Supplement

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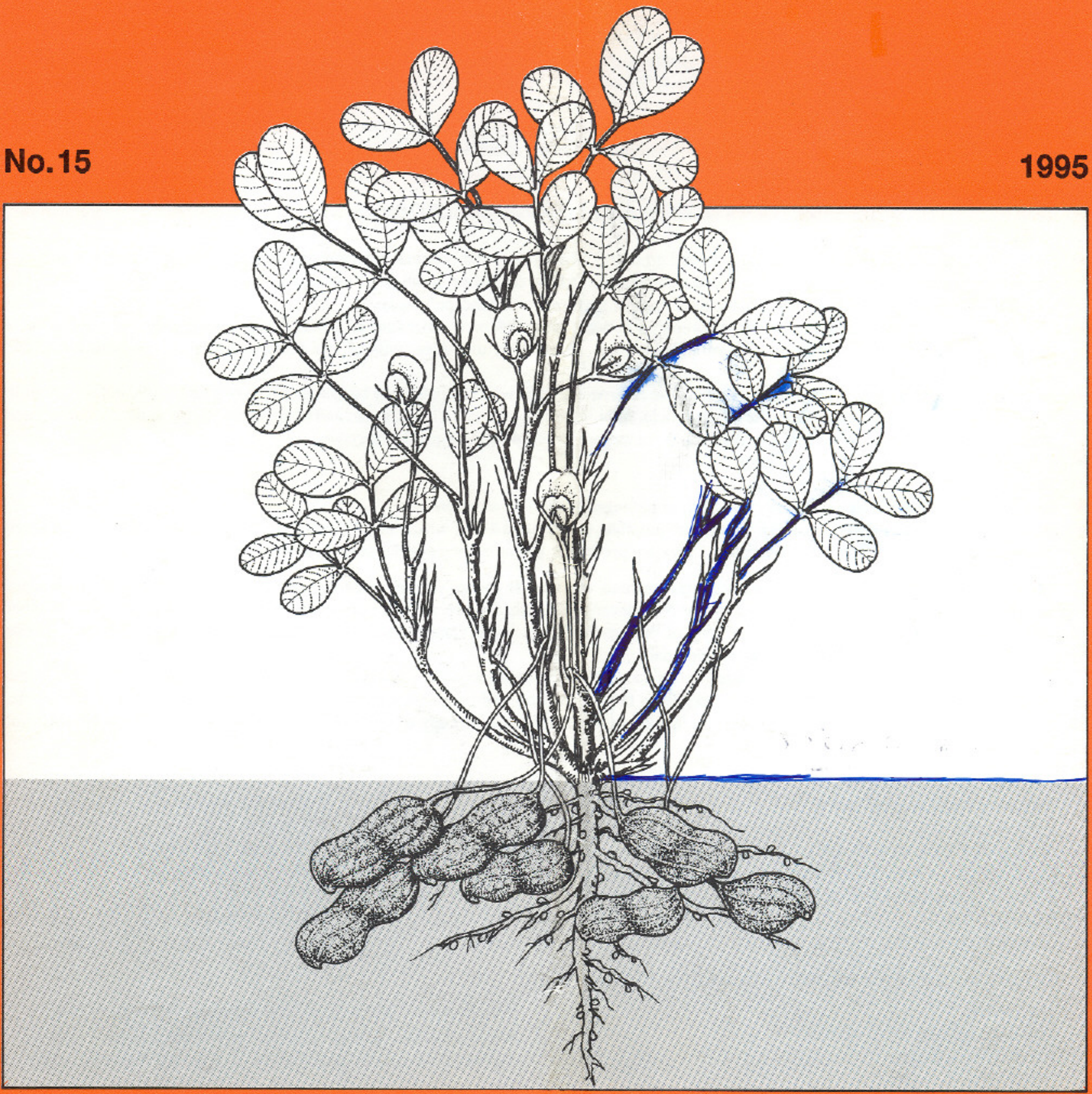

International Arachis Newsletter

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Publishing objectives

The *International Arachis Newsletter* (IAN) is published annually by ICRISAT, in cooperation with the Peanut Collaborative Research Support Program, USA. It is intended as a worldwide communication link for all those who are interested in the research and development of groundnut or peanut (*Arachis hypogaea* L.) and its wild relatives. Though the contributions that appear in IAN are peer-reviewed and edited, it is expected that the work reported will be developed further and formally published later in refereed journals. It is assumed that contributions in IAN will not be cited unless no alternative reference is available.

IAN welcomes short contributions (not exceeding 600 words) about matters of interest to its readers.

What to contribute?

Send us the kind of information you would like to see in IAN. An illustrative list is given here.

- Personal news (new appointments, awards, promotions, change of address, etc.)
- Reports of field days, meetings, tours, surveys, network activities, recently launched or concluded projects, etc.
- Short reports on recently held workshops, conferences, symposia, etc.
- Details of recent publications, with full bibliographic information and 'mini reviews' whenever possible.
- Results of recently concluded experiments, newly released varieties, recent additions to germplasm collections, etc.

How to format the contributions?

- Keep the items brief—remember, IAN is a newsletter and not a primary journal. About 600 words is the upper limit (no more than two double-spaced pages).
- If necessary, include one or two small tables (and no more). Supply only the essential information; round off the data-values to just one place of decimal whenever appropriate; choose suitable units to keep the values small (e.g., use tons instead of kg). Every table should fit within the normal type-written area of a standard upright page (not a 'landscape' page).
- Black-and-white photographs and drawings (prepared in dense black ink on a white card or a heavy-duty tracing paper) are welcome—photocopies, color photographs, and 35-mm slides are not. Please send disk-files (with all the data) whenever you submit computer-generated illustrations.
- Keep the list of references short—not more than five references, all of which should have been seen in the original by the author. Provide all the details such as author/s, year, title of the article, full title of the journal, volume, issue, and page numbers (for journal articles), and place of publication and publishers (for books and conference proceedings) for every reference.
- Express all the quantities only in SI units.
- Spell out in full every acronym you use.
- Give the correct Latin name of every crop, pest, or pathogen at the first mention.
- Type the entire text in double spacing. Whenever possible, please send a file, which should match the printout, on a double-sided/high density IBM-compatible disk. WordPerfect 5.1 files are preferred; if that is not possible, send an ASCII file instead.

We will carefully consider all submitted contributions and will include in the Newsletter those that are of acceptable scientific standard and conform to requirements. The language of the Newsletter is English, but we will do our best to translate articles submitted in other languages. Authors should closely follow the style of the reports in this issue. Contributions that deviate markedly from this style will be returned for revision, and could miss the publication date.

If necessary, we will edit communications so as to preserve a uniform style throughout the Newsletter. This may shorten some contributions, but particular care will be taken to ensure that the editing will not change the meaning and scientific content of the article. Wherever we consider that substantial editing is required, we will send a draft copy of the edited version to the contributor for approval before printing.

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High-Yield Technology for Groundnut

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Contents

Editorial

The *International* Arachis *Newsletter* is pleased to bring to you this special supplement on high-yield technology for groundnut in China.

China has had spectacular success in groundnut yields. The 1990 crop gave an average yield of 2.19 t ha^{-1}, and yields of 6.5–7 t ha^{-1} are not uncommon. A record yield of 10.5 t ha^{-1} over an intensively cultivated small area has been reported. Given the importance of the crop in many countries, and a need to improve its productivity, it is particularly useful to disseminate the techniques for such high yields.

The authors, Hu Wenguang, Duan Shufen, and Sui Qingwei, marshall a wealth of research results to summarize the many components of the Chinese success story. In brief, numerous large-seeded, short- or medium-duration varieties have been developed and released; further, several cultural practices have been evolved and extended across the country to raise yields, e.g., soil amendment, chiefly, deep tillage, a balanced application of organic and chemical fertilizers, optimal sowing patterns, a variety of field management techniques, and polythene mulching.

Thus, what follows is of interest in itself as a summary of recent research on groundnut in China. However, we would like to emphasize that we have no comparative data on the efficacy of the technology recommended by the authors. Therefore, we are particularly interested in the reproducibility of the Chinese experience, and eagerly await feedback from you.

Editor

Introduction

Groundnut is a staple industrial and oil crop in China; 17.5% of the world's total area sown to groundnut is in China, that produces 30% of the total world production. The average Chinese groundnut yield in the 1960s was 1.14 t ha^{-1}; it improved in the 1970s to 1.21 t ha^{-1}; the 1980s saw a rapid increase with an average yield of 1.78 t ha^{-1}; and the 1990 crop gave a record average yield of 2.19 t ha^{-1}: a 92.11% increase over the 1960s, 80.99% increase over the 1970s, and 23.03% increase over the 1980s. The average yield in Shandong and Jiangsu provinces, the country's two major groundnut producing areas, reached 3 t ha^{-1} in the best crop year.

Since the 1980s, research on groundnut in China has been characterized by two major developments. First, many new groundnut varieties have been bred and released. Large-seeded, short- or medium-duration varieties have generally taken the place of small-seeded, short-duration varieties, and large-seeded, long-duration varieties. And second, many cultural practices that have been developed and extended across the country result in high yields, e.g., deep tillage, balanced fertilizer, close sowing, chemical control, and polythene mulching. The use of new varieties and technologies has further enhanced groundnut.

This report makes recommendations about improved agronomy in China. Such cultural practices as deep tillage, rate of N application, and plant density that may differ from those in other groundnut-producing countries, are indicated for further discussion. It is hoped that this publication will help groundnut farmers to improve productivity, and promote groundnut researchers and extension staff to further studies of groundnut agronomy.

Soil amendment

Although 3 million ha of groundnut is grown in many areas in China, about two-thirds of the crop is grown in hilly regions, river deltas, and coastal areas, where the soils are hilly gravels, plain sands, sandy loams, and red and yellow hill soils. These soils usually have a shallow profile, poor texture, low fertility, and are either too clayey or too friable. Therefore, yields cannot improve unless fertilizers are applied or other measures of soil improvement are taken. Since the mid-1970s many soil-improvement practices have been widely adopted, including deep tillage, addition of sandy soil to clay soil, and increased application of organic manure. Significant improvements in yield have been recorded. Since the early 1980s, groundnut has also been grown on plain, clay loam, well-supplied with nutrients and a moderate amount of organic matter by adopting the techniques of polythene mulch.

Soil type and distribution

The hilly regions of the groundnut production area in northern China, including Shandong and Liaodong Peninsulas and parts of Hubei and Henan provinces have gravelly soil about 15-30 cm deep; the lower layer consisting of semi-weathered materials produced by various mother rocks, such as granite, shale, and gneiss. The slightly acidic soil is coarse, loose, and deficient, containing only 0.4–0.7% organic matter, 0.03–0.06% N, 0.05–0.1% P, and 0.5–0.9% K. Enriching the P and K content of the soil helps to produce high quality groundnuts with thin shells that mature early.

Most of the groundnut fields on the Song-Liao Plain, the Yellow River alluvial ground, the Jiang-Huai Plain, and the coastal and river alluvial areas in these provinces have sandy soils; only a few fields have sandy loam soils. The depth of the sandy soils ranges between 1-10 m. Its surface is whitish-yellow, or brown, fine to powdery, sandy or alkaline, and it is infertile. This soil contains 0.6–1.5% organic matter, 0.02–0.05% N, 0.03–0.08% P, and 0.09–0.20% K. A loose soil with good aeration favors cultivation. But the fertility, and the capacity to conserve moisture of this soil is low, given its vulnerability to drought and wind erosion.

