# Plant Research and Development

A Biannual Collection
of Recent German Contributions Concerning
Development through Plant Research

Volume 44

Institute for Scientific Co-operation, Tübingen

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Edited on behalf of the
Institute for Scientific Co-operation by Alfred Bittner,
in conjunction with Wolfram Achtnich, Nicolae Atanasiu,
Peter Böger, Knud Caesar, Carl Hoeppe, Liansheng Guo,
and the Federal Research Centre for Forestry and
Forest Products as well as numerous members of
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# PLANT RESEARCH AND DEVELOPMENT

A Biannual Collection
of Recent German Contributions

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Edited on behalf of the Institute for Scientific Co-operation by Dr. Alfred Bittner, Tübingen, in conjunction with Prof. Dr. W. Achtnich, Göttingen; Prof. Dr. N. Atanasiu, Giessen; Prof. Dr. P. Böger, Konstanz; Prof. Dr. K. Caesar, Berlin; Prof. Dr. C. Hoeppe, Witzenhausen and Prof. Dr. Liansheng Guo, Huhehot, People's Republic of China.

INSTITUT FÜR WISSENSCHAFTLICHE ZUSAMMENARBEIT
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# TRADITIONAL VILLAGE FOREST MANAGEMENT IN XISHUANGBANNA, SOUTH-WEST CHINA

*by*

ULRICH APEL

*Institute for Silviculture, University of Göttingen*

The traditional village forest management by the Dai people of Xishuangbanna, Yunnan Province, South-West China, is an example how management of forest and land is influenced by socio-cultural factors. Old animistic beliefs are the reason for the Dai people's attitude of preserving their forests. Parts of the village forest are totally protected and the used part is carefully managed. Religious restrictions preserve holy hills, sacred groves and holy trees.

Village forests are still used in a largely traditional way in the whole of the Indo-Chinese region, particularly in remote tribal areas of ethnic minorities. At the same time, socio-cultural aspects characterize in many instances the modes of behaviour in the treatment of land and forest (Mischung, 1980; Pei, 1985; Weidelt, 1993). They have also resulted in a wide variety of systems of land use among the different ethnic groups (Pei, 1991; Saint-Pierre, 1991; Guo, 1993).

In regions where subsistance economy is practised, the forest is an important life resource of the villagers. Apart from the use of timber for house-building and for fuel, it provides innumerable by-products such as fruit and vegetables, spices, medicinal plants, rattan, fodder plants, and much else. The forest is the most important structural element of an ecologically balanced use of land. Beyond the village eco-system, stabilizing influences are exerted upon the water balance and the climatic balance of larger areas by village forests. They can be islands of bio-diversity in cleared-out rural areas and are important as stepping-stones for the genetic flow between major natural reserves (Pei, 1991; Weidelt, 1993).

### *Xishuangbanna – the home of the Dai minority*

The autonomous prefecture of the Dai minority Xishuangbanna lies in the south of Yunnan Province and borders in the south-west on Myanmar and in the south-east on Laos. Xishuangbanna accommodates about one-quarter of the ethnic minorities recognized in China which are distinguished by their own culture and language. In Xishuangbanna 13 more minorities live in addition to the Dai, who represent the majority in the population, about 40 %. The most important are Hani, Yao, Yi, Lahu, Bulong and Jino. Around 30 % of the 800 000 inhabitants of Xishuangbanna are by now Han Chinese who migrated into this area, particularly in the years 1956–1982.

The Dai, who count among the Tai peoples, are Hinayana-Buddhists; but they have been able to preserve many elements of their old beliefs, usually designated by the term "animism". These original religions are not merely superstitions alone. Eberhard (1942) states that the religion of the Tai people was already a complicated intellectual construct in the pre-Buddhist era, characterized by myths, psychical notions and ancestor worship. Later on, Buddhist teaching on the migration of souls was linked up with the ideas of reincarnation in the Tai people's ancestor worship and Buddhism could therefore become generally established among the Tai peoples within a relatively short time.

The minorities living in Xishuangbanna each evolved their own form and manner of land use. They can be sub-divided broadly into mountain people growing mountain rice and engaged in shifting cultivation (Yao, Jino, Lahu, Hani, Bulang, Yi, with the respective minorities preferring different altitudes) and valley dwellers growing wet rice, among whom the Dai must be counted.

Xishuangbanna is just under 20 000 km$^2$ in area and lies between latitudes 21° and 22° N. The forest cover is 28 %; in the late '50s it was still over 60 % (IUCN, 1991). The village forests represent around 20 % of the total forested area of Xishunagbanna. By the 1982 land reform in China, the nationalized landed property was handed back to the villages in the form of long-term leases.

The topography of Xishuangbanna is mountainous, with altitudes between 500 and 2400 m a.s.l. Average annual temperatures are 21°C–22°C at the lower levels, and rainfall at intermediate levels amounts to 1200–1900 mm/year. Below 800 m a.s.l., evergreen tropical rainforest predominates, one of the northernmost areas of distribution in the northern hemisphere. At above 800 m a.s.l., green wet forest begins, to be replaced as from ca. 1000 m a.s.l. by evergreen tropical rainforest of the mountainous stage – indicating, with its dominance of Fagaceae, Lauraceae and Theaceae, the location of Xishuangbanna at the tropical margin (Li and Walker, 1986).

### *The Dai village Moxie*

Around 500 people live in Moxie. The village is situated within the rural district of Mengla in the administrative area Shangyong which, being 76 % forested, is the most densely forested area of Xishuangbanna. Moxie lies 40 km south-east of the town Mengla and only 20 km from the Laotian border. It is a very traditional village which has been established at this place for more than 250 years already. Like any Dai village, Moxie has a temple which is the cultural centre of each village. The cultural revolution, which was at its peak during 1966–1969, destroyed most of the temples and pagodas in this region. Nowadays, they are being rebuilt. Recovery of the intellectual and cultural life from the cultural revolution, and the return to the ancient traditions, are becoming more and more apparent today, the more so because the prohibition of religions was ended in 1979.

The total area of the village's landed property is about 1000 ha; the village forest is ca. 600 ha in area. It is embedded within the Dai system of land use. Other forms of land use in Moxie are the home gardens, *Cassia siamea*-cultivation for the production of fuelwood, cultivation of medicinal plants in the forest, agrarian forms of economy, particularly wet rice-growing, and also hunting, fishing and gathering. Particularly important for village forest management is *Cassia siamea*-cultivation for fuel production. High yields on small plots, problem-free establishment of stands and simple management of them by a coppice system, easy cropping and easy transport make the cultivation of *Cassia siamea* an opportunity to reduce the appropriation of natural forest.

### *Moxie's village forest*

#### *Used forest*

The bulk – about 95 % – of the village forest falls under this head. It belongs to the whole community; consequently, user-rights are the same for every individual. The greatest demand is for fuelwood, ca. 800 m³/year, of which only ca. 10 % can be covered by the *Cassia siamea*-plantations already mentioned. Annual demand for construction timber is about 500 m³. To build a Dai house, ca. 50–80 m³ rough timber is needed. Besides timber products, the village forest provides numerous non-timber products such as bamboo with its many and varied possible uses, rattan for furniture production, fruit, vegetables and medicinal plants.

Used forest is sub-divided by the Dai according to its functions into amenity forest and watershed forest, and into forest without special functions. In amenity forest and in watershed forest, clear felling or rededication of the plots is not permitted. Since almost all of the village forest falls into both of these two categories, at least sustainable plot management is assured. However, the utilizations are unplanned and largely unregulated. Only when substantial quantities are to be used – for building a house, for example – does the village headman have to be asked for permission. He must get permission from the district forestry authority; but this will hardly be refused when the timber is to be for personal use.

The amenity forest is used to make the village visually attractive. This is worth noting, since such an attitude is rare compared with forest in tropical Asia. The Dai villages are usually laid out in such a way that they have a mountain at the back of them. According to the Dai ideas, this must then be forested. In Moxie the amenity forest is immediately adjacent to the village. The watershed forest is the forest situated on the slopes above the rice fields, at a distance of 3–7 km from the village. The idea of conservation has quite clear ecological bases here. Adequate water supply for the village, particularly for irrigating the rice fields, is the mainspring of ecological thinking and action. Since the time interval between ecologically incorrect behaviour and the consequent water problems is relatively short and is reflected in the crop, this has led to insights such as: "large trees – much water, small trees – little water".

Amenity forest and watershed forest differ owing to the difference in intensity of use and to differences due to location. In Table 1, key data for the two types are listed.

Table 1 – *Key silvicultural data of the stand >10 cm DBH in the amenity forest and in the watershed forest*

| | Amenity forest | Watershed forest |
|---|---|---|
| Stems N/ha | 424 | 614 |
| Basal area m²/ha | 26.1 | 29.0 |
| Standing volume m³/ha | 291.2 | 334.1 |
| Tree species/ha[1] | 77 | 102 |

Note: [1] Trees >10 DBH; ha-value determined from species area-curve

The watershed forest far from the village has a higher number of stems, and basal area, volume and also tree species are likewise higher than in the amenity forest near the village. Both forests contain a great wealth of species. No possibilities of comparison with primary forests on comparable locations exist, unfortunately.

In the used village forest, selective use of individual stems is practised, based primarily upon the accessibility and transport of the stems and on the timber qualities. The essential ecological functions of the village forest are thus preserved, although valuable timber species are becoming scarcer and scarcer owing to unplanned use and the supplies of useful timber species are decreasing.

High intensity of use can lead locally to the impoverishment of species. This can be observed particularly in the vicinity of the village. Table 2 shows that, with increasing distance from the village, the species-counts in the stand >10 cm BHD increase. Their continuous increase from 26 to 51 species on the trial plots 0.25 ha in area cannot be explained by differences of location. The species-counts show a rising trend with increasing distance from the village also in regeneration. Stem-counts, on the other hand, are very uniform.

Table 2 – *Tree species and number of stems as a function of distance from village in the amenity forest*

| Trial plot | a 5 | a 4 | a 1 | a 2 | a 3 |
|---|---|---|---|---|---|
| Distance from village | 250 m | 330 m | 780 m | 900 m | 1030 m |
| Trees >10 cm DBH: | | | | | |
| Species N/0.25 ha | 26 | 27 | 33 | 41 | 51 |
| Stems N/0.25 ha | 87 | 57 | 112 | 139 | 135 |
| Trees >1.3 m ht, to 10 cm DBH: | | | | | |
| Species N/0.09 ha | 47 | 53 | 54 | 72 | 71 |
| Stems N/0.09 ha | 381 | 297 | 324 | 402 | 353 |

Note: a = amenity forest

If one breaks down the total volume/ha by use-potential of the individual tree species, the valuable timber volume (*a*-grade) and the construction timber volume (*b*-grade) are good indicators of use intensity. This applies also to the basal area of strangler fig (*Ficus altissima, F. stricta, F. benjamina, F. annulata,* etc.), which are not felled by the Dai, because they are considered to be representatives of the sacred tree and a preferred site for spirits.

Table 3 shows clearly that protracted selective use of the valuable tree species has reduced the volumes in the amenity forest compared with the

Table 3 – *Parameters of use intensity in the amenity forest and in the watershed forest; trees 10 cm DBH*

| | Amenity forest | Watershed forest |
|---|---|---|
| Valuable timber volume (*a*-grade) in $m^3$/ha | 6.6 | 35.1 |
| Construction timber volume (*b*-grade) in $m^3$/ha | 59.9 | 130.6 |
| Basal area of strangler figs in % | 23.3 | 1.6 |

watershed forest. As a result, the strangler figs spared from use in the amenity forest near the village occupy almost one-quarter of the total basal area. Even if the useful volume and hence also the increase of useful timber are therefore adversely affected, the strangler figs ensure a minimum degree of tillering which enables repeated regeneration of the village forest even with heavy use, prevents soil erosion and thus preserves the area of forestland. The taboo on felling for large fig-trees has, moreover, a favourable ecological effect, since *Ficus*-species in tropical ecosystems are almost invariably "keystone species" which help the frugivore animal populations ranging from birds to mammals, through their asynchronous fructification, over periods of food scarcity (Terborgh, 1986).

In order to be able to form a picture of the structure and species-composition in watershed forest and in amenity forest, two typical stand-structures are represented graphically. The profiles were recorded in a 10 x 50 m-wide strip in which all trees >10 cm DBH were included. In a 2 x 50 m-wide strip within this, trees as from 5 cm DBH were also entered.

Fig. 1 shows a typical profile of the amenity forest near the village. The stem-counts are low. In the upper story the strangler fig *Ficus altissima* predominates. The enormous crown dimensions of these trees are particularly noteworthy. The overused middle story is constituted mainly by Fagaceae, here *Castanopsis* spp. and by Lauraceae, here *Actinodaphne henryi*. The lower story is relatively rich in species. Typical lower story species are: *Knema* spp., *Garcinia* spp. and *Baccaurea ramiflora*.

Fig. 2 shows a typical structural profile of the watershed forest far from the village. The stand is stem- and species-rich. In the upper story there are *Symplocos* sp. and *Cinnamomum bejolghota*. The high number of stems in the middle story consists mainly of Myristicaceae, Lauraceae, Lecythydaceae and Styraceae. Typical lower story-species are *Baccaurea ramiflora, Garcinia tetralata, Knema globularia* and *Symplocos cochinchinensis*.

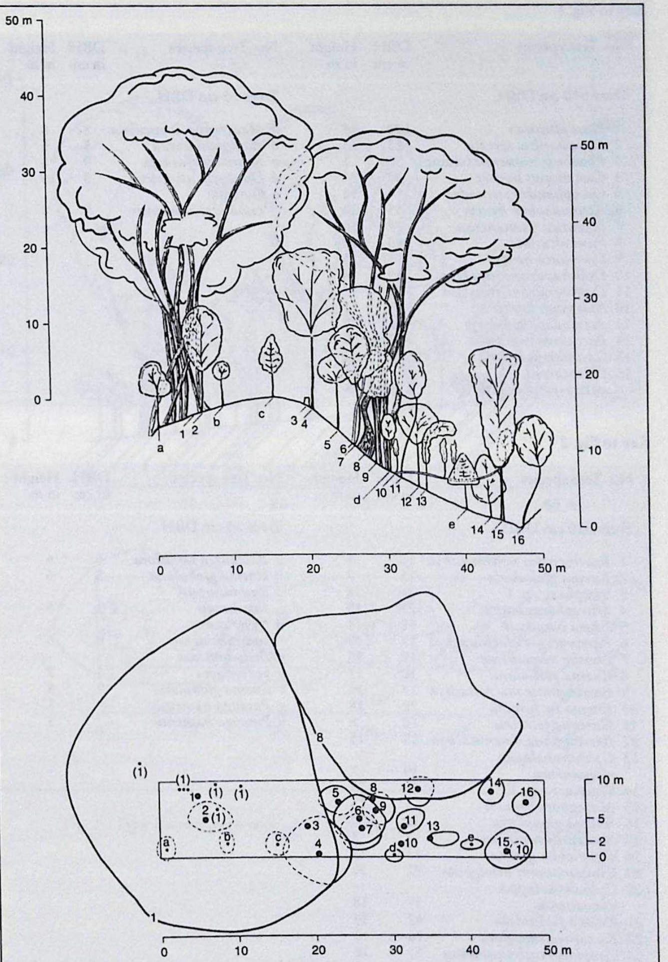


Fig. 1 – *Typical structural profile of the amenity forest, in elevation and plan.*

Key to Fig. 1

Trees >10 cm DBH

| No. | Tree species | DBH in cm | Height in m |
|---|---|---|---|
| 1 | *Ficus altissima* | 100 | 45 |
| 2 | *Engelhardtia serrata* | 23 | 13 |
| 3 | *Phoebe puwenensis* (stump) | 50 | 1 |
| 4 | *Castanopsis hystrix* | 30 | 21 |
| 5 | *Gomphandra tetrandra* | 14 | 10 |
| 6 | *Actinodaphne henryi* | 35 | 21 |
| 7 | *Myristica yunnanensis* | 17 | 16 |
| 8 | *Ficus altissima* | 140 | 42 |
| 9 | *Symplocos henryi* | 14 | 13 |
| 10 | *Dolichandrone stipulata* | 30 | 6 |
| 11 | *Dolichandrone stipulata* | 23 | 17 |
| 12 | *Alangium kurzii* | 22 | 11 |
| 13 | *Actinodaphne henryi* | 11 | 9 |
| 14 | *Baccaurea ramiflora* | 10 | 9 |
| 15 | *Castanopsis hystrix* | 33 | 24 |
| 16 | *Elaeocarpus austro-yunnanensis* | 12 | 14 |

Trees >5 cm DBH

| No. | Tree species | DBH in cm | Height in m |
|---|---|---|---|
| a | *Macaranga denticulata* | 8 | 8 |
| b | *Alangium kurzii* | 5 | 6 |
| c | *Knema furfuracea* | 9 | 8 |
| d | *Diospyrus atrotricha* | 8 | 6 |
| e | *Garcinia xishuangbannaensis* | 9 | 8 |

Key to Fig. 2

Trees >10 cm DBH

| No. | Tree species | DBH in cm | Height in m |
|---|---|---|---|
| 1 | *Barringtonia macrostachya* | 10 | 8 |
| 2 | *Knema globularia* | 15 | 7 |
| 3 | *Symplocos* sp. 1 | 81 | 38 |
| 4 | *Mitrephora thorelii* | 21 | 15 |
| 5 | *Litsea baviensis* | 18 | 14 |
| 6 | *Barringtonia macrostachya* | 17 | 13 |
| 7 | *Phoebe minutiflora* | 17 | 15 |
| 8 | *Knema globularia* | 10 | 11 |
| 9 | *Barringtonia macrostachya* | 17 | 16 |
| 10 | *Knema furfuracea* | 28 | 18 |
| 11 | *Garcinia tetralata* | 10 | 8 |
| 12 | *Barringtonia macrostachya* | 23 | 15 |
| 13 | *Cylindrokelupha yunnanensis* | 19 | 17 |
| 14 | *Symplocos* sp. 1 | 69 | 35 |
| 15 | *Mitrephora thorelii* | 15 | 15 |
| 16 | *Knema globularia* | 10 | 10 |
| 17 | *Baccaurea ramiflora* | 11 | 8 |
| 18 | *Horsfieldia glabra* | 11 | 13 |
| 19 | *Cinnamomum bejolghota* | 42 | 31 |
| 20 | *Cylindrokelupha yunnanensis* | 39 | 18 |
| 21 | *Knema furfuracea* | 42 | 24 |
| 22 | *Baccaurea ramiflora* | 16 | 10 |
| 23 | *Symplocos cochinchinensis* | 13 | 10 |
| 24 | *Knema furfuracea* | 35 | 17 |
| 25 | *Alniphyllum fortunei* | 11 | 13 |
| 26 | *Hydnocarpus* sp. | 15 | 12 |

Trees >5 cm DBH

| No. | Tree species | DBH in cm | Height in m |
|---|---|---|---|
| a | *Baccaurea ramiflora* | 6 | 6 |
| b | *Knema globularia* | 5 | 6 |
| c | *Drymicarpus racemosus* | 5 | 5 |
| d | *Symplocos cochinchinensis* | 8 | 6 |
| e | *Beilschmiedia percoriacea* | 6 | 7 |
| f | *Knema globularia* | 9 | 8 |
| g | *Pinanga baviensis* | – | 3 |
| h | *Pinanga baviensis* | – | 3 |

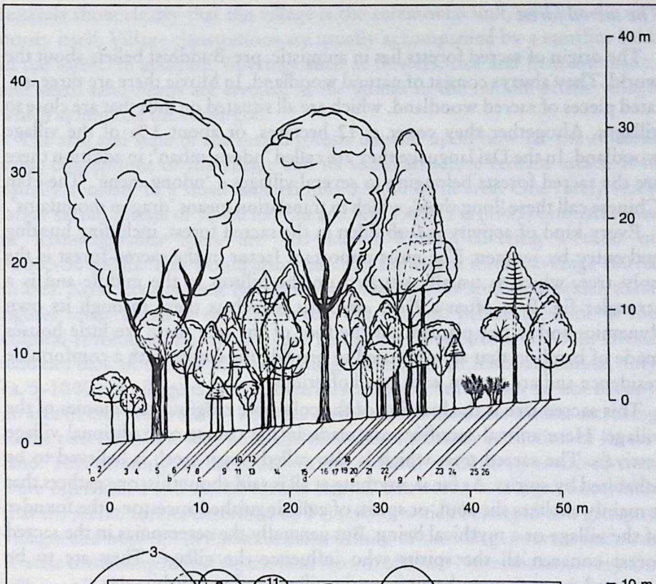


Fig. 2 – *Typical structural profile of the watershed forest, in elevation and plan.*

*The sacred forest*

The origin of sacred forests lies in animistic, pre-Buddhist beliefs about the world. They always consist of natural woodland. In Moxie there are three isolated pieces of sacred woodland, which are all situated on hills that are close to villages. Altogether they cover c. 12 hectares, or about 3 % of the village woodland. In the Dai language they are called 'ndong mban'; in addition there are the sacred forests belonging to several villages – 'ndong meng'. The Han Chinese call these 'long shan', which in translation means 'dragon mountains'.

Every kind of activity is forbidden in the sacred forest, including hunting and entry by women. The most important factor in the sacred forest is the holy tree, which is usually situated on the hilltop in the middle and is a strangler fig. It is often a *Ficus altissima*, which is there through its own dynamics and is not planted. At the foot of the tree there are little houses made of bamboo that are supposed to provide the spirits with a comfortable residence and are strewn with small offerings.

This sacred tree is the location of the collective religious ceremonies of the village. Here animal sacrifices are made in the course of traditional village festivals. The sacred tree, which is also called 'spirit tree', is believed to be inhabited by spirits. As far as anything at all is said about this, one gathers that it mainly shelters the soul, or spirit, of a distinguished ancestor – the founder of the village or a mythical being. But generally the ceremonies in the sacred forest concern all the spirits who influence the village. They are to be appeased, so as to avert harm from the village and its inhabitants.

Every year at least one sacrifice is offered. In the Dai village of Moxie a pig is offered every three years and a hen in each of the two intervening years. The sacrificial ceremony itself involves all the male villagers going into the sacred forest, presenting the victim and eating it there on the spot.

