## Cultural methods

Agronomic practices can also be used to reduce insect pest abundance and damage.

Plant resistance to insects is one of several cultural control methods. In IPM, plant resistance to insects refers to the use of resistant crop varieties to suppress insect pest damage. Plant resistance is used in conjunction with other direct control tactics.

## Trap crops

The aim of a trap crop is to attract pests and concentrate them in a small area where they are easy to control. In Vietnam, sunflowers are used as a trap crop for the two major pests of peanut, *Spodoptera litura* and *Helicoverpa armigera*. These insects prefer sunflower to peanut.

## Companion planting

Lemon basil (*Ocimum basilicum citriodorum*) repels aphids, tomato hornworm, mosquitoes and whitefly. It has small, pale green, serrated leaves, with a distinctive point to their end (Figure 29). It originated in Indonesia and, as the name suggests, has a lemony taste and aroma. Lemon basil seed grown in Cambodia is sold in Vietnam for use as a beverage.

In Thailand, lemon basil is promoted as a natural insecticide. The leaves are crushed and mixed with water and applied to other crops to repel leaf-eating insects. Lemon basil could, therefore, be useful as a companion plant in an upland crop IPM strategy, with the additional benefit of providing cash income.

**FIGURE 29.** Lemon basil

Some farmers in the Chamkar Leu district in Kampong Cham intercrop lemon basil with soybean in the main wet season. As lemon basil is a very competitive crop, it is recommended that it be planted after the soybean crop has reached maturity to avoid losing soybean yield. Alternatively, planting the lemon basil around the perimeter of the soybean crop could minimise competition while still providing pest-control benefits.

## Implementing IPM

Soybean crops in a tropical environment such as Cambodia are regularly subject to insect attack from a wide range of species, which may result in extensive damage. In the vegetative phase, soybean can suffer up to 35% leaf loss without yield reduction (Figure 30). However, once plants reach early pod fill, this figure drops to 15% leaf loss, as photosynthetic area is increasingly important to maximise yield potential. Damage to seedlings before the third node stage is fatal, as plants are unable to compensate and regrow until this stage, when they begin to form axillary buds (see Section 4, 'Vegetative development').

The first step in managing insect pests is to identify the insect and determine the numbers present. It is vital to know the difference between pests and beneficials (good insects).

Crops should be checked regularly to determine the extent of an insect infestation and to assess the damage being caused. This includes monitoring every 3 days from flowering to physiological maturity. This information can then be used to determine whether control is required and to decide on the most suitable management method.

A simple way to find out what types of insects are in the crop is to use a sweep net (Figure 31), which gives a quick indication of the species present. The operator sweeps the net back and forth across the top third of the leaf canopy eight times. They then close their hand around the net to stop insects escaping and observe what they have caught.

The beat sheet is the best method to accurately assess threshold levels for major insect pests and beneficials. Samples are taken early to mid morning, using a beat sheet that is 1.3 m × 1.5 m (Figure 32). The operator takes five samples within a 20 m radius, in three locations across the field.


**FIGURE 30.** Soybean leaves showing the range of leaf loss (5–45%) in the vegetative phase

**FIGURE 31.** Use of a sweep net to determine what insects are present in the crop

**FIGURE 32.** Use of a beat sheet to assess insect thresholds

## Economic thresholds

Pest and damage thresholds are a core component of IPM. They provide a rational basis for pest control decisions. Thresholds can be based on the abundance of the pest, the damage they cause or a combination of both.

The economic threshold is the level at which the pest population is likely to cause damage that is equal to the cost of control. Farmers should spray only when pest numbers are above the economic threshold.

Farmers should not apply insecticide when pests are below the economic threshold because:

- it is a waste of money
- it may result in an increase in the number of pests if beneficials are killed early
- it speeds up the development of insecticide resistance.

Effective use of thresholds depends on accurate, objective sampling to provide reliable estimates of the levels of pests and/or damage.

### Leaf loss in soybeans

Economic thresholds for leaf loss in soybean are:

- vegetative stage: up to 35% leaf loss can be tolerated until the start of flowering (Figure 30)
- early pod fill: the threshold decreases rapidly to 15% leaf loss
- pod fill: 2 larvae/m$^2$.

### Pod-sucking insects

The most common and most damaging pod-sucking insect is the green vegetable bug (*Nezara viridula*). Other important pod-sucking insects are the red-banded shield bug (*Piezodorus hybneri*) and the brown bean bug (*Riptortus linearis*).

Crops remain at risk from attack by pod-sucking bugs until very close to harvest, as even seeds in ripening pods can be damaged. Most yield damage occurs during a 2-week period from early to mid pod fill, but most seed quality damage occurs from mid pod fill to pod ripening.

When inspecting the crop, farmers need to look for eggs (noting the colour) and look in flowers and young leaves for larvae. Early detection and control are essential. Larvae larger than 5–10 mm may not be controlled effectively. Pest numbers should be recorded per metre of row, and this measurement should be converted to pests per square metre using the row spacing

The amount of damage from pod-sucking insects that the soybean can tolerate depends on:

- the age of the bugs (nymphs or adults)
- the time remaining to harvest
  - the longer to harvest, the more nymphs will reach a damaging size
  - the longer to harvest, the more bug damage, and the lower the threshold
- the size of the crop (seeds per unit area): the more seeds, the more bugs are needed to produce critical (2%) damage.

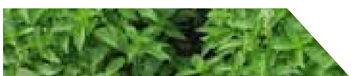
Spray thresholds are 1.0 bug/m$^2$ for the green vegetable bug, 1.3/m$^2$ for the red-banded shield bug and 1.5/m$^2$ for the brown bean bug. The damage potential of a mostly nymph population decreases as maturity approaches, and is only ever 56% of that for the adult-only population.

Spray thresholds for the green vegetable bug are 1.0/m$^2$ for crushing beans and 0.33/m$^2$ for edible beans.

The crop should be checked between 7 am and 9 am when the adult bugs are most likely to be active on top of the foliage canopy. They seek shade beneath the canopy during the heat of the day. Shield bug nymphs are easily seen because they are brightly coloured and live in clusters. Adult bugs are best sampled by shaking plants over a standard beat cloth. Brown bean bugs are more likely to fly away when disturbed.