Red and yellow acidic soils are found mainly in southern groundnut producing areas including Jiangxi, Henan, part of Guangdong, Guangxi, and Hubei provinces.

Yellow soils, including grey-yellow soil and brown-yellow soil, have adequate moisture and fertility, and are located at high altitudes with cool climates. On the other hand, red and brown-red soils, are found at low altitudes with moist climates. They are infertile, and have low Ca and Mg contents. Before the mid-1970s, most of the groundnuts in China were grown on soils with shallow profile, poor textures, and low fertility; yields were not high.

Improving soil texture

Part of Chinese groundnut is grown on fertile soils with a deep cultivation layer, a fairly dense texture, and poor air permeability—the last two being unfavorable to groundnut growth. However, soil texture can be improved by adding sand or weathered phosphorus-rich materials. The optimum amount of sand needed to ameliorate these fields is 150–300 m^3 ha^{-1}. This increases yields by about 18.8% compared to the control. By adding such soil amendments to the groundnut fields:

- soil texture in the active layer changes from heavy clay to sandy loam
- soil aeration and water-holding capacity improve
- soil temperature in the podding zone or upper layers rises.

Field trials have shown that adding 150 m^3 ha^{-1} of P-containing weathered materials to the soil can increase pod yield by 666 kg ha^{-1} over the control. The weathered materials contain approximately 0.5% total P, and 0.05% available P. One cubic meter of weathered P-rich materials corresponds to the P-content of 4.7 kg superphosphate. Soil amendments must be added after the winter or early-spring tillage.

Although adding amendments to soil to improve its texture is expensive, this long-term strategy results in high quality crops that yield well. Sandy soil must be broadcast evenly on the surface, and mixed with the host soil in the pod-setting zone by shallow tilling and harrowing.

Deep tillage

Multilocational experiments conducted over many years in China have shown that deep tilth in various types of soil helps to significantly increase groundnut yield. Pod yield increases by about 20% in soils of moderate or above-moderate fertility, deeply tilled to 25–30 cm, compared to those tilled to 10–12 cm. Pod yield increases by about 30% on hilly, dry upland fields of poor fertility, deeply tilled to 25–33 cm, compared to those tilled to only 10–12 cm depth. Deep tilth helps not only a present crop but also the following crops. In addition, deep tilth helps in reducing insect pupae, larvae, and fungi populations in the soil by exposing them to the winter cold, or burying them deep into the soil.

Deep tillage contributes to increase in yield in the following ways:

- It deepens the active cultivation layer, changes the texture, decreases the soil density, and increases soil porosity. Therefore, water retention in the soil improves, and infiltration rate increases. Experiments at Guangdong Scientific Institute of Agriculture on water content in the soil of groundnut fields at different treatments of turning depth showed that in the top 30 cm of the soil, the water content increased significantly with increase of tilling depth.
- Deep tilth improves soil conditions for soil microfauna. According to Tangshan Agricultural Research Institute, Hubei province, tilling to a depth of 50 cm rather than to 20 cm in sandy loam soil increases bacterial content by 3.3% in the top 20 cm of the soil, and by 82.2% in the soil layer 20–40 cm deep.
- Harrowing increases the soil's water-holding capacity: Shandong Scientific Institute of Agriculture determined that after a spring rain, the soil's water content up to a 5-cm depth was 16.7% with winter tilling and harrowing, and 15.9% with winter tilling, but without harrowing. After 4 days, the harrowed soil had a moisture content of 11.93%, while the nonharrowed soil had only 8.63% moisture. Thus, whether or not the soil is harrowed after winter tillage, it must be harrowed early in the following spring to break the soil crust and capillary pores in order to reduce water evaporation from the soil.
- Deeply tilled soil facilitates the development of groundnut roots. Work at Shandong Peanut Research Institute showed that groundnut root growth improved with increase in the depth of the cultivation layer; the tap root penetrated further, and the total number of roots increased significantly. An experiment on sandy loam soil by Shandong Agricultural School showed that most groundnut roots were distributed between 0–30 cm in deeply tilled soil, and between 0–20 cm deep in shallow tilled soil. Beyond a tilling depth of 30 cm, no significant difference was observed.
- Deep plowing helps break up the hardpans formed over many years by shallow plowing, or prevents the formation of hardpans, thereby enabling more efficient nutrient uptake. Experiments indicate that the rapidly available (RA) N increases by 21.9 ppm, RA P by 8.6 ppm, and RA K by 9.7 ppm in the top 30 cm of the soil, when a 40-cm deep tilth is compared to one 12-cm deep.

Deep tilth techniques

Shallow plowing to a depth of 30 cm is enough in soils with a deep profile if they have been deeply tilled over many years; otherwise, deep tilling is recommended. Deep tilling must be done frequently in late autumn or early winter to allow freezing, thawing, and decomposition of crop residues in the soil before sowing. The newly turned soil gathers and conserves the snowmelt and spring rainfall, resulting in greater tolerance to spring drought. The fertilizer applied while tilling should be mixed well with the soil so that it can be rapidly absorbed by the crop. Although local conditions determine optimum turning depth, tilling to a depth of 25–35 cm is generally considered adequate.

Deep tilling is also necessary for the shallow, mature soil layers in the hilly region; but the depth of tilling should not exceed 50 cm. If farm machinery is used, a pan breaker should be attached to the plowshare, so that the soil layers are not disturbed, and the mature soil remains on top. Hilly fields with a shallow, mature soil layer can be turned by a subsoiler. If a large amount of organic manure is broadcast on the field before turning, a higher yield is obtained. The beneficial effects of deep plowing last 4–5 years.

Winter tillage should be deeper than the spring tillage. Deep tilling is more effective if done in the previous season, when its effect is enhanced if organic fertilizer is also applied. This ensures direct supply of nutrients to groundnut crops, promotes microfaunal activity, accelerates decomposition of organic matter, and matures the soil—all of which improve soil fertility.

On account of the heavy rainfall and high temperature in southern China, sunning the fields after tillage is an important practice, especially on the heavy clay soils of the rice-groundnut cropping system. The tilled soil must be sun-dried before harrowing. This weathering loosens the soil. Experiments in Zhangpu county, Fujian province, have shown that pod yield from fields sunned for more than 30 days after tilling was 4.04 t ha^{-1}—1.38 t ha^{-1} more than that of the control sown soon after tilling.

Fertilizer application

Groundnut needs large amounts of such macronutrients as N, P, K, and Ca, and various micronutrients; Mg, S, Fe, B, Zn, Cu, and Mo. Research at Shandong Peanut Research Institute has shown that for the production of 100 kg of pods at a yield level of 5–7.5 t ha^{-1}, 5.18 kg N, 1.08 kg P, 2.5 kg K, 1.95 kg Ca, 1.58 kg Mg, and 1.28 kg S are required. Since the native nutrients in the soil, and the biologically fixed N in the root nodules are limited, fertilizer application is essential. Both organic and chemical fertilizers can be used.

Organic fertilizers

Organic fertilizers, composed of farmyard manure, human excrement, compost, green manure and sludge, abound in N, P, K, Ca, Mg, S, and other microelements. These nutrients can be extracted by the plant only after organic fertilizers are decomposed by microorganisms, during which process, they are released slowly and are thus available over a long period. Regular application of organic fertilizers increases the organic-matter content in the soil and its capacity to retain moisture; it also improves the nutrient status of the soil its structure by reducing compaction and crusting. Organic fertilizers in the soil provide an environment conducive to microorganisms, nodulation, and N fixation.

Farmyard manure consists of animal droppings, haulms, grasses, and soil. Usually, farmyard manure contains 0.15–0.45% N, 0.15–0.4% HPO_3, 0.3–1.1% K_2O, and 2–20% organic matter. Experiments show that pod yield is 150–375 kg ha^{-1} higher than the control after a farmyard manure application of 7.5 t ha^{-1}. Human excrement is an easily decomposed, quick-acting fertilizer. It has 0.5–0.8% N, 0.2–0.4% HPO_3, 0.2–0.3% K_2O, and 5–10% organic matter. Groundnut yield increases significantly when human excrement is mixed with farmyard manure and utilized as basic fertilizer, or diluted with water as side-dressing.

Plant ash is not an organic fertilizer because it does not contain organic matter or N. Plant ash is chiefly composed of fusible K, Ca, P, and other microelements. It serves as a major source for K. Multilocational experiments show that pod yield increases by 8.1–19.1% after application of 1.57–2.77 t ha^{-1} of plant ash. Care must be taken not to pile or mix plant ash with human excrement or farmyard manure as this results in loss of nutrients, particularly N and K.

Chemical fertilizers

Nitrogen. The major N fertilizers currently used in China include ammonium hydrogen carbonate (N content—17%), ammonium sulfate (20% N), ammonium chloride (24–25% N), ammonium nitrate (33–34% N), and urea (44–46% N). There is a positive correlation between the rate of N-application, stem and branch height, and branch number. Groundnut yield in infertile soils increases significantly if N-application is combined with organic manure as a basal and side-dressing fertilizer. Experiments indicate a 4.8–20% increase in pod yield following the application of 187.5 kg ha^{-1} fertilizer containing 20% N. Side-dressing 7.5–15 kg ha^{-1} of ammonium sulfate during the seedling phase results in a 9–11% increase in pod yield. However, overuse of N results in excessive vegetative growth, and reduced pod yield. Various factors determine the rate of N-application, e.g., the amount of N fixed by root nodules, the N content of the soil, and the cost-benefit ratio of N application. In low-yielding fields with <0.045% N, 94 kg ha^{-1} N is optimum; in medium-yielding fields with 0.045–0.065% N, 56 kg ha^{-1} N is recommended; and in high-yielding fields with 0.065% N, a single application of N fertilizer has almost no effect.

Phosphorus. Phosphatic fertilizers used in China include superphosphate and calcium magnesium phosphate. Superphosphate, a quick-acting fertilizer containing about 18% P_2O_5, is suitable for moderately fertile, alkaline soils. Calcium magnesium phosphate, a slow-acting fertilizer containing about 17% P_2O_5, 27% CO, and 17% MgO, is suitable for moderately fertile, acidic soils. Most soils in groundnut-producing areas in China are P-deficient. Experiments at 202 locations in Shandong province show a yield of 3.02 t ha^{-1} after 180 kg ha^{-1} of phosphatic fertilizer—a 477 kg ha^{-1} (18.75%) increase over the controls. Experiments in Guangdong province have shown a pod yield increase of 565 kg ha^{-1} following a phosphatic-fertilizer application of 75–450 kg ha^{-1}. Further, these experiments have shown that groundnut quality improves following the application of phosphatic fertilizer: shelled groundnut yield increased by 1.95%, oil content by 1.5%, and protein content by 4.28%. The balanced application of P and N fertilizer is better than a single application of N fertilizer. The best ratio of N and P fertilizer is 1:1.5.