The sacred forest symbolizes the counterpart of the village. This forest is the "outside" and the village the "inside". It is the representative of the one from which the everyday necessities are wrested. The polarisation between "outside" and "inside" becomes particularly clear in the so-called village "claustrations" – festivals at which the village is completely isolated symbolically from its outside world. At these, the village gates are first renewed and mottoes to ward off spirits are inscribed on them. Self-woven ropes are stretched all around the village. For the duration of the festival, no-one must go out of the village or come in. These festivals do not have an annual date; they are held as and when desired. They can become necessary at particular events such as a large number of deaths, poor harvests, disasters, etc. The community seems to want to draw itself closer together by means of such festivals, in order to defy better the influences coming from outside. These festivals show clearly that the village is the ceremonial unit, and not the minority itself. Village claustrations are usually accompanied by a sacrifice held in the forest. In addition, offerings such as flowers, rice and fruit are made, and small sand-heaps are erected, at the stones in the middle of the village which symbolize the earth-god.

The size and state of the sacred forests depend upon how far the cultural value conceptions of the village and its social structure remain intact. It is usually a matter of a small isolated hills 0.3–3.0 ha in area. One rarely finds larger sacred forests of 10–20 ha (Liu and Xu, 1989). Pei (1985) estimates that in Xishuangbanna there are 400 sacred forests covering a total of 30 000–50 000 ha. This would also mean that the sacred forests average 100 ha in area. Now account must be taken of the fact that the studies to which these figures relate began as early as in the '60s, i.e. still before the time of the cultural revolution, but in any case before the land reform in 1982. If one assumes that, of the 120 000 ha of village forestland in Xishuangbanna, only ca. 5–10 % per village is sacred, then nowadays sacred forests do not occupy an area of more than 6000–12 000 ha. Despite all of the uncertainties attaching to the two estimates, they nevertheless indicate a drastic reduction of forestland. This certainly has its causes in the cultural revolution, as sacred trees were often felled and sacred forests cleared. However, it is also conceivable that the sacred forests described by Pei (1985), which belonged to a group of villages and were not in the immediate vicinity of the village, were transferred to state ownership following the land reform of 1982. Nevertheless, every Dai village still has a sacred forest, even if today it has perhaps been reduced to only a clump of trees.

*The sacred trees*

Those trees at which sacrifices are regularly carried out should be designated as sacred trees. Here, too, a distinction can be made between sacred trees dating back to primordial beliefs and those attributable to Buddhism. The former grow wild and are worshipped through public rituals, whereas the latter are planted and are in many instances worshipped in individual ritual acts.

In the case of the wild sacred trees, they are almost without exception species of the genus *Ficus*. In Xishuangbanna *F. altissima* predominates. This is simply predestined to be a sacred tree. Its size and striking form of growth, its strength, expressed in it strangling other trees and the mysterious aerial roots, as well as the special features of pollination biology (blossom is never to be seen, yet *Ficus* can bear fruit all the year round) show clearly that this tree is controlled by an alien power. Certainly, the longevity and, ultimately, the uselessness of *Ficus*-wood, also play a role here.

According to the ideas of the Dai, all trees are endowed with a living spirit. When any favourite tree is felled and used for building in the house, the tree spirit is brought into the house. For this reason, therefore, the Dai never use wood from the same tree in the right angle. In every house there is a particularly thick pillar into which the tree spirits are intended to move and feel happy. For a similar reason, tree trunks must never be dragged into the village with foliage on them. They are either carried or the branches and leaves are removed in the forest.

Tree ritual has been handed down from all old popular religions. In almost every mythology, whether Germanic, Indian or Chinese, there is the cosmic tree. The tree as part of the cosmos, as an animated symbol of natural forces, is an object of veneration. Christianity, Buddhism and Hinduism took over the tree ritual of the older religions – with the difference that the tree was no longer worshipped as sacred itself, but deities living within it (Brandt, 1985) were.

### *The sacred groves*

Unlike the sacred forests, sacred groves are strongly characterized by Buddhist thought. They are usually to be found by temples. They are invariably planted groves containing many allochthonous species (*Ficus religiosa, Dipterocarpus turbinatus, Dialium ovoides*). The significance of the plants in the temple gardens is closely bound up with the life of Buddha and his 28 reincarnations, and they also serve as decoration for temple ceremonies. Fruit trees are used by the monks. Pei (1991) compared these sacred groves with botanical gardens in which rare plant species are protected *ex situ*.

### *The forest cemetary*

The Dai cemetary is a separate piece of forest in which all exploitation or similar activities are prohibited. The cemetary of a Dai village is invariably separate from its sacred forest. The cemetaries have two entrances. The dead are buried separately according to age and form of death. Old people and those who have died a natural death are buried higher up, while younger people and those who have died from accidents or disease are buried further down.

Choice of the right place for the cemetary is outstandingly important when villages are established or relocations take place. The welfare of the village depends decisively upon whether the spirits of the dead can be brought to rest and they do not penetrate into the sphere of the living. Whereas the sacred forests on hills are at a level higher than the village, as they virtually already belong to the spirit world, the cemetary lies below it, below the level of the living and hence usually downstream.

### *The importance of the Moxie village forest and possibilities for careful management*

The case study in Moxie points in many individual aspects to the importance of the village forest studied here as a principal life resource of its inhabitants. The demand for building and structural timber, including bamboo and rattan, and also fuelwood is covered exclusively from the forest. From the aspect of providing food, the gathering of non-timber products such as fruit, vegetables, spices, animal fodder and medicinal plants, and also hunting, are important.

As a structural element of an ecologically-balanced, traditional Dai system of land use, the forest is the prerequisite for a settled way of life. As a water catchment area for the rice fields in the valley, the watershed forest ensures a steady supply of water for wet rice-growing. Also important are the favourable effects – highly valued by the villagers – of the amenity forest upon the landscape and village scene.

The forest itself, especially the sacred forest-parts, the sacred trees and holy groves, form part of the villagers' cultural identity. Much of the cultural and religious life is bound up with it. As side-effects of this religiously motivated total conservation of forest segments and particular tree species – strangler figs, for example – beneficial effects upon the village ecosystem can be noted.

In view of the importance of the village forest, the question arises as to whether maintenance and sustainable management of the village forest are possible. In this connection, 4 requirements must be fulfilled:

– Requirement: sustainability of the forest land
  This condition is the easiest to fulfil. The forest of the Dai has been largely managed sustainably for decades. A danger exists in increased commercialisation which brings with it the cultivation of cash crops, particularly tea and *Hevea brasiliensis*. This danger exists especially on degraded forest areas, as stronger trees hardly still grow here and therefore the impedance threshold and also the cost of reclamation are lower than on an area planted with forest.

– Requirement: sustainability of mass production
  A rough estimate of the demand for timber and of the growth increment in the village forest as a whole shows that this requirement could be met.

However, this estimate depends upon the assumptions: firstly, that balanced selective felling exists in the village forest and a constant growth can be observed also; secondly, that the whole forest is uniformly managed, i.e. the annual cut must be distributed over the whole area.

These requirements do not exist. With current timber harvesting – and forest development-practice, the accessibility and extraction of the timber play a big part. In practice, it is found that easily-accessible areas are over-exploited and the increment there is decreasing. On areas difficult to reach, on the other hand, the increment cannot be exhausted. In the extreme case, areas with easy access are over-exploited completely. They then fall out of production.

– Requirement: sustainability of valuable timber-production

This requirement cannot be met at present, since it presupposes silvicultural treatment of the forest areas which takes account of the needs of the valuable timber species. However, fulfilment of this requirement must be sought, because the use of timber would otherwise greatly increase just owing to the lesser durability of replacement species.

– Requirement: sustainability of religious constraints

If the religious restrictions in Dai forest management disappear, this would have adverse effects upon the maintenance of village forests. Sacred forests and groves lose their conservation status and would be under threat of over-exploitation. In the used forest, removal of the taboo on felling for strangler figs could mean local degrading of the forest through over-exploitation because, without these tree-species, soil erosion and seeding with vegetation which inhibits regeneration – *Chromolaena odorata*, for example – occur.

It follows from the above requirements that sustained management of the village forest on a decisive scale will depend upon:

- how far the whole village forest can be successfully incorporated in exploitation,
- whether areas already degraded can be brought back into production,
- whether approaches to planned management are evolved,
- how long the religious constraints will last which benefit maintenance of the village forests.

*The importance of socio-cultural aspects and their applicability to the Indo-Chinese region*

Even if the sacred forests in Xishuangbanna occupy only small areas of land and their total area has obviously greatly decreased in the last few decades, they are still very important for the people's understanding of their forest.

Efforts to preserve and re-establish village forests can start here. Supporting this is the fact that, despite extreme scarcity of timber in forest-poor areas, sacred forests have been preserved, even if in many instances reduced to only small clumps of trees. New village forests are being established in some cases where they had disappeared (Weidelt, 1993).

An attitude of preservation in the Dai people is due to ancient animistic beliefs, in relation not only to their sacred forests, but to their exploited forests also. It becomes clear from the case study in the Dai village Moxie that the Dai's traditional practices of forest conservation can be encouraged or reactivated by external stimuli.

Socio-cultural factors influence the treatment of land and forest. Although local differences exist from village to village and from minority to minority, dominant common features running throughout the region are to be perceived. For all of the minorities in Xishuangbanna, large *Ficus*-species are sacred trees which are not felled. It is a known fact of several minorities that, going beyond the sacred trees-tradition, they have sacred forests also. This is so in the case of the Hani (Aini), Kemo, Zhuang, Wa, Jino.

Throughout the Indo-Chinese region, there are indications that socio-cultural factors influence the systems of land use and hence village forest management. Kunstadter (1988) describes this for the ethnic groups of the Lua and Hmong, Mischung (1980) for the Karen and Meo (Hmong). In south-west China it is documented for the Dai (Pei, 1985) and for the Hani (Xu et al., 1992). The traditional land use-systems generally make sustainable, resource-conserving management possible; but destructive commercial behaviour may have developed also – e.g. among the Hmong.

Most of the peoples are distributed over large parts of Indo-China. Homogeneous groups of a people show far-reaching similarities of language and of manners and customs across political boundaries. The Tai peoples in Laos and Thailand, where they are national peoples, are thus distributed further in north-east Myanmar (here Shan and Khun), in North Vietnam (here Tho, Nung) and in south-west China (here Dai, Lua). The Hani (Aini) of south-west China are to be found further in North Thailand as Akha and in Laos as Iko. The Hmong (or Meo, Miao) also have a wide area of distribution across several countries. All of this points to the great supra-regional importance of a forest-human-relationship within this region.

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*Author's address:* Dipl.-Forstw. U. Apel, Institut für Waldbau, Abt. Waldbau der Tropen, Universität Göttingen, Büsgenweg 1, D-37077 Göttingen.

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# TOWARDS THE DEVELOPMENT OF INTEGRATED PEST MANAGEMENT IN DESERT LOCUST CONTROL

*by*

STEPHAN KRALL

*Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn*

For thousands of years now, the desert locust has been one of the most spectacular and feared pests. Apart from burning hoppers driven into ditches, farmers had no real means of fighting this insect until the beginning of this century. And even then no substantial impacts were had on swarms. For the last 50 years, synthetic insecticides have been used in locust control and, in this time, neither the strategy of survey and control nor the kind of products have undergone any serious changes, apart from the replacement of organochlorines by organophosphates, carbamates and synthetic pyrethroids in the 1980s. Monitoring of populations has been greatly improved, thanks to the introduction of the Global Positioning System (GPS). However, the present control objective is still to locate desert locust populations and control early outbreaks, in order to suppress upsurges and plagues. Despite the obvious failure of this strategy, no change is in sight. At present, control decisions are not based on thresholds, since they are unknown, and cost-benefit analyses are still very new, only having been attempted very recently. In short, the current strategies do not meet IPM requirements, are difficult to justify from an economic point of view and do not appear to be effective. And yet, over the past six years, some research programmes have developed environmentally sound products to replace the synthetic insecticides, and, what is more, discussions on new control strategies were launched less than three years ago; the results are reviewed in this paper. The new strategy aims at developing a cheap monitoring system to detect early upsurges and combat these when swarms have already formed. In other words, control is only to be initiated when crops are directly endangered. Finally, in line with IPM requirements, alternative products are also to be part of the control package.

For centuries, the desert locust (*Schistocerca gregaria*) has been a feared, unpredictable pest in both Africa and Asia. Appearing in swarms at periodic intervals, the desert locust is able to cause considerable damage regionwide. The exact relationship between the destruction of agricultural produce and subsequent famines is not clear (Steedman, 1990), but there is no doubt that the first decades of this century witnessed substantial, large-scale damage. Baron (1972) delivered impressive, albeit general reports on losses and the history of desert locust control. A key breakthrough in this field was made about fifty years ago with the introduction of synthetic insecticides; chlorinated hydrocarbons in particular have been used with great success for 40 years. Early outbreak detection systems have also undergone continual improvement.

The United Nations' Food and Agriculture Organization (FAO) in Rome has played a key role since the 1950s and is responsible for coordinating early-detection activities and control measures. This provides a striking example of the overall scale on which the fight against a key pest can be organised. And yet, in spite of these joint efforts, and in spite of rapid technological improvements, such as the use of weather satellites (NOAA, METEOSAT) and the introduction of the Global Positioning Systems (GPS), to name just two, reliable forecasts of locust development are still not possible in every case. What is more, the banning of chlorinated hydrocarbons with their high level of persistence has left a vacuum that no other control means have been able to fill to date. The rapidly degradable, synthetic insecticides that have been used for the past 10 years no longer allow the old barrier technique to be used in which only approximately 100-meter strips were sprayed at quite large distances from each other, thus poisoning the locusts as they passed through, and ultimately killing them. Instead, the rapid rate at which the insecticides degenerate mean that now large areas have to be sprayed, much to the detriment of the eco-system (Everts and Ba, in press).

Although research projects on the biological and integrated control of the desert locust have been ongoing for the best part of a decade (Krall et al., in press; Lomer, in press), decisive advances leading to an integrated control strategy are still not forthcoming, as opposed to many other areas where they are now considered quite normal (Grosse-Rüschkamp, 1994). However, certain approaches do exist and are described in more detail below.

*Desert locust plagues and how they occur*

More or less quantitative records of desert locust development have been kept for the past 135 years or so (Fig. 1). Various theories were put forward in the past to explain the periodic fluctuations. Shcherbinovskii (1952, 1964) attempted to link the plagues with sunspot activities. In his opinion, large-scale sun-spot activity leads to recessions, whilst years with less activity correlate positively with outbreaks and plagues. Similar correlations with sun-spots were confirmed by Schuster in 1872 in the context of wine-growing

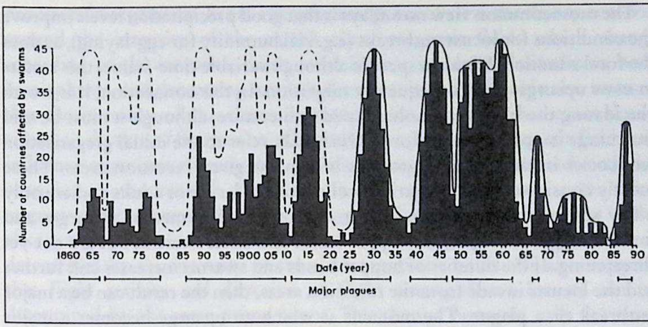


Fig. 1 - *Numbers of countries reporting either bands or swarms during a year. Broken lines denote estimated values (Symmons, 1992).*

in Germany. Shcherbinovskii talks of an 11-year cycle, and in some cases, a 22-year one. Eleven-year cycles of sun-spot activity with corresponding impacts on flora and fauna were confirmed by other authors for the past 500 million years (Berg, 1947). However, this correlation was no longer verifiable in the same regularity after 1920. In modern literature, the sun-spot correlation theory is no longer pursued, although considerable consequences could be derived from it with regard to forecasts. Current data on sun-spot activity and the dynamics of desert locust development do, however, point to a certain regularity over the last 20 years (Fig. 2).

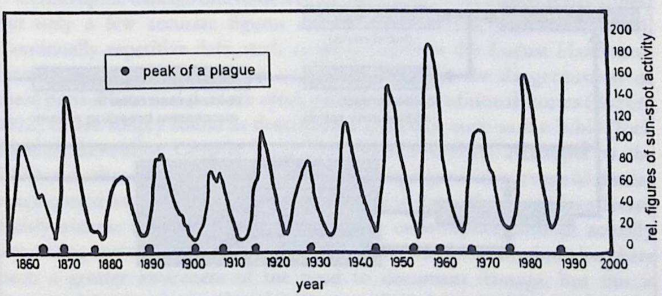


Fig 2 - *Peaks of desert locust plagues in relation to sun-spot activities.*

The most common view nowadays is that good precipitation levels improve the conditions for locust outbreaks (e.g. soil humidity for egg-laying), as does the food situation. Within a specific although variable time-frame, this results in mass upsurges and consequently migration. In this connection, it is worth elucidating the latest terminology used in literature, although it must be said that usage is not totally uniform. *Outbreaks* refer to the initial gregarisation tendencies in the breeding grounds within the given recession areas. These mostly consist of small, gregarious collections of larvae or adults and are only a few square meters in size. Larger outbreaks are termed as upsurges and involve bigger to large-scale hopper bands and adult swarms, but are not yet threatening. If the number of hopper bands and swarms increases still further and the locusts invade from the recession areas, then the result can be a major outbreak or a plague. The moment at which an upsurge becomes a major upsurge or a plague has not yet been clearly defined (Fig. 3).

Migration directions are primarily determined by the prevalent wind currents, because although locusts are good at flying, they unable or only seldom able to fly against the wind. However, since the wind directions are recurrent, certain forecasts can be made as to the direction of migration, although a lot is still down to pure chance. The Intertropical Convergence Zone (Meinzingen, 1993) has an important role to play in this context.

Another theory that has since been forgotten was put forward by Presman as far back as 1963 and 1971. The theory which he applied to the migration of birds, fish and other animals, including the desert locust, is basically that the earth's electromagnetic fields exert a great influence on practically all vital

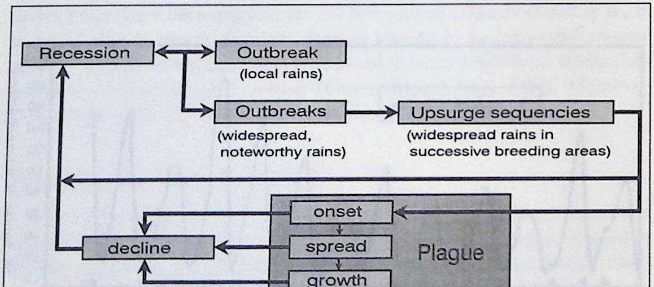


Fig. 3 - *Desert locust cycle from recession to plague (modified after Krall et al., in press).*

processes in organisms. From a geophysical point of view, the theory revolves around the intensity of the earth's electromagnetic fields which change according to the latitudes, being most intense in central latitudes in both hemispheres, and decreasing towards the equator and poles. He also stressed that the intensity of the electromagnetic fields has a regular seasonal and circadian rhythm of fluctuation. The activity of the electromagnetic fields can influence organisms directly, but can also affect the organisms indirectly by changing environmental conditions in the atmosphere and water. Bird migration, according to Presman, is triggered by the seasonal changes in the electromagnetic fields. The direction of flight, navigation and orientation is determined by the intensity of the electromagnetic fields. He also suggests that flight activity and direction of flight among desert locusts can be determined by the same prime factor. This theory, however, calls for more experimental data before it can be confirmed.

The theory of wind migration and that put forward by Presman do not necessarily contradict each other, as the weather is, to a large extent, determined by solar radiation which, in turn, affects the electromagnetic fields in the atmosphere and on earth.

Whether or not desert locusts have always migrated in the form known for the past 1000 years or so is not clear. The development and expansion of the Sahara might have influenced migratory behaviour. Other species from the genus Schistocerca do not migrate or at least not to extent of *S. gregaria* (Anonymous, 1982).

*Damage to agricultural crops*

Catastrophic damage due to desert locusts has been described many times, but only a few accurate figures are on hand (Herok and Krall, 1995). Continually repetitive data, such as those found in the Locust Handbook (Steedman, 1990) (Table 1), are quoted to underline the dangerousness of these pests. Historical data are often passed on via traditional stories (Byron, 1972) or are simply found as descriptions in books, such as the Bible (Joel, Exodus; Revelation Chapter 10; 2 Chronicles, Proverbs). Attempts by the FAO and other organisations to link locust campaigns with surveys of the damage caused have not met with great response to date. The countries affected tacitly assume that desert locusts can cause catastrophes without actually possessing any concrete evidence to this effect. Only in recent times has there been a greater awareness of the need to document damage, but this is hampered in many cases by the absence of any standardised methods of determining the actual harm sustained and crop losses (Wewetzer et al., 1993).

Table 1 – *Crop losses due to the desert locust (Steedman, 1990)*

| Year | Country | Amount of crop eaten by the Desert Locust |
|---|---|---|
| 1944 | Libya | 7 000 000 grapevines; 19 % of total vine cultivation |
| 1954 | Sudan | 55 000 tonnes of grain |
| 1957 | Senegal | 16 000 tonnes of millet, 2000 tonnes of other crops |
| 1957 | Guinea | 6000 tonnes of oranges |
| 1958 | Ethiopia | 167 000 tonnes of grain, which is enough to feed 1 000 000 people for a year |
| 1962 | India | 4000 hectares of cotton (value £ 300 000) |

*Monitoring and early-warning strategies*

There is general consensus that well-organised and carefully implemented early-detection systems are a basic prerequisite for targeted control measures. However, the type of monitoring and detection system is still a matter of dispute. At present, it is common practice in the countries with *S. gregaria* breeding grounds to drive through or fly over as much of the gregarisation areas as possible in the risk months, provided sufficient funds are available, of course. This approach involves considerable time and money, since the areas concerned are frequently difficult to reach and, in some cases, only accessible with a military escort for reasons of safety (e.g. Niger and Mali). Certain areas that are totally impassable with road vehicles are controlled with helicopters or fixed-wing aircraft, although, finances permitting, the latter are quite often used in areas that could really be monitored by car.

The lack of cartographic material means that surveys are not only complicated, but also time and cost intensive. Since the funds mostly come from external sources, at least in Africa, no great importance is attached to their rational usage.

Consequently, for example, specifying the right size of a survey team for monitoring and determining just when the very expensive helicopters and aircraft are justified are a matter of dispute. It is also questionable whether it is really necessary to investigate absolutely all areas that can be reached, in order to obtain an overview of locust development. However, since monitoring is frequently linked with the practice of preventive control described below, people are particularly reticent to renounce a comprehensive monitoring system.

The introduction of the Global Positioning System (GPS) heralded a significant improvement. This satellite-supported system, which is continually becoming cheaper to procure, enables the determination of precise locations, something which is vital to the retracing of gregarisation areas or swarms and hopper bands. GPS is the greatest and most innovative breakthrough in the field of prospecting in the last decades.