Because nymphs are very aggregated (i.e. not uniformly dispersed) in a crop, a large number of sites need to be sampled across the field to accurately assess the number of nymphs, or even to detect nymphal clusters where bug numbers are low.





# Types of insecticides

## Biological insecticides

Biological insecticides, which are known as 'soft' insecticides, preserve beneficial insects while being safe for the environment and user. NPV (e.g. Gemstar) is a virus specific to insects that was developed to control *Helicoverpa*. Bt (e.g. Dipel) is a bacterial biological insecticide that is used to control a wide range of caterpillar pests, including *Helicoverpa*.

Spinosad (e.g. Success) is based on naturally produced metabolites of the soil micro-organism *Saccharopolyspora spinosa*. Although spinosad is broken down in 2–3 days by ultraviolet light, its movement into the leaf results in the product having a longer residual effect. Spinosad has relatively low toxicity to most beneficial insects.

## Broad-spectrum insecticides

Broad-spectrum insecticides are known as 'hard' insecticides. They kill many natural enemies that help control pests, and application of these insecticides sometimes causes dramatic increases in pest populations. Examples of hard insecticides are organochlorines, synthetic pyrethroids and carbamates. Broad-spectrum insecticides such as cypermethrin should be used as a last resort because they kill beneficial insects as well as the pest. They will control larvae and some sucking pests.

# Integrated pest management strategy for soybean

## Vegetative stage—pre-flowering

Only soft biopesticides should be used pre-flowering for control of moth larvae such as *Helicoverpa* if vegetative thresholds are exceeded. Bt is currently the only option available in Cambodia.

## Reproductive stage (R)

**Podding (R3–R4)**

Steward (indoxacarb) should be used for *Helicoverpa* at podding but may not be available in Cambodia. The alternative is to use a hard insecticide such as cypermethrin, but only if the spray threshold has been reached.

**Early pod fill (R4–R5)**

Spraying of pod-sucking bugs should be delayed until early pod fill, and should only take place when the threshold is reached. Deltamethrin (a pyrethroid) and dimethoate (an organophosphate) can be used to control pod-sucking bugs. Deltamethrin is more effective than dimethoate. Various trade names of deltamethrin and dimethoate are available in Cambodian markets. These are hard insecticides but, unfortunately, no soft insecticides are available to control sucking pests.

# Insect pests

## *Helicoverpa armigera* (bean podborer)

### Description

Moths are 35 mm long. Newly hatched larvae are white in colour, with dark heads. Larvae go through up to six stages (instars). As they grow, they become darker, with dark spots on their segments, but they vary widely in colour. Medium larvae (10 mm long) have lines along the side of their body and a saddle of darker colour on the fourth segment back from the head. Large larvae are 35–40 mm long and have white hairs around the head and on the body.

### Damage

Most damage is from feeding on tips, buds, flowers and pods. Larvae will also feed on leaves, but this is not usually significant.

## *Spodoptera litura* (cluster caterpillar)

### Description

Moths are up to 25 mm long. Eggs are laid in clusters of up to 300. As larvae grow, they develop obvious black triangles along each side of the body. They grow up to 30 mm long. Larvae are narrowest at the head. They are generally quite hairless.

### Damage

The female lays clusters of eggs under the leaves, and the first larval instar feeds on the lower leaf surface, creating a 'window pane' effect. Later, the larvae feed on the whole plant at night. The larvae bury themselves in the soil during the day. The damage becomes progressively worse, starting at the margins of leaves and moving inward, as the larvae eat entire leaves or defoliate plants. Occasionally, the larvae will cut plant stems at ground level and feed directly on pods.

## *Aphis glycines* Matsumura (soybean aphid)

### Description

These pear-shaped insects are small and yellow, with a black tube protruding from each side of the rear end of their bodies. Some have clear wings. All growth stages may be living together.

### Damage

Both adults and nymphs feed on tender parts of young plants, resulting in stunted growth with poor development at the growing tips. If infestations are severe, the entire stem dries up and dies, sometimes followed by the plant. Aphids may also transmit viruses (see 'Diseases of soybean', below), which cause major yield reductions in soybean in Cambodia.

## *Nezara viridula* (green vegetable bug)

### Description

Adults are 15 mm long and bright green all over. Nymphs go through five different instar stages, when they change colour and pattern. Initially, they are orange and black; later, black, red and yellow patterns develop; eventually, green is dominant. Eggs are laid in rafts of 60 to 100 in a trapezium shape.

### Damage

Adults and nymphs pierce and suck developing seeds and pods, which may be lost or deformed, or show hard, dark marks. Feeding stunts and distorts the growth of immature fruit. Pods may drop off the plant before they are mature, reducing pod numbers. The feeding wound also provides an entry point for fungal and bacterial infections.

## *Stomopteryx subsecivella* (soybean leaf miner)

### Description

Larvae are grey–green, with a shiny black head. Moths are mottled grey, with a wing span of up to 18 mm, and are weak fliers.

### Damage

Heavy infestations of soybean leaf miner are common during the Cambodian wet season, especially during the vegetative to fruiting stage. Characteristic symptoms of leaf miner presence include leaves folded over with a small caterpillar inside each fold. Young larvae feed within the leaf for 3–4 days until they emerge and fold or web individual leaves together.

## *Callosobruchus chinensis* (Chinese bruchid) and *C. maculatus* (cowpea seed beetle)

(No photo available)

### Description

Adults are 3–4 mm long, globular in shape and mottled in appearance. They have long legs and antennae. Eggs are glued singly on the pod or seed.

### Damage

Crops may be first infested in the field before harvest, leading to transfer of insects with the harvested grain. Consequently, this may also lead to re-infestation of seeds contained in the same storage facility. When larvae hatch, they bore directly into the seed, where their development continues as they eat out the seed. Adults emerge through windows in the grain, leaving round holes that are the main evidence of damage. Insect damage can cause heating and extensive mould growth, reducing the quality of the grain.