Potassium fertilizers used in China include KCl (50–60% K_2O) and K_2SO_4 (48–52% K_2O). Application of K fertilizer in the soil should be basal and deep because the mobility of K in the soil is poor. Experiments show that application of 1 kg ha^{-1} of standard K fertilizer results in a pod yield increase of 1–3 kg ha^{-1} in brown soil, 5.3 kg ha^{-1} in calcareous wet soil, and 7.3 kg ha^{-1} in red soil. The application of K fertilizer in medium- and high-yielding fields increases the uptake of N and P. The recommended ratio of N:P:K is 1:1.5:2.

Calcium. This is not only an essential element, it also controls pH. Ca deficiency in groundnut fields results in reduced formation of flowers and pegs, in blind pods, and a darkening of the plumule of the seed embryo. Ca reduces ovule abortion, and increases the number of pods per plant, producing higher pod yields. Lime and gypsum are the major Ca fertilizers in China. Lime is applied to acidic soils to raise their pH; it improves the soil's physical properties, and prevents accumulation of toxic levels of Al and other elements. In the red and yellow acidic soils in Yinjiang, Guangdong province, adding 375–1500 kg ha^{-1} of lime combined with organic fertilizer increased pod yield by 5–20%. Yield increased with lime application. The application of lime at the rate of 750 kg ha^{-1} to red soil on Ji An Farm, Zhejiang province, increased pod yield by 394.5 kg ha^{-1} over the control. Gypsum is a suitable source of active Ca to adjust pH in neutral, Ca-deficient, brown soils, and saline-alkali soils. The application of gypsum at the rate of 375 kg ha^{-1} to brown soil at Weihai resulted in a pod yield of 4.61 t ha^{-1}, a 11.8% increase over the control.

Methods of application

Basal application. Basal fertilizers include fertilizers that are broadcast and those applied in the furrows before sowing; together they account for 80–90% of the total fertilizer applied to groundnut crops. When <30 t ha^{-1} of organic manure is used, it should be applied in the furrows. If 30 t ha^{-1} of organic manure is used, two-thirds of it should be broadcast and buried by winter tillage, and the rest applied in the furrows at the time of sowing. N and P are recommended as furrow-fertilizers, and plant ash and K as broadcast fertilizers. In the furrow, fertilizer and seed must be kept apart to avoid injury to the seed and seedlings. Fertilizer efficiency increases if P-fertilizer is mixed with organic manure 15–20 days before application. On account of the low temperature, drought, and strong winds during spring in northern China, fertilizers for the spring crop should be applied several months before sowing, so that there is enough time for organic matter to decompose.

Side-dressing fertilizer. The type and quantity of side-dressing fertilizers applied to groundnut at various crop growth stages depends upon soil fertility, crop growth, and cropping patterns. In a wheat-groundnut rotation, groundnut is sown in between wheat rows 20 days before the wheat harvest. This groundnut does not receive any basally applied fertilizers. Therefore, side-dressed fertilizers are necessary for intercropped groundnut. Similarly, summer groundnut also needs side-dressed fertilizers, because only a small amount of fertilizer is applied after harvesting the previous crop. Fertilizer should be applied at the seedling stage; a small amount will suffice. About 75 kg ha^{-1} ammonium nitrate or ammonium sulfate or 94 kg ha^{-1} ammonium hydrogen carbonate, and 188 kg ha^{-1} superphosphate mixed with 3.75 t ha^{-1} organic manure should be applied in opened furrows along the row direction, and then covered with earth by intercultivation.

Experiments at Laiyang Agricultural College showed that at peg and pod-setting stages, applying 37.5 kg ha^{-1} urea, and 150 kg ha^{-1} superphosphate increased pod numbers by 7.7% per plant, and pod yield by 26% over the control. As pegs and young pods absorb P and Ca directly from soil, broadcasting 300 kg lime ha^{-1} (or 90 kg gypsum ha^{-1}) combined with organic manure at the rate of 1.8 t ha^{-1}, or 180 kg ha^{-1} superphosphate mixed with 3 t ha^{-1} organic manure along the rows followed by intercultivation during the flowering phase significantly increases pod yield. Two or three foliar sprays of 2 t superphosphate ha^{-1} (2–3% concentration) or urea solution (0.5–1.0%) at 7–10 day intervals during the pod-filling stage can increase pod yield by 7–10%.

Balanced fertilizer

This technology—brought to China from India in 1980 by Shanghai Chemical Industry Research Academy—has given good economic results in many crops. N P K doses for groundnut depend upon the plants' requirement for these elements, soil nutrients, and fertilizer responses.

A combined application of N and P (1:1.5) over 85 000 ha at various locations in Shandong province during the 1987/88 crop season gave a 16.89–24.40% increase in pod yield over the traditional application of fertilizers. The results showed that compared to a single application of N, P, and K, a combined application increased the uptake of N by 7.33% and P by 3.58%, and combined application of N, P, and K increased the uptake of N by 2.0–6.1%, and that of P by 1.6–6.1%. The nitrogen fixed by root nodules increased by 13.15–21.23%, lost N decreased by 2.37–16.14%, and P by 2.81–4.39%. The residual N in the soil increased by 2.52–7.25%, and P by 2.68–4.02%. A few formulations for the combined application of N, P, and K have been given, but these are too complex to be used in production. Studies have also indicated that the optimum ratio of combined application of N, P, and K is 1:1.5:2. Since fertilizer application based on the results of soil analysis is still not a widely adopted practice, the application of fertilizers based on targeted yield has been suggested. For each 100 kg of pod yield 5 kg N ha^{-1}, 2 kg P_2O_5 ha^{-1}, 2.5 kg K ha^{-1} should be applied. It is also recommended that the N-levels be halved for moderately to highly fertile soils, and P be doubled in all soils.

Groundnut fertilizers. 'No. 1 groundnut fertilizer', developed by Shandong Peanut Research Institute in 1988, contains 5–6% N, 8–9% P, 11–12% K, and many other microelements, e.g., Ca, Mg, S, Mo, and Mn. It is suitable for soils of low to medium-fertility. Applying 600–750 kg ha^{-1} of this fertilizer increases pod yield by 15%. 'B-line groundnut fertilizer', developed by Shandong Academy of Agricultural Sciences, contains 7.25% N, 6.75% P, 8.0% K, and 12 microelements. It can be used for both basal and foliar application. Extension trials show that application of 110–150 kg ha^{-1} increases pod yield by about 20%.

The following principles of fertilizer application for groundnut are recommended:

- Organic manure should serve as the main source, and chemical fertilizer, as the subsidiary source of nutrient supply. This improves soil structure and fertility, and reduces costs.
- Organic manure and fertilizer should both be applied. This reduces the loss of the active component of the fertilizer, and improves the decomposition of organic manure by microorganisms.
- N, P, and K should be applied in the ratio 1:1.5:2.
- Enough basal fertilizer should be applied; if necessary, side-dressing during the crop growth period should be applied.

Pattern and time of sowing

Groundnut is widely distributed over a varied geography and climate in China: between 76–132°E, and 18–50°N, and from 150 m below sea level (Tulufan Basin, Xinjiang Uygur Autonomous Region) to an elevation of 1800 m (Yuxi, Yunnan province). The annual average temperature in the groundnut-growing areas in China varies from –5 to 4°C with 130 frost-free days in Jiamusi, Heilongjiang province, to 19–25°C in Hainan province with not a single day of frost. The annual rainfall varies greatly, from 20 mm in the Tulufan Basin to more than 2000 mm in the southern part of Hainan province. Thus, the patterns and times of sowing in these groundnut-producing areas are quite varied.

Pattern of sowing

Groundnut culture in China is divided into three patterns based on differences in soil texture, climate, and varieties (although almost all the varieties grown in China are the bunch type): flat, ridge, and bed cultures.

Flat culture. This is a traditional sowing method practiced on poor or hilly land under rainfed conditions. It involves the following steps: furrow the field with an animal-drawn plow, drop two seeds per hill, cover the seeds with earth, and stamp on it to compact the soil, thereby conserving soil moisture. Row-to-row spacing is 26–33 cm, and plant-to-plant spacing, 13.5–16.5 cm. Flat cultured groundnut is decreasing; it is practiced only in the alluvial plains along such rivers as the Yellow River and the Huaihe River, and a small area of poor, hilly land in northern China.

Ridge culture. Ridge culture consists of either one row or a flat ridge with two rows on it. The row on the ridge is cultivated twice without using a plowshare.

For small- and medium-seeded, short-duration, erect varieties such as Baisha 1016, and Luhua No. 9, the ridge is 10-cm high and 38-cm wide, with 14-cm plant-to-plant spacing. For large-seeded, erect, medium-duration varieties, such as Luhua No. 10, Hua 17, Haihua 1, 79266,

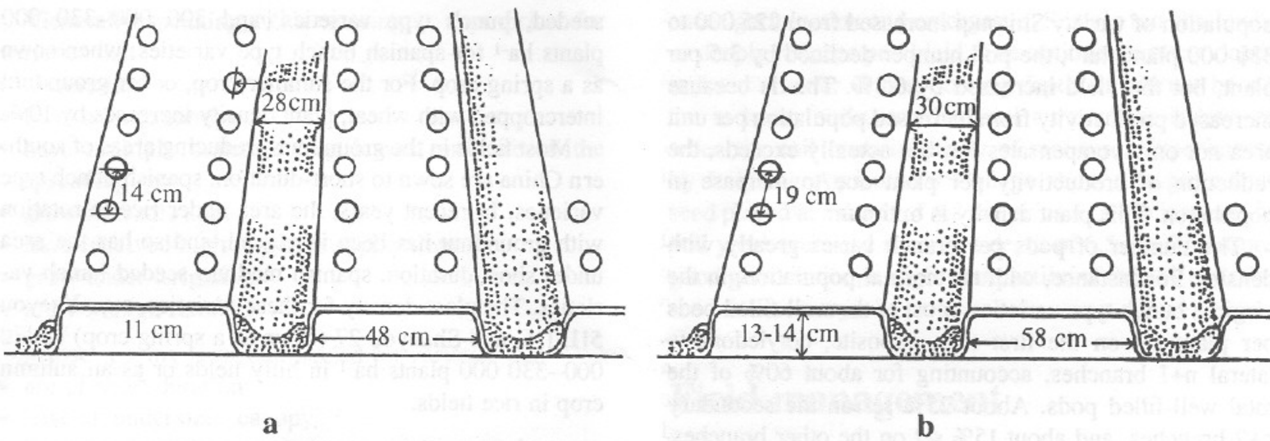

Figure 1. Dimensions of flat ridge for (a) small- and medium-seeded, short-duration, erect groundnut varieties, and (b) for large-seeded, medium-duration, erect, groundnut varieties in China.

and 8130, Luhua No. 37, and Xuzhou 68-4, the ridge is 12-cm high, 46-cm wide, with 19-cm plant-to-plant spacing. If the soil is fertile, the interrow spacing can be widened appropriately. The wider ridge is cultivated four times with a plowshare.

Figure 1 (a) shows the dimensions of a flat ridge with two rows of small- and medium-seeded, erect, short-duration groundnut varieties. The bed is 11-cm high, 48-cm wide, and has a 28-cm wide furrow. Figure 1 (b) shows the dimensions of a flat ridge with two rows of large-seeded, erect, medium-duration varieties. The bed is 13–14-cm high, 58-cm wide, and has a 30-cm wide furrow.