The use of satellite technology as tested by Voss and Dreiser (1994), has constantly improved the cartographic material available for prospecting. Maps produced on a model basis for classic breeding areas not only contained details of the vegetation necessary and suitable for propagation but also described the geomorphology and infrastructure of the respective region (Voss and Dreiser, 1996). Direct methods of locating migrating locusts on the ground or in the air are not yet available, although this is merely a question of time given the rapid pace at which satellite technology is developing.

*Desert locust control strategies*

There are basically two approaches to desert locust control: preventive control and plague control. These methods could also be described as *proactive* and *reactive*. Proactive control is geared to preventing locust plagues, an approach that is theoretically feasible at various junctures as described in Fig. 2. Attempts could be made to prevent any outbreaks whatsoever by prospecting for initial tendencies to hopper-spot formation and then counteracting them immediately. However, in view of the tough terrain and the difficulty in finding the locusts in the first place, this approach would seem to be thoroughly unrealistic and is not generally attempted in practice. In contrast, there is wide-spread belief that existent outbreaks could be controlled in such a way as to significantly reduce the overall population, thus precluding a later upsurge. This is why today most survey teams carry control equipment with them which they use to combat initial gregarisation tendencies of this kind. Although the inaccessibility of the given areas and the difficulty of locating the small-sized spots from a vehicle would seem to negate the effectiveness of such an approach, the countries concerned all agree that this theory is both realistic and promising.

Another approach focuses on the control of upsurges, i.e. hopper bands and adult swarms, both at the point where outbreaks transmute into upsurges or also during an ongoing sequence of upsurges. Controlling early and mid-upsurges is considered absolutely imperative and meaningful, at least in Africa and the Middle East. On the one hand, the targets are easily located and, on the other, intervention at the earliest possible juncture is regarded as most expedient. And yet, opposition also exists to this theory. Symmons (1992) considers the control of early and mid-upsurges to be of little use, as, in most cases, the targets are not only difficult to locate, but the national plant-protection services and regional locust organisations do not have the requisite logistical infrastructure and striking power. Van Huis (1994) goes on to state that successful control would have to encompass at least 80 % of all gregarious locusts, in order to attain any significant reductions in the overall population.

Experts normally only recommend intervention when upsurges have reached a cross-border level and are no longer restricted to the typical regression areas. Again, however, there is a series of unanswered questions:

- Can a plague that is in the process of development really be stopped by intervention?
- Should all hopper bands and swarms that can be reached be combated?
- Does it make sense to concentrate on areas with cultivated plants?
- How endangered is pasture?
- Is the control of hopper bands meaningful or should control activities target adult swarms only?

If, in spite of preventive action, a plague has developed and is now threatening large areas of cultivated plants and possibly also pastures, then general consensus is that this plague needs to be combated with a view to terminating it (reactive); however, once again, there are various ways of going about this. Protection of cultivated areas could be a priority, for example, or activities could focus on swarm control. Given the fact that numerous natural factors such as dryness, prevalent seaward wind directions, inter alia, could lead to the plague's breakdown, it might be conceivable that the overall aim is not to terminate the plague with the aid of chemical (and in future perhaps also biological) means, but to regard these as merely one of the many factors in the overall breakdown. The discussion is still extremely controversial and it can even be said that is has really only just begun (Van Huis, 1996; Krall, 1996; Krall et al., in press). For this reason, several of our own potential integrated control approaches are outlined below, the aim being to contribute to the ongoing debate and not to make a final judgement.

## *Potential approaches to integrated desert locust control*

### *Economic aspects*

Whilst economic aspects play an important role in the choice and application of plant protection for nearly all cultivated plants, it has been more or less completely neglected for decades in the field of desert locust control, thus making it all the more difficult to comment on. Since key data are missing in many areas, there is no basis for any reliable facts. Given this situation, the only option open to us today is that of working with relatively coarse estimates and models, as put forward by Herok and Krall (1995), who conclude that the current control methods used are no match for the potential damage to be expected from the desert locust. Considering other factors such as the potential impact of the locust in the African countries concerned (based on FAO data), the potential extent of the damage caused (damage is not always 100 %), and the limited efficiency of control measures, as is usually the case, any conclusions must be seen in very relative terms (Fig. 4).

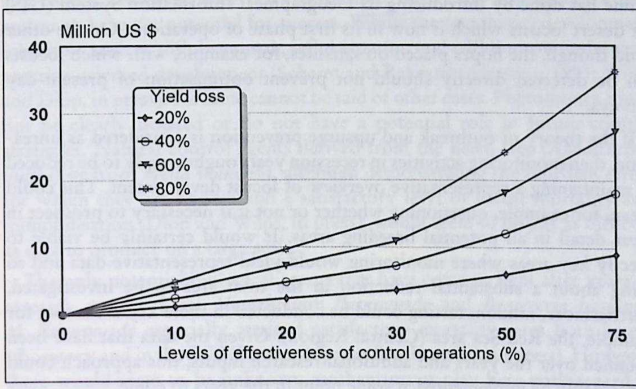


Fig. 4 - *Possible prevented annual yield losses due to locust control (in million US$) (Herok and Krall, 1995)*

Fig. 4 clearly illustrates that a high financial input is only justified when the potential loss is dramatic and the control measures are highly efficient. Taking an average loss of 40 % (which is even a bit higher than normal) and a control efficiency of 50 % (a realistic figure), the break-even point would be an (Africa-wide) input of US$ 12 million. Thus, the funds used for monitoring and control in all African countries together should not exceed the total of approx. US$ 10 million per annum (and should preferably be lower). However, according to the FAO, the donor input alone in recent years was somewhere in the order of US$ 25 million (Krall, 1995). And that is not all: considerable funds are made available by the countries themselves in the form of logistic inputs, salaries or contributions to international control organisations such as the Desert Locust Control Organisation for Eastern Africa (DLCO-EA).

The facts outlined briefly above make it quite clear that any integrated monitoring and control strategy that is developed would have to be considerably cheaper, unless other reasons were put forward that would justify heavy subsidies, an issue that is not to be delved into any further here.

*Potential early-warning systems*

As already stated above, monitoring technology has changed little in past years, apart from better climatic forecasts and the introduction of the GPS. On the one hand, it is meaningful to improve technology, as the FAO in Rome has done by introducing its Geographical Information System (GIS) for desert locusts which is now in its first phase of operations. On the other hand though, the hopes placed on satellites, for example, with which locusts can be detected directly should not prevent optimisation of present-day surveys.

If the theory of outbreak and upsurge prevention is considered as unrealistic, then monitoring activities in recession years ought simply to be reduced to maintaining a representative overview of locust development. This could mean, for example, questioning whether or not it is necessary to prospect in great detail in all potential breeding areas. It would certainly be viable to specify key areas where monitoring would yield representative data and so bring about a substantial reduction in the total area to be investigated. Furthermore, random testing could be conducted in these key areas too, for example, the Red Sea area (Central Region). Given the data that have been obtained over the years and additional research inputs, this approach could conceivably be implemented at some point in the years to come.

It would thus be feasible to restrict surveys in specific countries to an absolute minimum (e.g. Chad, Niger and Mali) and to conduct strategic prospecting in key regions (e.g. Mauritania, South Algeria, Central Region) in the form of (random) samples. Besides the GPS mentioned above and weather data, the cartographic material described earlier on could be of assistance in this context (Voss and Dreiser, 1994, in press).

If prospecting is to serve this purpose only, then it would be time to rethink the way in which the teams are put together. If control does not play a role in prospecting, since monitoring is now the main focus, it would be totally unnecessary to take along any control equipment. This would save on additional vehicles and application technicians and, above all, reduce the risks associated with the transport of application equipment and dangerous insecticides. If the teams were limited to two vehicles (as a rule) and a maximum of four to five persons, costs could be reduced quite substantially.

Another factor deserving a critical review is the use of helicopters and fixed-wing aircraft. Detailed assessment should be conducted in every case to determine whether or not they are really needed and/or economically justifiable. As things currently stand, the immense expense involved is by no means a deterrent when enough money is on hand.

*Biological and ecologically sound control agents*

Great hopes were placed on environmentally sound control as of the '90s. National and international research programmes were launched (Lomer and Prior, 1992; Krall and Wilps, 1994) which appeared to produce promising approaches. However, after years of research, only a few approaches would appear to have the potential for success. Whilst the (synthetic) development inhibitors such as diflubenzuron, teflubenzuron and triflumuron underwent practice-oriented development (Scherer and Rakotonandrasana, 1993; Wilps and Diop, in press), the same cannot be said of other cases. Pheromones could not be clearly isolated or do not have a potential role in future control strategies. Natural control agents derived from the neem tree (*Azadirachta indica*) or from *Melia volkensii*, although demonstrating the repellent effect for which they are known and a satisfactory level of locust mortality and immobilisation (Diop and Wilps, in press), would seem to be just as difficult as ever to produce on a large scale.

The only potential biological agents that have come to light after years of research are the fungi *Metarhizium flavovoride* and *Beauveria bassiana*. *M. flavovoride* especially attained satisfactory mortality rates both in the laboratory and in the field (Lomer, in press; Stephan et al., in press). However, there would seem to be unknown mechanisms at play here with regard to locusts that we have only just begun to understand. It was discovered, for example, that once a fungal preparation had been applied, the locusts deliberately allowed themselves to heat up to a temperature of 42°C in the sun, thus, in many cases, actually killing off the fungus or at least reducing the rate of infection (Goettel and Fargue, 1996). Yet another, perhaps insolvable, problem in the near future, is the great instability of the biological products under the given climatic conditions in the respective areas in Africa. Just brief exposure to high temperatures, as is common in practice, renders the products less effective (Stephan et al., in press). Another problem is that of finding producers for the frequently more expensive, biological products. These products that have been specially developed for locusts cannot serve a large, ongoing and thus profitable market and so large chemical companies have hardly any interest in developing and selling them.

In conclusion, it can therefore be said that of all the products investigated and researched to date, probably only the insect-growth regulators have a real chance of being used on a large scale. However, since they take several days to take effect, it would not be expedient to apply them close to cultivated areas. Natural preparations could be used to fill certain niches, but could also be applied on a more extensive scale in those areas that have sufficient plant resources for large-scale, local production. The future of biological agents depends, on the one hand, on whether products can be developed that are able to withstand the harsh climatic conditions, and, on the other, whether small, medium or even large companies can be found that are willing to produce them.

*Using different application techniques in control activities*

Without going into too much detail of this specialised area, this section is designed to provide some discussion points. The great number of individual application techniques available for insecticidal agents is confusing enough, but the greatest probable difficulty at present is their correct usage. Indeed, their frequently incorrect application results in corresponding losses in effectiveness and endangers both humans and animals; in most cases though the products are wasted due to what is sometimes immense overdosing, a practice costing thousands of dollars and causing the cost of locust control to soar sky high. Making overdosing of this nature transparent is not as easy as it is in other areas, since it is not possible to compare a directly treated field with a specific amount of substance used. In locust control the area treated is calculated from the total amount of substance used, on the basis of active ingredient per hectare as recommended. Whether or not this was really the case is difficult to check after it has happened, but from our own experience and a lot information we have received from experienced colleagues, it would hardly be right to assume so.

Improving application could therefore already result in drastic cutbacks in expenditure, whilst concomitantly enhancing efficiency. Furthermore, continual developments in application techniques are naturally most expedient. The ultra low volume (ULV) method that has been in use for a number of years now would, however, seem to be the ideal application technique in locust control. Whether it is to be applied on the ground, by vehicle or from the air is to be decided in each individual situation. But once again, it is most important to carefully weigh up the costs involved before resorting to the helicopters and fixed-wing aircraft which are very expensive to use in Africa. However, when large areas have to be covered, these not only fulfil their purpose, but are the cheapest method of application.

*An integrated approach - the strategy*

Given the great gaps in present-day knowledge, it is extremely difficult to draw any final conclusions as to integrated desert locust control. And yet, inter alia, various elements of the above are beginning to take on more concrete form:

- Since locusts know no borders, the coordination of monitoring and control activities requires a central institution. The FAO in Rome is currently fulfilling this task, one for which it is surely the best suited. Regional organisations such as OCLALAV (Organisation commune de lutte anitaviaire et de lutte antiacridienne) in West Africa have not proven themselves to be viable options in the long term.
- Monitoring activities should be conducted separately from control measures in future and take the form of random testing in key regions. Less important regions should restrict such activities to a minimum. Prospecting teams should be kept as small as possible and helicopters and fixed-wing aircraft only used in urgent cases.
- Control measures should only be launched once the target, in the form of hopper bands and adult swarms, is not only easily detectable but in acceptable proximity to the next control team. Priorities should always focus on the fact that control is not for its own sake but for the protection of agricultural crops. Consequently, control activities are only meaningful in the case of advanced-stage upsurges.
- Control should only ever be understood as an aid to naturally limiting factors, with the aim of making upsurges or plagues revert back to a recession phase. Thus, control should only be started when natural recession can no longer be expected, e.g. for climatic reasons.
- Natural products or biological control agents will in future probably only be able to contribute to integrated control as niche products (e.g. in frail eco-systems). They will not bring about any fundamental changes in strategy; this will be determined by other factors.
- Greater efforts should be made to improve the application of control agents – a great money-saving factor. When selecting application equipment and techniques, the costs should be considered in relation to the overall efficiency, whereby the cheapest solution should always be chosen.
- Economic studies, such as those currently supported by the FAO, should be promoted in the medium to long term, so as to obtain a better insight into the economic aspects of the desert locust problem. A precondition for such studies is ongoing data collection, e.g. together with control activities.

Final conclusions on integrated control will not be possible for a number of years. The project within the scope of the Emergency Prevention Systems (EMPRES) for Transboundary Animal and Plant Pests and Diseases, which is being supported by the FAO and various other donors in the Central Region, represents a sound approach to developing an integrated monitoring and control strategy for desert locusts.

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*Author's address:* Dr. S. Krall, Projekt Biologisch-Integrierte Heuschreckenbekämpfung, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Postfach 51 80, D-65726 Eschborn.

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# CONTRIBUTION OF AGRICULTURE TO EMISSIONS OF CLIMATICALLY RELEVANT TRACE GASES – POSSIBILITIES FOR ABATEMENT?

*by*

HEINZ-JÜRGEN AHLGRIMM

*Institute for Technology, Braunschweig Agricultural Research Centre*

If agriculture is understood to include the burning of tropical rain forests and savannas for purposes of land use change, then its contribution to the anthropogenic greenhouse effect amounts to approx. 30 %. These emissions hold a large abatement potential. The contribution of agriculture in the narrower sense accounts for approx. 12 % and could be reduced by cutting back the production and consumption of meat and dairy products ($CH_4$) and using organic or mineral fertiliser only as much as is required for plant growth ($NO_x$, $N_2O$). The potential of extensification and land diversion for reducing $CO_2$ emissions appears to be very small at best. Alternative cultivation methods could reduce $CO_2$, $N_2O$, and $NO_x$ emissions, though biomass production would also decrease. Cultivation of biomass as a renewable raw material and especially for energy production may slightly reduce $CO_2$ emissions from fossil fuel combustion.

The year of the Berlin Conference of signatories to the first World Climate Summit in Rio in 1992 gives us another fitting occasion to think and talk about the anthropogenic influences on the climate brought about by man's manifold activities, though massive measures would of course be much more to the point. Such measures are called for in almost every sphere concerned.

Just like other branches of industry, agriculture constitutes a major source of climatically relevant, ozone-destabilising trace gases. Unlike the former, however, it can also often act as a sink. Its important task of providing food for a steadily growing world population is reflected in the growing damage it is causing to the environment. A good example of this is the global rise in atmospheric methane concentration, whose temporal course closely resembles that of the world population. Further pollutants with progredient atmospheric concentrations are carbon dioxide ($CO_2$) and nitrogen oxides such as $NO_x$ and $N_2O$, all of which to some degree also arise through agriculture.

The present article attempts to give an overview, both at the national and global level, as to the contribution of agriculture to the emission of climatically relevant trace gases according to present knowledge. It also undertakes to point out and discuss possibilities of reducing such emissions. One should bear in mind, however, that the available knowledge on the sources and sinks of trace gases is strewn with gaps and uncertainties and that the figures quoted vary over a wide range. Realistic proposals on how to abate these emissions are scarcer still and generally give no figures at all. Where they are given, such figures are often purely hypothetical and speculative and hardly capable of practical realisation. Practicable abatement measures, it must be remembered, should take account of the need to feed a growing world population and exclude negative or incalculable ecological and/or economic side-effects. It appears that a vast field in need of research is emerging here. Nevertheless, there certainly are ways towards an environmentally acceptable agriculture, e.g., the cutback of excess production, a more sparing use of fertilisers, the reduction of livestock etc.

Apart from the new data of the IPCC, whose publication is not expected before the end of this year, there has hardly been anything new on the magnitudes of sinks and sources of climatically relevant trace gases during the last two years, so the corresponding data of the year 1994 are still considered valid (Ahlgrimm and Dämmgen). These are largely identical to those given in the Federal Government's National Report (Federal Ministry of the Environment [BMU], 1993) and in the report of the Enquete Commission (Enquete, 1994).

## *The contribution of agriculture to trace gas emissions and to the greenhouse effect at the global and national level*

Using the synopsis (Table 1) of anthropogenic trace gas emissions and their respective contributions to the greenhouse effect as a reference, this section will deal with the more important agricultural activities giving rise to emissions of climatically relevant trace gases. Possible abatement measures will be discussed further on.

Beside total anthropogenic emissions (column 1) Table 1 gives the main sources attributable to agricultural activities at the global level (column 3) and the corresponding figures for German agriculture (column 5). The Global Warming Potential given for each gas in column 2 refers to weight units and a

Table 1 – *Global warming potentials and global and national agricultural sources of greenhouse trace gases*

| Sources total anthropog. emissions (mil. t/a) | Global warming potential by weight unit assuming $CO_2$=1, time horizon: 100 ha | Global emissions from agricultural sources (mil. t/a) | Contribution to greenhouse effect of agricultural sources by gas, global level (%) | (%) | National emissions from agricultural sources (mil. t/a) | Contribution to greenhouse effect of agricultural sources by gas, national level (%) |
|---|---|---|---|---|---|---|
| $CO_2$: 29 000 | 1 | | 52[2] | 6.5[3] | | 46 |
| Trop.def./bms.burn.[1] | | 5900 | | | | |
| fossil $CO_2$ (machines, fertiliser production) | | 300 | | | 38.4 | |
| $CH_4$: 350 | 11 | | 21[2] | 47[3] | | 30 |
| Trop.def./bms.burn.[1] | | 30 | | | | |
| rice paddies | | 60 | | | | |
| cattle | | 100 | | | 1.4 | |
| animal excreta | | 35 | | | 0.8 | |
| $N_2O$: 6,7 | 270 | | 12[2] | 26[3] | | 24 |
| Trop.def./bms.burn.[1] | | 1 | | | | |
| N mineral fertiliser/ soils | | 2 | | | 0.075[4] | |
| manure/soils | | 2 | | | | |
| recultivation | | 0.4 | | | | |
| $NO_x$: 31 | 40 | | 4[2] | 3.5[3] | | |
| Trop.def./bms.burn.[1] | | 7 | | | | |
| N mineral fertiliser | | 2 | | | | |
| manure | | 2 | | | | |
| CO: 1540 | 2 | | 11[2] | 17[3] | | |
| Trop.def./bms.burn.[1] | | 300 | | | | |
| methane oxidation | | 394 | | | | |
| NH3: (54) | | ca. 40 | | | ca. 0.7 | |

[1] tropical deforestation (land use change and biomass burning)
[2] including tropical deforestation and biomass burning
[3] excluding tropical deforestation and biomass burning
[4] counting N mineral fertiliser and manure together

time horizon of 100 years and has served to calculate the shares of the individual gases in agriculture's contribution to the greenhouse effect at the global and national level (columns 4 and 6, respectively).

A large part of the emissions arising from the destruction of the tropical forests (biomass burning) and savanna fires must ultimately also be attributed to agriculture because they serve the purpose of land use change. This means that agriculture altogether contributes more than 30 % to the greenhouse effect at the global level. Seen this way, carbon dioxide contributes more than 50 % to that fraction of the greenhouse effect attributable to agriculture (left side of column 4) and a stately fraction of about 22 % to total anthropogenic $CO_2$ emissions, while the contributions of methane and other trace gases fall correspondingly. Leaving this source (destruction of tropical rain forests) out of consideration makes methane the greatest agricultural contributor to the greenhouse effect (65 % of total anthropogenic methane emissions and almost 50 % of the global warming potential attributable to agriculture) followed by $N_2O$, as can be seen from the right side of column 4.

At present there are no data on the national emissions of the indirectly acting greenhouse gases $NO_x$ and CO through agriculture. For this reason, only nitrous oxide ($N_2O$), methane ($CH_4$), and carbon dioxide were taken into account in determining agriculture´s contributions to the greenhouse effect by gas. Here carbon dioxide, rather surprisingly, comes first with a share of 46 %, or 38 mil. t $CO_2$/a in absolute numbers. In contrast to this, its contribution to total anthropogenic carbon dioxide emissions in Germany amounts to no more than 3.6 %.

## *The contributions of individual gases*

### *Carbon dioxide ($CO_2$)*

Carbon dioxide is the largest contributor to the additional (= anthropogenic) greenhouse effect. Nevertheless the 29 bil. t $CO_2$/a (or 7.9 bil. t C/a) quoted in Table 1 only amount to approximately 4% of global C fluxes involving the atmosphere. This (relatively small) fraction is evidently capable of disrupting the steady state of atmospheric $CO_2$ because the return flows from photosynthesis (plants, algae) and exchange processes between reservoirs are not sufficient to balance it. Thus, an annual average of 2.9 Gt (bil. t) of carbon has accumulated in the atmosphere over the past 20 years, while the oceans are supposed to have absorbed an annual 2.1 Gt and the biosphere between 0.8 and 2.49 Gt C/a of the anthropogenic C flux. According to recent studies the forests of the northern hemisphere act as a $CO_2$ sink with a capacity of 2–3 Gt C/a (Enquete, 1992).

However, the contribution of agriculture to $CO_2$ emissions from the direct or indirect utilisation of fossil fuels and consequently to elevated atmospheric $CO_2$ levels is very small. If mineral fertiliser production is included, it amounts to approx. 38.4 mil. t $CO_2$ (Table 2) or approx. 3.6 % of the total amount originating from fossil fuels (Ahlgrimm and Dämmgen, 1994, quoted from Smukalski et al., 1992). One can assume that for other industrial countries this fraction is of about the same order, while it is probably far smaller for developing countries. If one takes this latter fraction to be around 1 % ( of that country's total $CO_2$ emissions), then global $CO_2$ emissions from agriculture in the narrow sense amount to about 300 mil. t/a (Table 1).