## *Riptortus linearis* and *R. serripes* (brown bean bug)

### Description

*Riptortus linearis* and *R. serripes*, the large brown bean bugs, have yellow or cream stripes along each side, respectively. The nymphs look like ants but have the sucking mouthparts of bugs. Eggs are laid singly and are dull purple in colour. They are flat on top and rounded underneath.

### Damage

Adults and nymphs pierce and suck on developing seed and pods, resulting in deformed or discoloured seed. Pod development is reduced in heavy infestations.

# Beneficial insects

Some beneficial insects (predators and parasitic wasps) commonly occur in soybean crops. Farmers should be able to distinguish these insects from soybean pests and use them as a tool in IPM. When present in high numbers, these beneficial insects may be effective in controlling pests and preventing yield loss.

## *Oechalia schellenbergii* (spined predatory shield bug)

### Description

Adults are 12 mm long and shield shaped, with obvious spines at either side of their shoulders and a light mark in the middle of their backs. Nymphs are almost black, with a red ring on their backs. Eggs are laid in rafts and are dark in colour with white spines sticking out.

### Impact on pests

The adult and older nymphs use their beaks to pierce insects, especially *Helicoverpa*, loopers and other caterpillars, and suck out the body contents.

## Predatory ants

### Description

Ant colonies 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 but are more numerous. Queens are obviously larger than all other ants. Predatory ants will have conspicuous ant mounds in the field or nearby.

### Impact on pests

Predatory ants attack termites, wireworms, moth eggs, small larvae and leafhoppers.

## Earwigs

### 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.

### Impact on pests

Earwigs commonly occur in field crops such as maize, soybean and mungbean as a predator of caterpillars, pupae and wireworms.

## *Cheilomenes sexmaculata* (six-spotted ladybird)

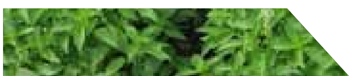
### Description

Adults are 3.3–6.2 mm long and 3.0–5.3 mm wide. They are oval in shape and shiny, with orange, light red, yellow or pinkish colouring. Six black spots are present on the wings, including two zigzag lines and a rear black spot. Larvae are a dark slate-grey to brown, with yellowish patches. Pupae are yellow with black spots.

### Impact on pests

The adults and larvae of ladybirds are important predatory insects in field crops. Adults mainly feed on *Helicoverpa* eggs and aphids, while nymphs will also eat *Helicoverpa* hatchlings. Other pests targeted include whitefly, leafhopper, thrip and scale insects. Two or more per plant may make a useful contribution to IPM.





# Diseases of soybean

It is difficult to determine the extent of yield losses in soybean in Cambodia as a result of disease. However, soybean diseases can reduce yield potential, interfere with normal physiological development, induce lodging and lower grain quality. The occurrence and impact of a disease depends on a number of factors, including climatic conditions, plant health and variation in resistance of host plant varieties.

It is important that farmers and advisers are able to recognise diseases in the field so that management strategies can be implemented in the affected crop as well as for future crops. Diseases can be difficult to identify and should be diagnosed by a qualified plant pathologist or crop specialist.

The following is a list of diseases that infect soybean crops and may be a problem if conditions are favourable to disease spread. Several viruses infect soybean across Asia, and some of these probably occur in Cambodia. The major viruses likely to be present in Cambodian soybean are included below.

## Soybean mosaic virus

### Symptoms

Infected seeds may either not germinate or produce spindly, diseased seedlings with crinkled leaves and low vigour. Infected plants become chlorotic (yellow), stunted and mottled (mosaic patterns). Leaf edges often curve down at the sides. Pods may be affected in susceptible varieties, which produce flat, small, highly curved pods. Yield may be reduced significantly, with less seed produced and reduced seed weight. Quality can be reduced, as well as the price received due to discoloured seed.

### Management

Soybean mosaic virus is a potyvirus that can be transmitted in infected seed to other farms or fields. Within the field, the virus is also transmitted from plant to plant by aphids. Planting resistant or tolerant varieties is the best management practice. It is essential to use clean, high-quality planting seed that is free from disease and has high germination and vigour. Diseased plants should be pulled out in the field when they are first observed.

## Bean yellow mosaic virus

### Symptoms

Initial symptoms are the same as for soybean mosaic virus, and mixed infections of the two viruses are common. Infected plants become chlorotic and stunted, with a distinct yellow mottling of the leaves. Brownish red, dead spots occur in the yellow areas of the leaf as the leaf matures.

### Management

Bean yellow mosaic virus is a potyvirus that may remain in infected seed until the next planting and is also transmitted from plant to plant by aphids. Planting resistant or tolerant varieties is the best management practice. It is essential to use clean, high-quality planting seed that is free from disease and has high germination and vigour. Diseased plants should be pulled out in the field when they are first observed.

## Mungbean yellow mosaic virus

### Symptoms

Bright yellow patches give leaves a mottled appearance. Plants become chlorotic and stunted and have significant yield reductions.

### Management

Mungbean yellow mosaic virus is a bigeminivirus that is transmitted by whitefly but is not seed borne. Planting resistant or tolerant varieties is the best management practice. Diseased plants should be pulled out in the field when they are first observed.

## *Peronospora manshurica* (downy mildew)

### Symptoms

The disease occurs wherever soybean is grown, but does not generally reduce yield because it does not occur until late in the season. Pale green to light yellow spots appear on the upper leaf surface and enlarge into pale to bright yellow lesions of indefinite size and shape. Later, the spots become dark brown and brittle. A grey, downy growth occurs on the underside of the leaf. The seeds are covered with a thin, white coating in infected pods.

### Management

Planting resistant or tolerant varieties is the best management practice. It is essential to use clean, high-quality planting seed that is free from disease and has high germination and vigour. Soybean should not be sown in the same field two seasons in a row.

## *Phakopsora pachyrhizi* (rust)

### Symptoms

The defining symptoms of rust are the tan to dark brown or reddish brown spots (pustules) that are present in abundance on the lower surface of the leaf. The upper leaf surface develops small, brown spots with yellow rings around them.