Ridge culture is widely used in northern and northeastern China. Under the same conditions, ridge culture gives a 10% increase in pod yield over flat culture, for the following reasons:

- Since ridge culture exposes more soil surface to air and sunlight, the soil temperature is higher. Experiments by Tangshan Agricultural Research Institute in Hubei province show that during seedling emergence, the temperature in the top 5 cm of soil is 1.3–3°C higher, and seedlings emerge 1–3 days earlier in ridge culture than in flat culture. Moreover, the large surface of the ridge allows for a rapid rise in temperature during the day, and a sharp fall at night, which is good for seedling growth.
- Ridges facilitate irrigation and drainage.
- In ridge culture, the earth around the seedlings tends to be removed, thus exposing cotyledons to the sun; this makes the seedlings strong. (This point will be discussed in greater detail in the section on Field management.)

Bed culture. Bed culture is practiced along the Yangtze River, and in the southern groundnut-producing areas of Sichuan, Hubei, Guangdong, Guangxi, and Fujian provinces, where there is high rainfall, and groundnut, being grown in rotation with rice, suffers from waterlogging.

Bed culture decreases the water content of the soil, as rainwater tends to seep into the canals between beds and drains away. In case of drought, the same canals can be used to carry irrigation water. Experiments show that bed culture increases pod yield by 20% over the control. Beds for groundnut in paddy fields are 12–15-cm high and 120–150-cm wide; 4–5 rows of groundnut are sown on each bed, with interrow spacing of 20–27 cm. The canal between beds is 20–30-cm wide, and 25–30-cm deep. Beds in hillside fields are 12–15-cm high, and 150–180-cm wide, 6–7 rows of groundnut are sown on them, with an interrow spacing of 20–27 cm. The canal between beds is 20–30-cm wide and 15-cm deep.

Close sowing

Groundnut yield depends upon two critical factors: the number of plants per unit area, and productivity per plant (measured by pod number and weight). There is a mutually influencing relationship between individuals and populations. An individual occupying a large nutrient area and growing well gives high productivity under sparse sowing, although the population yield is not high. To a certain extent, productivity per plant reduces with increase in density, nevertheless, total productivity rises. Laiyiang Agricultural College reported that with increasing plant population (135 000, 180 000, and 270 000 plants ha^{-1}) the productivity per plant decreased (15.65, 14.10, and 10.29 g) but the yield increased (2.1, 2.5, and 2.8 t ha^{-1}). Similar results were obtained in trials by Guangdong Academy of Agricultural Sciences. When the population of variety Shitouqi increased from 225 000 to 330 000 plants ha^{-1}, the pod number declined by 3.5 per plant, but the yield increased by 6.3%. This is because increased productivity from increased population per unit area not only compensates for, but actually exceeds, the reduction of productivity per plant due to increase in population. This plant density is optimum.

The number of pods per branch varies greatly with density. For instance, with the normal population, in the virginia bunch type varieties, most of the well-filled pods per plant set on the first two, opposite, cotyledonary, lateral n+1 branches, accounting for about 60% of the total well-filled pods. About 25% set on the secondary n+2 branches, and about 15% set on the other branches. Experiments show that the total number of branches per plant decreases with increasing plant density, but the number of n+1 branches, especially those bearing pods, increases with increase in population, while, generally, no n+3 or higher order branches appear. In other words, most of the branches that are reduced because of the increased population per unit area are ineffective ones. This is why, up to a point, high yields result from an increase in plant population which gives greater pod number per unit area, because of higher total photosynthetic production. The rate of photosynthesis, total leaf area of a population, partitioning coefficient, and yield are closely correlated. Laiyang Agricultural College reported that when the population is 135 000 plants ha^{-1}, the total leaf area is 20 547 m^2 ha^{-1}, the photosynthetic rate was 6.75 g m^{-2} per day, and the total photosynthetic rate is 138.69 kg ha^{-1} per day. When the population goes up to 180 000 plants ha^{-1}, the photosynthetic rate decreases to 6.07 g m^{-2} per day, but the total photosynthetic rate increases to 169.55 kg ha^{-1} per day because of the increase of total leaf area to 27933 m^2 ha^{-1}.

Optimum plant densities. In northern China the optimum plant density for virginia bunch type varieties sown as a spring crop, e.g., Luhua 4, 9, 10, Hua 17, Xuzhou 68-4, Haihua 1, Shuangji 1, 8130 and 79266 is 110 000–135 000 hills ha $^{-1}$ (with two seeds per hill) on soils of medium fertility, and 107 000–120 000 hills ha^{-1} on soils of high fertility. Optimum density of spanish small- medium-seeded, bunch type varieties (sown as a spring crop), e.g., Baisha 1016, Luhua 8 and 13, is 180 000–210 000 hills ha^{-1} under rainfed conditions, and 150 000–190 000 hills ha^{-1} under irrigation. For the summer crop, or when groundnut is intercropped with wheat, plant density increases by about 10%.

In the Yangtze River valley the optimum plant density is 270 000–300 000 plants ha^{-1} for virginia medium-seeded, bunch type varieties, and 300 000–330 000 plants ha^{-1} for spanish bunch type varieties, when sown as a spring crop. For the summer crop, or for groundnut intercropped with wheat, plant density increases by 10%.

Most fields in the groundnut-producing areas of southern China are sown to short-duration, spanish bunch type varieties. In recent years, the area under rice in rotation with groundnut has been increased, and so has the area under short-duration, spanish medium-seeded bunch varieties. The plant density for these varieties, e.g., Yueyou 511, 116, and Shanyou 27 (sown as a spring crop) is 270 000–330 000 plants ha^{-1} in hilly fields or as an autumn crop in rice fields.

Principles of close sowing

Researchers in China suggest that the following points should be noted.

Natural conditions. Plant density should be high in areas where there is less rain, temperatures are low, and mature groundnut plants are of small size. Plant spacing should be increased in regions of high temperature and rainfall where plants are well developed.

Under the same climatic conditions, if the soil is poor and shallow, close spacing should be adopted to cover the ground fully, and exploit the production potential of the population. Groundnut sown on deep soils of good texture, and high fertility should be widely spaced.

Varietal characteristics. Virginia spreading-type groundnut varieties have many long branches, and the mature plants are large. When temperature, moisture, and nutrient levels favor growth, individual plants should be widely spaced. Since virginia semi-spreading cultivars are compact, and their pod-setting zone is small, their plant populations should be higher than those of the spreading types. Compared to semi-spreading cultivars, spacing for erect types should be closer still. Spanish types have a short growing period, few branches, and terminate flowering and pod setting at a desired level; therefore, plant populations for these types should be increased.

Cultural practices. Fertilizer and water use interact closely with plant density. Other things being equal, there is a positive correlation between the quantity of fertilizer applied and plant growth. Thus, when more fertilizer is applied, plant density should be low, and vice versa. Under conditions of high rainfall, high levels of ground-water, or irrigation, plant spacing should be wide.

Generally speaking, wide spacing is appropriate for varieties that

- mature late
- form a large canopy
- have multiple branches, big leaves, and are of the spreading type
- grow in fertile soils
- have received high fertilizer applications
- grow under irrigation
- grow in high rainfall.

Close spacing is recommended for varieties that

- are of short duration
- have an undersized canopy
- have few branches, small leaves, and are of the compact type
- grow on poor soil
- receive less fertilizer
- grow under of poor rainfall conditions.

Time of sowing

The optimum sowing time for groundnut depends on natural conditions, of varietal characteristics, and the cultural system adopted. Genotypes respond differently to temperature. Short-duration varieties germinate at soil temperatures above 12°C, and long-duration varieties at temperatures above 15°C. If the soil moisture accounts for 60–70% of the maximum water-holding capacity, short-duration varieties germinate well at 15°C, and long-duration varieties at 15–18°C. Experiments conducted in Fujian, Shandong, Hubei, and Liaoning provinces show that when the mean daily soil temperature over 5 days at 5-cm depth is 15°C, it is a good time to sow groundnut. When the temperature ranges between 12.5–13°C, groundnut should be sown with polythene mulch because the soil temperature under polythene mulch is 2.5–3°C higher than that of unmulched soil.

The optimum sowing time for spring groundnut in China is the second fortnight of Feb in Guangdong, and Guangxi provinces; the last week of Mar, and the first week of Apr in Zhejiang, Fujian, Jiangxi, and Sichuan; and the last week of Apr, and first week of May in Shandong, Liaoning, Hubei, Henan, Jiangsu, and Anhui provinces.

Groundnut is intercropped with wheat from wheat heading to blooming stages in northern China, and during the milk stage in Jianghuai River valley because of the long frost-free period there.

Summer groundnut is sown soon after harvest of the preceding crop, to allow for the required crop duration before the cool weather of autumn. Sowing depth influences germination and emergence. Sowing too shallowly or deeply reduces pod yield. The optimum sowing depth is 5 cm all over China. Sowing depth should not be <3 cm in heavy soils, or when soil temperature is low, or when the soil contains plenty of moisture. Experiments by Laiyiang Agricultural College show that groundnut seed placed at a depth of 4.8 cm gives a 12.8% increase in pod yield over seed sown at a depth of 6.5 cm. To ensure good germination, a slight compaction of the soil over the seed is necessary.

Field management

High yields of groundnut depend crucially on such field management practices as: removal of earth from around the seedlings (REFAS) to make them strong, intercultivation, use of growth regulators, side-dressing with fertilizer, control of diseases and insect pests, and irrigation at the appropriate time.

REFAS

Removing earth from around the seedlings exposes to the sun the two cotyledons and the two opposite cotyledonary lateral n+1 buds, which grow sturdy as a result. This practice is combined with the first intercultivation at full seedling emergence. It has been distilled out of farmers' experience, and perfected by Shandong Peanut Research Institute after many years' experiments at multiple locations. The effect of REFAS on pod yield is significant. Results from 80 trials in the districts of Yantai, Linyi, and Weifang show that REFAS gives an average increase of 12.9% (the highest being 23%) over the control.

Reasons for yield increase

Most pods of groundnut set on the first pair of n+1 branches. During seedling emergence, cotyledons are sometimes fully or partially buried in the soil. So, the first pair of n+1 buds attached to the cotyledonary axils are often in the soil in the early stages of growth, causing the basal internodes to enlarge, forming 'long-legged seedlings'. Timely REFAS exposes the first pair of n+1 buds to the sun and makes them grow strong. Trials at multiple locations over many years show that both stems and n+1 branches thicken, and their basal internodes are shortened after REFAS. Compared to the control, the stem basal internodes of REFAS-treated plants are on average 0.2-cm shorter, the first basal internodes of the first pair of n+1 branches are 0.2-cm shorter. The second ones 0.9-cm shorter, and the third ones 0.4-cm shorter. The total number of flowers increases by 7.4%, effective flowers by 10.2%, and pods per plant by 30.6–31.3%. Kaifeng Agricultural Research Institute, Henan province, showed in the 1972/73 crop season that REFAS-treated groundnut flowers two days earlier, and has 9.86–29.37% more flowers than the control.