Table 2 – *Agriculture's share in German $CO_2$ emissions from direct and indirect fossil fuel utilisation (data for the old federal states given in mil. t/a according to Schoedder, 1990; data for the whole of Germany calculated according to the method of Schoedder by Smukalski et al., 1992)*

| | Old states | Reunified Germany |
|---|---|---|
| Motor fuel | 5.9 | 9.0 |
| Heating oil | 5.0 | 7.6 |
| Electricity | 5.5 | 8.4 |
| Commercial fertiliser | 8.8 | 13.4 |
| Total | 25.2 | 38.4 |

Of far greater significance is the escape of carbon into the atmosphere due to biomass burning (fire clearing of tropical forests, savanna and grassland burning for purposes of land use change), 70 % of which must be attributed to agriculture (Enquete, 1994). The net $CO_2$ release through these activities is estimated at 1.6±1 Gt C/a (Enquete, 1992 and 1994). More than 40% of these $CO_2$ emissions are due to the gradual degradation of above-ground biomass after fire clearing, 13 % to microbial humus degradation, and the remainder to the combustion itself and to rotting. If one cumulates $CO_2$ release for the period between 1860 and 1980, then 50 % of these emissions are accounted for by agricultural measures for land use change such as fire clearing, cultivation of moorland etc. (Enquete, 1992; Isermann, 1992). Today fossil fuel utilisation is by far the greatest anthropogenic $CO_2$ source. Large-scale fire clearing of tropical forests is currently being practised in South America and south-eastern Asia, especially in Brazil and Indonesia. In 1989 the area cleared by fire in the tropics amounted to 144 000 $km^2$/a with an annual increase rate of 1.8 %, while total deforestation reached ca. 169 000 $km^2$/a in that year (Enquete, 1992). Although the validity of the data on deforestation in the tropics, at least for 1989, remains somewhat uncertain, they allow the conclusion that the rate of destruction increased markedly from 1980 to 1989 and that if this trend continues, some countries will soon lose the last of their intact forest areas.

### *Methane ($CH_4$)*

Methane is a climatically significant trace gas with both a direct and an indirect warming potential. It affects the ozone balance of the troposphere and stratosphere, the water vapour balance of the stratosphere, and tropospheric OH and CO levels. Global methane emissions are currently estimated at approx. 500 mil. t/a. However, some of the sources included here are still poorly known and there may well exist yet more (possibly also agricultural) sources. As the total sink capacity is somewhat less than the current total emissions, methane is at present accumulating in the atmosphere at a rate of 0.7 %/a (Sanhueza, 1991; Enquete, 1992), this marking a decrease from the growth rate of more than 1 %/a found some years ago. Further details on the flows and the temporal and global distribution of methane are given by Ahlgrimm and Dämmgen (1994) and Ahlgrimm and Gädeken (1990).

A distinction should be made between natural methane emissions, to which quite substantial sources such as wetlands, moors, swamps, shallow lakes, tundras, and temporarily flooded regions contribute, and anthropogenic emissions, which largely stem from agricultural activities (Table 1). The left part of Figure 1 allocates methane emissions to various origins. Thus, at the global scale, agriculture accounts for more than 40 % of the total and for more than 60 % of anthropogenic $CH_4$ emissions (Table 1). The right part of Figure 1 breaks down agricultural emissions into individual source categories (compare also Table 1).

Emissions from biomass burning (i.e., destruction of tropical forests and savannas) and rice cultivation have recently been estimated at 30 and 60 mil. t/a, respectively, which in both cases is far less than the values quoted in earlier studies. This means that the share of agricultural in total anthropogenic emissions has slightly decreased for the present. The largest agricultural source is now considered to be ruminant husbandry with an estimated 65–100 mil. t $CH_4$/a, the upper value of which has meanwhile been corroborated by a very thorough analysis (Ahlgrimm and Gädeken, 1990). For Germany this source is quoted at 1.4 mil. t $CH_4$/a (Basis, 1990), though it is estimated meanwhile to have dropped to around 1.2 mil. t/a following the drastic reduction in cattle stock in the new federal states (Enquete, 1994).

Excreta from animal husbandry also give rise to considerable quantities of methane, estimates for global emissions ranging from 14 to 37 mil. t/a. This wide variation is due to major imponderabilities in data acquisition. For

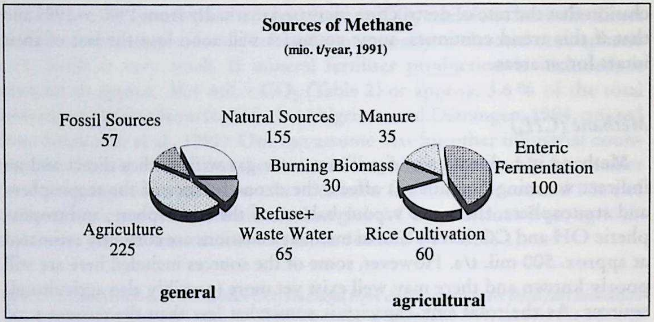


Fig. 1 – *Total (left) and agricultural (right) global methane sources (various literature sources representantive of the end of 1991).*

reunified Germany emissions from this source are rated between 0.6 (BMU 1993) and 1 mil. t $CH_4$ /a. Ahlgrimm and Dämmgen (1994) assume a slightly higher value (0.8 mil. t/a).

To date global methane statistics have not taken account of methane emissions from the treatment and storage of organic residues and wastes from agro-industrial production. These activities could hold another significant potential for methane emissions.

The largest methane sink, accounting for more than 70 % of total methane elimination, is represented by the oxidation of $CH_4$ (to $H_2O$ and via CO to $C_2O$) through OH radicals, while its degradation through the soil and the stratospheric $ClO_x$ cycle is distinctly lower.

*Nitrous oxide (laughing gas, $N_2O$)*

$N_2O$ is considered a both directly and indirectly effective greenhouse gas (destruction of stratospheric ozone). While chemically inert in the troposphere, upon reaching the stratosphere it decomposes via reactive nitrogen oxides. This together with its longevity is why despite the small quantities in which it arises the hazard potential of $N_2O$ should be rated at least as high as that of CFCs.

As Fig. 2 shows, a large part of $N_2O$ emissions comes from natural sources beyond man's influence such as oceans, lakes, and natural soils (through nitrification and denitrification processes). More than 40 % originate from soils, particularly those of the tropics.

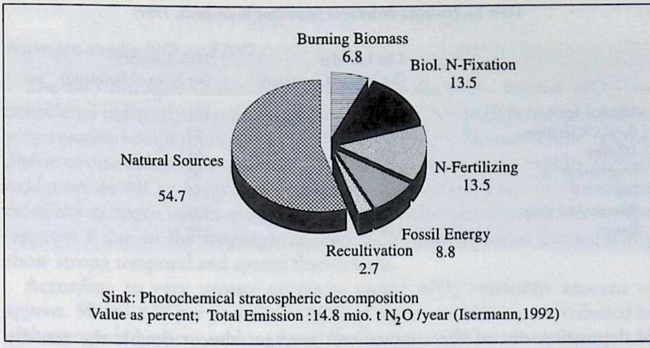


Fig. 2 – *Global sinks and sources of $N_2O$ in percentage terms (according to Isermann, 1992).*

Biomass burning included, agriculture contributes more than 35 % to overall $N_2O$ emissions (Isermann, 1992). Its share in anthropogenic $N_2O$ emissions under this definition even amounts to 81 %. However, the available data on the sources and sinks of $N_2O$ still bear a great deal of uncertainty, as emissions from agricultural sources (especially from soils) vary widely both temporally and spatially, and some sources are possibly still undiscovered (Haider and Heinemeyer, 1990; Sanhueza, 1991; Isermann, 1929; Enquete, 1992). This can be inferred from the difference in the overall magnitude of sinks and sources, which is rated between 8 and 19 Mt/a (Isermann, 1992). Emissions from agriculture in Germany are estimated at 75 kt/a, of which approx. 65 kt are thought to escape from the soil and 11 kt/a from animal excreta, but these figures, too, appear very uncertain (BMU, 1993; Ahlgrimm and Dämmgen, 1994). According to recent findings solid manure and compost could also be significant sources of $N_2O$.

Global $N_2O$ emissions are currently increasing at a rate of 0.25 %/a, that is, at about the same pace as the consumption of mineral fertiliser, which is put at 80 mil. t/a for the year 1990. However, the rate of mineral fertiliser consumption varies widely by region, average quantities amounting to, for example, 11 kg/ha*a for Africa, 21 for Latin America, 125 for the EU, and 467 for the Netherlands (Enquete, 1994). In Germany a total of 2.4 mil. t of mineral fertiliser (or 130 kg /ha) are spread on the fields each year, this rate showing a slight downward tendency. Table 3 represents an attempt to set up separate N balances for Germany's old and new states. As can be seen, total nitrogen input (through mineral fertiliser, farm manure, biotic N fixation, and

Table 3 – *Tentative N balance (according to Enquete, 1994)*

| | Old Laender (kg N/ha of farmland) | New Laender (kg N/ha of farmland) |
|---|---|---|
| Mineral fertiliser | 137 | 132 |
| Biotic N fixation | 30 | 30 |
| Manure | 83 | 61 |
| Deposition | 30 | 30 |
| Input | 280 | 253 |
| Removal by plant | 145 | 133 |
| Excess | 135 | 120 |

N deposition out of the atmosphere) averages almost double the actually required amount.

This excess of nitrogen must be interpreted as a loss. According to Kuntze (cited in Enquete, 1994), 25 kg/ha*a of 120 kg N/ha*a are lost through denitrification (i.e., escape as $N_2$), 50 kg/ha*a are washed into the groundwater in the form of nitrate, and 44 kg/ha*a escape into the atmosphere as ammonia. $N_2O$ may form through nitrification as well as through denitrification of nitrogenous fertilisers (manures such as in liquid form may also contain large amounts of nitrogen). This is why the use of ammoniacal fertilisers produces more $N_2O$ than does that of nitrate fertilisers (Enquete, 1994) where the only remaining reaction path is denitrification. It is assumed that between 0.4 and 3.2 % of the nitrogen added to the soil escapes as $N_2O$-N through denitrification processes. For Germany, supposing an annual average N input equivalent to 200 kg of N fertiliser per hectare, which is a conservative estimate, this would mean $N_2O$-N emissions between approx. 14 000 and 108 000 t (Enquete, 1994). In the extreme case, this exceeds the values for Germany given above and in Table 1 by far.

Flows of nitrogen compounds caused by human (agricultural) activities may also lead to a substantial contribution to nitrous oxide emissions from shallow waters, estuaries etc. (Isermann, 1992), which would explain the apparent discrepancy in the overall magnitude of known sinks and sources. The share of $N_2O$ released through fossil fuel utilisation in overall $N_2O$ emissions is just below 10 %. This fraction has obviously been overestimated in the past, all the more if one takes the recent spread of cars equipped with three-way catalytic converters into account, which emit more $N_2O$ than do those without (Enquete, 1992; Sanhueza, 1991).

The main sink for $N_2O$ is its photochemical degradation in the stratosphere. Whether soils can also act as sinks is still a moot point.

### *Indirectly effective greenhouse gases*

#### *Nitrogen oxides NO and $NO_2$*

The two nitrogen oxides NO and $NO_2$ (collectively termed $NO_x$) are considered indirectly effective greenhouse gases. The catalytic action of these very reactive compounds has a particularly strong influence on the tropospheric ozone balance. In polluted atmospheres $NO_2$ forms rapidly though oxidation of NO (Ahlgrimm and Dämmgen, 1994). Due to their great reactivity nitrogen oxides only reside for a very short time in the atmosphere (approx. 1 day in the troposphere) and their concentrations consequently show strong temporal and spatial fluctuations.

According to very unsure estimates global $NO_x$ emissions amount to approx. 50 mil. t N per year. Some 60 % of these emissions are attributed to anthropogenic sources such as fossil fuel combustion, road transport, and aviation (Fig. 3a). Here, too, agriculture takes a large share in overall emissions. The soil microbial degradation of urea (after manure spreading) and that of mineral fertilisers are thought to contribute around 2 mil. t/a, respectively (Table 1). Substantial quantities are also released through the burning of biomass, i.e., savanna burning, tropical deforestation, use of firewood, all of which activities can largely be subsumed under agriculture.

Thus, agricultural $NO_x$ emissions account for approx. 20 % of overall and a notable 35 % of anthropogenic emissions. As yet there are no data at all on $NO_x$ emissions from agriculture at the national level. Known natural sources of $NO_x$ include soil nitrification and denitrification, lightning discharges during thunderstorms, and photooxidation of ammonia in the troposphere (Fig. 3b).

The main sinks of tropospheric $NO_x$ are its photochemical oxidation to nitric acid and subsequent wet deposition through acid rainfall and the dry fallout of $NO_2$ and nitric acid on plant surfaces (Enquete, 1991).

#### *Ammonia ($NH_3$)*

Although ammonia absorbs infrared light to a high degree, it has a low warming potential because it resides in the atmosphere only for a few days. However, since 10 % of atmospheric ammonia oxidises to $NO_x$ through the action of OH radicals or atmospheric discharges, it does have a certain influence on tropospheric OH levels and the ozone balance and must therefore be regarded as an indirectly effective greenhouse gas. Furthermore, it can form $N_2O$ through nitrification. Through its photochemical oxidation to $NO_x$ and subsequent wet deposition $NH_3$ indirectly makes a substantial contribution to soil acidification and the forest dieback (Enquete, 1994).

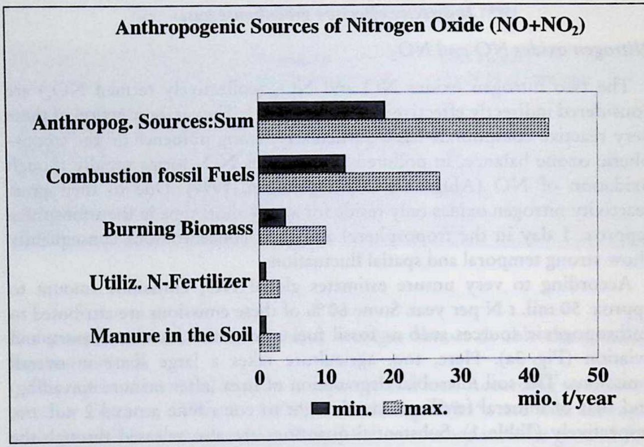


Fig. 3a – *Anthropogenic sources of nitrogen oxides (global; 31±12 mil. t/a; according to Enquete, 1991).*

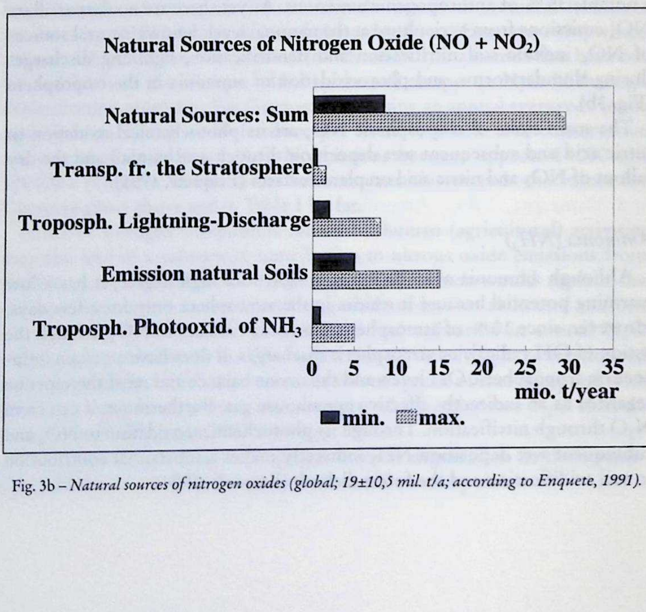


Fig. 3b – *Natural sources of nitrogen oxides (global; 19±10,5 mil. t/a; according to Enquete, 1991).*

Here again, statements on global emissions bear a high degree of uncertainty, estimates ranging between 1200 mil. t/a (quoted by Ahlgrimm and Dämmgen, 1994) and 28 to 45 mil. t/a (Enquete, 1994). Table 1, referring to Warneck in Isermann (1992), gives 54 mil. t/a and a stately 47 mil. t/a as agriculture's share in this amount. The largest agricultural source is livestock farming (quoted at 32 mil. t/a, 2/3 of which stem from ruminants), where $NH_3$ escapes almost exclusively via excreta, that is, mainly from stables and during the storage, treatment, and spreading of liquid manure. Liquid manure and dung water are particularly strong emitters because they have a higher ammonia content than does dry manure (Table 4).

Table 4 – *Average nutrient content and form of organic fertilisers (Enquete, 1994, according to AID, 1992)*

| Fertiliser | Dry matter (%) | Total N (kg/t) | $NH_4$ nitrogen (kg/t) | $NH_4$-N (%) | $P_2O_5$ (kg/t) | $K_2O$ (kg/t) |
|---|---|---|---|---|---|---|
| Solid manure of cattle | 25 | 5 | 0.5 | 10 | 3.0 | 6 |
| Solid manure of swine | 23 | 6 | 0.6 | 10 | 5.0 | 3 |
| Liquid manure of cattle | 10 | 4 | 2.0 | 50 | 2.0 | 6 |
| Liquid manure of swine | 7.5 | 4.5 | 3.1 | 70 | 4.5 | 3 |
| Dung-water | 3 | 3.0 | 3.0 | 100 | 1.0 | 7 |

The increased use of liquid manure systems concomitant with the rationalisation and intensification of livestock farming has led to a sharp rise in $NH_3$ (and $CH_4$) emissions. Latest estimates for reunified Germany put $NH_3$ emssions from agriculture at 743 kt/a (Isermann, 1992). However, because of the recent decrease in cattle stock, these emissions are now declining (Enquete, 1994). Providing nitrogen compounds in soluble form makes them more readily available to plants but also increases losses through leaching of nitrate and escape of ammonium in form of ammonia. Organic nitrogen (manure), by contrast, must mineralise before becoming available and therefore serves as a long-lasting nitrogen source (Enquete, 1994).

Compared with the foregoing, $NH_3$ emissions from mineral fertilisers, combustion of fossil fuels and biomass, and from road traffic are relatively insignificant, in the latter case due to the action of the three-way catalytic converter.

The largest sink for $NH_3$ is represented by its neutralisation reactions with atmospheric acids ($SO_2$, $HNO_3$) in aerosols. Aerosol particles can be carried over long distances before they are deposited on soil and plants in wet form, i.e., via rain, snow, dew, fog etc., or in dry form via dusts or aerosols or as gases.

*Carbon monoxide (CO)*

Carbon monoxide, like ammonia, is also infrared-active, but due to its short lifetime of only a few months it does not contribute significantly to the greenhouse effect and is therefore only considered an indirectly effective greenhouse gas. Nevertheless, it has a strong influence on the tropospheric ozone balance, and its decomposition draws on the tropospheric OH depot, thus also affecting the decomposition paths of other trace gases. As with many other trace gases, the current statements on CO concentrations and emissions bear a great deal of uncertainty (Table 1).

It is assumed that almost 2/3 of global CO emissions are attributable to human activity and that 30 % are contributed by agriculture. This latter figure becomes plausible when one considers that it includes burning of biomass (which must largely be alloted to agriculture) and tropospheric methane oxidation (about 50 % of atmospheric methane stems from agriculture) as sources (Fig. 4). A small fraction of overall carbon monoxide emissions is thought to be contributed by plants, microorganisms, and the oceans.

As with methane, by far the largest sink for carbon monoxide is its tropospheric degradation through the action of OH radicals. Besides this it is also degraded by soils. Nothing is known of direct carbon monoxide sources in agriculture as practised in Germany, but national methane emissions must at least be counted as an indirect source of CO because it arises as an intermediate product in atmospheric methane degradation. This would add another 3 mil. t CO/a (from agriculture, author's own estimate) to the emissions stated in the National Report (BMU, 1993).

*Possibilities of lowering climatically relevant agricultural trace gas emissions*

Theoretically it would be possible to reduce agricultural emissions of almost all the trace gases discussed above in quite a number of ways. However, the practicability of most such measures appears doubtful in view of the new problems they may evoke and the uncertainty as to their effectiveness. The measures and values mentioned in the following are largely opinions of individual authors or teams and should therefore be regarded as subjective. They require further critical study and are also intended to incite new ideas on certain measures.

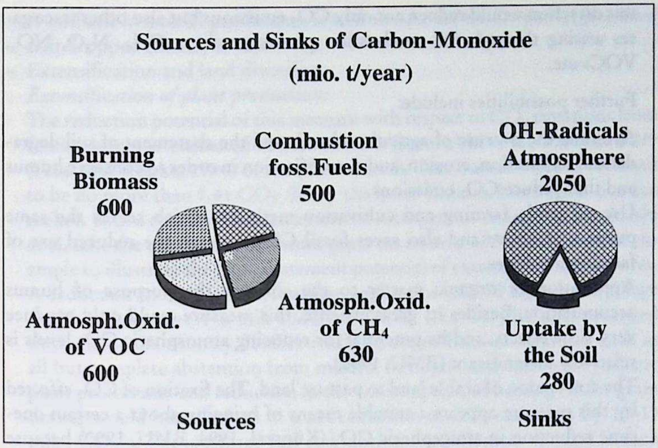


Fig. 4 – *Sinks and sources of carbon monoxide (Sanhueza, 1991; quoted by Crutzen and Zimmermann).*

*Carbon dioxide ($CO_2$)*

Possible measures for abating $CO_2$ emissions from agriculture can be divided into the following base categories: measures for the conservation or enlargement of C sinks for fixation of $CO_2$; abatement of agricultural $CO_2$ emissions, in particular from fossil sources; and substitution of cultivable biomass for fossil fuels. These categories are not always distinct from each other but rather overlap to some degree in certain cases.

Conservation or enlargement of C-sinks

A very important global measure would be to:

– Slow down or put an end to the destruction of tropical forests for purposes of land use change and to savanna burning for cultivation purposes. This could save a loss of 1.6±1 Gt C/a or 5.9±3.7 bil. t $CO_2$/a, which is by far the greatest abatement potential within the sphere of agriculture. However, it should prove very difficult to achieve a substantial abatement within the near future because this requires a long reeducation process in those who pursue these activities on a large scale. Nevertheless, any improvement in this direction would reduce not only $CO_2$ emissions but also other trace gases arising through the combustion process such as $CH_4$, $N_2O$, $NO_x$, VOCs etc.