### Management

The rust spores survive on volunteer soybean plants and some native legumes. They are spread by wind to neighbouring crops, and infection increases with rainy weather. It is important to keep volunteer soybean plants under control between crop seasons and try to plant resistant varieties. An early application of a fungicide to prevent rust build-up may be warranted.

## *Xanthomonas axonopodis* pv. *glycines* (bacterial pustule)

### Symptoms

Small, yellow spots with light brown centres develop on both leaf surfaces. The underside of the leaf harbours small, raised pustules containing bacterial cells developing in the centre of the spot. It is hard to distinguish this disease from rust.

### Management

The bacteria survive on volunteer soybean plants and crop residue. They are spread by wind and/or machinery to neighbouring crops, and infection increases with rainy weather. It is important to keep volunteer soybean plants under control between crop seasons, try to plant resistant varieties and always sow clean, disease-free seed.

# Weed management

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

In upland crop situations, water is often the most critical factor in determining potential crop yield. Crops can often fail due to drought, especially in the early wet season when rainfall is variable and unreliable (see Section 2). As weeds can compete with the crop for soil water, good weed control is essential, especially before sowing.

Farmers should use an integrated approach to weed management that combines all available control options. The aim is to keep numbers of weeds low and prevent them from producing seeds throughout the cropping cycle. However, many of the weeds in upland situations 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 (Figure 33).



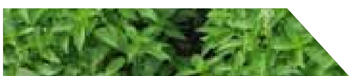


**FIGURE 33.** Late removal of grass weeds could result in yield losses in soybean

Weed management should be considered well before the crop is sown. This means preventing weeds from setting seed in the previous crop and controlling weeds around the edge of the field, along waterways and in adjacent non-cropped areas. Special attention needs to be given to weeds such as nut grass (kravanh chruk) that grow from underground tubers or rhizomes. Cuttings from these plants are spread by cultivation and regrow after the crop is sown.

The following practices can be used in an integrated weed management program.

## 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. A trade-off may be needed between the soil water used by the weeds and the soil water required by the crop. This is important in the early wet season, when water stored in the soil before 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 soil moisture to help ensure success of the crop.

## Good agronomic practice

Good agronomic practice includes making sure that the crop seed used for sowing is clean and free from weed seeds and has a high germination percentage. Good seedling vigour is important because fast-growing, vigorous seedlings are more competitive with weeds. Correct sowing rate for soybean is important to establish a uniform plant population that is optimal for the conditions.

## Timely weed control

Traditionally, cultivation has served the dual purpose of killing weeds and preparing a seedbed. However, cultivation can reduce the amount of soil water available to the crop. Some upland soil types, such as Labansiek and Kampong Siem, are friable and self-mulching and may require little or no cultivation to prepare a seedbed. In this case, 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 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 groundcover, increasing soil surface temperature, reducing soil moisture and causing soil degradation. Burning also reduces the organic matter content of soil. 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. Different species also vary in their response to cultivation and susceptibility to herbicides. It is therefore important for the adviser and farmer to be able to recognise different weed species and understand their weaknesses.

## Herbicides

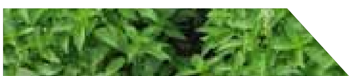
Herbicides are chemicals that inhibit or interrupt normal plant growth and development. They are used widely to manage weeds in agriculture, industry and urban areas. Herbicides can provide cost-effective weed control with a minimal amount of labour. However, improper herbicide use can injure crops, damage the environment, and pose a threat to the operator and others exposed to the chemical.

The best source of information for herbicide use is the label, and herbicides should always be applied according to the directions on the label. Unfortunately, in Cambodia, very few herbicide labels are in Khmer; most are in either Thai or Vietnamese. This poses a serious problem for Cambodian farmers who cannot read the labels. However, farmers appear to have solved this problem by obtaining the information from the seller. Farmers have also been innovative and experimented with herbicide application to fit local conditions. However, the circumstances under which herbicides are currently being used are far from satisfactory for human and environmental health.

Herbicides can be broadly classified as 'selective' or 'non-selective'. Herbicides that kill or suppress the growth of most plant species are relatively non-selective. Use of non-selective herbicides is limited to situations where control of all plant species is desired, or where the herbicide is directed onto the target weed and away from desirable plants. Glyphosate and paraquat are non-selective herbicides. Glyphosate can be applied to weeds before planting of the crop and can replace the final cultivation. Directed applications of paraquat are used by farmers to control weeds in maize.

Herbicides are now being used for weed control in soybean in Cambodia because of the increased cost of labour for hand weeding. In 2010, the most popular selective herbicides used by upland soybean farmers were Fomesafen and Quizalofop. Fomesafen is used for selective post-emergence control of broadleaf weeds, and Quizalofop is used for selective control of grass weeds in soybean. The two chemicals are applied together and are usually purchased as a package.





# 10 Processing soybean

## Harvesting

Soybean should be harvested just after physiological maturity (Figure 34). This is when the seeds have started to shrink and are no longer attached to the pod by a white membrane, leaves are yellow and falling off, and at least 95% of the grains are creamy yellow in colour and hard. After physiological maturity, another 5–7 days of dry weather are needed before harvest.

Soybeans are mainly hand harvested in Cambodia; the plants are cut and taken to the edge of the field for threshing. Machine harvesting of soybean, which is likely to increase in the future, provides opportunities for the crop residues to be left in the field and for a no-tillage farming system to be introduced. Machine harvesting requires even maturity across the field to maximise yield and quality.

Rain at harvest time can spoil the seeds and downgrade quality. Fine weather is needed for harvesting to prevent loss of yield and quality in the field. Crops should be harvested as soon as they are ready, to minimise the risk of weather damage and pod shattering before harvest. Soybeans should be planted according to their time to reach maturity (see Table 3) to ensure that they are not ready to harvest in September when prolonged heavy rainfall can occur. If harvesting occurs in heavy rainfall, the seeds may germinate in the pod, resulting in a low-quality product that is not suitable for human consumption or crushing.