Root growth and resistance to drought can improve with REFAS. The tap roots penetrate deeper, and the axillary roots increase. Tangshan Agricultural Research Institute, Hebei province, showed that 25 days after REFAS the plant has a tap root 14.7-cm long, and 78 axillary roots, while the control has a tap root 11.5-cm long and 52.7 axillary roots. Kaifeng Agricultural Research Institute reported that 20 days after REFAS the plant has a tap root 43.5-cm long (a 50.95% increase over the control), and 111.2 axillary roots (a 28.18% increase), and total root length is 991.1 cm (a 25.8% increase over the control). Well-developed roots improve both resistance to drought, and uptake of water and nutrients. Less damage by weeds and aphids at the seedling stage are other benefits resulting from REFAS.

REFAS timing

REFAS timing is important: if done too early, the young seedlings are too tender to adapt themselves to the atmospheric conditions. If REFAS is carried out late, the first pair of n+1 branches will be buried in the soil causing the basal internodes to enlarge, forming 'long-legged seedlings'. Experiments by Shandong Peanut Research Institute show a 14% increase in pod yield (414 kg pods ha^{-1} over the control) when REFAS is done at full seedling emergence; a 7.8% increase (231 kg pods ha^{-1}) when REFAS is done 5 days after seedling emergence; and a 7% increase 10 days after seedling emergence. The best time for REFAS is when most of the seeds have sprouted and cracked the soil.

REFAS techniques

The REFAS technique involves hoeing between rows along the direction of the row, and then removing the earth from around the seedlings with a small hand-hoe to expose the two cotyledons (Fig. 2). REFAS should be neither too deep nor too shallow. Optimally, it should just expose the cotyledons. Care should be taken not to injure them. Irrespective of whether sowing is deep or shallow,

Figure 2. Removal of earth from around the seedlings (REFAS) increases pod yields of groundnut in China.

REFAS makes a significant difference in pod yield. Trials show that groundnut sown at a depth of 3 cm, and treated with REFAS, gives a 9.1% increase in pod yield over the control, a sowing depth of 6 cm gives a 14.3% increase, and a 9-cm sowing depth increases pod yield by 7.2%.

Intercultivation. This practice helps in retention of soil moisture. During droughts, intercultivation breaks the soil capillaries, thereby preventing soil water loss. Under irrigation, intercultivation retards soil crusting, facilitates evaporation of water from the surface layer, and soil aeration. Intercultivation also controls weeds that compete with crop plants for soil moisture, nutrients, and light. Weed control, in turn, reduces to some extent the damage to groundnut plants caused by aphids, red spider mites, and root-knot nematode that parasitize and propagate in some weeds that serve as its alternate hosts.

Three intercultivations are recommended for groundnut. The first is combined with REFAS at full seedling emergence. In northern groundnut-producing areas, intercultivation is repeated up to 15–20 days after REFAS, and up to 10 days after REFAS in southern groundnut-producing areas. The last intercultivation should be completed by the time the flowers bloom, or by the time the vines cover most of the field; at the same time, the plants should be earthed up to increase the depth of soil around the pod-setting zone. Only the first and last intercultivations need to be deep. It is also beneficial to hand-weed once before harvest.

Use of growth regulators

Applying growth regulators to groundnut promotes or inhibits seed dormancy, germination, vegetative and reproductive growth, translocation, and allocation of nutritional materials, photosynthesis, and metabolism. Growth regulators used on groundnut in China include DPC (dinocap), Paclobutrazol (P333), Fosamine, 2,3,6 trichlorobenzoic acid (TCBA), and chlora choline chloride (CCC).

DPC. DPC inhibits stem growth, enhances root development and branching, and increases pod yield. Demonstration trials in Hubei and Guangxi provinces gave pod yield increases ranging from 7.02–25.53%. When the seed was soaked with 80-ppm DPC for 3–4 hours before sowing, the root length of 17-day seedlings increased by about 50%, and root mass per plant by about 33.3%. The number of pods per plant was 16.5% higher than the control. With foliar application of DPC at early or peak flowering stages, the stems are 3–4-cm shorter, have 1–2 more branches, and pod number per plant increases by 28.8% over the control. The early flowering stage is the best time to apply 80-ppm DPC as a foliar spray.

Paclobutrazol (P333). Rapid and luxuriant vegetative growth during the middle growing stage in groundnut can threaten optimum population structure. Foliar application of P333 at this stage inhibits vegetative growth, and enhances reproductive growth, resulting in high yield. Experiments show that, after a foliar spray of P333, the average stem growth rate in 20 days was 1.6 mm per day, 54.3% less than the control; the average growth in the next 30 days was 0.4 mm per day, 81.8% less than the control. When harvested, the average pod number per plant increased by 0.8, 100-pod mass by 7 g, 100-kernel mass by 3 g, and the yield increased by 7.1–10.8% over the control. If groundnut plants in highly fertile soils grow more vigorously than expected 25–30 days after the first flowers appear, foliar application of P333 at 60-ppm concentration is recommended.

Fosamine. Fosamine strongly inhibits the growth of the aerial parts, and flowering of groundnut. The effect is seen 3 days after a foliar spray, and lasts till plant maturity. Experiments in Henan province show that Fosamine treatment resulted in 14.87% pod increase, and 17.63% kernel increase over the control. Fosamine reduces ineffective late flowering. Therefore, foliar application of 500-ppm Fosamine is recommended at late pod-forming stage. Fosamine-treated groundnut should not be used as seed for the next year's crop because it does not germinate well, and produces abnormal seedlings.

Trichlorobenzoic acid (TCBA). Spraying 250-ppm TCBA on groundnut at peak or late peak-flowering stage inhibits growth of the aerial parts, and late ineffective flowers. It facilitates pod development resulting in yield increases in the range of 9.5–19.6%. If applied earlier, the chemical inhibits flowering, and reduces the number of flowers. Once the effect of the chemical wanes, the crop grows more rapidly and its height may exceed that of the control. Pod yield on foliar application of TCBA varies with genotypes. TCBA gives good results with large-seeded varieties of medium- or long-duration. But yields of spanish type varieties are affected little by TCBA treatment.

In general, promoters should be selected for use in the early growing phase, inhibitors in the middle growing period, and protectants in the late growing stage. Growth regulators cannot compensate for the lack of other sound cultural practices. The maximum effect a growth regulator on crop yield would probably be expressed when all other factors contributing to crop production are optimum.

Chemicals for drought resistance

Drought is a major constraint to groundnut yield in China. Besides development of irrigation, and cultivars resistant to drought, there have been many studies on the use of chemicals to moderate the impact of drought stress. It has been found that foliar sprays of chemicals during the growing stage can control leaf stomatal aperture, thereby reducing transpiration, and consumption of soil moisture. If applied during drought, these chemicals significantly moderate the impact of moisture deficiency in the plants, and increase the capacity of resistance to drought in groundnut. These chemicals presently include Triadimefon, calcium chloride, fulvic acid, and succinic acid.

Triadimefon. This fungicide increases crop resistance to drought. Triadimefon is thought to increase the level of endogenous abscisic acid and free proline in leaves. A 300-ppm spray of Triadimefon, 25–30 days after the first flowers appear is recommended. If it rains after Triadimefon application, the crop needs to be sprayed again. Since Triadimefon inhibits vegetative growth, it must be used on well-developed crops sown in fertile soils. Under dry conditions, foliar application of Triadimefon increases yield by 10%.

Fulvic acid. Fulvic acid is used to control leaf stomatal aperture, and decrease transpiration, thereby alleviating drought stress. Experiments conducted in the 1989/90 crop season show that foliar application of fulvic acid results in yield increases, ranging from 8.54–16.07%. Spraying the chemical from flowering to peg-forming gave the highest increase in pod yield (16.07%), and spraying at the pod-filling stage an increase in pod yield of 14.02% over the water-treated control. Groundnuts treated with a combination of fulvic acid and Carbendaxol gives better results than those treatmented individually with the two chemicals.

Management of diseases and insect pests

Diseases cause great losses to groundnut in China. The most important diseases infecting groundnut are root-knot nematode (*Meloidogyne hapla*), collar rot (*Sclerotium rolfsii*), bacterial wilt (*Pseudomonas solanacearum*), rust (*Puccinia arachidis*), early leaf spot (*Cercospora arachidicola*), late leaf spot (*Phaeoisariopsis personata*), and web blotch (*Didymella arachidicola*). Disease incidence and losses range from 10–30%, with severe losses as high as 50–60%.

Insect pests are another major constraint to groundnut yield; e.g., white grubs (*Lachnosterna* spp), aphids (*Aphis craccivora*), cotton bollworms (*Helicoverpa armigera*), and leaf miners (*Aproaerema modicella*), are economically significant pests. Integrated disease and pest management consisting of such cultural practices as crop rotation, winter tillage, clearance of polluting resources, and extension of polythene mulch, and chemical control is practiced in China.

Crop rotation. It is well known that groundnut grown on the same land in successive years yields poorly, but yields well when rotated. One reason is that rotation reduces the damage to groundnut caused by such diseases as root-knot, collar rot, bacterial wilt, and foliar diseases. Pathogens infecting groundnut lose their ideal living conditions when rotated with different crops. In northern China, root-knot nematode injures crops like groundnut, soybean, and cotton, but not cereals like wheat, barley, and maize. Similarly, in southern China, rotation with rice helps to control bacterial wilt. Maize, wheat, foxtail millet, rice, and sweet potato are considered good to rotate with groundnut. The optimum rotation cycle is at least 2–3 years. The recommended sequences of 3-crop, 2-year rotations in northern China are:

- Winter wheat <> summer maize (or foxtail millet or sweet potato) – spring groundnut
- Winter wheat <> summer groundnut – spring maize (or sweet potato or sorghum)
- Winter wheat > summer sweet potato a winter cover crop – spring groundnut.

The recommended sequences of 3-year crop rotations in southern China are:

- Rice > autumn groundnut <> wheat or sweet potato – short-duration rice > long-duration rice > rape – short-duration rice > long-duration rice > sweet potato
- Groundnut > long-duration rice > sweet potato or soybean or wheat intercropped with sugarcane – sugarcane – sugarcane
- Groundnut > wheat – sweet potato > pea – soybean > sweet potato

where < = intercropping,
> = previous or post crop, and
– = 1-year interval.

Winter tillage. This destroys over-wintering insect pests, their pupae and larvae, and fungi by exposing them to the cold, and to the hot sun.

Clearing pollutants. This includes

- destroying weeds that harbor insect pests and diseases in and around groundnut fields
- burying deeply or burning diseased vines at harvest
- not making compost with diseased soil, especially soil infected with root-knot nematodes
- controlling aphids that disseminate viruses.

Chemical control. Broad-spectrum chemicals with long-term efficacy like aldicarb, carbofuran, and fenamiphos should applied in the furrows at sowing time to control soil pests, and root-knot nematodes at the seedling stage, and to prevent virus diseases from being transmitted by insects. Foliar application of methiocarb and omethoate may be effective in controlling aphids and cotton bollworms at the peak growing stage. Bordeaux mixture and chlorothalonil are foliar sprays recommended to prevent groundnut leaves from attack by such foliar diseases as early or late leaf spot, and rust at the late growing stage.

Mulching. Plastic film repels some insect pests and diseases. Some kinds of insect pests may be lured to destruction or killed manually. Further, natural enemies should be protected as far as possible; the chances of killing natural enemies can be lessened by reducing the frequency, and improving the methods of chemical application.