Further possibilities include:

- Avoiding the overuse of agricultural soils and the abatement of soil degradation, salinisation, erosion, and desertification in order to conserve humus and thus reduce $CO_2$ emissions.
- Use of gentle farming and cultivation methods, which serves the same purpose as above and also saves fossil $CO_2$ through the reduced use of farming machines.
- Application of organic matter to the soil for the purpose of humus accumulation. Besides its great expense, this measure could only produce very slow effects, and its potential for reducing atmospheric $CO_2$ levels is relatively insignificant (BMU, 1990).
- The conversion of arable land to pasture land. The fixation of $CO_2$ effected by this measure appears a suitable means of bringing about a certain one-time reduction in atmospheric $CO_2$ (Küntzel, 1994; BMU, 1990) because the growth of a dense vegetation cover can remove atmospheric $CO_2$ for the time of its duration. This process also increases the C content of the soil.
- The afforestation of fallow land could remove 13 to 15 t $CO_2$/ha*a in the first years of growth (FAL, 1992; BMU, 1990). Through the accumulation of biomass and expansion of woodland to an area between 1.5 and 3 mil. ha in Germany, this measure could lead to an absorption of 20 to 40 t $CO_2$/a (BMU, 1993).

Abatement of $CO_2$ emissions through the reduction of fossil fuel utilisation

In Germany, agricultural $CO_2$ emissions from fossil fuels amount to an average of approx. 2.25 t $CO_2$/ha of farmland. In the aggregate this makes approx. 38 mil. t $CO_2$/a (Table 1), or a slim fraction of just under 4% of total German $CO_2$ emissions. Relatively minor as they are, these emissions are still capable of further reduction:

- A reduction of tillage, which currently accounts for 60% of fossil fuel consumption in agriculture, could abate total emissions from this source considerably (BMU, 1990) (see also section on conservation of C sources).
- As the manufacture of mineral fertilisers contributes approx. 1/3 of agricultural $CO_2$ emissions from fossil fuels, a reduction in the use of mineral fertilisers could lead to a further substantial diminuition of this source. At the same time this measure would lower nitrogenous emissions ($NH_3$, $NO_x$, $N_2O$; see section on nitrogenous compounds).

- A cutback in animal production is said to save 0.7 t $CO_2$ per large animal unit dropped (BMU, 1990).
- Extensification and land diversion
  *Extensification of plant production:*
  The reduction potential of this measure with respect to $CO_2$ emissions from fossil sources is estimated at between 1/3 (Smukalski et al., 1992) and 2/3 (Haas and Köpke, 1994) of the present level. This overall value is assumed to be no more than 1.4 t $CO_2$ /ha by the latter authors. Here again one can reckon with a concomitant abatement of nitrogenous emissions. Smukalski et al. take the cultivation of winter grain on an area of 5.1 mil. ha as an example to illustrate the $CO_2$ abatement potential of extensification measures. A reduction in nitrogenous fertiliser application (20–70 kg/ha) and tillage could initially save 4–6 mil. t $CO_2$ or 0.8 to 1.2 t $CO_2$/ha*a. If practised throughout the country, further-reaching extensification measures such as all but complete abstention from mineral fertilisers and chemical synthetic plant protectants and reduction in the consumption of heating oil for grain drying would initially lead to a net reduction in $CO_2$ emissions by 12–13 mil. t $CO_2$/a. The increased fuel and lubricant requirement entailed in such measures is already considered in this calculation. Further effects are the concomitant reduction in nitrogenous emissions and, unfortunately, a 40 % reduction in the crops' capacity to temporarily remove atmospheric $CO_2$ (Smukalski et al., 1992).
  *Land diversion:*
  Land diversion on the order of 4 mil. ha and the development of new biotopes on 1 mil. ha would initially save 5 mil. t $CO_2$/a. However, the sink capacity of land thus converted is distinctly lower than when cultivated conventionally (Smukalski et al., 1992). According to BMU (1990) this measure could reduce $CO_2$ emissions by 1.5 t/ha*a.
- Transition to organic farming (abstention from synthetic production agents such as fertilisers, plant protectants; use of own animal feedstuffs). Haas and Köpke, working from a value of 1.4 t $CO_2$/ha*a for conventional farming methods, estimate the $CO_2$ emissions abatement potential of this measure at 0.85 t/ha, while BMU (1990) arrives at a value of 0.6 t/ha*a. Here again there is a concomitant abatement of nitrogenous emissions but also a 10–30 % decrease in yield and a consequent loss in temporary sink capacity for $CO_2$.

Abatement of $CO_2$ emissions from fossil fuels through the use of biomass for power generation

By promoting the use of biomass (organic residues, cultivable raw materials) for power production agriculture could contribute to the substitution of renewable energy sources for fossil fuels and thus to a reduction of $CO_2$ emissions from fossil sources. The carbon dioxide released from biomass during its conversion to energy is recycled through the photosynthetic formation of new biomass in subsequent crops. Of course this process does not lead to a net reduction in atmospheric $CO_2$, which is only possible by a decrease in fuel-driven power generation or energy saving in general. Even in that case the slow exchange of carbon between its reservoires (atmosphere, oceans, biosphere etc.) would only allow a very gradual decrease in atmospheric $CO_2$, that is, over a period of many centuries. The following estimates of the potential for substituting biomass and organic residues for fossil fuels are a selection from numerous (usually over-optimistic) data on $CO_2$ saving potentials published and frequently quoted.

- Substitution of fossil fuels : Use of rape oil as fuel is estimated to permit saving 2.25 t $CO_2$/ha*a (BMU, 1990).
- Cultivation and utilisation of vegetal fuels: The $CO_2$ saving potential of this measure is valuated as follows (BMU, 1990):
  wheat (whole plant cultivation?): up to 15 t/ha*a
  C4 plants: up to 25 t/ha*a
  short rotation wood: 10 to 15 t/ha*a
- Thermal utilisation of residues and wastes (forest wood residues, wastewood, straw etc.) according to the 1991 Enquete report:
  abatement potential up to 2005: approx. 15 mil. t $CO_2$/a
  realistically substitutable: approx. 4.5 t $CO_2$/a
- Anaerobic utilisation of liquid manure in biogas plants. Germany´s present biogas potential is approx. 3.5 bil. $m^3$ with a methane content of approx. 60 % and a calorific value of 10 kWh/$m^3$ of methane, which is equivalent to a $CO_2$ abatement potential of approx. 4 mil. t/a. Due to the frequent lack of uses for energy from biogas (heat and electricitiy) and to the high investment costs for biogas plants, which currently range between 300 and more than 1000 marks per $m^3$ of digester, only around one thousandth of liquid manure arising in Germany is used for fueling a total of approx. 200 such plants (latest count in March 1995).

*Methane ($CH_4$)*

Agricultural activities are responsible for a large part of anthropogenic methane emissions. Primary agricultural sources are ruminant farming (e.g. cattle), paddy rice cultivation, burning of biomass (tropical deforestation for purposes of land use change), and excreta from livestock. Proposals for abatement measures should therefore address these large sources. An end to tropical deforestation would of course completely stop up or at least substantially reduce the methane source of "biomass burning". However, for the same reasons as with carbon dioxide (see above), it will hardly be possible here to achieve a substantial abatement of $CH_4$ emsissions.

Methane from paddy rice cultivation

Estimates of methane emissions from flooded rice fields have been repeatedly corrected downward from their initial high values. Global emissions from this source are now put at 60 mil. t/a. In view of the fact that at its present growth rate the world population will require a rice production increase by the year 2020 of almost 50 % through expansion of cultivated area and/or increase in productivity it seems that $CH_4$ emssions will continue to rise even if all conceivable abatement measures are implemented. A great many abatement measures have been put to discussion in the past. According to the IPCC, methane emissions from rice paddies hold an abatement potential of 10 to 30 % (FAL, 1990). Heyer (1994) discusses the following measures, which may serve to represent those of many other authors.

- Selection and breeding of suitable varieties (with low root mass).
- Change of irrigation regime, e.g., intermittent flooding to allow oxygen to enter the soil.
- Organic fertilising with compost or residues from biogas plants (this leads to a reduction in the amount of organic substance capable of rapid degradation and thus in methane emissions).
- Use of additives in fertilisers, e.g, calcium carbide (inhibition of methanogenesis through formation of ethine) or ammonium sulphate (promotion of desulphurication).
- Better adapted N fertiliser application (increase of the ratio of inorganic to organic N fertilisers used).

Methane from ruminant farming

Cattle raising is unquestionably the largest agricultural methane source with a fourfold increase since 1890 (IPCC, 1990). Global emissions from this source are currently estimated at between 70 and 100 mil. t/a. The corresponding figure for Germany was last put at approx. 1.4 mil t/a, but the drastic reduction in cattle stock in the new states following reunification has led to a considerable decrease down to an estimated 1.2 mil. t/a (Enquete, 1994). Success in breeding in Germany and other industrial countries has gradually raised the milk performance of dairy cows, leading to a 30 % decrease in methane production per liter of milk over the last 40 years (FAL, 1992).

The following are the most important out of the wide array of conceivable abatement measures, most of which appear hardly practicable. (Heyer, 1994 has nevertheless attempted to quantify the scope of some of them.)

- Change of feeding plan for cattle: substititution of feed with a low methane potential for the more methanogenic types (only applicable to developing countries as feeding practices in developed countries are already largely optimised in this respect, EPA, 1992).
- Change of feed composition: (additives, nutrients) to compensate for deficits and thus increase animal productivity (mainly applicable to developing countries, as feed composition is near optimum in developed countries, EPA, 1989; IPCC, 1990).
- Increase in reproductive performance (IPCC, 1990).
- Increase in herd reproductive performance in order to reduce the size of pedigree cattle herds (developing countries, EPA, 1989).
- Productivity increase through hormone treatment (e.g., BST for eliciting and prolonging lactation). Hormone residues remain in the product. This practice is prohibited in Germany and the EU (EPA, 1989; IPCC, 1990; Heyer, 1994).
- Use of anabolic steroids (weight increase, improved feed utilisation), application via ear implants (Heyer, 1994).
- Alteration of bacterial flora in the ruminant stomach (promotion of digestibility, inhibition of methanogenesis, EPA, 1989) including removal of rumen protozoa (Heyer, 1994).
- Cattle breeding for minimisation of methane production (long-term measure, EPA, 1989).

Of all the above-listed measures essentially only the first four will be of any practical value in attempts to abate methane emissions from cattle raising in less developed countries. Industrial countries have already more or less exploited these possibilities to the full. One measure remaining here might be systematic breeding for greater animal productivity combined with improved husbandry and feeding methods (to promote animal health and prolong the useful life of the animals), which could permit a reduction of cattle stocks and thus an abatement of methane emissions from feeding and dairy cattle by approx. 10 to 15 % (FAL, 1992).

Methane from animal excreta

Methane emissions from animal excreta are of a lesser order than those specific to ruminants (unfortunately there are still no data on emissions at the global or at national levels) but they nevertheless hold a substantial abatement potential of altogether 30 to 50 % using relatively simple measures:

- Use of high-performing animals so as to reduce cattle stocks (which also reduces the total quantity of animal excreta) while maintaining production at the initial level (FAL, 1992). This would also abate $CO_2$ emissions by 0.7 t/a per large animal unit saved (BMU, 1990) as well as nitrogenous emissions.
- Abatement of surplus production in livestock farming and change of consumer behaviour (less animal products). A reduction in overall animal stock would also reduce emissions of $CO_2$ and nitrogenous gases (Isermann, 1994).
- Extensification of livestock farming. More cattle raising on pasture land. This could lead to a shift in the use of feeds from concentrates to roughage and thus to greater ruminant methane production. Assuming demand for animal products to remain constant the drop in animal performance entailed in extensification would necessitate keeping more cattle, which is equivalent to a greater methane production (FAL, 1992).
- A faster transition from liquid to solid manure management. There are still ongoing studies attempting to ascertain whether this measure really can reduce methane emissions. While the fixation of $NH_3$ to the litter added would certainly reduce $NH_3$ emissions (Heyer, 1994), $N_2O$ emissions would possibly be enhanced.
- Covering up of liquid manure reservoires such as lagoons, earth basins, and other storage facilities and recovery and conversion to energy of the methane escaping from reservoirs (reduction potential of methane emissions from lagoons 50–90 %) (IPCC, 1990).
- Shortening of storage periods (Heyer, 1994). The practicability of this idea appears rather uncertain.
- Anaerobic treatement of liquid manure in biogas plants. Germany's potential for biogas production from liquid manure is put at $3.5*10^9$ $m^3$of gas with a calorific value of approx. 6 kWh/$m^3$; of which currently no more than about 0.1 % is used in altogether approx. 200 plants. Investment costs are high, ranging from 300 marks /$m^3$ of digester upward.

*Nitrous oxide (laughing gas, $N_2O$)*

Emissions of laughing gas are largely from natural sources which man can influence to a negligible or only a very small degree. However, these sources also include forests, estuaries, waters etc. whose strong $N_2O$ emissions can no longer be considered altogether natural because they are due in part to flows of nitrogenous compounds stemming from human and in particular agricultural activities (Isermann, 1992). Together with the $N_2O$ directly released through fertiliser application these indirectly anthropogenic emissions are estimated at a global 0.2 to 3.2 mil. t/a (Enquete, 1994; Beese, 1994). This is where abatement should prove easiest to realise. Examples include:

- Reduction in the use of nitrogenous fertilisers prevention of excesses of nitrogen, as $N_2O$ emissions correlate positively with soil nitrogen excess (Munack, 1994; quoted in Enquete, 1994; Beese, 1994). For example, a 10 % reduction in nitrogenous fertiliser application would abate $N_2O$ emissions by just that rate (FAL, 1992).
- Optimisation of fertiliser quantities used, possibly successive applications according to requirements (Beese, 1994).
- Better adaptation of animal husbandry to available surface (not more than 1.5 to 2 dung units/ha, 1 dung unit being equivalent to approx. 80 kg N) (Beese, 1994).
- Selection of suitable types of fertiliser. High contents in ammonium produce greater $N_2O$ emissions (through nitrification and denitrification processes) than do high contents in nitrate (Beese, 1994).
- Better crop rotation, particularly in succession to rape, legumes, sugar beet (Beese, 1994).
- Gentle soil treatment, i.e., only superficial application of organic matter and avoidance of soil compaction (Beese, 1994).
- Water-saturated soils emit next to no $N_2O$ (Beese, 1994).

*Ammonia ($NH_3$)*

Numerous measures suitable for reducing $CO_2$, $CH_4$, $N_2O$, and $NO_x$ emissions would also help abate $NH_3$ emissions. The following list of possible measures lays no claim to completeness:

- Application of nitrogenous fertilisers according to actual requirements, i.e., avoidance of excesses of nitrogen.
- Adjustment of consumer behaviour to bodily requirements and corresponding adaptation of the output of animal products. The degree of overfeeding (in the industrialised world) is approx. 100 % for protein and 80 % for fats, so eating habits hold a substantial potential for reducing the number of animals kept. However this presupposes that people can change their way of thinking and so their eating habits (Isermann, 1994).
- Reduction in the number of animals kept and use of high performing animals to retain yields (Isermann, 1994).
- Efficient, well-balanced animal nutrition (Isermann, 1994).
- Sealing of liquid manure reservoirs or covering up of stored liquid manure with surface mats.
- Anaerobic treatment of liquid manure in biogas plants.

- Cool storage of liquid manure without stirring.
- Cool, damp storage of solid manure (Enquete, 1994).
- Addition of straw to solid manure to improve the C:N ratio (Enquete, 1994). This measure could well augment $N_2O$ emissions, however.
- Filtration of exhaust air from stables and enclosed dungyards.
- Ammonia stripping (hot fermentation through liquid manure aeration) and recovery in dilute sulphuric acid (production of ammonium suphate fertiliser); thus removal of 60 % of the nitrogen originally contained in the liquid manure; attendant reduction of methane emissions through C degradation during hot fermentation.

*Nitrogen oxides and carbon monoxide ($NO_x$ and CO)*

Aside from biomass burning and tropical deforestation little remains to be said about strategies for the abatement of other indirectly active trace gases such as nitrogen oxides and carbon monoxide. As there are no specific data on agriculture's share in anthropogenic $NO_x$ emissions, it is of course impossible to say anything about abatement measures in this area. There is a relationship between CO and methane emissions because CO constitutes an intermediate product in atmospheric methane degradation. Release of CO will decrease in proportion to the abatement of agricultural methane emissions.

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*Author's address:* Dr. rer. nat. H.-J. Ahlgrimm, Bundesforschungsanstalt für Landwirtschaft, Institut für Technologie, Bundesallee 50, D-38116 Braunschweig.

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# SOLAR TUNNEL DRYER FOR FRUITS

*by*

ALBERT ESPER and WERNER MÜHLBAUER

*Institute for Agricultural Engineering in the Tropics and Subtropics, University of Hohenheim*

Inadequate conservation and storage facilities and lacking marketing structures lead to the spoilage of large quantities of agricultural produce in many tropical and subtropical countries. Drying of agricultural products, still the most widespread preservation technique, is becoming more and more an alternative to marketing fresh fruits, since the demand for high quality dried products is permanently increasing all over the world.

The solar tunnel dryer developed at the Institute for Agricultural Engineering in the Tropics and Subtropics of Hohenheim University proved to be successful in drying fruit, vegetables and other agricultural produce in about 30 countries with arid and humid climates. In 1995 these solar tunnel dryers were used for producing more than 100 tonnes of dried products of premium quality. The experiences showed that in comparison to traditional sun drying, the use of a solar tunnel dryer led to a considerable reduction of the drying time and to a significant improvement of the product quality in terms of colour, texture and taste. Furthermore the contamination by insects, microorganisms and mycotoxins can be prevented. Since the dried products meet all international quality standards they can be marketed at high prices both on domestic and international markets. The storage losses could be reduced to a minimum while the shelf life of the products could be increased significantly. Due to the extremely low power requirement of the fans, the dryer can be operated with a PV-drive. This facilitates use in areas far away from mains electricity.

Within a comparative test of solar dryers conducted in 1995 at the Plataforma Solar de Almeria, Spain, the solar tunnel dryer showed the best performance. It is recommended for professional use where fast drying and marketable quality is required. An economic analysis showed its economic viability. The payback period amounts to between one and five years depending on product, location and rate of utilization. Local production of the solar tunnel dryer is already established in Morocco, Sri Lanka, Thailand and Turkey.

Inadequate conservation and storage facilities and lack of marketing structures lead to the spoilage of large quantities of agricultural produce in many tropical and subtropical countries. According to investigations of the FAO [1] between 10 and 30% of the basic food supply such as cereals, legumes, oil seeds and tubers and 50 up to 70% of the fruits are lost after harvest before reaching the consumers.

In tropical regions a high percentage of the fruit produced by smallholders either for home consumption or for sale on the local market contribute to some extent a considerable supply of micro nutrients for the rural population. However, in case of seasonal overproduction, tremendous losses occur because the farmers have neither the access to the markets in big cities nor to the international market due to low quantities, poor product quality and the absence of sufficient marketing and distribution structures.

As an alternative to the marketing of fresh fruit, smallholders are also producing dried products. Drying of agricultural produce still remains the most widespread preservation technique in the world since it is the easiest and most cost effective method to implement. In spite of the abundance of fresh fruits throughout the year, dried fruits are popular as a snack item both for rural and urban populations. In industrialized countries, besides the traditional dried fruits such as apple, raisins, apricots and figs the demand for dried tropical fruits such as mango, banana, papaya and pineapple has increased due to their exotic aroma and appearance for use as basic ingredients in breakfast food products or as snacks. The same trend is observed in developing countries for nutrition reasons.

Consumer demand for dried products is rather high during the off-season. In terms of the international market, the product quality does not meet, in most cases, the requirements of the foreign consumers in terms of colour, texture, taste and contamination by insects or microorganisms. These consumers are expecting a hygienic product which should be produced without any chemical preservatives. This aspect needs special attention in order to boost dried fruit production.

The most commonly used way of drying agricultural produce in tropical and subtropical countries is sundrying. Crops are spread in thin layers on mats, trays or paved grounds and exposed to sun and wind. Turning the crop at short intervals promotes uniform drying. Collecting the crop during the night and rainy days and storing it under shelter prevents remoistening, but requires high labour input. Since the drying process is relatively slow, considerable losses can occur. In addition, a reduction in the product quality takes place due to insect infestation, enzymatic reactions, microorganism growth, and mycotoxin development. Non-uniform and insufficient drying, which happens normally when the crops are dried during the rainy season, also leads to deterioration of the crop during storage [2]. Even though production costs are very low, in many cases the products cannot generally fetch costcovering prices on the world market.

In order to ensure the micro nutrient supply of the growing population and to enable the farmers to produce high quality marketable products, the development of efficient drying methods is of urgent necessity. Studies have shown that even small and very simple oil-fired batch dryers are not applicable due to the lack of capital and insufficient supply of energy for operating the dryers. The high temperature dryers used in industrialized countries are found to be economically viable in developing countries only if they are used in large plantations and big commercial establishments [3]. To overcome the existing preservation problems, the introduction of solar dryers seems to be a promising alternative [3].

Numerous solar drying technologies were developed by research institutions in the past, but only a few manufacturers were involved in production and marketing. As a result of these efforts several types of solar dryers exist ranging from small dryers for family use up to large units for industrial applications [3], but most of them do not suit commercial use so as to justify users' requirements.

Considering that a high percentage of farms in tropical and subtropical regions are not connected to mains electricity, the dryers are designed to utilize only wind and sun as energy sources. Covering the crop, spread out on the ground in a thin layer, with a transparent foil is an example of the most simple solar dryer. This method is used mainly for drying grapes, coffee and cocoa [4]. For on-farm drying of small quantities of fruit and vegetables, box and tent dryers were developed which can be constructed by the farmers themselves using locally available materials. The transparent cover reduces heat losses and at the same time offers a certain protection of the product from dust and rain. Air ventilation required for removing the evaporated water is provided by ascending air forces due to natural convection. However, investigations have shown that neither insect infestations nor crop deterioration during extended periods of adverse weather conditions can be totally avoided. Due to the low capacity of box and tent dryers, their use is limited to subsistence farmers [4]. Since application of such dryers has no considerable contribution to the income of the farm households, smallholders are reluctant to invest in them.