When seeds dry down to 25% moisture they become susceptible to weather damage. If seeds are repeatedly wet and dried on the plant, they will lose germination viability and vigour. Hence, it is important to begin by first harvesting the seed that will be kept for planting the next soybean crop and to store it separately from the remaining seed.

**FIGURE 34.** Soybean not yet ready to be harvested (front) and ready to be harvested (back)

# Threshing

Threshing should occur as soon as possible after harvest, and the seed should be dried and stored correctly to prolong seed viability. After cutting, the plants should be dried for about 2–4 days under natural conditions until seeds contain approximately 13–18% moisture. They can then be threshed using a threshing machine (Figure 35) at 350 revolutions per minute. Alternatively, if the crop is machine harvested, the harvesting and threshing are carried out in one operation.

# Drying

Seed drying should begin immediately after threshing. The seed needs to be dried until it is at or below 13% moisture. Soybean seeds are relatively quick and simple to dry as they lose moisture easily through the seed coat. However, they are susceptible to overdrying, which can lead to splitting and cracking of the seed coat and reduced viability, germination percentage and seed quality.

## Drying methods

### Mats or plastic sheets

Mats or plastic sheets can be used for drying the crop of both soybean pods and shelled seeds, in the same way that mungbean is dried (Figure 36). 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 by dust or soil. Grain stained by soil may receive a lower price.

### Concrete slab

The crop can be dried on a layer of concrete on the ground that keeps the grain clean. Concrete 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.

**FIGURE 35.** Typical soybean threshing activity

FIGURE 36. Mungbean seed spread out to dry on matting

Concrete slabs (Figure 37) can be 5 m × 5 m or 10 m × 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 m × 5 m slab can dry 1 tonne of grain in one day, and a 10 m × 10 m slab can dry up to 4 tonnes 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.

FIGURE 37. Soybean seed spread out for drying on a concrete slab

### Commercial machine drying

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

Farmers can deliver their freshly harvested wet soybean directly to the drying plant, reducing the labour required for drying and cleaning the grain and resulting in quicker payment to the farmer.

## Storing

Traditionally in Cambodia, farmers have stored soybean seed in plastic or steel containers. They spread ash underneath and on top of the soybean kernels in each container and then seal the container.

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

Storage of soybean at higher moisture levels can lead to heating, mould development and spontaneous combustion. Soybean should be stored in a cool, dry area and protected from pest infestation.

The major pests of soybean in storage are cowpea weevils (*Callosobruchus* spp.), which prefer warm, tropical regions such as Cambodia. Cowpea weevils can infest the grain while it is still in the field or later in storage (see 'Insect pests' in Section 9). The shortest life cycle for the weevil is 21 days at 32 °C and 90% relative humidity, and numbers of the weevil can increase by 50 larvae per adult per month. Infestation with this pest often causes heating, leading to extensive mould growth.

# soybean

soybean

# 11 Economics and marketing

## Soybean production, distribution and use

Cambodia produced 117,900 tonnes of soybean in 2007 (National Institute of Statistics 2008). The majority of soybean production is in the provinces of Kampong Cham and Battambang. Production is expanding in Battambang in north-western Cambodia and now exceeds that in the long-established growing region of Kampong Cham in eastern Cambodia. Battambang produced 57,692 tonnes of soybean in 2007 (49% of the total for Cambodia). Production in Battambang in 2009 was 71,073 tonnes.

Soybeans are used for two distinct markets: human consumption and stockfeed. Production of soy milk and soy sauce are the two major human consumption markets. In Samlout district, Battambang province, farmers donate soybean seed to the local school, where it is crushed daily in a small production plant. The children are fed fresh soy milk during the day, which is important to raise their nutrition levels, improving their concentration and ability to learn.

## Markets and quality

The market prefers grain that is clean, dry and plump, with good colour. Shrivelled grain or grain with holes in it from insect damage may be downgraded. Drying soybean in the field risks the grain being stained by soil contamination if rain occurs. Buyers do not want lower-quality grain that has been stained by soil, so the price for such grain is lower.

About 80% of soybeans are exported, primarily to processors in Vietnam and Thailand. Within Cambodia, the main companies involved in soybean processing include Heng Heang Co. Ltd. (soy sauce and soy milk), Hagar Soya (soy milk) and CP Cambodia (feed).

Soybeans can be stored for 5 months in good facilities. Improved storage facilities would help farmers keep soybeans longer until the market price improves from harvest-time lows.

## Gross margins

A gross margin is the gross income gained from a crop less the variable costs incurred in growing the crop. Calculation of a gross margin is the essential first step in farm budgeting and planning, and is a starting point for choosing an overall combination of crops to grow. By calculating gross margin on a per hectare basis, farmers can directly compare the gross margins expected for different cropping options. 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 received for the crop. US dollars are used as the basic currency for budgets.

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 quantity used per hectare by the price per unit. For example, 45 kg of seed per hectare multiplied by US$1.00 per kilogram equals US$45 per hectare. The cost per hectare of other inputs, including labour and hired machinery, must also be included.

The profitability summary shown in Table 9 was estimated from information provided at a series of farmer workshops held in upland districts in July and August 2005 and at an extension workshop at the Cambodian Agricultural Research and Development Institute in February 2006.

# Effect of new technology on economics

## Mulching

A trial was conducted with soybean in 2005 (ACIAR project ASEM 2000/109) in Tbaung Khmum district, Kampong Cham province, to observe the effect of spreading crop residues on the soil. As discussed in Section 2, retaining crop residues has many advantages, including increasing water infiltration and moisture retention, and reducing weeds. Also, as the crop residues gradually decompose, the humus and nutrients in them provide benefits to the following crops. Using crop residues as mulch helps to maintain soil fertility over a long period, 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. The rice straw was estimated to cost US$18 per tonne, including transport and spreading. Application of rice straw led to large yield increases. Soybean grown without rice straw mulch yielded 0.6 t/ha, whereas soybean grown with rice straw mulch yielded more than double (a 133% increase in yield), at 1.4 t/ha.