Irrigation and drainage. Rainfall is distributed mainly during summer in most groundnut-producing areas. Another important step in groundnut production, therefore, is irrigation when it is dry, and drainage when there is waterlogging. Drought is common in northern groundnut-producing areas during the early flowering stage in spring, and at the pod-filling stage in autumn, but waterlogging is common in summer. Most parts of the southern and Changjiang Valley groundnut-producing areas have high rainfall. Waterlogging or high soil moisture causes pod rot, low yield, and poor quality. It also influences soil aeration, retards root respiration, and uptake of nutrients, and reduces the number of root nodules and their capacity to fix nitrogen.

Experiments indicate that when drought lasts 10 days at the flowering or pegging stage, the water-holding capacity in 0–30-cm soil layer declines from 57.5% to 20.9%, and pod yield is reduced by 28.7%. When the water-holding capacity of the soil declines to 19.3% at the pod-forming stage, pod yield decreases by 30.6%; and when water-holding capacity is diminished to 28.6% at the pod-filling stage, the yield is reduced by 21.6%. This shows that drought occurring at any stage influences groundnut yield; that the pod-forming stage is the most vulnerable, followed by the pod-filling, and flowering-pegging stages. Experiments also show that groundnut irrigated in dry conditions gives significant increases in pod yield ranging from 39.1–53.8%.

There are many ways to judge whether the crop needs to be irrigated or not. The most convenient method is determine the soil water content. If the soil water content is below 40% of the maximum field capacity, irrigation is required. Though the area under groundnut has increased, irrigation is not commonly employed, especially in hilly regions, due to the lack of water resources and infrastructure, and the high costs involved. Most farmers who irrigate their fields follow the furrow method of irrigation; a very few use sprinkler or drip irrigation. The frequency and timing of irrigation depends upon the quantity of rainfall, soil water content, and water requirement of groundnut at different stages. If it is dry at the seedling stage, irrigation is not needed. Groundnut suffers from drought more frequently at the pod-filling stage than at other stages, the sensitive period being early autumn. Irrigation, if required, should be given in the morning or late in the afternoon. In general, one to two irrigations for the spring crop in northern groundnut-producing areas, and two to three irrigations for the autumn crop in southern groundnut-producing areas are adequate.

Polythene mulching

Polythene mulch was introduced from Japan into China in 1978. Trials with polythene mulched groundnut (PMG) were conducted at Shandong Peanut Research Institute in 1979, resulting in significant increases in pod yield. Extension trials were carried out in the early 1980s. The area under PMG was only about 130 ha in 1980. Technology extension during the 1984 cropping season increased the area under PMG to 92 000 ha. The area under PMG is now reported to be 330 000 ha—more than 10% of the total area under groundnut in China. This so-called 'white revolution', is one of the most important cultural practices in groundnut production in China.

Advantages of polythene mulch

The reasons for the popularity of PMG are:

- This practice is ideal, not only for cold regions in the north, but also for semi-tropical regions in the south in all kinds of soils; and for both the spring and summer crops of almost all varieties.
- PMG increases pod yield significantly. Pod yields from over 220 000 ha of PMG in five provinces and one municipality in Liaoning, Shandong, Hebei, Henan, Shanxi, and Beijing in 1985 averaged 4.19 t ha^{-1}—an increase of 2.05 t ha^{-1} over nonmulched groundnut (NMG) that gave an average yield of 2.14 t ha^{-1}. The Ministry of Agriculture, Animal Husbandry and Fishery of China summarized the trials of PMG conducted by the agricultural extension departments in 16 provinces and municipalities from 1979–84. The results showed that the pod yield of PMG was 3.75–4.5 t ha^{-1}, with a maximum of 10.5 t ha^{-1}. These yields were 20–50% higher than those of NMG.

  The results of 131 PMG trials conducted by Shandong Agricultural Bureau in 1985 on soils of varying fertility, show that PMG gives significant increases in pod yield (Table 1).
- PMG increases seed oil and protein contents, and raises the ratio of oleic to linoleic fatty acid in the seed. Qingdao Seas and Oceans University reported after analysis of Hua 17 that the ratio of oleic to linoleic acid increases from 1.49 under NMG to 1.67 under PMG. The levels of eight essential amino acids, e.g., lysine,

Table 1. Pod yields from polythene mulched groundnut (PMG) and nonmulched groundnut (NMG) in soils of varying fertility, Shandong Agricultural Bureau, China, 1985.

Soil fertility	Locations	PMG ($t\ ha^{-1}$)	NMG ($t\ ha^{-1}$)	Increase ($t\ ha^{-1}$)	Increase (%)
Low	11	2.84	1.91	0.93	48.69
Medium	38	4.14	3.01	1.13	37.90
High	40	6.34	4.94	1.40	28.34
Very high	36	8.09	6.66	1.43	21.47
Very very high	14	9.56	8.08	1.48	18.32

increased by 27.8%, and those of 17 other amino acids, e.g., glutamic acid, increased by 24.46% over the control.

- Groundnut with polythene mulch is sown approximately 10 days earlier than NMG, and it emerges, blooms, sets pod, and matures about 8 days earlier than NMG. The crop period is shorter by 8 days. This has extended the groundnut-producing areas in the north. For instance, without PMG, groundnut in Yinchun, Helongjiang province, cannot mature, but with PMG, the pod yields reach 2.25–3 $t\ ha^{-1}$. In the past, in parts of northern China, only short-duration varieties were used because of the short frost-free period. Now, with PMG, medium-seeded, medium-duration varieties with high yield potential are used. PMG use increases the cropping intensity in some regions by making it possible to grow two crops in a year or three crops in 2 years because of the shorter cropping period.

However, PMG has some disadvantages:

- All the film used in mulching cannot be retrieved, and causes environmental pollution. Residual film in the soil may interfere with the root development of the next crop.
- Sowing PMG takes much more time and labor, and the cost is higher than that of NMG.
- Seeds produced under PMG are less viable than those under NMG.

Reasons of yield increase of PMG

Soil temperature. Polythene mulch increases soil temperature. The polythene film used usually has a transmittance above 80%, and retains the sun's heat. Soil temperature in the top 5 cm of soil with polythene mulch is 2.5–3.9°C per day higher during the early growing stage, and 0.6–1.1°C per day higher during the late growing stage, i.e., 1.4–2.7°C per day higher than the control when averaged over the whole growing period. The total accumulated temperature under PMG is 3467.6–3528.4°C; 195.3–370.8°C higher than that of NMG. The increased accumulated temperature shortens the crop period, and increases the pod yield of PMG.

Moreover, during the hot season, the polythene film protects the soil from direct sunlight, and its impermeability to hot air ensures optimum temperature for the middle growth phase of groundnut. When atmospheric temperature in Guangxi province is above 26°C, the temperature in the top 5 cm under PMG is 0.3–0.6°C per day, and that in the top 15 cm of soil is 0.1–0.5°C per day lower than the control. Thus, PMG regulates soil temperature.

Soil moisture retention. Evaporation from the soil accounts for 25–50% of the total quantity of water used. An important practice for rainfed agriculture, therefore, is to decrease evaporation of soil water. Polythene mulch prevents soil water evaporation, and thus helps retain soil moisture. The soil moisture of PMG 60 days after sowing was 40.9–62.6% of the maximum field capacity in one experiment, and 24.5–57% in another. These values were 9–10.9%, and 2.6–15.1% higher than NMG. These experiments were conducted at Shandong Peanut Research Institute. It has been reported that water vapor flux density in the top 20 cm of soil with polythene mulch at the end of May was 1.7 times that of the control, indicating greater movement of water from the deeper layers upward. Jinzhou Agricultural Research Institute showed that the water content in the top 5 cm of soil was 16–17% before mulching with polythene; from the time the polythene film is spread, to the emergence of seedlings, water content increased by 4.7% in clayey soil, by 3.1% in loamy soil, and by 0.8–1.8% in sandy soil. During heavy rains, the polythene film retards soil erosion, and rapid infiltration of rainwater into the soil. Optimum soil moisture ensures good emergence and seedling growth.

Soil texture improvement. The soil under PMG is not tilled during the growing period. Thus, with polythene mulch, at harvest, the weight of a cubic centimeter of soil from the top 50 cm of soil is 1.30–1.44 g, which is 0.11–0.20 g less than that of the control. The total porosity increases by 3.0–5.2%, capillary porosity by 1.7–7.6%, and aeration porosity by 0.4–3.5% over the control. The total number of roots of PMG in the top 50 cm of soil increases by 55% over that of NMG, and the number of nodules of PMG increases by 88.7% at the first-flower stage, by 70.0% in the pod-setting stage, and by 27.5% in the pod-filling stage compared to NMG.

Soil microorganisms. Dalian Agricultural Research Institute reports that the number of microorganisms in the soil with polythene mulch goes up significantly; fungi increase by 58.3%, actinomycetes by 36.7%, ammonifiers by 25.8%, nitrogen-fixing bacteria by 47.3%, phospho-bacteria by 56.3%, and potassium bacteria by 56.1%, compared to the NMG control. The increase in soil microorganisms accelerates the decomposition and transformation of organic matter in the soil, thus increasing the levels of available nutrients in the soil. Liaoning Agricultural Academy of Sciences showed that total P in the soil with polythene mulch increases by 4.37%, total K by 7.57%, available phosphate by 0.17%, and available K by 2.95% during the growing period compared to the NMG control.

Microclimate improvement. The reflection of sunlight by polythene film increases illumination between rows. In the middle of the growing period, reflection of sunlight 30 cm above the soil surface is 5.3–13.0% when polythene film is used, but only 2.4–4.0% without it. The accumulated temperature by PMG from 0600–1400 is 3.7°C higher but somewhat lower from 1400–2000; and wind speed within PMG rows is 0.01–0.03 m s^{-1} faster compared to NMG. Faster wind speeds favor air exchange and CO_2 movement. All these increase the photosynthetic efficiency of PMG. During the peak growing stage, total biomass is 351 kg ha^{-1} per day, (21% higher than the control), 270 kg ha^{-1} per day of which is vegetative (22% higher than the control), and 81.0 kg ha^{-1} per day is reproductive (31% higher than the control). Table 2 shows the changes in temperature, moisture, wind speed, and illumination in PMG and NMG.

Increase in well-filled pods. Pegs developing during the late growing stage cannot penetrate the film to enter the soil, thus saving nutrients for pods which set earlier and are now developing. Hua 37, a large-seeded, medium-duration variety sown with polythene mulch gives a 13–25% increase of well-filled pods; and the percentage of shelled seeds increases by 4–5%.

Growth characteristics under PMG

Polythene mulch improves groundnut crop growth and nodule development (Table 3). The Biology Department of Southern China Teachers' University measured the dry root mass of the variety Yuyou 551-116 at the seedling, flowering-pegging, and pod-setting stages. The dry root mass of PMG was 12.23–50% higher in 1984, and 20.94–128.7% higher in 1985, during the various stages. The nitrogen-fixing activity of PMG increased by 3.28–148.84% over the control. There are differences in plant height between PMG and NMG at the 3-leaf stage. Plants under PMG were 3.25–4.02 cm tall, 45.28–77.88% taller

Table 2. Changes in moisture, temperature, wind speed, and illumination in polythene mulched groundnut (PMG) and nonmulched groundnut (NMG) during the late growing stage, Liaoning, China, 1981.