The drying capacity of these natural convection dryers can be increased by connecting a solar air heater to the drying chamber. Instead of using only the crop as absorber, solar radiation is further converted into thermal energy in the solar air heater. In these cabinet dryers, the inclined collector has to be mounted facing south and is tilted at an optimum angle depending on the region and the particular season. The drying air is heated up in the solar air heater and enters at the base of the drying chamber. It then moves upward and passes across the crop which is spread in thin layers on vertically stacked trays. Air circulation is effected by ascending air forces due to natural convection. The air flow rate can be increased either by wind coming from the south or by a chimney [3].

Due to the high air resistance encountered when forcing the air through the crop, only a small number of trays can be staked without significantly affecting the air movement. Furthermore, investigations have shown that during night and cloudy weather, the air circulation breaks down completely. This causes spoilage of the crop due to enzymatic reactions and the growth of microorganisms. The comparatively high investment, limited capacity, and the risk of crop spoilage during adverse weather conditions have, up to now, prevented the wide acceptance of these dryers [3].

The high weather-dependent risk of using natural convection type solar dryers stimulated the development of a solar tunnel dryer with incorporated fans which provide sufficient air flow to remove the evaporated moisture.

In the following the design of the solar tunnel dryer is described and the results of scientific investigations and of field tests conducted with different crops in arid as well as in humid regions are reported.

### *Solar tunnel dryer*

The solar tunnel dryer developed at the Institute for Agricultural Engineering in the Tropics and Subtropics of Hohenheim University consists basically of a plastic foil-covered flat plate solar air heater, a drying tunnel and small axial flow fans [5] (Fig. 1). To simplify the construction and to reduce the production costs, the solar air heater is connected directly to the drying tunnel without additional air ducts. Both the collector and the drying tunnel are installed on concrete block substructures to ease loading and unloading of the dryer. All parts of the dryer, including back insulators and metal frames, are designed using modular concepts which facilitate the transport and installation.

The floor of the solar tunnel dryer consists of plastic foam sandwiched between two metal sheets with a groove and tongue system. For dryers locally produced in tropical and subtropical countries, concrete or waterproofed plywood boards provided with heat and water resistant insulation material can be alternatively used as substructure and backside insulation. The insulator sheets are connected by a corrugated metal frame which also enables easy fixing and replacement of the transparent plastic cover foil by using reinforced plastic clamps (Fig. 2).

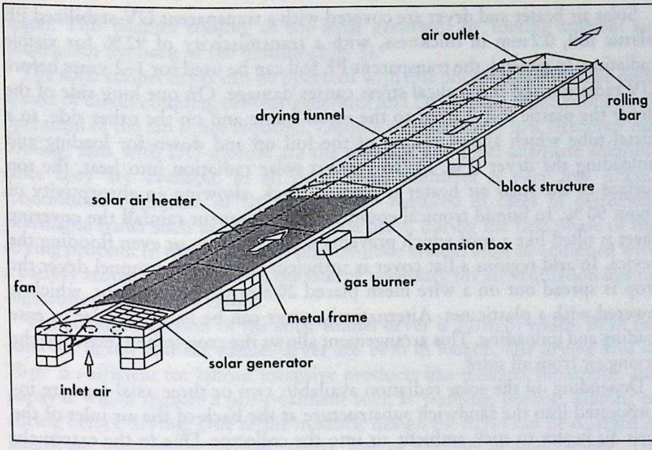


Fig. 1 – *Solar tunnel dryer for agricultural products [5].*

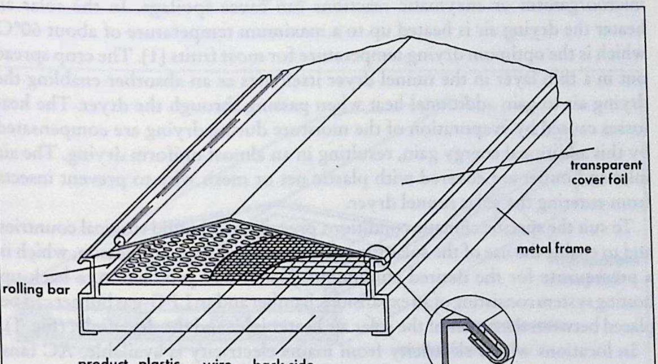


Fig. 2 – *Drying tunnel with rolling bar [6].*

Solar air heater and dryer are covered with a transparent UV-stabilized PE plastic foil, 0.2 mm in thickness, with a transmissivity of 92 % for visible radiation. In general, the transparent PE foil can be used for 1–2 years before UV radiation and mechanical stress causes damage. On one long side of the dryer the plastic foil is fixed to the metal frame and on the other side, to a metal tube which allows rolling of the foil up and down for loading and unloading the dryer (Fig. 2). To convert solar radiation into heat, the top surface of the solar air heater is painted black, showing an absorptivity of about 90 %. In humid tropical countries with frequent rainfall the covering sheet is tilted like a roof which prevents water entering or even flooding the device. In arid regions a flat cover is sufficient. In the solar tunnel dryer the crop is spread out on a wire mesh placed 20 mm above the floor, which is covered with a plastic net. Alternatively, trays can be used in order to ease loading and unloading. This arrangement allows the crop to be exposed to the drying air from all sides.

Depending on the solar radiation available, two or three axial fans are incorporated into the sandwich substructure at the back of the air inlet of the solar air heater to suck ambient air into the collector. Due to the extremely low pressure drop of 20 Pa, a maximum 20 to 30 Watts of electrical energy are required to force 800 to 1000 $m^3/h$ of air between floor and cover foil, which is sufficient to ensure drying to safe storage conditions before growth of microorganism or enzymatic reactions can cause spoilage. In the solar air heater the drying air is heated up to a maximum temperature of about 60°C, which is the optimum drying temperature for most fruits [1]. The crop spread out in a thin layer in the tunnel dryer itself acts as an absorber enabling the drying air to gain additional heat when passing through the dryer. The heat losses caused by evaporation of the moisture during drying are compensated by this additional energy gain, resulting in an almost uniform drying. The air inlet and outlet are covered with plastic net or mesh wire to prevent insects from entering the solar tunnel dryer.

To suit the specific climatic conditions prevailing in humid tropical countries and to enable the use of the solar tunnel dryer during the rainy season, which is a prerequisite for the desired continuous year-round production, a back-up heating system consisting of an expansion chamber and an LPG-gas burner can be placed between the outlet of the solar air heater inlet and the dryer inlet (Fig. 1).

In locations where electricity from mains electricity is available, AC fans can be used for air ventilation of the dryer, providing a constant air flow. Due to the extremely low power requirement for driving the fans photovoltaics can be economically used for providing the required electrical energy in remote areas far away from the mains electricity or in areas without reliable energy supply. The solar generator is installed at the inlet of the solar air heater. This enables cooling of the solar generator by forcing ambient air underneath the back of the module (Fig. 3).

The solar tunnel dryer can be operated with one photovoltaic module only in case of direct coupling of solar generator and DC-motor, when continuous operation of the fan is not required. Despite comparatively low efficiency car cooling, fans with DC-motors are the cheapest and most adequate solution since they are available in all developing countries at very low prices. Continuous operation of the fan is only required in cases of extremely perishable fruits such as grapes or cocoa beans during the first phase of the drying process. In those cases the photovoltaic system must be equipped with a battery storage for providing the energy necessary for air ventilation during nighttime or adverse weather.

The standard version of the solar tunnel dryer is 2.0 m in width. Both the solar air heater and the tunnel dryer are 10 m in length. The drying area of 20 m² is sufficient for labour intensive products like mangos, pineapples and papayas which require a pre-treatment such as washing, peeling, dipping or slicing before drying. Due to the modular design the dryer can be enlarged in length up to 20 m for drying raisins, figs or apricots in arid regions. The capacity of the dryer is mainly influenced by the size, shape and moisture content of the fruit to be dried. The loading capacity ranges from 100 kg for medicinal plants to 300 kg for figs, apricots or coffee.

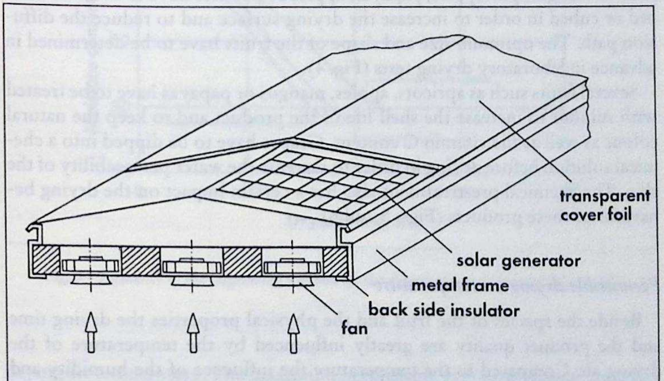


Fig. 3 – *Solar air heater with axial flow fans and integrated solar generator [5].*

## *Results*

The solar tunnel dryer was successfully tested under field conditions in about 30 countries with different climatic conditions, drying numerous agricultural commodities ranging from fruits, vegetables, root crops, cereals, oil crops, medicinal plants to fish and even meat. In Morocco and Thailand systematic scientific investigations of the drying behaviour of apricots and bananas were conducted under arid and humid conditions. In the following the most important results are briefly summarized.

### *Harvesting and pre-treatment*

The drying tests with the solar tunnel dryer have shown that the quality of dried fruits is greatly influenced by the method of harvesting, the maturity of the crop and the pre-treatment used. In general, selective picking of fully mature fruits, the optimum procedure, is a prerequisite to reach the desired quality. Shaking the trees or the use of mechanical harvesting devices in many cases leads to damage of the skin which causes undesired enzymatic reactions and growth of microorganism, both having negative effects on the quality characteristics of the product.

Before drying, all fruits have to be washed in clean water and damaged or spoiled fruits have to be selected. Small fruits like grapes, strawberries or sweet varieties of apricots can be dried without prior cutting, larger fruits such as mangos, pineapples, papayas, apples or peaches have to be peeled, sliced or cubed in order to increase the drying surface and to reduce the diffusion path. The optimum size and shape of the fruits have to be determined in advance in laboratory drying tests (Fig. 4).

Several fruits such as apricots, apples, mangos or papayas have to be treated with sulphur to increase the shelf life of the product and to keep the natural colour as well as the vitamin C content. Grapes have to be dipped into a chemical solution before drying in order to increase the water permeability of the skin. The chemical pre-treatment also has a certain impact on the drying behaviour of these products (Figs. 5 and 6).

### *Permissible drying air temperature*

Beside the species of the fruit and the physical properties the drying time and the product quality are greatly influenced by the temperature of the drying air. Compared to the temperature the influence of the humidity and velocity of the drying air is of minor importance. To make optimum use of the solar tunnel dryer the dryer has to be operated at the maximum permissible

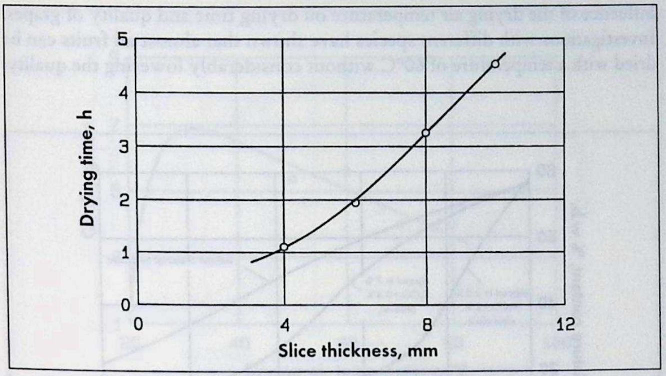


Fig. 4 – *Influence of the thickness of sliced apple rings on the drying time [10].*

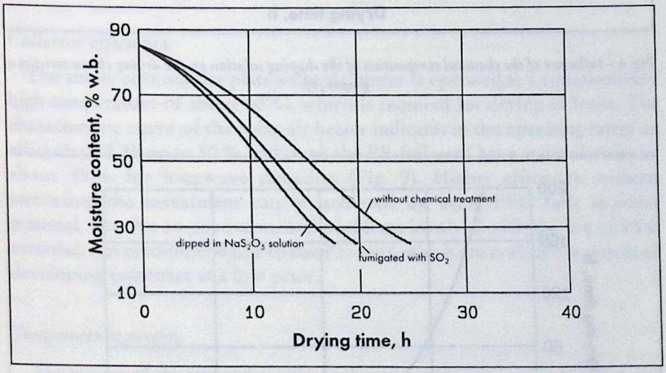


Fig. 5 – *Influence of the sulphuring method on the drying characteristics of apricots [9].*

drying air temperature. The maximum permissible drying air temperature has to be determined in laboratory drying tests followed by an analysis of the quality characteristics of the product. Figs. 7 and 8 show exemplarily the influence of the drying air temperature on drying time and quality of grapes. Investigations with different species have shown that almost all fruits can be dried with a temperature of 60°C without considerably lowering the quality.

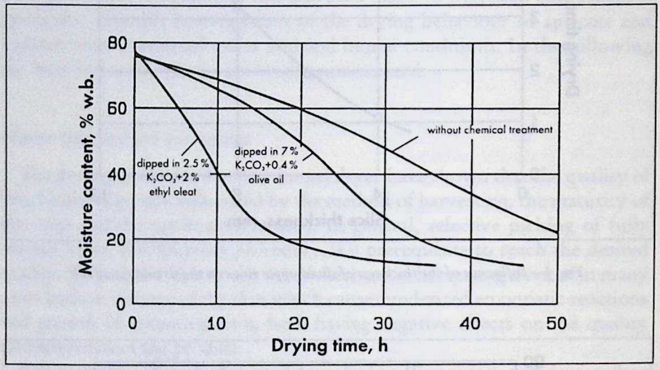


Fig. 6 – *Influence of the chemical composition of the dipping solution on the drying characteristics of grapes [4].*

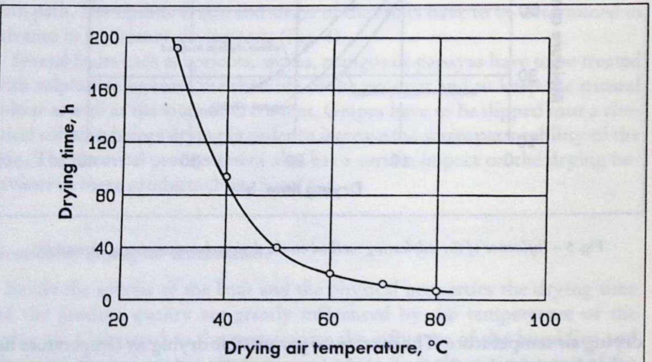


Fig. 7 – *Influence of the drying air temperature on the drying time of grapes [4].*

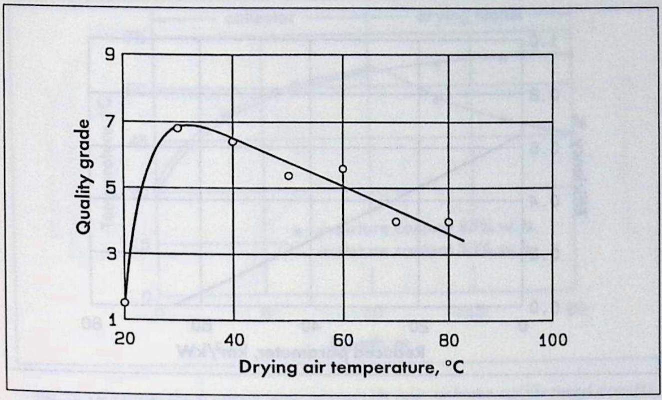


Fig. 8 – *Influence of the drying air temperature on the quality characteristics of raisins [4].*

*Collector efficiency*

The single covered flat plate solar air heater is operated at a comparatively high temperature of about 60°C, which is required for drying of fruits. The characteristic curve of the solar air heater indicates in the operating range an efficiency of 35 up to 50 %, although the PE-foil used has a transmissivity of about 45 % for longwave radiation (Fig. 9). Higher efficiency without increasing the investment can be achieved by using PVC foils as cover material, but due to environmental problems involved with the use of PVC material, it is recommendable to use PE-foils, which are available in almost all developing countries at a low price.

*Temperature profile*

The course of the air temperature in the solar air heater is mainly influenced by the collector design, the materials used as cover and absorber, the solar radiation and the air flow rate. Investigations have shown that the maximum permissible drying temperature for fruits is about 60°C. Higher temperatures lead to browning reaction and case hardening, which greatly effects the product quality. The choosen maximum air flow rate guarantees that the permissible temperature will be not exceeded even at maximum solar irradiation.

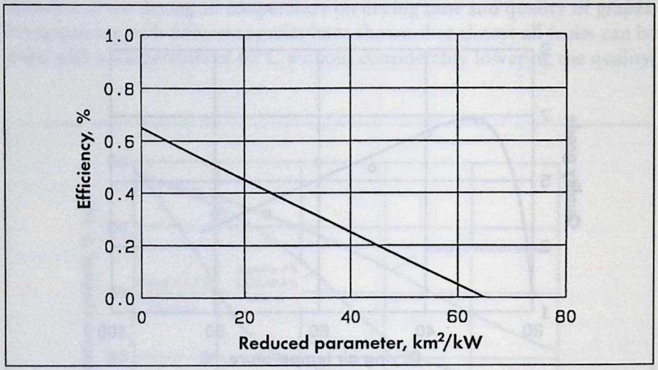


Fig. 9 – *Efficiency curve of the single covered flat plate solar air heater [9].*

Along the length of the solar air heater the slope of the temperature increase shows a parabolic shape with a temperature maximum at the collector outlet (Fig. 10).

At the beginning of the drying process, when a high amount of water is evaporated, the temperature of the drying air in the tunnel dryer is decreasing. In the second phase of the drying process the additional heat gained at the surface of the crop by absorption of solar radiation is sufficient to keep the drying air temperature almost constant over the length of the tunnel.

Using a grid-connected AC-motor which provides a constant air flow results in a temperature profile at the outlet of the solar air heater which is similar to the course of the global solar radiation since its heat storage capacity is almost neglectible (Fig. 11).

This means that in the morning and late afternoon the drying air temperature ranges near ambient temperature, which is not sufficient to accelerate the drying process. At noon at high solar radiation the drying air temperature exceeds the permissible temperature. The requirement of an almost constant drying air temperature can be much better matched by a PV operated fan (Fig. 12).

The temperature of the drying air is automatically controlled by the irradiation when using a PV-drive. During periods of low radiation the air flow rate results in a comparatively high temperature rise. High radiation causes a high air flow rate, which results in a relatively low temperature increase.

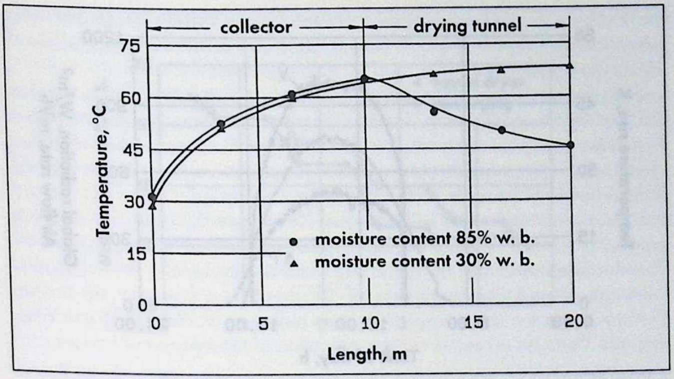


Fig. 10 – *Course of the drying air temperature in the solar air heater and the tunnel dryer [9].*

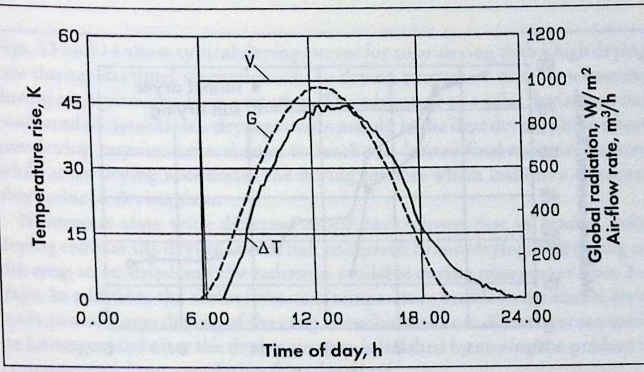


Fig. 11 – *Course of temperature rise and air flow rate in a solar tunnel dryer, equipped with an AC-fan [9].*

*Drying time*

Heating the drying air in the solar air heater results in a significantly higher product temperature compared to sun-drying, which causes a considerably higher drying rate. Fig. 13 shows exemplarily the drying course of apricots

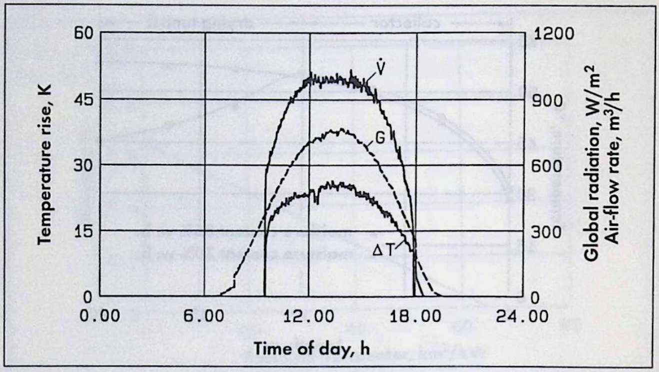


Fig. 12 – *Course of temperature rise and air flow rate in a solar tunnel dryer, equipped with a direct coupled photovoltaic driven DC-fan [5].*

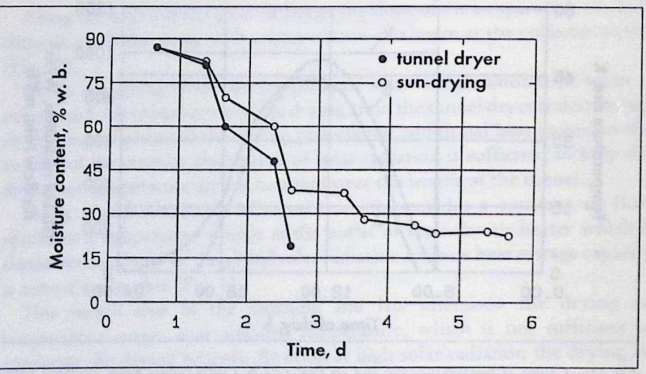


Fig. 13 – *Drying curves of apricots dried in the solar tunnel dryer compared to sun-drying [11].*

dried in Morocco under arid conditions, and Fig. 14 indicates the drying characteristics of bananas dried in a humid tropical environment in Thailand using the solar tunnel dryer. Simultaneously additional samples were sundried.