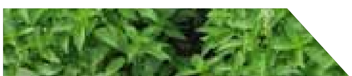
The estimated gross margin also increased significantly, from a significant loss of US$97.51 per hectare without rice straw mulch (Table 10), to a profitable US$10.77 per hectare with rice straw mulch, as shown in Table 11. The other costs involved in growing the soybean in the trial were higher than average farmers' costs. This was due to the extra land preparation required, the additional fertiliser required for the poor soil type where the trial was undertaken, and the extra hand weeding that was required due to high weed burdens.

The practice of applying mulch is of particular benefit to crops grown in the early wet season, because the increased moisture conservation provided by the mulch helps to droughtproof the crop. It is often too wet in the main wet season for the mulch to be of benefit. However, if growers were to plant soybean earlier than is currently the practice, such as May to early June, this would greatly help to establish a uniform plant population and conserve moisture. Work by the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) in Kampong Cham province, where the soybean is directly sown into 10 t/ha of dry matter at this earlier sowing time, has shown that very good yields are achievable using this system.

**TABLE 9** Average profitability summary for soybean in upland Cambodia

| District | Yield (tonne/ hectare) | Price (US$/ tonne) | Income | Costs | Gross margin/ hectare |
|---|---|---|---|---|---|
| Chamkar Leu | 1.50 | 210 | 315 | 196 | 119 |
| Tbhum Khmom | 1.50 | 210 | 315 | 141 | 174 |
| Ratanak Mondol | 2.00 | 220 | 440 | 197 | 243 |
| Kamrieng | 2.00 | 220 | 440 | 238 | 202 |
| Sampaov Loun | 2.00 | 220 | 440 | 207 | 233 |





## Rhizobium inoculation

On-farm experiments in Kampong Cham and Battambang provinces by ACIAR (project ASEM 2000/109) from 2004 to 2006 showed that inoculation of soybean with rhizobia increased grain yields by an average of 12%.

Rhizobium inoculation also significantly increased the number of pods per plant (by 12%) and yielded 66% more nodules per plant than the treatments that were not inoculated. For further information about rhizobium technology, see Section 8.

**TABLE 10.** Crop costs of soybean trial without rice straw mulch

Crop: Soybeans without mulch
Area: 1 hectare

**Yield and income**

**0.587 tonne/hectare × US$210/tonne** **Total income (A) $123.20**

| | | Machinery/labour | | Seed/fertiliser/chemicals | | | |
|---|---|---|---|---|---|---|---|
| **Operation** | **Month** | **Details** | **Total US$/ha** | **Rate /ha** | **Cost (US$)** | **Total US$/ha** | **Total cost (US$/ha)** |
| Land preparation | | Plough twice | 40.00 | | | | 40.00 |
| Land preparation | | Harrow once | 11.25 | | | | 11.25 |
| Fertiliser—Mo superphosphate | | | | 114 kg | 0.34 | 38.76 | 38.76 |
| Fertiliser—KCl | | | | 50 kg | 0.36 | 18.00 | 18.00 |
| Planting and seed | June/July | 2 people + machine | 17.5 | 60 kg | 0.50 | 30.00 | 47.50 |
| Fertliser—topdressing urea | | 1 person/ha/day | 1.25 | 50 kg | 0.32 | 16.00 | 17.25 |
| Hand weeding | | 10 people/ha/day | 12.50 | | | | 12.50 |
| Insecticide | | 1 person/ha/day | 1.25 | 1 bottle | 5.00 | 5.00 | 6.25 |
| Harvest | Nov./Dec. | 20 people/ha/day | 25.00 | | | | 25.00 |
| | | | | | **US$/tonne** | | |
| Threshing | | 5000 riel/120 kg bag | | 0.59 tonne | 6.11 | 3.59 | 3.59 |
| Transport | | 500 riel/bag | | 4.89 bags | 0.13 | 0.61 | 0.61 |
| | | | | | | **Total costs (B)** | **220.71** |
| | | | | | | **Crop gross margin (A–B)** | **–97.51** |

ha = hectare; KCl = potassium chloride; kg = kilogram; Mo = molybdenum; US = United States

**TABLE 11.** Crop costs of soybean trial with rice straw mulch

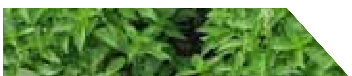
Crop: Soybeans with mulch
Area: 1 hectare

**Yield and income**

**1.387 tonne/hectare × US$210/tonne** **Total income (A) $291.20**

| | | Machinery/labour | | Seed/fertiliser/chemicals | | | |
|---|---|---|---|---|---|---|---|
| Operation | Month | Details | Total US$/ha | Rate /ha | Cost (US$) | Total US$/ha | Total cost (US$/ha) |
| Land preparation | | Plough twice | 40.00 | | | | 40.00 |
| Land preparation | | Harrow once | 11.25 | | | | 11.25 |
| Fertiliser—Mo superphosphate | | | | 114 kg | 0.34 | 38.76 | 38.76 |
| Fertiliser—KCl | | | | 50 kg | 0.36 | 18.00 | 18.00 |
| Planting and seed | June/July | 2 people + machine | 17.5 | 60 kg | 0.50 | 30.00 | 47.50 |
| Spread rice straw | | | | 3 tonnes | 18.00 | 54.00 | 54.00 |
| Fertliser—topdressing urea | | 1 person/ha/day | 1.25 | 50 kg | 0.32 | 16.00 | 17.25 |
| Hand weeding | | 10 people/ha/day | 12.50 | | | | 12.50 |
| Insecticide | | 1 person/ha/day | 1.25 | 1 bottle | 5.00 | 5.00 | 6.25 |
| Harvest | Nov./Dec. | 20 people/ha/day | 25.00 | | | | 25.00 |
| | | | | | US$/tonne | | |
| Threshing | | 5000 riel/120 kg bag | | 0.59 tonne | 6.11 | 8.47 | 8.47 |
| Transport | | 500 riel/bag | | 4.89 bags | 0.13 | 1.44 | 1.44 |
| | | | | | | **Total costs (B)** | **280.43** |
| | | | | | | **Crop gross margin (A–B)** | **10.77** |