		Time (hours)							
Factor	Treatment	6	8	10	12	14	16	18	20
Temperature (°C)	PMG	17.5	22.3	25.5	25.5	26.5	23.9	22.0	19.2
	NMG	17.0	22.0	24.2	25.0	25.4	24.2	22.2	20.0
Moisture (%)	PMG	91	82	72	68	71	89	77	84
	NMG	93	83	75	74	72	91	92	94
Illumination (%)	PMG	15	18	20	70	38	30	26	
	NMG	13	17	19	59	37	25	24	
Meter candle ('000 lux)	NI[1]	9	11	56	82	75	15	2	
Wind speed (m s^{-1})	PMG	0.14	0.15	0.19	0.15	0.23	0.18	0.06	
	NMG	0.13	0.13	0.15	0.14	0.23	0.16	0.05	
	NWS[2]	0.63	0.66	1.00	0.90	1.24	1.00	0.49	

1. NI = natural illumination
2. NWS = natural wind speed

Table 3. **Various growing stages of polythene mulched groundnut (PMG) and nonmulched groundnut (NMG), Liaoning, China, 1980.**

Varieties	Treatment	Sowing	Emergence	Flowering	Pegging	Pod setting	Pod filling	Duration (days)
	PMG	15 Apr	12 May	14 Jun	27 Jun	16 Jul	12 Sep	149
	NMG		22 May	24 Jun	10 Jul	29 Jul	18 Sep	165
Baisha 1016	PMG	25 Apr	15 May	13 Jun	29 Jun	18 Jul	12 Sep	140
	NMG		27 May	25 Jun	10 Jul	24 Jul	18 Sep	146
	PMG	5 May	19 May	16 Jun	5 Jul	25 Jul	12 Sep	130
	NMG		24 May	26 Jun	8 Jul	30 Jul	18 Sep	136
	PMG	15 Apr	13 May	16 Jun	29 Jun	19 Jul	18 Sep	156
	NMG		24 May	25 Jun	8 Jul	29 Jul	28 Sep	161
Jinjiao 4	PMG	25 Apr	16 May	13 Jun	1 Jul	19 Jul	20 Sep	148
	NMG		24 May	25 Jun	8 Jul	28 Jul	23 Sep	151
	PMG	5 May	20 May	18 Jun	6 Jul	27 Jul	20 Sep	138
	NMG		24 May	27 Jun	9 Jul	29 Jul	23 Sep	141

than those of NMG at this stage. This difference diminishes gradually as the crop grows. The chlorophyll content of PMG fresh leaves was 1.24 mg g^{-1} (seedling), 1.195 mg g^{-1} (flowering), and 1.448 mg g^{-1} (flower-pegging), while the chlorophyll content of NMG fresh leaves was 0.876 mg g^{-1}, 0.744 mg g^{-1}, and 0.428 mg g^{-1} at those stages.

Early blooming of reproductive buds. Because of the good vegetative growth of PMG, more reproductive buds differentiate and bloom early. Experiments from 1983–85 show that with PMG, reproductive buds increase by 63.36–94.05% at the three-leaf stage, and by 2–57.03% at the seven-leaf stage over NMG. Xuzhou 7101-43 bloomed 7 days earlier, giving 16.8 more flowers per plant, and 64.2 more effective flowers per plant than NMG sown on the same date in spring. Using PMG with Luhua 1 and Xuzhou 68-4, as a summer crop, the peak flowering stage advanced by 9 days, with only 1.79 more flowers per plant than NMG; but the increase in well-filled pods over NMG was 21.15%.

Recommendations about polythene film

The polythene film currently used to cover groundnut is transparent. The recommended specifications for this film are:

- A width of 850–900 mm is optimum for spring-sown, large-seeded varieties, 800–850 mm for spring-sown, small-seeded varieties, or for the summer crop, and 750–800 mm for groundnut intercropped with wheat.
- Although a film of 0.004–0.014 mm thickness can be used, a thickness of 0.007 mm is optimum and more economical. If the film is less than 0.005 mm thick, it does not maintain soil temperature and moisture well, and does not stop late-set pegs from penetrating the soil; furthermore, such a thin film is hard to retrieve after the crop has been harvested. If the film is thicker than 0.018 mm, it hinders peg penetration, and it increases costs.

A film of light transmittance of ≥ 70% is optimum; if transmittance is < 50%, less heat from the sun reaches the soil.

The elasticity of the film should be ≥ 100%.

Soil preparation and fertilizer application

In recent years, PMG has been extended gradually from highly fertile soils to poor, hilly land; from sandy loam soil to clayey soil. Whatever the soil, if mulch is to be used deep tillage must be carried out in late autumn or early winter. A tilth to a depth of 20–30 cm in medium to fertile soils or 30–40 cm in hilly fields is adequate. The recommended doses of fertilizer application are given in Table 4. PMG needs more fertilizer than NMG under the same soil conditions. If the rate of fertilizer application is calculated by target yield, then the target yield of PMG

Table 4. Fertilizer doses for polythene mulched groundnut (PMG), Shandong, China, 1989.

Soil fertility		Fertilizer rates			
Content of organic matter	Content of total N	Farmyard manure (t ha^{-1})	Superphosphate (kg ha^{-1})	Potassium sulfate (kg ha^{-1})	Urea (kg ha^{-1})
≈ 0 1%	>0.065%	37	370–450	220–300	60– 75
≈ 0.5%	0.045–0.065%	45	450–520	150–220	75–150
≈ 0.3%	<0.045%	60	600–750	75–150	150–220

should be set 30% higher than that of NMG. Broadcast application of farmyard manure is suggested in combination with winter tillage, and basal chemical fertilizer should be used when the beds are formed.

Bed formation and plant population

Bed formation. The beds for PMG are made 4–6 days before sowing, either by bed-formers drawn by tractors (Fig. 3) or manually (Fig. 4). If the bed for PMG is made manually, the field is cultivated four times with a plowshare and the soil is leveled with a rake. During PMG bed-making, the following must be noted:

- There should be sufficient soil moisture.
- The beds should be neither too high nor too low: a height of 11–12 cm is adequate; if too high, it is difficult to cover the beds entirely with the film; if the beds are too low, the extra film gathers in the furrows, and retards infiltration of rainwater into the soil.
- Both sides of PMG bed should be vertical, the bed profile rectangular, and the surface smooth without clods or pebbles so that the film hugs the soil surface and is not dislodged by strong winds.
- PMG beds should be uniform in dimension.

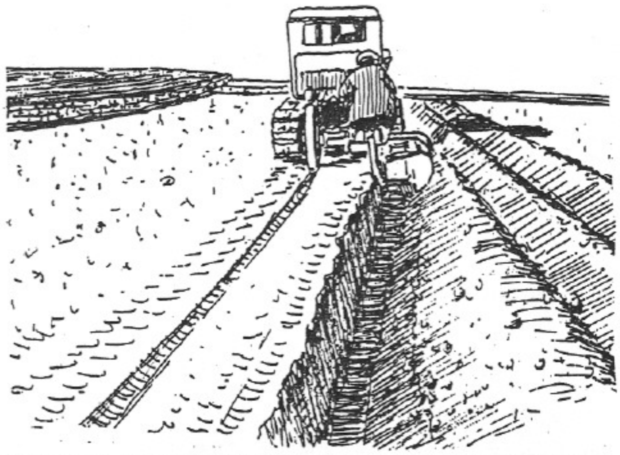

Figure 3. Machine-made beds for polythene mulched groundnut in China.

Figure 4. Manual preparation of beds for polythene mulched groundnut in China.

Plant population. The optimum plant population of PMG on soils with medium or low-medium fertility for medium-seeded, short-duration varieties is 150 000–180 000 hills ha^{-1} (with two seeds per hill). The bed is 50-cm wide with two rows of groundnut on it, and a plant-to-plant spacing of 13–16 cm; the furrow between the two beds is 30-cm wide (Fig. 5a). The optimum population of PMG on high fertility soils for large-seeded, medium-duration varieties is 110 000–138 000 hills ha^{-1} (with two seeds per hill). The bed is 50–60 cm wide with two rows of groundnut on it, and a plant-to-plant spacing, 16–20 cm; the furrow between beds is 30 cm (Fig. 5b).

Varieties respond differently to polythene mulch. Multilocational trials in Wendeng, Penglai, and Muping, organized by Shandong Agricultural Bureau in 1980/81, showed that the pod yields of such medium-duration varieties as Haihua 1, Xuzhou 68-4, Hua 37, and Hua 17 increased by 10.9% over a short-duration variety, e.g., Baisha 1016, and by 7% over long-duration varieties, e.g., Wendengdaliden, and Penglaiyiwohou. Results from other provinces confirm these findings. Virginia type varieties have the highest yield increase with polythene mulch followed by spanish types, and then the valencia types. Varieties with wide adaptiveness and resistance to such stresses as early leaf spot, late leaf spot, rust, and

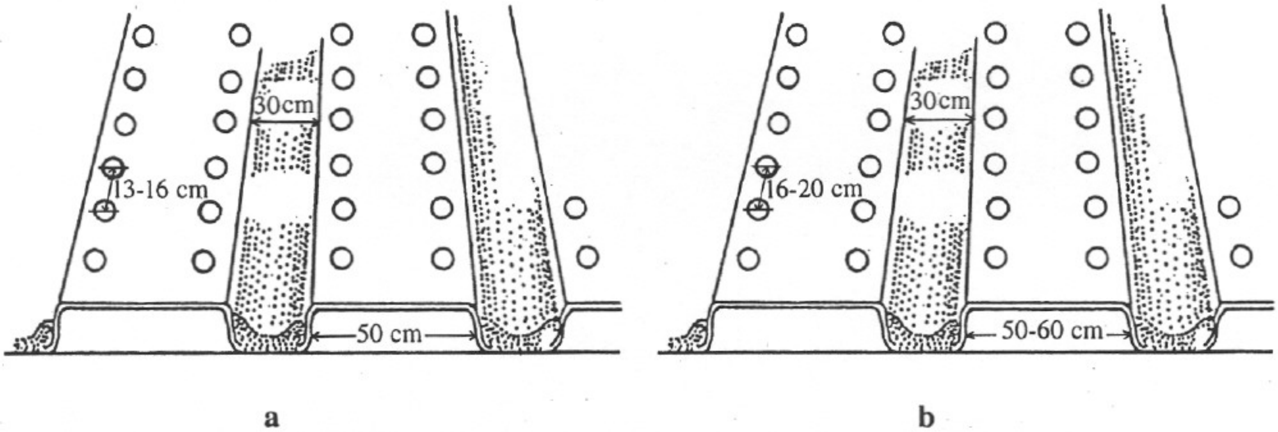

Figure 5. Dimensions of bed for (a) polythene mulched groundnut in China for medium-seeded, short-duration varieties, and (b) for large-seeded, medium-duration groundnut varieties.

drought, are the best choice for PMG. Large-seeded, medium-duration varieties such as Haihua 1, Hua 37, Hua 17, Xuzhou 68-4, Luhua 4, Luhua 10, 8130, Luhua 11, and Luhua 14 are recommended for northern China. Medium-seeded, short-duration varieties like Luhua 3, Luhua 8, Luhua 9, Yueyou 551-116, Baisha 1016, and Jinxi 1 are better as summer crops or in areas with a short frost-free period.