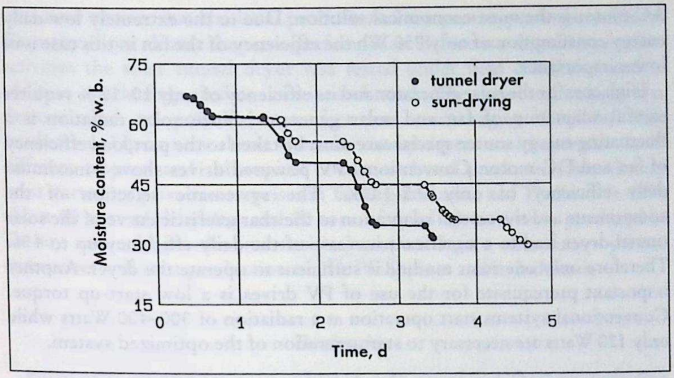


Fig. 14 – *Drying curves of bananas dried in the solar tunnel dryer compared to sun-drying (6).*

Figs. 13 and 14 show typical drying curves for solar drying with a high drying rate during daytime, stagnation of the drying process or even remoistening during nighttime or adverse weather. The advantage of a solar drying process compared to natural sun-drying occurs mainly in the final drying phase where sun-drying requires several days to reach the desired final moisture content while solar drying accelerates the drying process which leads to a considerably reduced drying time.

Numerous tests with different crops have shown that in general, solar drying reduces the drying to one half compared to sun-drying. Depending on the crop to be dried and the radiation available drying time ranges from 2–5 days. In addition, the almost constant temperature profile in the tunnel dryer leads to a uniform drying of the crop. Possible moisture differences can easily be homogenized after the drying process is finished by storing the product in containers without ventilation for a few days.

*Energy requirement*

By a systematic optimization of the motor and blades of the fan as well as a reduction of the air flow resistance inside the dryer the electrical power requirement could be reduced from originally 250 to 20 Watts. The extremely low power requirement enables an economical use of photovoltaics for driving the motor. If electricity from the mains is available the use of an

AC-motor is the most economical solution. Due to the extremely low daily energy consumption of only 250 Wh the efficiency of the fan in this case is of lower importance.

High cost for the solar generator and its efficiency of only 10–12 % requires careful adaptation of fan and solar generator. Since solar radiation is a fluctuating energy source special care must be taken to the part load efficiency of fan and DC-motor. Conventional PV powered drives show a maximum daily efficiency of only 0.5–1.0 %. The systematic selection of the components and the careful adaptation to the characteristic curve of the solar tunnel dryer lead to a significant increase of the daily efficiency up to 4 %. Therefore only one solar module is sufficient to operate the dryer. Another important prerequisite for the use of PV drives is a low start-up torque. Conventional systems start operation at a radiation of 300–400 Watts while only 120 Watts are necessary to start operation of the optimized system.

### *Dissemination*

The reduction of the post-harvest losses and the improvement of the product quality is one of the great challenges in the future. Both can have a significant contribution to improving the food supply of the population on the one hand; on the other hand the production of high quality products which can be sold on international markets can have a significant impact on the smallholders' income in tropical and subtropical countries. The tests with various commodities in several countries have shown that the newly developed solar tunnel dryer is technically and in most cases economically feasible and the technology is ready for dissemination. However, experience obtained from numerous R&D projects showed that the introduction of technologies developed in industrialized countries in most cases failed because the prevailing local conditions and users' needs were not properly considered. Especially for the dissemination of technologies using renewable energies the existing marketing structures are not sufficient since neither the potential users of the technology nor the manufacturers have sufficient information about these new technologies [12, 13]. To overcome this situation a new approach for the introduction of the solar tunnel dryer was developed. After the technology was tested, a small enterprise in Germany picked up the idea and started the production of prototypes. These prototypes were installed in several countries and tests were conducted in close cooperation with local scientists. Based on the outcome of the preliminary tests the solar tunnel dryers were modified, if necessary, and adapted to the local conditions. Afterwards the local counterparts were encouraged to construct the solar tunnel dryers mainly using local materials and components. Comparative tests have shown that the local produce and the prototypes imported from Germany show almost the same performance. Before starting dissemination activities the solar tunnel dryer was tested under field conditions and in addition marketing studies were conducted. The new technology was demonstrated to potential manufacturers, encouraging them to start production. Up to now about 150 solar tunnel dryers are in operation in 28 different tropical and subtropical countries. Local production has already been started by private enterprises in Turkey, Sri Lanka and Thailand. In 1996 about 80 tons of dried figs and 20 tons of dried apricots were produced in Turkey and sold on the international market. In the near future private enterprises will start production on the Philippines and in Indonesia.

### *Evaluation*

Based on the investigations conducted in Morocco and Thailand, including the experience gained in the field tests, the solar tunnel dryer can be rated as follows:

- The solar tunnel dryer can be used in arid, semi-humid and humid regions. In locations where rainfall is expected during the drying period the cover foil has to be tilted. For continuous operation during the rainy season a supplementary heater should be integrated.
- Almost all agricultural products can be dried in the solar tunnel dryer, apart from crops which are sensitive to solar radiation. The multi-purpose utilization improves the working capacity and leads, compared to high temperature dryers, to low drying costs.
- In comparison to traditional sun drying the drying time can be reduced by about 50 %. Even products with low equilibrium moisture content like cocoa, copra or peanuts can be dried to safe storage conditions.
- During the drying process the product is completly protected from rain, dust, insects, birds and rodents. The losses during drying are less than 1 % and are on the same level as in sophisticated high temperature belt dryers.
- The quality of the dried products meets the international quality standards. Microorganism growth and foundation of mycotoxins can be prevented.
- The extremely low power requirement allows the use of photovoltaics for driving the fan. This enables application in remote areas where electricity from the mains is not available or not reliable.
- Due to the modular system the solar tunnel dryer can be easily adapted to the users' needs.
- The solar tunnel dryer can be produced in tropical and subtropical countries using locally available materials and components.

- The production costs range from 8000.– DM for prototypes produced in Germany to 2500.– DM when produced in series in Turkey and Sri Lanka using locally available materials and cheap labour forces.
- An economic analysis showed the viability of the system. The payback period ranges from 1 to 5 years depending on the rate of utilization, weather conditions and the price difference between high and low quality products.

## *Conclusions*

The solar tunnel dryer is particularily apt for proper and safe drying of agricultural produce cultivated in tropical and subtropical countries such as fruit, vegetables, medicinal plants, coffee or cocoa. In comparison to natural sun-drying the use of the solar tunnel dryer leads to a considerable reduction of the drying time and a significant improvement of the product quality in terms of colour, texture and taste.

The solar tunnel dryer can be easily adapted to the requirements of the users and the prevailing local climatical conditions regarding energy supply, product to be dried and capacity. In remote areas the solar tunnel dryer can be operated with one solar module only, independent of the mains electricity, due to the low air resistance. To enable a year-round production of high quality dried fruit under humid tropical condition a supplementary heater should be integrated.

Up to now in about 30 countries around 150 solar tunnel dryers are in operation for commercial production of dried products. In 1995 these dryers were used for producing more than 100 tonnes of dried products of premium quality. More dried fruits have been produced in Turkey using the solar tunnel dryer than in all other solar dryers together running in member countries of the European Union [8]. At the end of 1996 it is expected that at least 200 solar tunnel dryers will be operated by farmers or small-scale industry. Furthermore the solar tunnel dryer showed the best performance in a comparative test of solar dryers conducted in 1995 at the Plataforma Solar de Almeria, Spain [7].

The solar tunnel dryer has already attained economic viability. It shows a payback period between 1 and 5 years depending on the product, location and rate of utilization. Local production of the solar tunnel dryer is already established in Morocco, Sri Lanka, Thailand and Turkey. The dryers can be produced locally at a price between 2500 and 3000 DM in Sri Lanka, Turkey and Morocco and for about 4500 DM in Thailand including the supplementary heater.

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*Authors' address:* Prof. Dr. W. Mühlbauer, Institut für Agrartechnik in den Tropen und Subtropen, Universität Hohenheim, Garbenstraße 9, D-70593 Stuttgart.

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# TOLERANCE RESPONSES OF PLANTS TO STRESS – THE UNUSED RESERVE IN PLANT PROTECTION?

*by*

PETRA SEIDEL

*Federal Biological Research Centre for Agriculture and Forestry, Institute for Integrated Pest Management, Kleinmachnow*

Knowledge about tolerance responses of plants, the physiological causes of tolerance and the degree of tolerance of varieties and cultivars is insufficient. Changes in ecological and economic conditions for agricultural production require a reduction in pesticide-usage and the more intensive use of natural mechanisms of plants to reduce losses. Tolerance of plants is one possibility to meet this demand. The relationship between stress responses, tolerance, yield and physiological productivity of plants is explained. Possibilities to use the capability of plants for tolerance are demonstrated and the source of innovation involved in plant tolerance research from a practical viewpoint is discussed.

For a number of years, agricultural production, and in particular chemical protection of agricultural crops, have been under criticism from the public. This situation has been created by overproduction, due to intensification of cropping procedures, and also by increased environmental awareness combined with a certain amount of fear about the future; and all this is having an increasing effect in shaping agricultural policies. These emotionally understandable reactions do not do justice to the importance of agriculture and of plant protection in supplying the population and the economy with high-quality products, in securing the natural basis for life, and in caring for our cultural landscape. When viewed in such a one-sided manner, the important role of agriculture in determining the development of mankind is totally ignored. Nevertheless, there is a positive side to this crisis of acceptance. It demonstrates clearly the need to recognize hitherto ignored aspects of the problem and to use them to help create more environmentally compatible production methods – this is an interesting challenge for agricultural research to deal with. In this context, the procedures of integrated pest management which have long been known, are gaining in importance. However, this means more than just making sensible use of traditional agricultural experience and cultivation techniques, including biological methods; it also involves deliberately promoting the use of natural regulatory mechanisms. In order to exploit such mechanisms to the full, it is first necessary to know what causes them, how they function, and under what conditions they are effective. These studies should not be restricted just to the pest organisms (insects, fungi, viruses, bacteria) and the beneficial organisms, but must also include the plants themselves. In the past, this aspect has not been sufficiently considered; take, for example, the ability of the plant to balance out the effects of abiotic or biotic stress factors, i.e. to tolerate them. This is where untapped reserves can be found. The goal of modern plant protection is to preserve the productivity of the plant, and it is less concerned with eliminating pest organisms. Before this goal can be achieved, we have to know the mechanisms which are activated to preserve the productivity of the plant while under stress.

## *General principles and relationships*

### *The concept of stress*

The word "stress", which is so commonly used in everyday language, often refers not only to external stress, in the meaning of a harmful stimulus, but also to the internal response to the stimulus (Schlee, 1992); both these meanings may therefore be used as general definitions of the term "stress". Strictly speaking, according to Levitt (1980), a distinction should be made between the external stress, seen as a "stressor" or "stress factor", and the internal consequence of the stress ("strain"). When it is infested with pests, this also creates a stress for a plant. Studies on the reaction of plants to stress usually concentrate on identifying the action of abiotic stressors. A host-parasite relationship, which is an interaction and fluid equilibrium between two living organisms, is a specific type of relational structure. Nevertheless, the reactions are fundamentally the same as those following the action of abiotic stressors. These are described under the heading "general adaptation syndrome". The following reactions take place within the framework of this syndrome (Larcher, 1994; Schlee, 1992): The stressor triggers a state of alarm in the organism, and this initially leads to a reduction in vitality (phase I).

After a short restitution phase, there then follows a phase of resistance (phase II) which comprises not only resistance reactions but also tolerance reactions, including increased productivity on the part of the plant, with the aim of adapting to the stressor. Only if adaptation fails does the plant enter the exhaustion phase (phase III), which is associated with irreversible damage.

*Tolerance and resistance – two different components*

The vitality and survival capability of plants under stress can be influenced in two different ways (Fig. 1). On the one hand, the plant can ward off the pest and/or reduce the intensity of the infestation. This is what would happen in a resistant plant once resistance had been induced or after the application of pesticides. On the other hand, the vitality can also be increased by reducing the loss caused by the disease. In this case, one would talk of a tolerance reaction or of induced tolerance.

The definitions of resistance and tolerance are helpful in differentiating between resistance and tolerance reactions.

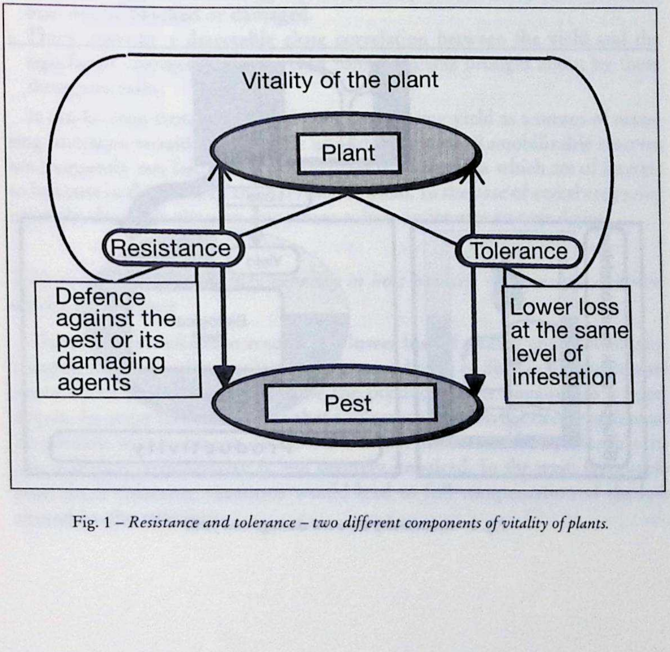


Fig. 1 – *Resistance and tolerance – two different components of vitality of plants.*

Resistance is the basic ability of an organism to defend itself up to a certain point against the attack of a potential damage factor or to withstand the action of a harmful agent (Aust et al., 1993).

Tolerance is the ability of a plant to survive infestation by a pest, or the action of abiotic stress factors, with less loss of vitality and productivity than would be suffered by sensitive plants exposed to the same degree of stress (Aust et al., 1993).

Resistance is thus directed against the pest organism or the substances which it emits, and it is expressed, for example, in a reduction in the degree of infestation. Tolerance, on the other hand, denotes a lower level of loss or less impairment of the productivity of the plant, compared to intolerant plants at the same degree of disease. In order to measure tolerance, it is necessary to evaluate loss and physiological productivity while excluding the influence of the degree of disease.

The loss caused by a disease is, by definition, any reduction in quantity or quality of the yield (Fig. 2). However, the yield is an economic parameter which reflects only part of the biological yield produced by the plant (total substance). The size of the yield is determined in the course of the yield formation process, which in turn is characterized by the physiological

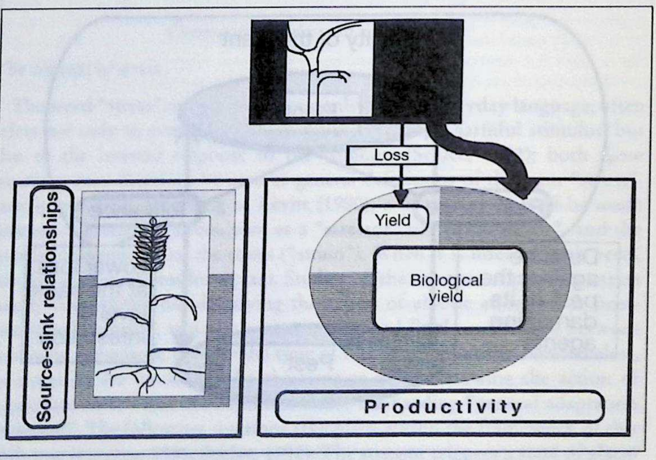


Fig. 2 – *Relationship between damage and yield.*

productivity of the plant. Close correlations between certain significantly modified physiological parameters and the yield prove that changes in the physiological productivity have an effect on yield (Seidel, unpublished). What are the special characteristics of a tolerant plant?

*Evaluation criteria for detecting tolerance reactions affecting yield*

The following criteria are used to assess tolerance reactions:

- In tolerant plants, the source or sink functions of individual organs which have been knocked out of action by external influences can be quickly taken over by other organs, without any loss of productivity. This also means that the potential source and sink capacity of these plants is not attained under stressor-free circumstances; however, under the influence of stressors, the necessary room for expansion is quickly made available. (The components of source and sink relationships are as follows: 1. Source = the sites where the substances are produced. 2. Sink = the sites where the substances are consumed. 3. The flow of matter between source and sink.)
- Tolerant plants may build up reserves.
- Tolerant plants may mobilize reserves quickly under the effect of stressors. Sufficient reserves of energy must be available. The transportation routes may not be blocked or damaged.
- There must be a detectable close correlation between the yield and the significant changes in the parts of tolerant plants brought about by these three processes.

It can be seen from this that simply considering yield as a means of assessing tolerance would ignore some important criteria. Remobilizable reserves are frequently not laid down by the plant in those parts which are of interest to humans in the form of the harvestable yield. In the case of cereal crops, for example, the stalk plays an important role as an interim storage depot.

*Tolerance and compensatory capacity in host-parasite relationships and new aspects of tolerance*

Tolerance by definition results in a lower loss of vitality and productivity compared with intolerant plants at the same degree of disease. Tolerance thus exists when the loss is reduced or the productivity is impaired to a lesser degree. In order to demonstrate that a tolerance reaction has occurred, it must be possible in each case to detect that the loss has been minimized or that the physiological productivity is less severely impaired. In the most favourable case, these tolerance reactions would lead to full compensation of the loss caused by the stressors.

It has been demonstrated that tolerance reactions occur in various host-parasite relationships (Seidel, 1996a). However, reducing loss to the point of achieving compensation of the loss is only one aspect of tolerance.

In studies carried out on compatible host-parasite systems, it had been shown that the plants not only compensate for the effects caused by pest organisms, but also their productivity is stimulated beyond the level of performance achieved by healthy plants (Seidel, 1992; Seidel, 1995b; Seidel, 1996a and b). Short-term increases in performance by infested plants beyond the level achieved by healthy control plants are often described. In most cases, an increase in photosynthesis, transpiration and its effectiveness in terms of WUE (water use efficiency) is reported (Seidel, 1995b). These parameters are therefore frequently used as indicators of tolerance, because they react quickly and in a measurable way to stressors (Kral, 1993). But, the interpretation of these measurements is by no means unambiguous. More decisive than the net rate of photosynthesis is the effectiveness of photosynthesis, which is expressed as its relationship to respiration. When photosynthesis is elevated for a short period of time, this usually goes together with increased respiration, so that no effective increase in efficiency occurs. Therefore, other parameters have to be measured. For example, in order to determine tolerance reactions, it is important to show whether reserves laid down before the onset of the stress are used to guarantee higher and lasting productivity by the plants during the period of stress (Kral, 1993). This can be done by studying the anabolic processes (Kral, 1993). However, tolerance is more than just the ability to use stored reserves; it also involves the ability to store the reserves in the first place. This means studying source-sink relationships (Seidel and Détrie, 1996), e.g. in tracer experiments using radioactive isotopes. In this way, the stimulation of physiological processes was detected in earlier studies on the host-parasite system "barley-*Drechslera teres* (net blotch)" (Seidel, 1992). For several weeks, the nitrogen uptake ($^{15}N$) was significantly higher than that of healthy (non-inoculated) plants (Fig. 3). Obviously, during this time more than just a simple compensation had taken place, e.g. of the type frequently described for cereal plants infested with mildew (an obligate parasite). When a plant is infested with mildew, non-infested organs temporarily compensate for the drop in productivity of the affected parts of the plant by boosting their own productivity. In the case of the host-parasite system "barley-*Drechslera teres*", it was shown for the first time that the infested organ is an additional sink for N-compounds. Large amounts of the $^{15}N$ supplied for application as an ammonium nitrate fertilizer were transported into the infested organs. The plant reacted to the increased demand for nitrogen resulting from the formation of another sink (affected plant part), in addition to the usual main sink (ears/kernels), by increasing its

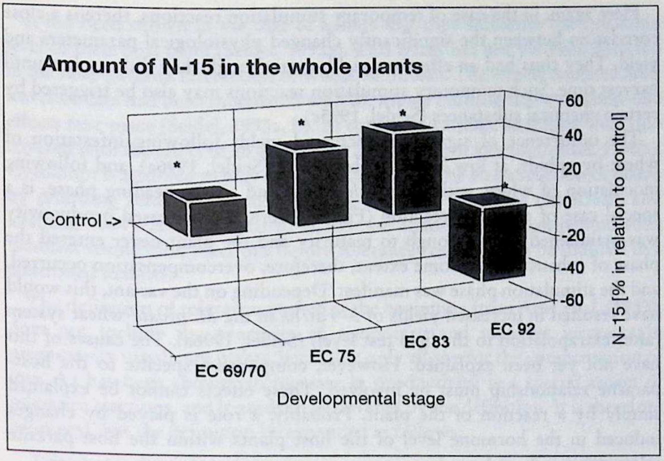


Fig. 3 – *Influence of inoculation of barley with net blotch disease Drechslera teres (Sacc.) on nitrogen uptake (*significant effects compared with healthy control, p ≦ 0.05).*

nitrogen uptake (Fig. 3). The nitrogen was not only taken up in increased amounts, but it was also transported in increased amounts into the above-mentioned sinks (Seidel, 1992). Thus, not only the individual organs but the entire plant, the whole organism, was temporarily raised to a higher level of productivity, as is shown clearly by the amounts of $^{15}N$ contained in the whole plant (Fig. 3). Thus, the organism "infested barley plant" had obviously entered the adaptation phase II of the general adaptation syndrome described above, and it exhibited a customary stress reaction, which in this case lasted for up to 3 weeks following the inoculation (Fig. 3). By the time the plant reached maturity, the amount of $^{15}N$ in the whole plant was significantly reduced.

This observation would not have been possible without studying the processes taking place in the plant prior to harvest and drawing up a "balance sheet" for the whole plant; only the damaging effect of the net blotch would have been seen, but not the progress of the plant through the classical sequence of the general adaptation syndrome up to phase III, i.e. exhaustion and chronic damage, but without the organism dying. Even though quite specific mechanisms and interactions take place in this host-parasite relationship, of a kind which cannot take place between abiotic stressors and the plant, a typical stress response occurs.

Here again, in the case of temporary stimulation reactions, there is a close correlation between the significantly changed physiological parameters and yield. They thus had an effect on yield, even though they did not last until harvest time. Such temporary stimulation reactions may also be triggered by certain chemical substances (Seidel, 1995c).