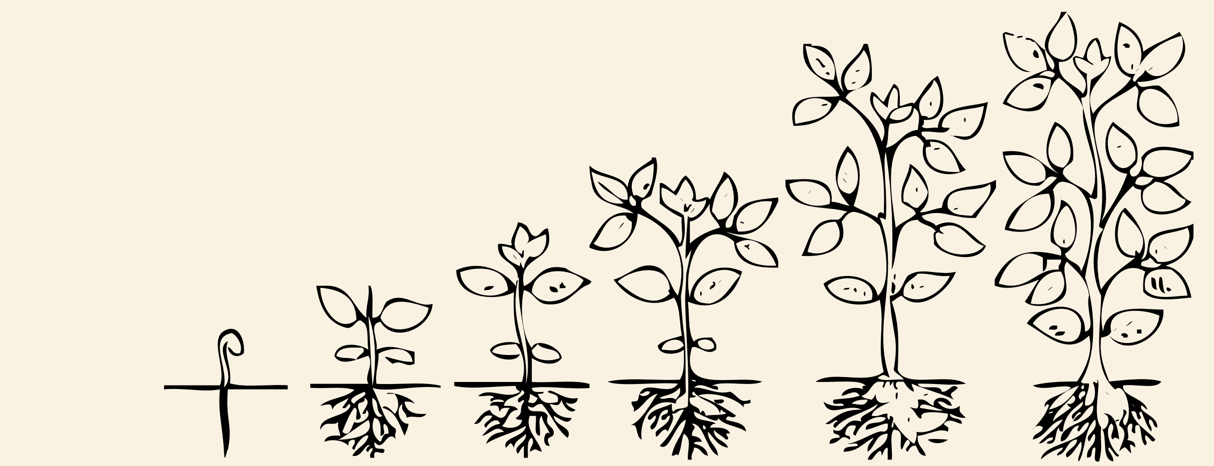
ha = hectare; KCl = potassium chloride; kg = kilogram; Mo = molybdenum; US = United States



# Appendix 1

## Growth stages in soybean

### Vegetative growth stages



| Stage abbreviation[a] | VE | VC | V1 | V3 | V5 | Vn |
|---|---|---|---|---|---|---|
| **Stage title** | Emergence | Cotyledon | First node | Third node | Fifth node | Node n |
| **Trifoliate leaves** | 0 | 0 | 1 | 3 | 5 | n |
| **Days to achieve stage[b]** | 10 | 5 | ~5 to fully expanded trifoliate leaf | ~5 to fully expanded trifoliate leaf | ~5 to fully expanded trifoliate leaf | ~3 to trifoliate leaf (V6–Vn) |
| **Range (days)[c]** | 5–15 | 3–10 | 3–10 | 3–10 | 3–10 | 2–6 |
| **Notes** | • Seedlings emerge from soil.<br>• Emergence can be hindered by soil crusting. | • Hypocotyl straightens and cotyledons unfold.<br>• Unifoliate leaves open. Growing point is above soil surface.<br>• Frost can kill the plant.<br>• Stem severed below the cotyledons will kill the plant. | • First fully developed trifoliate leaf unfolds at first node.<br>• Start of critical weed-free period. | • Trifoliate leaves at three nodes.<br>• End of critical weed-free period.<br>• Nitrogen fixation begins at a slow rate. | • Trifoliate leaves at five nodes.<br>• 50% leaf loss has little impact on final yield.<br>• Early maturity soybeans reach R1 (see table over page) at approximately V4. | • Number of nodes to develop is a function of maturity rating, planting date and climatic conditions. |

a Vegetative stages of soybean development. Vn = number of nodes on the main stem with fully developed leaves, beginning with the unifoliate node. A fully developed leaf is defined as one that has a leaf above it (at the next node) with an unrolled leaf.

b Estimate of the number of days required to move from one stage to the next.

c Estimate of days within a specific stage of development. It is influenced by planting date, maturity rating and climatic conditions, and can vary considerably within and between seasons.

Source: Ontario Ministry of Agriculture, Food and Rural Affairs (2002)

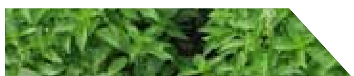
# Reproductive growth stages

| | R1: Beginning bloom | R2: Full bloom | R3: Beginning pod | R4: Full pod |
|---|---|---|---|---|
| **R stage**[a] | One open flower visible from any node on stem | Open flowers at highest nodes of main stem | Short pods visible at upper nodes of main stem, with fully developed leaves | Pods 2 cm long at upper nodes of main stem |
| **Corresponding V stage**[b] | V4–V7 | V5–V10 | V8–V13 | V11–V16 |
| **Days to achieve stage**[c] | 3 | 8 | 10 | 10 |
| **Range (days)**[d] | 1–10 | 3–15 | 4–22 | 6–25 |
| **Target event** | Flowering | Flowering | Pod development | Pod development |
| **Notes** | • Triggered by changing day length and temperature.<br>• Flowering begins near node 5 (V4) and moves up and down the stem.<br>• Root growth rates increase.<br>• Extreme heat (over 32 °C) can reduce growth, flowering and pod development. | • 50% height and dry weight accumulation.<br>• Stress does not usually reduce yield.<br>• Nitrogen fixation increasing rapidly. | • Look for 2–3 seeds per pod.<br>• Flowering peaks. | • Stress occurring between R4 and R6 can result in significant yield loss. |

a Reproductive stages of soybean development.
b In Ontario, where the majority of soybeans grown are indeterminate in habit, vegetative and reproductive stages of developent overlap for much of the plant's development.
c Estimate of the number of days required to move from one stage to the next.
d Estimate of days within a specific stage of development. It is influenced by planting date, maturity rating and climatic conditions, and can vary considerably within and between seasons.