Good seed

In order to ensure a uniform stand of PMG, genetically pure, disease-free seeds with high viability, and uniform size should be selected. The minimum percentage of germination must be 98%. Before shelling, seed pods should be dried in the sun for 2–4 days on a dry floor. Shelling pods by hand a few days before sowing is adequate though hand shelling is labor-intensive and time-consuming. Sowing with graded seeds ensures a uniform crop stand. In order to control the damage to the seedlings caused by over-wintering soil insects (like grubs and wireworms), and snout beetles and aphids, it is necessary to mix the seeds with methamidophos at a rate of 1:20:80 (seed:chemical:water).

Time of sowing

When the mean daily soil temperature over 5 days in the top 5 cm of soil is 12.5°C, then it is the ideal time to sow PMG in northern China, while a temperature of 13°C is ideal in southern China. In general, the optimum time to sow PMG is from 20–30 Feb in southern Guangxi, 15–25 Mar in southern Jiangxi, 20–30 Mar in northern Sichuang, and 5–25 Apr in both Shandong and Liaoning.

Sowing PMG

The two ways to sow PMG are to mulch polythene before sowing (MPBS), and to mulch polythene after sowing (MPAS). Both methods have their disadvantages. MPBS prevents seedlings from being 'sun-burned' after emergence, but the seeds emerge slowly. MPAS takes less time and labor, and the seeds emerge sooner than with MPBS because of the higher soil temperature maintained by the unbroken film, but the seedlings are 'sun-burned' unless released on time by breaking the film. Farmers should choose the method most suitable for local conditions.

MPBS. The following steps are involved:

Step 1. Mulch polythene. If done manually, 4–5 people are needed for the following tasks: to dig a shallow ditch along the outside edge of the bed; to spray herbicide with a sprayer on the bed surface; to lay polythene film to cover the bed; and to bury the edges of the polythene film on either side of the bed with a pick so that the film is tautly drawn over the bed to protect the film against damage by wind (Fig. 6).

If conditions permit, polythene mulching machines should be used, since they raise polythene mulch efficiency and quality (Fig. 7). About 2 ha are covered in 8 hours with the mulching machine FM-1 drawn by a power-tiller. About 1 ha can be mulched in 8 hours with a DM-95 operated by two people.

Step 2. Make holes. The holes, 3–4 cm deep, are made on the bed with a hole-maker at the desired spacing (Fig. 8).

Step 3. Sow the seeds. Two seeds are placed in each hole (Fig. 9). If the soil moisture is poor some water is poured into the hole.

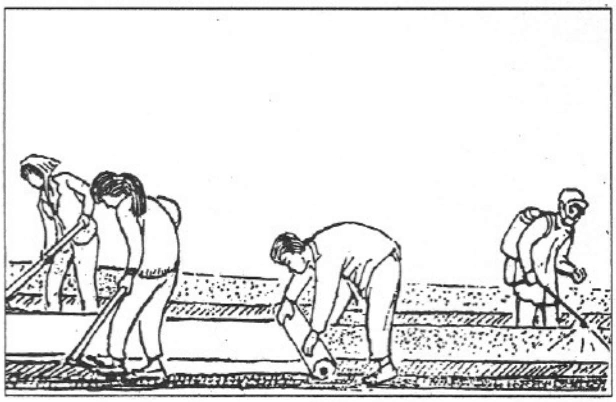

Figure 6. Manual polythene mulching requires 4–5 people.

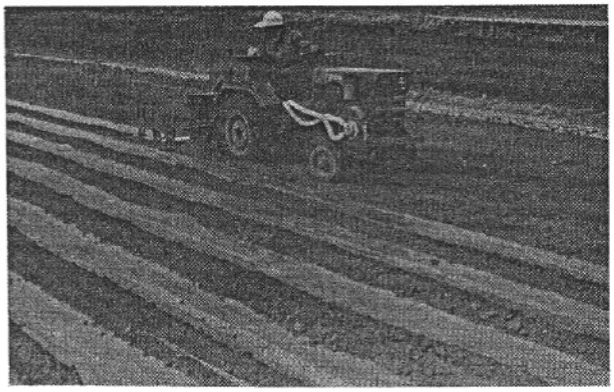

Figure 7. Polythene-mulching machines cover about 2 ha in 8 hours.

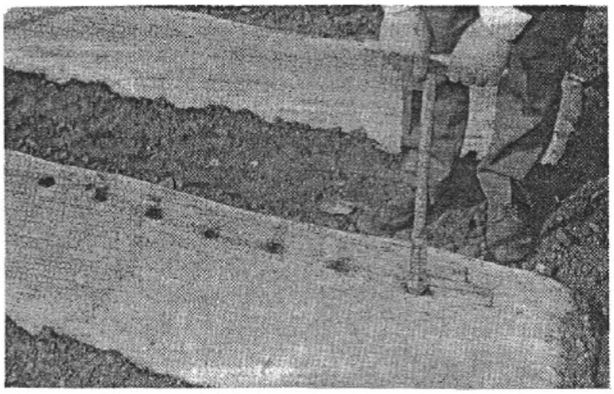

Figure 8. Holes are punched in the polythene film with a hole-puncher.

Step 4. Cover the seeds. Moist earth is put into the seeded hole and pressed by hand; then about 3 cm more soil is added.

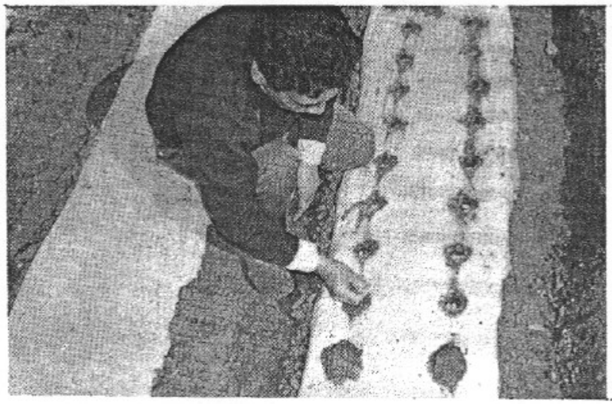

Figure 9. Two seeds are placed in each hole.

MPAS. The following steps are involved:

Step 1. Open seed rows. Two seed rows (3-cm deep and 30–40-cm apart) are opened on the bed with a pick. Seeds are placed neither too deeply nor too shallowly. If too deep, the two cotyledons would be buried in the soil, if too shallow, the seeds would be 'burnt'.

Step 2. Sow the seeds in the rows with hills 13–18 cm apart. Two seeds are placed close together in each hill. If the seeds are wide apart, the hole is made in the film to allow the seedlings to emerge will be wide, thereby causing loss of heat and moisture.

Step 3. Fill up the seeded rows and rake the soil level.

Step 4. Spray herbicide and then mulch polythene as described in Step 1 of MPBS.

Manually done PMG is time-consuming. A machine for PMG has been developed in Laiyiang Agricultural College. This tractor-drawn machine can make beds, sow the seeds, spray herbicide, and mulch polythene at the same time. Two operators can sow 1 ha in 4 hours.

Management of PMG

PMG seeds crack the soil and emerge about 10 days after sowing. The film must be broken in time to allow MPAS seedlings to emerge from the mulch. Otherwise, the seedlings are 'burnt' by the high temperature under the film, resulting in significant reduction in yield. The film must be broken before 0900 or after 1600 because the seedlings are too young to be exposed to the hot sun. The seedlings should be released by making a hole 4–5 cm in diameter in the film over the seedling using three fingers, and then putting 3–5 cm of moist earth on it, to conserve moisture and temperature (Fig. 10).

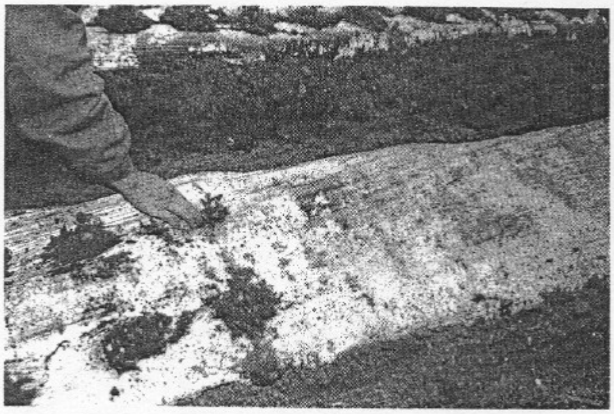

Figure 10. Holes must be made in the polythene film for the emerging seedlings.

When there are four leaves on the main stem of groundnut, the crop field should be inspected to see whether any lateral branch is still growing under the film; if there are any, they should be brought above the film. If lateral branches grow under the film, their development is retarded causing yield reduction, or if any groundnut seeds have not emerged, the gaps should be filled with germinated seed.

Hoeing and irrigation. Hoeing shallowly along the furrow is necessary for PMG (Fig. 11). This stirs the surface to create a dust mulch to conserve moisture and to control weeds growing in the furrows without application of herbicide. Hand-hoeing once or twice before the crop covers the field is enough. Hand weeding is needed if there are big weeds in the furrow during the late-growing stages.

Irrigation along the furrows should be done if prolonged dry spells occur during the moisture-sensitive periods of peak flowering, peg penetration, and pod formation of PMG. Experiments by Shandong Peanut Research Institute in 1983 show that one timely irrigation of PMG along furrows gives a pod yield of 6.4 t ha^{-1}, a 49% increase over the control. Two irrigations give 7.7 t ha^{-1}—a 78.7% increase over the control.

Application of chemicals. Well-developed PMG (Fig. 12a) withstands viral infections to a certain extent; and the light reflection by the film reduces the number of viruliferous alate aphids on the plants. However, this does not mean that no insect pests or diseases attack the crop. It is necessary to watch conditions closely, and apply control measures as needed.

Since it develops rapidly during the early growing period, PMG would tend to be etiolated (excessive vegetative growth) in the hot, rainy summer days. Foliar ap-

Figure 11. Hoeing along the furrows in a polythene mulched groundnut field in China.

plications of growth regulators such as Paclobutrazol and Fosamine effectively prevent this excessive growth. Experiments on large areas under PMG treated with growth regulators show that a 15–24.5% increase in pod yield is possible.

Harvesting, and retrieval of wasted film. PMG matures 7–10 days earlier than NMG if sown at the same time. Harvesting should be done at the optimum time (Fig. 12b). If lifting is delayed, large number of fully developed pods sprout on the plant (in the case of nondormant cultivars) or separate from the vine and remain in the soil, or rot away, causing great losses. Also, large numbers of seeds may turn yellow or brown, and the oil content declines, affecting both yield and quality. The maturity of PMG is comparatively uniform because late pegs are not able to set pods. Therefore, when 90% of pods are mature, harvesting must begin. After harvest, about 40% of the polythene film remains undecomposed. This retards root development of the subsequent crops and the movement of soil water. About 30% of the film remains attached to the vines, and another 30% is dispersed by the wind. All film should be retrieved for recycling to avoid environmental pollution.

Figure 12. (a) A full crop of high-yielding polythene mulched groundnut in China, and (b) its harvest.

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