The occurrence of significant increased yields following infestation of wheat by aphids, at low levels of abundance (Seidel, 1996a), and following inoculation of wheat with *M. nivale* at the end of the heading phase, is a special case of tolerance reaction (Fig. 4). Here, the increased productivity was maintained right through to maturity and the plant never entered the phase of exhaustion. To some extent, therefore, overcompensation occurred, and the stimulation phase was manifest. Depending on the variant, this would have resulted in increased yields of 3–9 dt/ha in the *M. nivale*-wheat system (after extrapolation to the field test level) (Seidel, 1996a). The causes of this have not yet been explained. However, components specific to the host-parasite relationship must be involved. These effects cannot be explained simply by a reaction of the plant. Probably, a role is played by changes induced in the hormone level of the host plants within the host-parasite relationship.

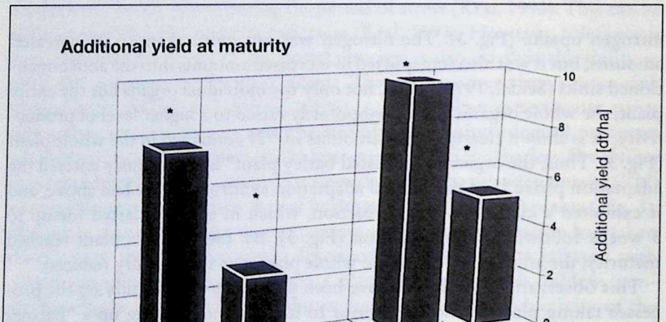


Fig. 4 – *Surplus yield of wheat after inoculation with Microdochium nivale at EC 57–59, depending on diseased part of the plant (*significant for healthy control, p ≦ 0.05, 3 upper leaves – flag leaf, 2nd leaves, 3th leaves).*

It has been shown in the case of aphids that they influence the cytokinin level of their host plant (Seidel, 1995a). This effect has not yet been detected in the host-parasite interaction of wheat-*M. nivale*. The effects detected after leaves or ears had been inoculated with *M. nivale* indicate that cytokinin-like effects take place (Seidel, 1995a, b). In comparative tests, analogies were discovered with the effect of an exogenous application of kinetin (Seidel, 1996b). Cytokinin is assumed to play an important role in the stress reaction of plants by retarding senescence and triggering tolerance reactions (McKersie and Leshem, 1994). It is essential to clarify the action mechanism behind such manifest stimulation reactions before tolerance reactions can be induced in a controlled manner.

The definition of tolerance quoted at the beginning from Aust et al. (1993), does not include the processes of temporary and manifest increases in productivity in tolerant plants, because it only allows for the compensation of loss. As has been shown, an increase in productivity is a special aspect of tolerance reactions, and it needs to be covered by the definition. It is therefore proposed that the definition be expanded as follows:

Tolerance is the ability of the plant to survive, without defending itself against the stressor "pest infestation" or the action of abiotic stress factors, while suffering a lower reduction in vitality and productivity than intolerant plants exposed to the same intensity of stress. As part of the adaptation mechanisms that occur, the productivity of the plants may be temporarily increased beyond that achieved by unstressed plants, and this increased productivity also helps to compensate for stressor-induced loss. In special cases, such increased productivity may be manifest and result in increased yield.

These processes of temporary and manifest stimulation of the productivity in infested plants, compared with non-infested plants, are of practical economic and ecological interest in the field of plant protection. However, the following conditions must be met:

- this phenomenon should occur in many host-parasite relationships, i.e. it must be generally valid;
- the external and internal conditions under which it occurs must be known;
- it must be possible to increase the intensity and duration in order to bridge critical phases for yield formation;
- an effective test system must be available with whose help such reactions can be recognized;
- it must be possible to predict when the plant will enter phase II of the adaptation syndrome (e.g. to permit more precisely targetted application of pesticides).

The general validity of this principle has already been demonstrated (Seidel, 1995c). Research still needs to be carried out to clarify or meet the other requirements. Once the causes and mechanisms of tolerance, as well as the reactions of tolerant plants to stressors, are known, possible ways can be derived to make use of the plant's ability to tolerate stress, in the broader definition of the term "tolerance"; in the past, such possibilities may have been ignored or were not adequately exploited.

### *Discussion of the possible ways of making practical use of the tolerance phenomenon and current limitations on its use*

#### *Breeding*

Research has concentrated so far on resistance mechanisms and on breeding resistant varieties. The overall emphasis on resistance was logically correct in view of the fact that this is the most effective way to avoid disease-induced losses. If infestation does not take place, or with less severity, then no losses or fewer losses will result. So far, this concept, combined with the targetted application of pesticides, has yielded very satisfactory solutions.

For a long time, the goals of plant breeding were primarily to obtain higher yields and/or resistance to pests or abiotic stress. No selection for tolerance has been carried out, nor even, as a minimum, has the tolerance of economically relevant crop plants been systematically recorded. This is clear when one examines the lists of varieties. Resistance and tolerance may exist side by side in a plant, but they presumably have genetically different backgrounds (Lauenstein, 1992). The targetted selection of plants for resistance and the selection of high-performance varieties may have led to the elimination of tolerance characteristics in many crop plants (Clarke, 1984). Wild plants and low-yield varieties frequently possess greater tolerance (Seidel, 1995b). High-performance varieties were selected solely for maximum yield, i.e. the ratio of economic yield to biological yield is higher than average. In the case of cereal crops, this means, for example, that a high percentage of ears is produced at the expense of the vegetative organs. This is equivalent to limiting the source capacity, while at the same time maximizing the sink capacity and reducing the potential to build up reserves. These high-performance varieties no longer have the ability to compensate if they encounter an unforeseen stress situation in the cultivation regime. Using the low-input varieties which breeders have produced might be a step in the direction of utilizing tolerance properties. These varieties are characterized by a highly developed capacity to take up nutrients, especially nitrogen. At the same time, they were selected for high resistance properties in order to reduce the need for pesticides (Garbe and

Bartels, 1995). Even though no evaluation of tolerance was carried out, a good ability to take up nutrients might indicate a high degree of tolerance.

It should further be remembered that both resistance and tolerance are the result of complex processes which are activated by the reaction of the plant to external influences. The two possible reactions, namely tolerance and resistance, are usually graduated in the way they manifest themselves. Total (100 %) tolerance or resistance is rarely achieved, and it is not desired in the case of resistance because such resistance can be more readily broken. Breeders should examine whether resistance and tolerance characteristics can be jointly selected. A certain degree of resistance would minimize the influence of the stressor and the remaining influences would then be tolerated (Clarke, 1984; Kral, 1993). This presupposes a knowledge of the degree of tolerance of the varieties to a wide range of stressors, either singly or, even better, combined. Usually, the plant is affected by several stressors (several pests, or pests and abiotic stressors). Thus, it is necessary to know the "stress threshold" of the varieties. Another requirement, however, would be to have more knowledge about the causes and mechanisms of tolerance. Making joint use of resistance and tolerance assumes that the tolerance mechanisms do not come into play until the resistance mechanisms are exhausted. What happens, though, if the plant is exposed simultaneously to a stressor to which the plant is resistant and to another stressor against which it is not resistant? Or how do resistance mechanisms act on stimulation reactions occurring as part of the tolerance reactions? Stimulation reactions obviously rely on an interaction between the host and parasite and require a certain level of infestation.

*The use of resistance and tolerance inducers*

The use of resistance inducers increases the ability of the plants to withstand attack or stress. This is achieved not just by reducing the intensity of the infestation (resistance induction), but also by minimizing the loss (tolerance induction) (Seidel and Détrie, 1996b).

The ability to induce resistance by using substances such as trigonellin, 2,6-dichloroisonicotinic acid, extract of *Reynoutria sachalinensis, Bacillus subtilis* culture filtrate B50, and oryzemate, which are classified as resistance inducers, has been extensively studied and will not be further discussed here.

By comparison, the aspect of inducing tolerance through the use of resistance inducers has received little study, although this might be a starting point for seeking more effective inducers. Substances which would bring about not only a lower level of infestation but also reduce the loss caused by the residual infestation, would be superior to resistance inducers that are directed solely at warding off the pest. This new way of approaching the problem is also reflected in the efforts, which have been stepped up since the early 90s, to determine whether resistance inducers also induce tolerance (Seidel and Détrie, 1996b). It has been shown that some resistance inducers can in fact also induce tolerance. This has so far been proved in the case of B 50 (purified culture filtrate of *Bacillus subtilis*) (Seidel and Détrie, 1996b), trigonellin (N-methyl-nicotinic acid) and a total extract of *Reynoutria sachalinensis* (Seidel and Détrie, 1995b). Trigonellin and the total extract of *R. sachalinensis* exerted direct effects on the yield or on the physiological performance of the plant. This means that these substances raised the performance capacity of the plant prior to inoculation. However, they were also able to trigger simple compensation reactions, i.e. compared to the yield or performance values of the infested, non-induced controls, they suffered a lower loss of yield or productivity at the same level of infestation.

None of the resistance inducers tested so far was able to trigger or reinforce manifest stimulation phases specific to the host-parasite system. The yields of the induced, infested plants were never higher than those of the inoculated, non-induced (healthy) control plants. On the other hand, temporary stimulation phases, affecting physiological processes and the dry matter production of vegetative parts of the plants, did occur when certain inducers were applied.

Simultaneous induction of tolerance thus appears to be possible in the case of some resistance inducers and makes these inducers more effective, especially when the infestation is not reduced to a very large extent. However, the effectiveness of the tolerance induction depends very much on the ontogenetic phase of the plant (Seidel and Détrie, 1995). It cannot generally be concluded that resistance inducers always induce tolerance.

Stimulation reactions specific to the host-parasite system, and in particular the manifest stimulation phases, can probably only be induced or reinforced by using special "tolerance inducers", which have not yet been discovered. It might be possible, for this purpose, to use substances which play a role in the course of the general adaptation syndrome. They could be signal substances as well as adaptive hormones and stimuli. This is indicated, for example, by the observations made in the wheat-*M. nivale* host-parasite system (Seidel, 1995a, b; 1996a, b). Similarly, certain stress metabolites, the production of which permits adaptation to stress, might also have a tolerance-inducing effect when exogenously applied.

### *Use of pesticides*

No studies have been carried out to determine the influence of conventional pesticides on the tolerance reactions. Thus, it is not known whether they act synergistically, additively, antagonistically, or not at all. It is known that some pesticides are themselves a stressor for the plant. It is conceivable that, fungicides, for example, by directly attacking the phytopathogenic fungus, may prevent the occurrence of tolerance reactions. On the other hand, applying reduced amounts of fungicides after the temporary stimulation phase has ended might prevent the plant from sliding into the exhaustion phase. Such fungicides would then have to act quickly and have a curative effect.

It is known, with respect to some fungicides, such as benzimidazoles, that they are capable of increasing yields regardless of their fungicidal action. This is due to their cytokinin-like effects. They may thus have triggered a tolerance reaction in the form of a manifest stimulation or "overcompensation". The reduction of loss or the increase in yield caused in this way by tolerance induction, might explain the effects of certain insecticides or herbicides, which so far have not been adequately explained by the primary action mechanism of pesticides.

*Yield-loss analysis, loss forecast*

The analysis of yield and loss can take place in several stages (Fig. 5); under practical conditions, Level 1, which can be expanded in various ways, is currently the best one to use. In this case, the visible extent of the disease (symptoms) on the plant is recorded and compared with the loss (e.g. grain yield) measured at the time when the plant is harvested. Using economic parameters, threshold values for economic loss can be derived. However, since these relationships are modified by different influencing factors, i.e. they are unstable, flexible damage thresholds are being developed. The plant is indirectly included by evaluating various influencing parameters acting on it, such as fertilizers, other pathogens, weed population, previously implemented plant protection measures and cultivation measures, as well as by evaluating plant-specific factors (developmental stage, varietal characteristics). This constitutes a transition to Level 2 (Fig. 5). Loss forecasts, which are often sufficiently accurate for practical purposes, can be arrived at in this way.

The relationships between visible damage and later loss of yield are modified, however, by the current condition of the plant and the accumulated reserves. In the procedures used up to now, the current condition of the plant is not taken into account. But, recording the population dynamics or the epidemiological parameters of pests can only reflect the resistance, not the tolerance of host plants, because only the resistance reduces the final density of the pests, while tolerance does not (Lauenstein, 1992). This means that the tolerance of the plant is not recorded. Since the current productivity level of the plant is not

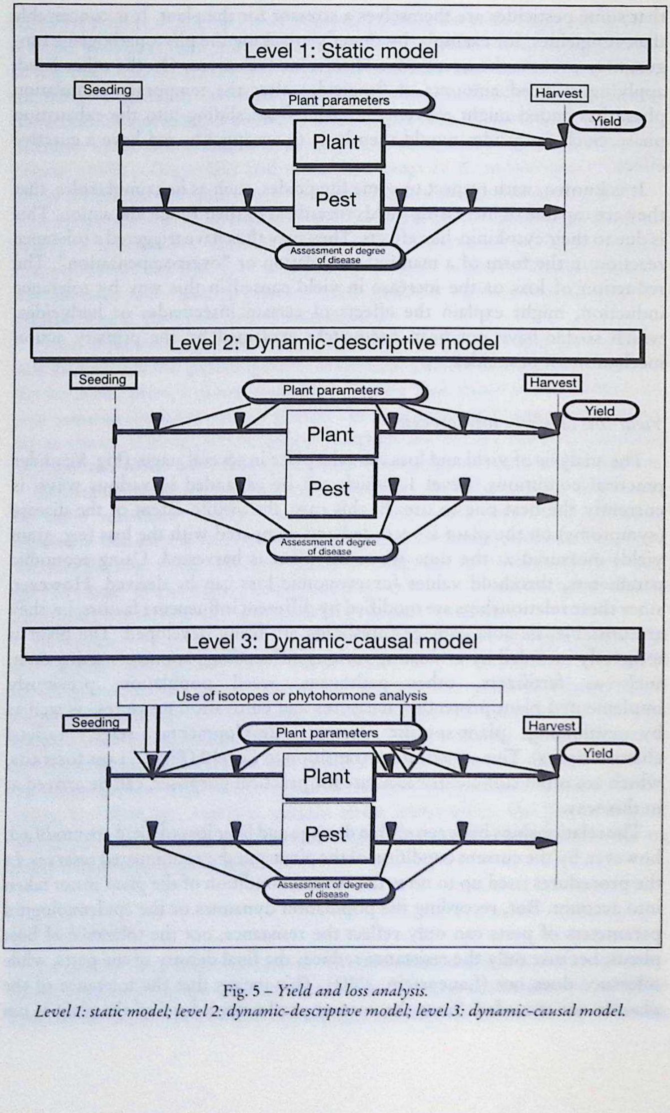


Fig. 5 – *Yield and loss analysis.*
*Level 1: static model; level 2: dynamic-descriptive model; level 3: dynamic-causal model.*

known, it might be assumed that its productive capacity has been impaired, when in fact it is not; and it might also be assumed that loss has been sustained, although it will not occur under these conditions. The effects of tolerance on loss thresholds have not been investigated (Gaunt, 1981; Kral, 1993). Because of the less severe loss caused by infestation in tolerant plants, the loss threshold would have to be shifted upwards (Kral, 1993). A tolerance reaction which occurred, but was not allowed for in the yield-loss analysis, might impair the accuracy of the predicted need for plant protection measures. This is perhaps a reason for the hitherto inexplicable inaccuracies in loss prognoses.

This situation might also be reflected in models which simulate the damaging effect of diseases. In mathematical models for host-parasite systems, the complex interactions are reduced to principal effects such as: Destruction of nutrient reserves, prevention of seed metabolism, interruption of energy supply, interruption of transport processes, disruption of nutrient production, and redistribution of nutrients due to infestation by pests. This contributes to systematization and covers some of the possible effects. However, these models can only reflect the true influence on the yield-forming process if the production of matter by the plant is modified by the pest merely within a certain, fixed framework. But this only happens if redistributions take place, flow rates are changed, etc. With such a concept, it is not possible to record the changeover to substitute processes, the stimulation of uptake, transport and storage processes beyond what is normal in healthy plants; nor can the changed reaction norm of the plant to environmental influences be measured.

From the state of our knowledge as presented here, and from the criteria for evaluating tolerance which have been developed in this study, it is possible to derive minimum requirements for models whose purpose is to reflect and/or predict tolerance reactions towards pests:

- they must take account of the fact that the host-parasite system is qualitatively a new system, i.e. it is not the sum of its individual components;
- they must include the means for expanding the source and sink capacity of the plant; such means are activated once the infection has taken hold;
- they must reflect the current condition of the plant during the various ontogenetic phases;
- they must include the means for building up and consuming reserves.

Gathering data on plant parameters is even more complicated and time-consuming than collecting the data on infestation parameters, which is already running into difficulty in practice. In addition, the parameters required to characterize tolerance reactions, are only now being developed (Seidel, unpublished).

Models can be very helpful in this process. Under practical conditions, the only model that could be handled is one in which data must be collected about one characteristic of the plant. The characteristic could be a morphological, i.e. visible, characteristic or an easily measurable feature, such as the length of the stalk. The model should, however, reflect the relationships of these characteristics to possible tolerance reactions, and it should be able to evaluate them by including other current input data (climatic conditions, cultivation measures, etc.). These are input parameters which can modify the tolerance (Kral, 1993; Gaunt, 1981). This in turn requires a definition of the tolerance potential of the varieties. As far as the plant components are concerned, this might be conceivable. Based on the tolerance potential, it would be possible to define a stress threshold which includes all the stressors that reinforce or reduce tolerance. Therefore, it would first be necessary to quantify the external stressors, the endogenous conditions and the specific prior history of the crop. But the pest-related factors which might trigger temporary or manifest stimulation phases are virtually impossible to determine. This can only be done by drawing conclusions from a comparison of healthy plants with diseased plants, and this requires that such data be gathered in preliminary, expensive tests in order to integrate them into the model.

*Evaluation of beneficial organisms*

Various methods are employed to evaluate biological pest control, i.e. the utilization of natural control mechanisms and the avoidance of pesticide use. Biological control methods are often evaluated simply by determining the quantity of pests which are destroyed. But, if these biological methods are to be a true alternative to chemical methods of plant protection, their use must lead to detectable and relatively reliable reductions in the loss levels (Freier et al., 1994).

In the "wheat-aphid" system, the losses in yield are correlated with the number of sucking aphids. The losses in yield decreased with declining abundance, and at low abundances even increases in yield were detected (Seidel, 1995a).

However, in the "wheat-aphid-ladybird" system, a shift was observed in the yield-loss relationship. Differences were apparent when the losses caused by, in each case, an equal number of aphids with and without the presence of ladybirds, were compared with one another. The losses in yield due to the aphids were not compensated for by the ladybird effect (Freier et al., 1994). Confirmation of such observations could lead one to conclude that, despite the reduction in pests, the beneficial organisms do not offer any measurable benefit. However, it is equally conceivable that the beneficial organisms have the effect of reducing the loss in productivity, so that when further stressors are added, the plant still possesses sufficient reserves for tolerance reactions. There are indications that the loss of productivity is indeed reduced (Freier, oral communication), but the effects on tolerance reactions still need to be investigated.

## *Conclusions*

A tolerant plant is characterized by a less severe loss of vitality and productivity compared with intolerant plants, given the same degree of disease or the same intensity of the effect exerted by a stressor. In addition, under certain circumstances in compatible host-parasite relationships, the productivity may be stimulated beyond that found in an unstressed plant.

Little is known as yet about the physiological causes of tolerance as well as the degree of tolerance of many varieties (Kral, 1993; Clarke, 1984). Therefore, we still do not have any fully developed practical solutions on how to make use of tolerance or tolerance induction. The existing gaps in research must be closed. Changes in the general conditions for plant production (overproduction, increased environmental awareness) are creating growing interest in the cultivation of tolerant varieties.

The following are possible, relevant areas of application in which knowledge derived from researching tolerance reactions and mechanisms can be applied and also tolerant plants can be cultivated: Breeding, the use of inducers, the use of pesticides, as well as yield-loss analysis and loss forecasting.

Breeding for combined resistance and tolerance, as well as breeding for tolerance alone, could open up new prospects. In the final analysis, the ratio of input and output during cultivation is the decisive factor in determining the success of a variety. If the costs for intensive measures are increased, for example by the introduction of levies to cover environmental pollution, then low-input varieties, and thus probably also more tolerant varieties, will attract greater interest. Gaps in our defences, such as exist where no pesticides are available to deal with certain diseases or pests, and no resistance is known, or which are found in crops that are not widely cultivated, could be avoided by growing more tolerant varieties. This is also of interest in connection with the complex of problems known as "sustainable resources". But before any of this can be put into practice, it will probably be necessary to re-evaluate the cultivated species and varieties to determine their tolerance. This means that an effective test system will have to be developed.

Researching the tolerance mechanisms in host-parasite relationships prepares the ground for developing tolerance inducers. Thus, a new class of compounds could be developed which would be different from the pesticides used so far and against which the pests would not, for example, become resistant. The tolerance inducers would reinforce naturally occurring processes or could induce tolerance during phases which are critical for yield formation.

As interest in the cultivation of tolerant varieties continues to grow, the effects of existing pesticides on such varieties will become more important. Since the effects are not known, they need to be studied. There might then be an increased demand for "tolerance-friendly" pesticides.

At present, it is still not possible, or if so then only to a limited extent, to identify yield-loss relationships which allow tolerance to be measured and thus predicted. Existing yield-loss relationships do not take account of tolerance, and at the most it can only express itself in the form of a shift in these relationships. This might be the cause of the error rate which occurs when forecasts are based on these relationships. It is initially an expensive proposition to establish tolerance-related yield-loss relationships and loss forecasting procedures. But, given the increasing importance of cultivating tolerant varieties under changed overall ecological and economic conditions, the availability of such tools might be essential.

Researching tolerance mechanisms and tolerance properties of plants is a source of innovation which will be of practical benefit. It is a necessary step to take, and at the same time it poses an interesting challenge to phytopathologists, plant breeders, plant physiologists, molecular biologists and mathematicians who will be working together on the problem.

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*Author's address:* Dr. P. Seidel, Biologische Bundesanstalt für Land- und Forstwirtschaft, Institut für integrierten Pflanzenschutz, Stahnsdorfer Damm 81, D–14532 Kleinmachnow.

## *Editorial Note*

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Erratum: Dear Reader, in Volume 43 our printing computer caused a technical error. The correct title of the publisher of the article by Ulrich Burth and Bernd Freier, pp. 7–15, in the editorial note is as follows: "Stuttgart: Verlag Eugen Ulmer GmbH & Co".

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