Source: Ontario Ministry of Agriculture, Food and Rural Affairs (2002)





| | | | | |
|---|---|---|---|---|
| | R5: Beginning seed | R6: Full seed | R7: Beginning maturity | R8: Full maturity |
| | Seed 0.3 cm long within upper pods | Seeds within pods fill cavity in the upper pods | One major pod has changed to brown colour on the main stem | 95% of pods have changed to brown colour |
| | V14–V19 | V17–V21 | – | – |
| | 14 | 27 | 7 | – |
| | 10–22 | 20–40 | 1–30 | – |
| | Seed development | Seed development | Plant maturity | Plant maturity |
| | • Flowering completed except for some branches.<br>• Plant reaches maximum height, nodes and leaf area.<br>• Nitrogen fixation rates reach maximum and begin to decline.<br>• Rapid nutrient uptake and redistribution to pods. | • Pods reaching full length.<br>• Root growth slows substantially.<br>• Above-ground dry weight accumulation slows.<br>• Rapid leaf yellowing begins.<br>• Leaves in lower canopy begin to fall. | • Moisture begins to decline in seeds.<br>• Physiological maturity reached, maximum dry weight.<br>• Seed moisture is about 60%. | • Harvest moisture reached in 1–2 weeks after R8. |

# Further reading


Bailey K.L., Gossen B.D., Gugel R.K. and Morrall R.A.A. 2003. Diseases of field crops in Canada, 3rd edition. Canadian Phytopathological Society: Saskatoon.

Blamey F.P.C., Bell M.J.N. and Moody P.W. 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.

CABI (Centre for Agricultural Bioscience International) 2011. Crop protection compendium. CABI: Wallingford, United Kingdom. At <cabi.org/cpc>, accessed 18 May 2011.

Charleston K., Sparkes D. and Garside A. 2005. Growing soybean for green manure in a sugarcane fallow: a guide for growers in the wet tropics. Queensland Department of Primary Industries: Brisbane.

Colton R.T., Rose I.A. and Goodyer G.J. 1995. Soybeans Agfact. New South Wales Department of Primary Industries: Orange.

English M., Ryley M., Fuhlbohm M., Barnes J. and Cahill M. 2003. Mungbean and soybean disorders: the ute guide. Queensland Department of Primary Industries and Grains Research and Development Corporation: Australia.

FCRI (Field Crops Research Institute) 2001. A guide book for field crops production in Thailand. FCRI, Ministry of Agriculture and Co-operatives: Bangkok.

Imsande J. 1986. Inhibition of nodule development in soybean by nitrate or reduced nitrogen. Journal of Experimental Botany 37, 348–355.

Martin R. and Belfield S. 2007. Improved technology practices for upland crops in Cambodia: technical methods demonstration manual. New South Wales Department of Primary Industries: Orange.

Martin R. and Chanthy P. 2007. Weeds of upland crops in Cambodia. Cambodian Agricultural Research and Development Institute: Phnom Penh.

Michigan State University Extension 2000. Soybean growth and development—growth stages. At <web1.msue.msu.edu/msue/iac/mspc/develop.html, accessed 18 May 2011.

Moore N., Clarke B., Moore K., Desborough P. and McCaffery D. 2004. Soybean: north coast NSW planting guide. New South Wales Department of Primary Industries: Orange.

Mulongoy K. 1995. Technical paper 2: biological nitrogen fixation. Food and Agriculture Organization of the United Nations (FAO) Corporate Document Repository, ILRI Training Manual 2. FAO: Rome. At <fao.org/wairdocs/ilri/x5546e/x5546e05.htm>, accessed 18 May 2011.

National Institute of Statistics 2008. Statistical yearbook of Cambodia. National Institute of Statistics, Ministry of Planning: Phnom Penh, Cambodia.

Ontario Ministry of Agriculture, Food and Rural Affairs 2002. Agronomy guide for field crops. Publication 811, Agdex 100. Ministry of Agriculture, Food and Rural Affairs: Ontario. Accessible at <omafra.gov.on.ca/english/crops/pub811/p811order.htm>.

Pol C., Belfield S. and Martin R. 2010. Insects of upland crops in Cambodia. ACIAR Monograph No. 143. Australian Centre for International Agricultural Research: Canberra. At <aciar.gov.au/publication/mn143>, accessed 18 May 2011.

Qazi J., Ilyas M., Mansoor S. and Briddon R.W. 2007. Legume yellow mosaic viruses: genetically isolated begomoviruses. Molecular Plant Pathology 8(4), 343–348.

Rees D. 2007. Insects of stored grain—a pocket reference, 2nd edition. CSIRO Publishing: Collingwood.

Rose I.A., McCaffery D., Lowien J. and McGufficke R. 2004. Soybean: inland northern NSW planting guide 2004–2005. New South Wales Department of Primary Industries: Orange.

Sale P.W.G. and Campbell L.C. 1980. Patterns of mineral nutrient accumulation in soybean. Field Crops Research 3, 157–163.

Sinclair J.B. 1999. Compendium of soybean diseases, 4th edition. American Phytopathological Society: Minnesota.

Singh B.B. 2006. Success of soybean in India: the early challenges and pioneer promoters. International Institute of Tropical Agriculture: Nigeria.

Sys C., Van Ranst E., Debaveye J. and Beernaert F. 1993. Land evaluation part III: crop requirements. Agricultual Publication No 7. General Administration for Development Cooperation: Brussels.

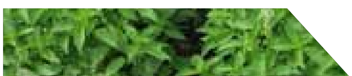
Texas Tech University. Crop plant anatomy II. Part II Reproductive anatomy. Department of Plant and Soil Science. At <pssc.ttu.edu/pss1321/Web topics/cpa2.htm>, accessed 18 May 2011.

Vance W., Bell R. and Seng V. 2004. Rainfall analysis for the provinces of Battambang, Kampong Cham and Takeo, the Kingdom of Cambodia. School of Environmental Science, Murdoch University: Perth.

White P., Dobermann A., Oberthür T. and Ros C. 2000. The rice soils of Cambodia. I. Soil classification for agronomists using the Cambodian Agronomic Soil Classification system. Soil Use and Management 16, 12–19.

White P.F., Nesbitt H.J., Ros C., Seng V. and Lor B. 1999. Local rock phosphate deposits are a good source of phosphorus fertiliser for rice production in Cambodia soil. Science and Plant Nutrition 45, 51–63.



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